

Technical Memorandum

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Subject: Results of Geomorphic Analysis of Hydraulic, Hydrologic, and Sediment
Conditions in the Lower Skykomish River Below the Sultan River

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1. INTRODUCTION

R2 Resource Consultants Inc, (R2) is assisting Snohomish County Surface Water Management (SWM) with reach scale geomorphic analyses that will be used to support assessment and prioritization of restoration possibilities in the lower Skykomish River reach, extending from the town of Sultan downstream to the confluence with the Snoqualmie River (Figure 1). The goal of the analyses is to identify projects that are consistent and compatible with natural reach scale hydraulic and sediment transport processes and that will restore and protect salmon habitat as well as protect infrastructure in the reach. R2 worked closely with SWM staff in the collection and analysis of data specific to the reach geomorphic assessment and directed at the following goals:

1. Identify reach scale processes that influence channel morphology;
2. Identify hydraulic and sediment transport processes that will influence future condition and channel location in the reach;
3. Identify the most geomorphically active and inactive segments in the reach; and
4. Qualify risk associated with different restoration activities for each level of geomorphic activity, including channel connectivity, floodplain connectivity, instream/bank stabilization structures, and bank revetment removal.

The geomorphic analysis involved the following elements that are described in this memorandum:

1. Collection and analysis of pebble count data, and analysis of long profile characteristics.
2. Development of a HEC-RAS model for use in hydraulic and sediment transport analyses relative to identifying river segments with aggradational vs. degradation tendencies and for estimating hydraulic characteristics at various flow levels.
3. Digitizing of former main and side channel locations and unvegetated gravel bars using available aerial photography up to and including 2007, and calculating channel migration rates and changes in active gravel bar areas
4. Delineation of potential floodplain avulsion channels and assessment of avulsion risks.
5. Review and synthesis of the sediment transport, channel migration rate, and gravel bar data to develop ratings for each parameter for sub-reaches within the project reach (called analysis segments).
6. Identification of appropriate restoration project types for different segments based on segment characteristics developed in the preceding tasks.

The work products will be used to guide future specific restoration grant applications for completing projects that are consistent with natural geomorphic processes in the Lower Skykomish River below the Sultan River. This work represents an extension of analyses performed previously in the Braided Reach of the Skykomish River upstream of the Sultan River to Gold Bar, which has been integral in the identification, design, and construction of restoration projects initiated in that reach in 2009 and continuing through 2011.

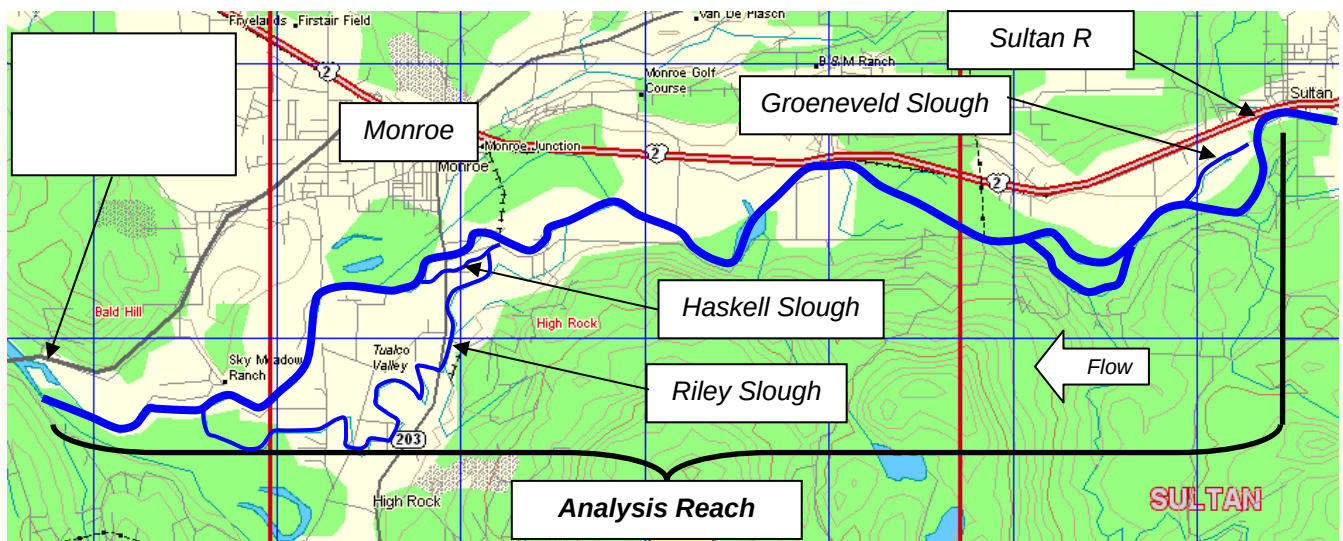


Figure 1. Location of the lower Skykomish River reach analyzed in this memorandum, near Monroe, WA.

1.1 Relevance to Recovery Planning

The analysis reach is roughly 13½ miles long and provides important spawning and rearing habitat for Skykomish Chinook salmon (*Oncorhynchus tshawytscha*), one of two distinct Chinook stocks identified as being important for recovery in the Snohomish River basin and for which escapement numbers are estimated at 10% of historic levels according to the 2005 Snohomish Basin Salmon Recovery Plan. A key component for recovery identified by the Plan is to restore and preserve watershed processes and provide juvenile rearing habitat in the mainstem Skykomish River. The analyses documented in this memo are key to understanding the reach scale processes that control the distribution, quality, and persistence of juvenile habitat. Habitat and fish surveys conducted as part of the Braided Reach analysis by Washington Trout (now Wild Fish Conservancy) indicated that side channel habitat is particularly important for juvenile salmonids living within the mainstem river corridor. Thus projects that increase side

channel habitat availability and quality are considered desirable for enabling recovery of salmon and steelhead stocks in the basin.

The work and results described in this memorandum can be used to assess opportunities and risks of specific restoration activities designed to improve juvenile and spawning habitats, as well as more general risks to floodplain development and infrastructure. To accomplish this, a strategy was employed of identifying the extent to which shorter, distinct segments within the reach are geomorphically active or inactive in terms of sediment transport, deposition, channel migration, and overall erosion tendency. This strategy allowed evaluation of specific locations on the floodplain in the context of local and reach scale constraints. In addition, the results facilitate explanation of the physical cause of specific effects to infrastructure and private land in an intuitive way to stakeholders.

2. METHODS

A suite of analyses was selected over focusing on a specific method, any one of which on its own would provide some information but would not yield a sufficiently complete picture. Quantitative, process-based analyses (e.g., sediment transport modeling, bank migration rates, gravel bar areas) were favored over channel form (e.g., see Kondolf et al. 2001) or process-based classifications (e.g., channel migration zone mapping; Rapp and Abbe 2003), so that the results could be used to better answer the question, “What would happen if...” The analysis involved identifying and quantifying (1) physical processes that influence reach channel morphology, (2) hydraulic and sediment transport processes that will affect future condition and channel location in the reach, and (3) the most geomorphically active and inactive segments in reach. To accomplish these tasks, information was analyzed that was critical for assessing processes acting at the reach and site scales (Wissmar and Beschta 1998; Kondolf 2000): (1) longitudinal profiles of elevation, gradient, and grain size distributions, (2) hydraulics and hydrology using HEC-RAS, USGS gage data, and surveyed cross-section and flood stage data, (3) bedload transport potential based on a 50-year duration, (4) aerial photographs for evaluating changes in active channel locations and cumulative active gravel bar storage and side channel areas, and (5) LiDAR and other available GIS data for characterizing flood engagement frequency and avulsion risk potential of floodplain channels. Salient details of the methods are described below.

2.1 Longitudinal Profiles

Longitudinal profiles provide an indication of effects of large scale slope changes on sediment transport and deposition patterns that control fish habitat form. Longitudinal profiles were

developed for water surface and thalweg elevations and mean velocity over the analysis reach and upstream, using the HEC-RAS model data and predictions for the 2-yr flood event. The longitudinal profiles were used to identify general sediment transport trends in the reach and upstream.

A total of 13 pebble counts were sampled to characterize upstream-downstream variation in grain size and depositional patterns in the reach, and compare with upstream data collected previously. It was generally not feasible to collect data near the thalweg given channel size. Instead, a sample size of 100 stones was selected randomly by moving over the mid-point of active depositional point bars between the water and floodplain and measuring the intermediate axis diameter of each stone. Sampling locations were selected to be geomorphically similar in terms of bar type and relative location on the bar, so that observed longitudinal variation in grain sizes would not reflect locally variable depositional processes, but rather larger scale geomorphic variation. Various percentile particle sizes, including D_{50} (size for which 50 percent of stones were smaller), were computed for each sample and plotted against river mile. Inspection of the longitudinal scatter in D_{50} and D_{90} values indicated that there were three sub-reaches in the plot corresponding to large scale breaks in channel confinement and flood flows. Pebble count data were accordingly pooled within each sub-reach to develop three general grain size distributions that were used in sediment transport analyses.

2.2 Sediment Transport Modeling

Sediment transport modeling involved first creating a hydraulic HEC-RAS model of the reach and using the model output to predict sediment transport rates within the active channel, and develop a within-reach sediment transport budget.

2.2.1 HEC-RAS Model Geometric Data

A HEC-RAS steady flow model was constructed to simulate flood flows and predict longitudinal shear stress variation for estimating bedload transport rates and their effect on a coarse sediment budget within the reach. The model was developed as a blend of two different models, one developed previously for SWM to model the 100 year flood in the lower 9 miles of the reach ('nhc model'), and a second model developed more recently by R2 to model flood flows upstream specifically for the geomorphic analysis. The upstream model was developed using bathymetric longitudinal and cross-section profile data collected in the field in 2007 by County staff, and using 2003 LiDAR data. All elevations were calculated relative to the NAVD 88 vertical datum. Benchmarks were established and tied-in using real time kinematic (RTK) GPS

and a total station. Profile data were collected using a raft that was rowed across channel. Cables were not used to maintain position, and thus the data did not represent a perfectly perpendicular line as is needed for computing flow rate and stage in HEC-RAS. Cross-sections were correspondingly developed by projecting the bed elevation surveyed at points along the boat trajectory stream-wise onto a perpendicular transect. Elevations were computed by subtracting the water depth from the water surface elevation, which was determined using RTK GPS. The bare earth model LiDAR data were used to complete dry-land portions including exposed bars, side channels, and the floodplain.

The upstream and downstream boundary conditions were approximated using the normal depth assumption in lieu of having measured rating curves. Transect spacing was specified in the HEC-RAS model for the channel centerline, and shoreward of the left and right banks. Transect names were set equal to centerline stationing using a river mile designation. Left and right bank longitudinal stationing was measured on scaled color aerial photographs using GIS. Ineffective flow areas were specified at most transects to help distribute the flow better or to delay engagement of side channels and floodplain areas until higher flows, based on review of aerial photographs and assessing land cover and side-channel size characteristics. The model cross-sections (Plate 1) generally defined “analysis segments” for which other quantities were calculated such as bank migration rate and gravel bar area. There were also a few transects added later in the analysis to improve model accuracy that did not define analysis segments. Table 1 lists the analysis river mile for each HEC-RAS model transect defining an analysis segment, and Plate 1 depicts the corresponding analysis segment locations.

Table 1. River mile (RM) system used in the analysis (RM 0 = confluence with Snoqualmie and Snohomish rivers.

Analysis Segment	Analysis RM (Downstream Boundary)	Landmarks, Notes
1	13.24	Head of Groeneveld Slough
2	13.09	Interpolated HEC-RAS Transect
3	12.98	
4	12.80	
5	12.57	
6	12.28	
7	12.03	Exit of Groeneveld Slough
8	11.75	
9	11.63	

Table 1. River mile (RM) system used in the analysis (RM 0 = confluence with Snoqualmie and Snohomish rivers).

Analysis Segment	Analysis RM (Downstream Boundary)	Landmarks, Notes
10	11.44	
11	11.20	Top of Channel Split
12	10.98	
13	10.86	Elwell Creek
14	10.69	
15	10.33	
16	10.15	
17	9.95	Bottom of Channel Split
18	9.71	BPA Power Line
19	9.50	
20	9.36	
21	9.17	
22	8.95	
23	8.72	BPA Power Line
24	8.58	
25	8.40	
26	8.15	Next to SR2
27	7.93	
28	7.71	
29	7.54	
30	7.29	Barr Creek
31	7.12	
32	6.90	
33	6.68	
34	6.50	Public Boat Access
35	6.27	
36	6.11	
37	5.91	Top of Haskell Slough
38	5.70	
39	5.48	

Table 1. River mile (RM) system used in the analysis (RM 0 = confluence with Snoqualmie and Snohomish rivers).

Analysis Segment	Analysis RM (Downstream Boundary)	Landmarks, Notes
40	5.23	
41	4.85	
42	4.66	Old Rail Bridge Location
43	4.53	
44	4.31	
45	4.11	
46	3.99	Above 203 Bridge at Monroe
47	3.96	Below 203 Bridge
48	3.71	
49	3.50	
50	3.23	Bottom of Haskell Slough
51	3.09	
52	2.80	
53	2.56	
54	2.32	
55	2.07	
56	1.91	
57	1.65	
58	1.53	
59	1.33	Bottom of Riley Slough
60	1.14	
61	0.92	
62	0.62	
63	0.21	

2.2.2 HEC-RAS Model Calibration

The HEC-RAS model was calibrated upstream of RM 9 using water surface elevations surveyed after the December 1980 (90,100 cfs), November 1990 (102,000 cfs), November 2006 (129,000), and November 2008 (67,500 cfs) peak flow events, with discharges as reported at the USGS gage located at Gold Bar (Station No. 12134500). High water surface elevations were provided by Chris Nelson, SWM for various locations along the river. The November 2006 event was the flood of record at the Gold Bar gage. The November 2008 event corresponded to a flood with an approximately 7 year recurrence interval and was also representative of hydraulic conditions and coarse bedload transport in the main channel during extreme events. The model should not be considered accurate for predicting water levels that can be used to delineate the 100-year floodplain per FEMA standards, but the predicted levels should be approximately correct for assessing sediment transport rate imbalances between adjacent transects and for developing relative avulsion risk ratings (see below).

Calibration focused first on establishing the order of magnitude of Manning's n -values occurring at the November 2006 peak flow level. Predicted water surface elevations were compared with the surveyed values available to estimate the approximate magnitude of n for the 100 year flood. The model was then recalibrated to the November 2008 peak flow level, which corresponds closer to the range of most geomorphically effective flows in the main channel, via adjustments of Manning's n , expansion, and contraction coefficients until the predicted water surface elevation was similar to the measured. The two sets of calibration values of Manning's n were compared to confirm consistency, with slightly higher n -values needed to calibrate to the lower flood discharge at specific locations upstream of the Wallace River. Given the general consistency in calibration coefficients between the two flow levels and with hydraulic principles, the results were considered suitable for modeling of sediment transport flows in general. The calibration values determined for cross-sections near the calibration water surface elevation locations were applied to other locations in the reach. Based on the calibration results, it was decided that the HEC-RAS model developed for below RM 8 did not need to be recalibrated, given that the Manning's n values for both calibration flows were generally identical at most locations evaluated between RM 9 and the Sultan River, and were similar in overall magnitude above and below RM 9. Calibration details are presented in Appendix A.

The model was calibrated and run using the interpolated transect feature of HEC-RAS. The extra transects were needed to ensure (i) more reasonable calibration n -values, (ii) reduce modeled head loss between transects to avoid model warning messages regarding a 1 ft criterion, and (iii) increase numerical accuracy. Adding extra transects stabilized the model better by

smoothing between-transect changes in depth and velocity, and distributing energy losses across shorter model segments. Interpolated transects were generally spaced less than approximately 200 ft apart, resulting in energy losses between transects generally equal to about 1.0 ft or less at flood stage, a resolution considered sufficient for the river size.

2.2.3 Sediment Transport Simulation Flows

Simulation flows were developed using the USGS gage at Gold Bar as an overall basis. Flows were adjusted downstream based on basin-wide hydrology analyses performed for the County (nhc 2008). Major inflows included in the model were the Wallace River and the Sultan River. Additional flow change locations were included in the nhc model portion that accounted for losses to the floodplain in the vicinity of Monroe and downstream. These flow change locations were not modified in the combined model and the affiliated flow splits from the nhc model were relied on to estimate other simulation flows for the various flow change locations. Details on flow estimation are provided in Appendix A.

A flow duration curve was generated for the Gold Bar gage using available daily mean flow data for the period of record (Figure 2). The curve was discretized into a histogram approximating the duration of various simulation flow magnitudes as a percent of the length of the record. The temporal distribution of flows was determined based on matching total volume under the curve and total number of days over a 50-year period while also approximating the curve shape. Corresponding flows at other locations downriver were estimated using the relations and data sources described above and in Appendix A.

2.2.4 Bedload Transport Analysis

The simulation flows were modeled in HEC-RAS using the steady flow option, for a series of discharges equal to and greater than the 5 percent exceedance flow, up to the 50 year flood. Relatively little bedload transport occurs in general in alluvial rivers when discharge is below the 5 percent exceedance flow. A 50-year period was simulated to predict the total volume of bedload transported at each HEC-RAS transect and evaluate corresponding long term deposition and erosion trends in the reach over a representative project design life.

The HEC-RAS main channel shear stress predictions were input with grain size distribution data to a Fortran program that predicted sediment transport rate per unit width based on Parker's (1990) bedload transport equation. An approximate sediment budget was developed to characterize analysis segments within the reach regarding their deposition or erosion tendencies,

and use that knowledge as a guide to the type of project that may or may not succeed in the segment. For example, fish habitat structures constructed with large wood would not be expected to succeed in an analysis segment that was predicted to strongly experience a net gain in sediment over time, because the structures would have a higher risk of burial or abandonment by the river.

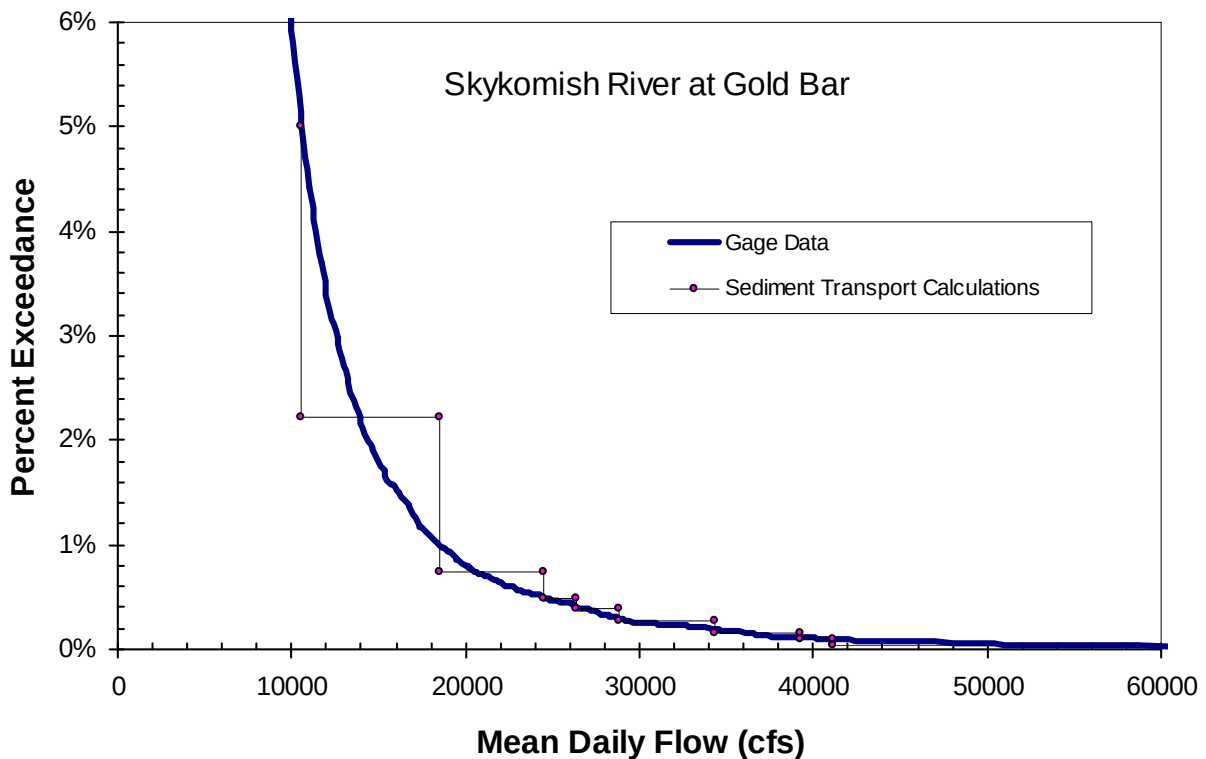


Figure 2. Flow duration curve for the Skykomish River at Gold Bar USGS gage (Station No. 12134500) and corresponding discretization employed to approximate flow duration for the 50-year bedload transport sediment budget analysis.

The sediment budget was computed for each flow and analysis segment by estimating sediment transport rates at the bounding upstream and downstream HEC-RAS cross-sections, and applying a mass balance equation for bed elevation change between transects as a function of estimated input and output bedload mass transport rates per unit width (q_B), active width (W), distance between transects (L), sediment density (ρ_s), and porosity (P) (DeVries, 2000):

$$Y_T = \int_{t1}^{t2} \frac{\partial Y}{\partial t} dt \cong - \sum_{t1}^{t2} \left[\frac{(q_B W)_{out} - (q_B W)_{in}}{0.5L(W_{in} + W_{out})\rho_s(1-P)} \right] \Delta t \quad (1)$$

where the incremental change in bed elevation ($\partial Y/\partial t$) was evaluated for each simulation flow and then multiplied by the histogram time increment (Δt) over which the modeled flow occurred during the 50-year period. This was repeated for other flows, and the results summed to estimate a net mean change in bed elevation Y_T between successive HEC-RAS transects. A strongly positive value of the $\partial Y/\partial t$ sum was inferred as an indication of a strong tendency towards aggradation, and a strongly negative value as an indication of a stronger tendency towards degradation (at the same time recognizing that the reach as a whole may be aggradational over a geologic time span).

The active width used in Equation (1) was specified as the smaller of the wetted main channel width computed by HEC-RAS and an active bottom width in the main channel as judged from a review of cross-section profile morphology and scaled 2003 aerial photographs, consistent with what was done for the previous Braided Reach geomorphic analysis. Length was set as the main channel distance between HEC-RAS transects.

The resolution of the HEC-RAS modeling and physical characteristics of the modeled reach were such that predictions of bed elevation change at several pairs of adjacent analysis segments were strongly negative for the upstream segment and strongly positive for the adjacent downstream segment. To resolve this, the two analysis segment predictions of bed elevation change were combined using the following weighted formula based on computing total volume between three successive transects consecutively numbered 1, 2, and 3:

$$Y_{T1-3} = \frac{Y_{T1-2}L_{1-2}(W_1 + W_2) + Y_{T2-3}L_{2-3}(W_2 + W_3)}{L_{1-2}(W_1 + W_2) + L_{2-3}(W_2 + W_3)} \quad (2)$$

Seven aggradation/deposition potential classes were developed subsequently and used to characterize deposition trends based on the sign and magnitude of the predicted bed elevation change (Table 2). Each analysis segment was classified accordingly and the results depicted graphically in ARC-GIS.

Table 2. Predicted bed elevation change rate and sign used to classify analysis segments according to sediment transport and deposition characteristics in the lower Skykomish River below the Sultan River.

Aggradation/Degradation Potential Class	Bed Elevation Change Rate (ft/yr)
1	< -1.0 (Extreme Degradation Potential)
2	-1.0 to -0.20 (High Degradation Potential)
3	-0.20 to -0.05 (Moderate Degradation Potential)
4	±0.05 (Minor Change)
5	0.05 to 0.20 (Moderate Aggradation Potential)
6	0.20 to 1.0 (High Aggradation Potential)
7	> 1.0 (Extreme Aggradation Potential)

2.3 Aerial Photograph Interpretation

Aerial photographs were available from 1938, 1965, 1969, 1978, 1984, 1991, 1998, 2001, 2003, 2006, and 2007. The photographs were mosaicked and georeferenced. The reach was divided into ‘analysis segments’ using hydraulic modeling transects as boundaries (a few transects were added later in the HEC-RAS model, but the analysis segment boundaries were preserved for consistency throughout the analysis). This permitted a common framework for synthesizing the results from the various analyses. Spatial and temporal patterns in channel migration rate and gravel bar area were derived from the aerial photographs to infer relative stability of specific analysis segments of the analysis reach associated with varying geomorphic activity levels. The 2001 and 2006 photographs were digitized but were not included in quantitative analyses so that average migration rates and changes in gravel bar area would be calculated over roughly similar time intervals.

2.3.1 Historic Channel Planform Mapping

Right and left river bank locations were digitized by SWM GIS staff for each year photographs were available. Main and major side channels were mapped. The resulting digitized poly lines were overlaid chronologically and locations compared between consecutive sets of photographs. Migration rates were estimated as the local average offset distance within an analysis segment between successive main channel river bank traces, divided by the number of years between the two sets of photographs. The visual changes and calculated migration rates were used as the basis for classifying an analysis segment according to planform changes, using rates established in previous analyses for the Skykomish and Sauk rivers (Table 3). The riverbank with the greater average annual migration rate was used to classify a segment.

Table 3. River channel migration rate classification for assessing channel planform changes. Migration may be to either left or right bank directions.

Planform Change Index	Average Migration Rate (ft/yr, one or both banks)
1	< 15 (minor change)
2	15-30 (small change, meandering tendency)
3	30-80 (moderate change, meandering/wandering tendency)
4	>80 (severe change, braiding tendency)

2.3.2 Gravel/Sand Bar and Side Channel Area Mapping

Exposed, unvegetated (i.e., active) main channel gravel/sand bar and clearly visible active side channel areas were digitized from the aerial photographs as discrete polygons. Most bars were point bars, although mid-channel bars were also mapped at specific locations where the channel widened substantially so that flow depth was very shallow across the hydraulic control formed by depositing coarse bedload. The area of gravel bar mapped in each segment was then computed and summed cumulatively from upstream to downstream in ARC-GIS to reflect the direction of sediment transport and deposition. A running sum was computed for the main channel; separate sums were computed for major side channels, with the river mile determined by the location at which the side channel branched off from the main channel.

Not all of the aerial photographs were taken at similar flows, and differences were expected in gravel bar areas due to differential inundation. An adjustment was performed by calculating an average active gravel bar cross-channel width (W_{GB}) as the segment area digitized divided by segment centerline length, and determining an average wetted width (W_w) across upstream and downstream segment boundaries, at each flow in GIS. The photograph year with wetted widths falling in the middle of the other years (1991) was used as a reference wetted width (W_{wref}), and wetted widths from all other years used to adjust the respective year's value of W_{GB} to an estimated equivalent reference year width (W_{GBref}), via the following formula:

$$W_{GBref} = W_{GB} + (W_{wref} - W_{wref}) \quad (3)$$

Resulting values less than zero were set to zero. The adjustment effectively converted measured gravel bar widths (W_{GB}) to the equivalent width for the flow at which the 1991 photographs were taken (W_{GBref}).

The mean adjusted (or equivalent) widths allowed for making comparisons across different years without the influence of changing thalweg lengths (e.g., associated with channel migration). Locations were identified where mean widths changed by more than 130 ft between photographs, indicting a substantial change in storage and erosion activity. This threshold value approximates the upper limit to average correction in gravel bar width for each set of sequential aerial photographs, and thus filtered out potential instances of interpretation and measurement error. Each analysis segment was classified according to whether or not a substantial change in mean width of active bar or side channel slope occurred, and whether the change represented an overall decrease or increase in area between successive photographs. The resulting classifications were coded for each analysis segment and presented spatially in GIS format.

2.4 Avulsion Risk Assessment

Avulsion risk was assessed using LiDAR topographic data, HEC-RAS flood modeling results, and various GIS data. Factors evaluated as contributing to the potential for avulsion included the presence of concentrated flow pathways evident on the topographic surface, the average slope of pathway segments, the general flow level at which the upstream inlet would be inundated, and the inherent erosivity of soils associated with the pathway. Potential factors that could reduce the risk of avulsion were also identified, including vegetation and the presence of infrastructure. The methods used to characterize and identify these various factors are described below.

2.4.1 Individual Avulsion Risk Factors

Flow Paths: Potential avulsion pathway segments were traced on 2 ft contour maps generated from the 2003 LiDAR data as linear features with elevations that were generally lower than the surrounding floodplain. Segments began and ended at the main river channel or junctions with other segments. A GIS layer was then constructed by Laura Audette (SWM GIS staff) that depicted each potential pathway segment as a linear feature.

Inundation Flow Level: The elevation of pathway segments branching from the river was used to estimate the return interval event at which each segment and connected segments downstream and upstream would become wetted, using water surface elevations estimated for the 2-year, 10-year, and 100-year event based on the HEC-RAS modeling. Segments below junctions with upstream segments were assumed to be connected at the same level as upstream segments as long as there was no significant break in slope evident on the map downstream. For example, if a downstream segment was connected to two upstream segments with one flowing at the 2 year

flood level and the other at the 10 year flood level, the downstream segment was assigned a 2-year flood level risk.

Slope: A longitudinal profile for each pathway was developed by extracting elevation data from a DEM for selected points spaced 100 ft apart along each segment. Average slope was calculated as the average of slopes calculated between points, for each segment. Slope between points was calculated as the difference in elevation between points divided by the length between points (100 ft or shorter, depending on the total length of the segment).

Soil Erodibility: The avulsion pathway layer was overlaid in GIS on a soils map produced by the NRCS. Each soil type is assigned a K_w -factor which represents both susceptibility to erosion and the infiltration rate. Soils with lower K_w -factors are more resistant to erosion due either to high clay content or high infiltration. Soils with higher K_w -factors are more erodible. Soils within the study area were classified as follows based on the NRCS K_w -factor, with greater emphasis placed on the uppermost soil horizon:

- 1 = K_w -factor > 0.3 (higher erodibility)
- 2 = K_w -factor 0.2-0.3 (moderate erodibility)
- 3 = K_w -factor <0.2 (lower erodibility)

Where potential avulsion pathways crossed soils with different K_w -factors, a weighted average class was calculated based on the relative length of channel crossing each soil type.

Vegetation Cover: In general, the presence of forest vegetation is anticipated to reduce the risk of avulsion, as trees provide deep, dense root masses that are more resistant to erosion and may inhibit braiding. In addition, if channels do avulse through forested areas, trees that fall into the new channel provide roughness elements that reduce erosive energy and may temporarily block flow. Vegetation was assessed visually for each avulsion pathway using 2007 aerial imagery. Potential avulsion pathways were classified as forested, non-forested or open water. Only forest vegetation was considered to potentially reduce the likelihood of avulsion.

Road Grade Controls: The presence of roads can act as both a mitigating factor or exacerbate the risk of avulsion. Paved roads, and to a lesser extent gravel roads represent a “hard point” that is more resistant to erosion over the short-term. However, roads that cross avulsion pathways may also exacerbate the risk if they contain undersized drainage structures or temporarily hold back water then fail catastrophically. This analysis assumes that roads are monitored and/or protected during floods and thus moderate the risk of avulsion where they are present. Road

crossings were identified from aerial imagery. Paved roads were considered to be more resistant and more likely to be protected during floods, and thus were assigned a greater mitigative factor.

Bank Hardening: The presence of bank hardening can retard avulsion if the river does not erode around the structure and it is designed and built to counter the potential for undermining at the bank toe. Risk needs to be evaluated on a case-by-case basis, however, where type of structure (i.e., rip rap or LWD), condition of the structure, distance from the upstream and downstream ends of the structure to a floodplain swale, and respective structure end point and swale elevation differences can either be a mitigating factor or not substantially affect avulsion risk depending on the particulars of the site. For that reason bank hardening was not explicitly included as a factor in this reach-scale avulsion risk analysis. An existing SWM survey of bank modifications was available for providing context when interpreting the results, however.

2.4.2 Joint Avulsion Risk Factors

The factors above were considered for ways to combine them into a joint risk rating system. Weighting factors were conceived and assigned to ranges of each factor. It was decided to combine the flow level, slope, and soil erodibility factors into a weighted joint risk rating system, and apply vegetation and road characteristics as mitigating factors. Each pathway segment identified on the LiDAR topographic surface was rated accordingly, following the gradations and weightings proposed in Table 4. The joint avulsion risk was calculated for each segment as the sum of the weights assigned in Table 5 for return interval event at which the pathway may flow, pathway slope, and soil erodibility. The following joint risk classes were defined based on professional judgment:

- o Joint Risk Weight Sum >14 = Class 1 (Highest risk)
- o Joint Risk Weight Sum = 10-14 = Class 2
- o Joint Risk Weight Sum = 6-10 = Class 3
- o Joint Risk Weight Sum <6 = Class 4 (lowest risk)

The joint risk rating may be modified by subtracting weights for mitigating factors, with initial recommendations for weights given in Table 4. Alternatively, the mitigating factor ratings can be used on a case-by-case basis in consideration of greater site specific knowledge as to the relative importance each factor could play in mitigating joint avulsion risk.

Table 4. Summary of parameters used to assess relative avulsion risk, and the weights assigned to each parameter.

Parameter	Criterion (weight)			
Risk Factors:				
Flood Return Interval Causing Inundation	>100 yr (1)	100 yr (3)	10 yr (6)	2 yr (9)
Slope	<0% (1)	0-1% (3)	1-3% (6)	>3% (9)
Soil Erodibility Class	3 (1)	2 (2)	1 (3)	
Potential Mitigating Factors:				
Vegetation	Forested (-2)	Non-Forested (0)	Open Water (0)	
Road Crossing	Paved (-3)	Gravel (-1)		
Bank Hardening Across Pathway	Rip Rap (-4)	Large Wood (-2)		

3. RESULTS

3.1 Longitudinal Profiles

The longitudinal profile of the Skykomish River is strongly concave upstream of the Sultan River and mostly uniform in gradient ($S=0.0012$) downstream to approximately RM 1.9 (Figure 3). The river bed gradient is substantially lower below RM 1.9 ($S=0.0003$), a reflection of the backwater effect from the confluence with the lower gradient Snoqualmie and Snohomish rivers. The predicted water surface elevation in the lowermost mile was steeper than upstream, but this reflected primarily the assumed downstream boundary condition for the water level and flow at the confluence. Thus, for purposes of this assessment, hydraulic predictions of flood levels upstream to approximately RM 1 are uncertain for purposes of assessing overall avulsion and sediment transport potentials.

Review of the aerial photographs indicates a meandering river planform exists upstream of the BPA lines located near RM 9.7. The river planform downstream is represented by a straighter, channelized sub-reach to about RM 3.5 near the outlet of Haskell Slough, by a mildly sinuous channel between RM 3.5 and RM 1, and by a deltaic morphology in the lowermost mile (cf. Plate 1).

Substrates in the reach generally fall into cobble and gravel size classes (Figure 4). In general, the grain size distribution indicates three sub-reaches that are consistent with the river planform breaks. Upstream of about RM 9.7, the grain size distribution is approximately constant and similar to the distribution upstream of the Sultan River (Figure 5). Bedload and high flows originating from the Sultan River do not appear to influence grain size distributions in the mainstem Skykomish River. Grain size distributions are either approximately constant or may be gradually coarsening in the downstream direction in the channelized sub-reach. Grain sizes become finer downstream of the outlet of Haskell Slough and more closely approximate grain size distributions upstream of the channelized subreach. Figure 5 also depicts the range of Chinook salmon and steelhead trout spawning habitat D_{50} values reported by Kondolf and Wolman (1993) in their review. Substrates appear most suitable for Chinook salmon spawning in the sub-reaches upstream and downstream of the channelized sub-reach.

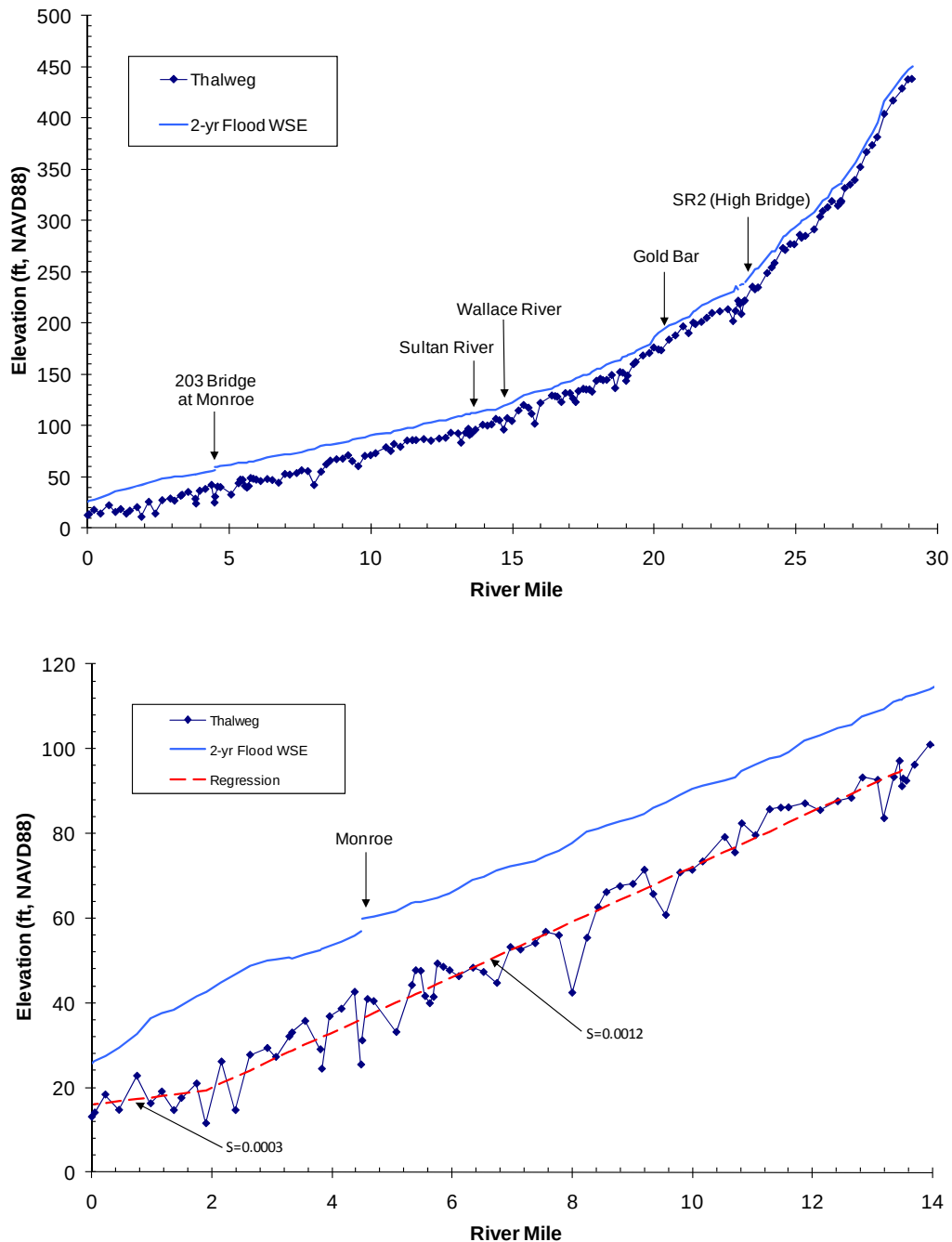


Figure 3. Longitudinal elevation and gradient profiles of the Skykomish River from its confluence with the Snoqualmie and Snohomish rivers to upstream of Gold Bar (upper graph) and the lower reach extending upstream to the Sultan River (lower graph). The water surface elevation predicted for the 2-year flood is also depicted.

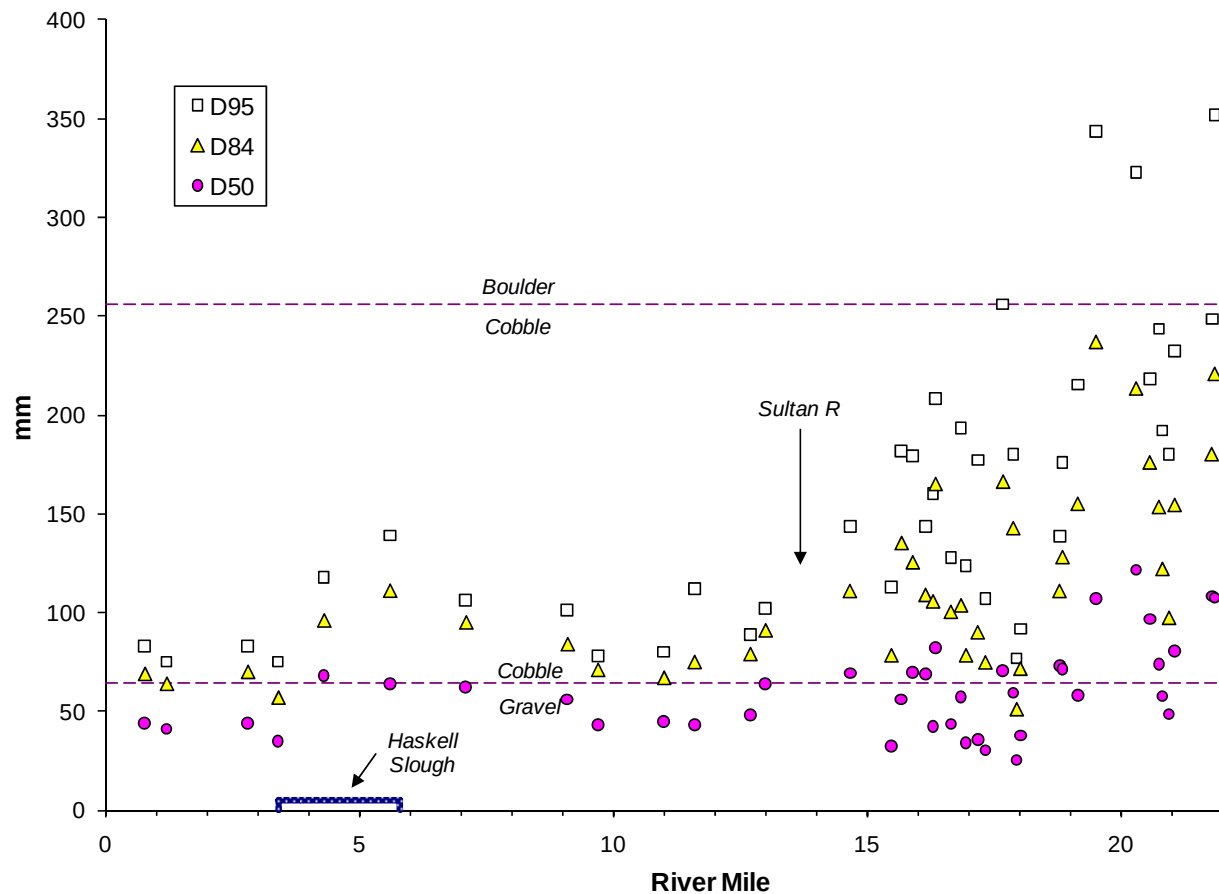


Figure 4. Longitudinal trends in selected grain size distribution percentiles measured on depositional gravel bar surfaces in the Skykomish River upstream and downstream of the Sultan River. Data upstream of the Sultan River are presented from earlier analyses for a broader scale comparison of reach processes. Horizontal lines depict the approximate transition from gravel- to cobble- to boulder-sized stones.

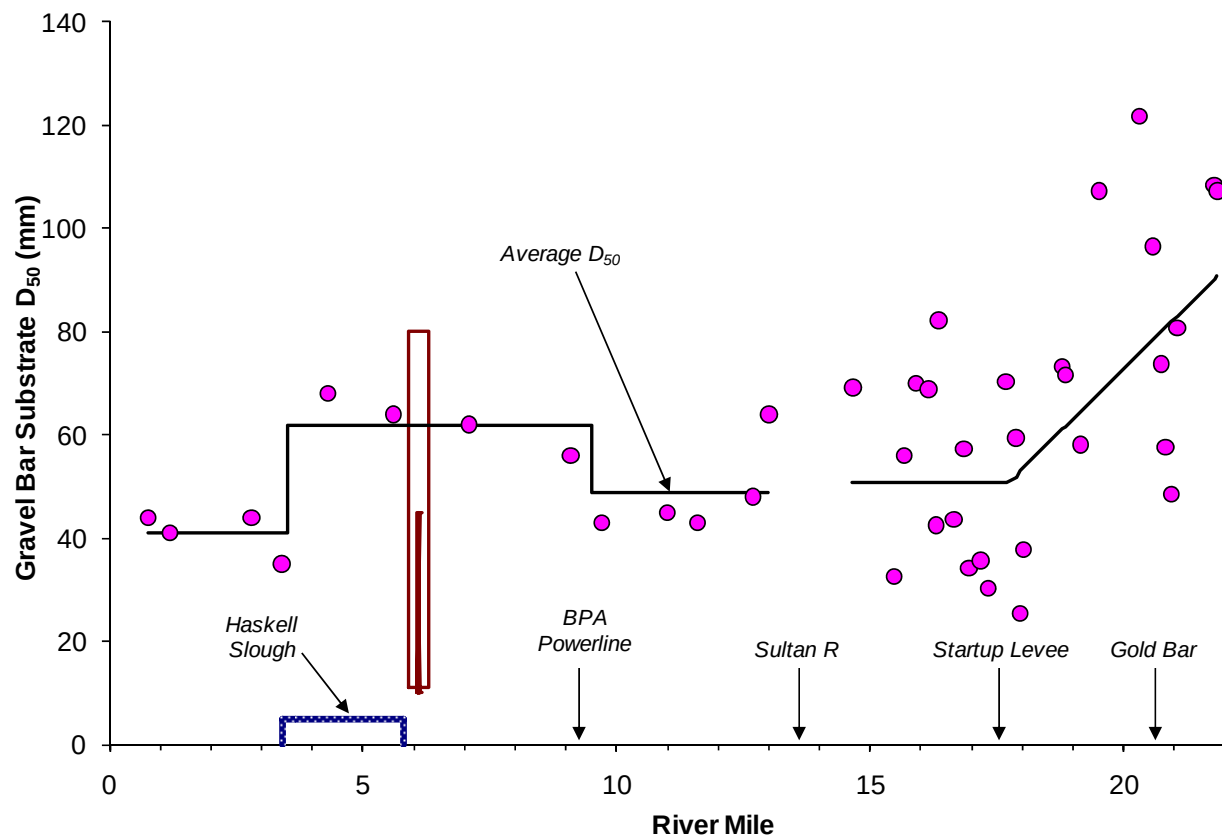


Figure 5. Longitudinal trends in average D_{50} on gravel bars in the main Skykomish River channel, and corresponding sub-reach breaks in distributions suggested by scatter in the pebble count data. The average values were used in the sediment transport modeling for each sub-reach below the Sultan River. The vertical bars indicate the range of D_{50} values reported for suitable Chinook (outer clear bar) and steelhead (inner solid bar) spawning substrates by Kondolf and Wolman (1993).

3.2 Sediment Transport Modeling

The HEC-RAS model was calibrated as closely as possible to the surveyed flood marks (Appendix A). Calibration errors were generally within ± 0.5 ft and the resulting Manning's n values appeared consistent with values for other rivers presented in Barnes (1967) and Hicks and Mason (1998), and thus were reasonable for purposes of reach scale sediment transport budgeting.

Table 5 summarizes the flows selected for modeling in the HEC-RAS and sediment transport analyses, and their modeled duration.

Table 5. Simulation flows modeled in HEC-RAS for the sediment transport analysis. Additional flow changes were modeled at a number of locations downstream of the Sultan River as described in Appendix A.

HEC-RAS Profile Name	Percent Exceedance	Modeled Duration (days)	Flow (cfs)		
			At Gold Bar Gage (Station # 12134500)	Below Wallace River	Below Sultan River
PF1	5	506	10600	11635	13325
PF2	1	268	18500	20109	22379
PF3	0.5	44	24500	26699	29939
PF4	0.4	24	26400	28737	32117
PF5	0.3	20	28800	31408	35298
PF6	0.2	18	34300	37557	42707
PF7	0.14 (~2-yr flood)	15	40900	42500	47000
PF8	0.1	11	41100	45470	53250
PF9	0.03 (~10-yr flood)	6	77000	82900	97900
PF10	0.01 (~25 year flood)	0.5	97500	103000	120000
PF11	0.005 (~50 yr flood)	0.5	113000	119200	139200

The HEC-RAS model resulted in extreme variation in predicted bedload volume gains and losses across adjacent analysis segments at eight locations. Smoothing using Equation (2) resulted in a more reasonable appearing plot of predicted bed elevation changes based on Parker's (1990) bedload transport equation (Figure 6). Plate 2 depicts the corresponding spatial variation in aggradation and degradation potentials in the Lower Skykomish River analysis reach. Upstream-downstream patterns in variability of aggradation and degradation potential are generally consistent with the three sub-reach breaks identified above. Most of the meander planform sub-reach above about RM 9.7 is associated with equilibrium transport potential (Figure 6), suggesting bedload transport through the sub-reach is balanced with supply from upstream. This sub-reach appears to process coarse sediment downstream in a more uniform manner than elsewhere in the analysis reach. There is a large discontinuity in the vicinity of the sub-reach break located at about RM 9.7, with moderate variability in the channelized sub-reach downstream to the lower reach break located at about RM 3.5, in the vicinity of the downstream end of Haskell Slough. Downstream of Haskell Slough, the river exhibits the greatest variability and magnitude of upstream-downstream bedload transport rate imbalances.

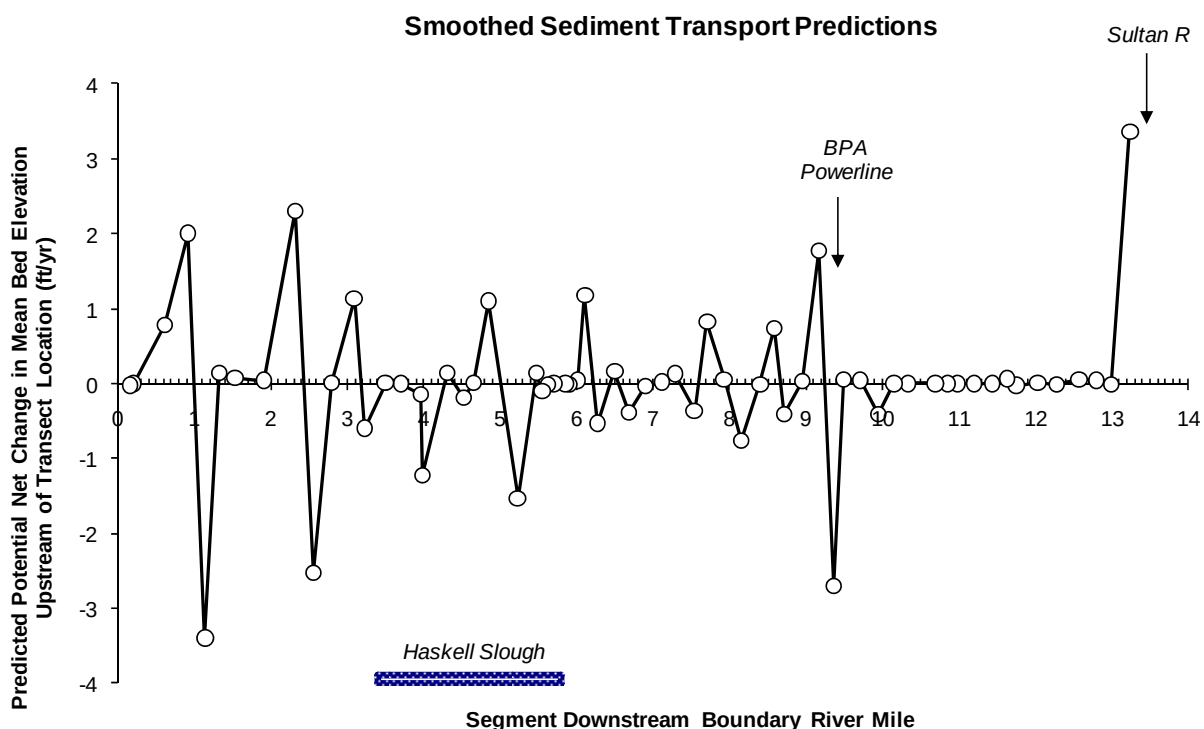


Figure 6. Longitudinal variation in predicted potential bed elevation changes within analysis segments over a 50 year period, as determined by evaluation of HEC-RAS hydraulic modeling output using Parker's (1990) bedload transport equation.

3.3 Channel Migration Patterns

The aerial photograph series provided a relatively periodic determination of channel location, with intervening periods associated with at least one large flood event occurring that exceeded the 2-year event level. The largest events occurred between the 1978-84, 1984-91, and 2003-7 photographs (Figure 7).

The aerial photography mapping and LiDAR data indicate that areas of greatest channel migration in the analysis reach tend to be concentrated at a few locations, and appear to have translated in the downstream direction at most locations (Figure 8). Side channels have not tended to capture the mainstem flow at least since 1938, and have generally remained side channels with limited connectivity. Channel migration has been generally constrained within a moderately confined floodplain between the Sultan River and about RM 6, upstream of Monroe (Plate 3, also see avulsion channel mapping results below). There is evidence of limited

meander migration occurring between 1938 and 1965 within the meander planform sub-reach above RM 9.7, and little to none after that (Plate 3).

Downstream to about RM 2.5, channel migration has been relatively restricted by the settlement of Monroe and by bank armoring and resulting channelization (Plate 4). However, there has been considerable planform instability in the vicinity of the old railroad bridge locations in segments 44 and 45 (Figure 8). Removal of the bridge piers may be associated with significant readjustment in the future in these analysis segments.

Downstream of RM 2.5, there is a broader distribution of relict channels over the floodplain compared with upstream (see avulsion channel mapping results), yet channel migration has remained limited there as well (Plate 3). It appears that riprap is preventing channel migration from occurring in most of this sub-reach (Plate 4). Accordingly, channel planform instability appears manifest in most of the analysis reach through primarily local channel braiding, for example at analysis segments 31 and 32 (Figure 8). These two segments are located along the upstream side of a sharp bend in the channelized sub-reach (cf. Plate 1) and are confined artificially by riprap that has been placed along both banks. This is a location where deposition and erosion of sediments appears to occur frequently and rapidly over the short term, forcing the main channel thalweg to migrate actively between the armored right and left banks (Plate 4). Over the long term, erosion and deposition appear to be more balanced in these two segments (Plate 2). A similar but likely smaller tendency appears in the migration rate data in the vicinity of analysis segments 39 and 40, which are confined by riprap along the outside bend.

3.4 Gravel/Sand Bar Storage and Side Channel Area Trends

Figure 9 depicts cumulative plots of active gravel/sand bar and side channel areas, adjusted to a common flow level, for the various years of aerial photography analyzed. The vertical differences between curves to some extent reflects the time between the previous large flood event and the date the photographs were taken (shorter time interval → greater amount of deposit surface area that has not become vegetated yet), error in interpreting older aerial photographs (2003 and later photographs were in color; older photographs were lower resolution black and white), and error in adjusting gravel bar areas to a common flow rate.

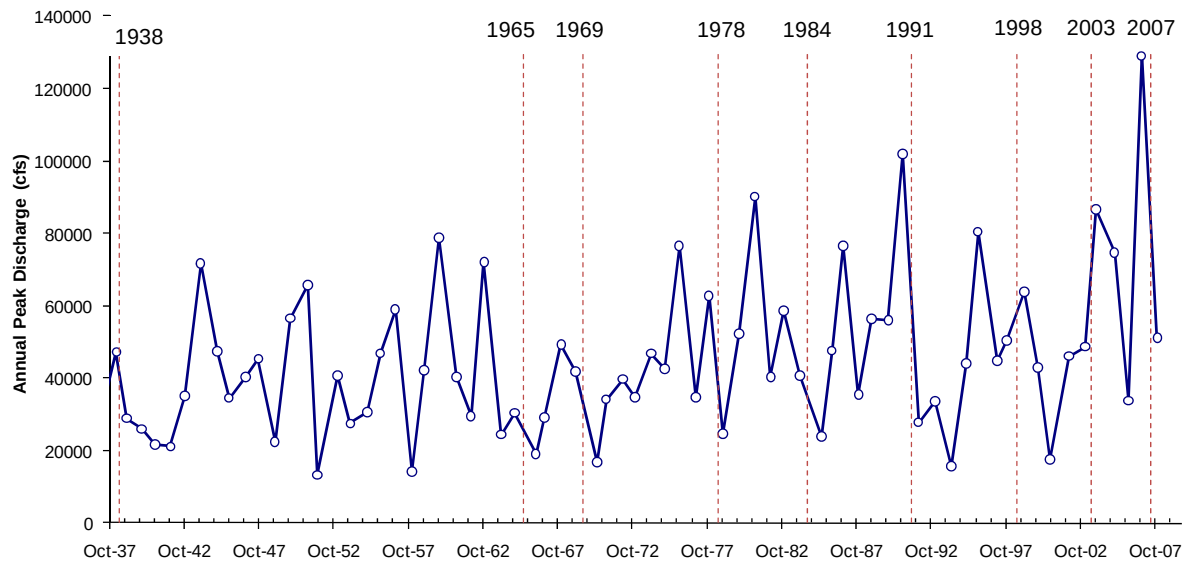


Figure 7. Annual peak flow time series encompassing the aerial photography date range, for the USGS gage Skykomish River near Gold Bar (Station #12134500). Dates when each set of aerial photographs were taken are indicated by the dashed vertical lines.

Analysis Segment	Downstream Boundary RM	Planform Instability Index Calculated From Aerial Photography Series							
		1938-1965	1965-1969	1969-1978	1974-1984	1984-1991	1991-1998	1998-2003	2003-2007
Meander Planform Sub-Reach	1	13.24	1	1	1	1	1	1	1
	2	13.09	1	1	2	1	1	1	1
	3	12.98	1	2	3	1	1	2	1
	4	12.80	1	2	1	1	1	2	1
	5	12.57	1	1	1	1	1	1	1
	6	12.28	1	1	1	1	1	1	1
	7	12.03	1	1	1	2	1	1	2
	8	11.75	2	3	1	1	1	1	1
	9	11.63	2	3	1	1	1	1	1
	10	11.44	2	3	3	1	1	1	1
	11	11.20	2	1	1	1	2	1	1
	12	10.98	1	2	1	1	2	2	1
	13	10.86	1	2	1	1	2	2	3
	14	10.69	1	2	1	1	2	3	1
	15	10.33	1	1	1	1	2	2	1
	16	10.15	1	1	1	1	2	1	1
	17	9.95	1	2	1	1	2	1	1
	18	9.71	1	1	1	1	1	1	1
Channelized Planform Sub-Reach	19	9.50	1	1	1	1	1	1	1
	20	9.36	1	1	1	1	1	1	1
	21	9.17	1	1	1	1	1	1	1
	22	8.95	2	3	1	1	1	1	1
	23	8.72	1	3	1	1	2	1	1
	24	8.58	1	1	1	1	1	1	1
	25	8.40	1	1	1	1	3	2	1
	26	8.15	1	1	1	1	1	1	1
	27	7.93	1	1	1	1	1	1	1
	28	7.71	1	1	1	1	1	1	1
	29	7.54	1	1	1	1	1	1	1
	30	7.29	1	1	1	2	1	1	2
	31	7.12	2	2	1	4	2	2	3
	32	6.90	1	2	2	3	3	2	3
	33	6.68	1	1	1	1	1	2	1
	34	6.50	1	1	1	1	1	1	1
	35	6.27	1	2	1	1	1	1	1
	36	6.11	1	2	1	2	1	1	1
	37	5.91	1	1	1	3	1	1	1
	38	5.70	2	1	1	1	1	1	1
	39	5.48	1	2	1	1	2	1	1
	40	5.23	1	3	1	1	1	2	1
	41	4.85	1	1	1	1	1	1	1
	42	4.66	1	1	1	3	1	1	1
	43	4.53	1	1	1	1	1	1	2
	44	4.31	1	2	1	1	1	3	3
	45	4.11	1	1	1	1	2	1	4
	46	3.99	1	1	1	1	1	2	1
	47	3.96	1	1	1	1	1	1	1
	48	3.71	1	1	1	1	1	1	1
	49	3.50	1	1	1	3	1	1	1
Below Haskell Slough	50	3.23	2	1	1	1	1	1	1
	51	3.09	2	1	1	1	1	1	1
	52	2.80	1	1	1	3	1	1	1
	53	2.56	1	1	1	1	1	2	1
	54	2.32	1	1	1	1	1	1	1
	55	2.07	1	1	2	1	1	1	2
	56	1.91	1	2	3	1	1	1	2
	57	1.65	1	3	2	1	1	1	1
	58	1.53	2	4	1	1	1	1	1
	59	1.33	1	3	2	1	1	1	1
	60	1.14	1	1	1	2	1	1	1
	61	0.92	1	1	1	1	2	2	1
	62	0.62	3	1	1	3	4	2	3
	63	0.21	1	2	1	1	4	2	2

Figure 8. Spatial and temporal variation in channel migration tendencies within analysis segments of the Skykomish River below the Sultan River, as indicated by successive series of ortho-corrected and geo-referenced aerial photographs. Planform change index values are described in Table 3. Arrows indicate possible upstream/downstream shifts in location of zones of greater channel change over the aerial photographic record.

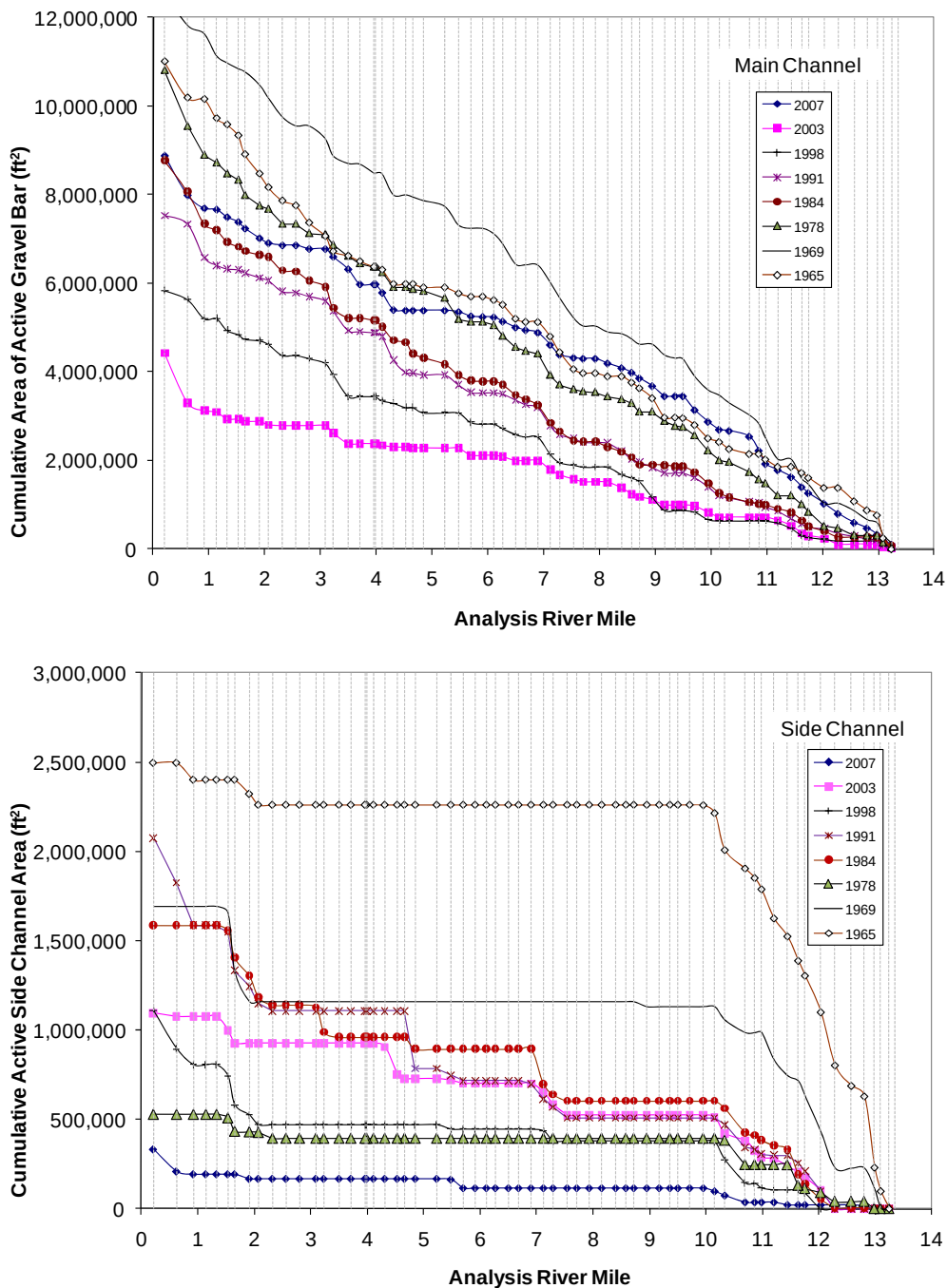


Figure 9. Cumulative active gravel/sand area mapping results for all years that aerial photography was digitized. Results are presented separately for exposed gravel areas occurring in the main channel (top graph) and total area of active side channels (bottom). The locations of the HEC-RAS transects are indicated by the dashed vertical lines.

Nonetheless, useful information may be derived from the data depicted in Figure 9 based on the following observations:

- For analysis segments where successive year's curves are approximately parallel, it may be inferred that there was probably negligible change in gravel bar storage volumes or side channel areas between the two years photographed.
- In other locations, the slopes of the plots differ notably, where main channel storage volumes and side channel areas either appear to have decreased or increased between successive photograph years. The rate of change in curves between successive aerial photographs may be calculated as a change in average width of active gravel/sand bar or side channel area. Segments with substantial changes in average main channel gravel bar width, and thus storage of material readily available for bedload transport, are depicted for each pair of successive photographs in Figure 10, in a format similar to that presented in Figure 8 for the channel migration results. Figure 10 represents substantial changes in gravel/sand bar area, where changes between successive photographs exceed approximately +/- 130ft. The results indicate that while gravel appears to be distributed relatively uniformly along the length of the main channel, most active gravel bar storage changes occur in the meandering planform sub-reach and in the sub-reach below Haskell Slough. In addition, this trend appears to have strengthened over time, with temporally increasingly stability evident in the central portion of the channelized sub-reach.
- The channelized sub-reach contains little to no side channel habitat. Most side channel habitat occurs above RM 10 and below RM 2.

3.5 Avulsion Risk

Plates 5-7 depict the individual avulsion risk factor ratings for each delineated pathway segment. Plate 8 depicts the joint avulsion risk rating based on flow level, slope, and soil erodibility. Plates 9 and 10 depict the ratings for the vegetation and road mitigating factors. The individual and joint ratings represent relative risks amongst all potential flow paths based on physical characteristics known to affect the likelihood of avulsion. These risk ratings cannot be used to predict exactly where the channel will move during future storm events, but can be used to prioritize alternatives to reduce the risk of failure, or of potential impacts to property and infrastructure.

Main Channel		Segments With Significant Changes in Gravel Bar Area Between Successive Aerial Photograph Series (average equivalent bar width change > +/- 130ft)						
Analysis Segment	Downstream Boundary RM	1965-1969	1969-1978	1978-1984	1984-1991	1991-1998	1998-2003	2003-2007
Meander Planform Sub-Reach	1 13.24	+	--					+
	2 13.09							
	3 12.98	--	--					
	4 12.80							+
	5 12.57		--					
	6 12.28							+
	7 12.03							
	8 11.75	+		--				+
	9 11.63							
	10 11.44	+	--					
	11 11.20							
	12 10.98	+	--	--				
	13 10.86	+	--			--		+
	14 10.69	+		--				+
	15 10.33							
	16 10.15		--					
	17 9.95					--		
	18 9.71							
Channelized Planform Sub-Reach	19 9.50	+	--					+
	20 9.36							
	21 9.17							
	22 8.95	--		--		+	--	
	23 8.72	--				+	--	
	24 8.58				--			
	25 8.40							
	26 8.15							
	27 7.93							
	28 7.71							
	29 7.54		--					
	30 7.29		--					
	31 7.12		--					
	32 6.90						--	
	33 6.68							
	34 6.50							
	35 6.27		--					
	36 6.11	+		--				
	37 5.91							
	38 5.70							
	39 5.48							
	40 5.23	+		--		--		
Below Haskell Slough	41 4.85							
	42 4.66							
	43 4.53			+	--			
	44 4.31				+	--		
	45 4.11	+	--		+	--		+
	46 3.99		+					+
	47 3.96							
	48 3.71							
	49 3.50		+	--				+
	50 3.23				+		--	
	51 3.09		--	+	--			
	52 2.80		--					
	53 2.56	--	+					
	54 2.32		--					
	55 2.07						--	
	56 1.91		--					
	57 1.65							+
	58 1.53	--	+	--				+
	59 1.33							
	60 1.14				--	+		
	61 0.92		--			--		
	62 0.62		+			--	--	
	63 0.21		+	--	--		+	

Figure 10. Spatial and temporal variation in active gravel/sand bar storage areas within the main channel for analysis segments of the lower Skykomish River, as indicated by successive series of geo-referenced aerial photographs. Change is represented as a substantial gain (+) or loss (--) in mean width of non-vegetated bar surface in excess of +/- 130 ft.

The results depicted in Plates 5-10 are based on LiDAR data collected in 2003 and hydraulic data collected in 2007. Specific ratings may change in the future depending on flooding and future channel migration. It is not feasible to update the ratings each year after flooding because of the expense, however the ratings resulting from this analysis can still be used to assess general risk as described below, and provide an indication of relative differences in avulsion potential for possibly the next 10+ years.

In general, there appear to be many potential pathways evident in the topographic data with medium to high risk of avulsion distributed across the analysis reach floodplain (Plate 8). Most of the highest joint risk pathway segments (Class 1) are connected downstream of moderate joint risk pathway segments (Class 2), suggesting that the most likely mechanism for avulsion would be through upstream propagation of head cuts starting in Class 1 segments, assuming other factors do not mitigate for risk. It is notable that while the LiDAR data indicate the presence of potential avulsion pathways over broad portions of the floodplain surface, the channel migration traces in Plate 3 suggest that they rarely if ever pose a substantial avulsion risk overall. Class 2 segments are more typically associated with inundation at the 10 year flood level, and include the majority of Haskell Slough.

Class 3 segments would become higher risk segments likely only after the river avulses through upstream Class 1 or 2 segments. Most Class 3 segments are located well away from the main channel. Riley Slough is one such channel, and appears to be associated with minimal risk of avulsion.

4. SYNOPSIS OF ANALYSIS RESULTS AND SELECTION OF CONCEPTUAL PROJECTS

The following general patterns are indicated by the analysis results. The features indicated lead to river and fish habitat restoration projects that vary across the four primary geomorphic reaches identified, reflecting characteristic river processes and erosion/deposition risks observed at the reach scale.

4.1 Summary of Large Scale Variation in Reach Geomorphic Characteristics

Four geomorphic sub-reaches are identified that are defined by three breaks in longitudinal trends for the following physical attributes:

- ~RM 9.7, above the BPA powerlines:
 - Change from meander planform tendency upstream to channelized sub-reach downstream
 - Channel migration: distributed over more analysis segments upstream, limited to two highly concentrated locations downstream
 - Side channels: more prominent, persistent, and connected to mainstem upstream
 - Aggradation/degradation potential: General equilibrium transport conditions prevail upstream, greater variation downstream
 - Degree of reworking of active gravel bars in main channel: Greater upstream, limited downstream
 - Grain size distribution: Upstream similar to above Sultan River, coarser downstream in channelized sub-reach
- ~RM 3.5, at the exit of Haskell Slough:
 - Grain size distribution: downstream similar to above RM 9.7, finer than upstream
 - Aggradation/degradation potential: Greater variation downstream
 - Number and degree of reworking of gravel bars: Greater downstream, limited upstream
 - Floodplain and side channel connectivity appears to be more artificially confined downstream
- ~RM 1-2, Transition to Delta Morphology:
 - Reduced slope downstream of RM 2 reflecting backwater effect from confluence with Snoqualmie and Snohomish rivers
 - Number and size of gravel bars: Larger and more braided downstream of RM 1

- Confinement: Less downstream of RM 1

4.2 Potential Restoration Projects

Four general types of restoration projects are identified here along with the locations where they would be consistent with natural processes and the Snohomish River Recovery Plan (Plate 11).

4.2.1 Channel Migration/Side Channel Connectivity Projects

Channel migration and side channel connectivity could be effected for the purpose of enhancing or restoring juvenile salmonid side channel habitat. However, much of the river is artificially constrained by riprap (cf. Plate 4) which has precluded channel migration in many locations where reach-scale morphology and sediment transport conditions would otherwise facilitate the process. There are two ways in which migration could be (re)induced: (i) removal of riprap and (ii) construction of instream wood structures (flood fence or log jams). Riprap removal would allow the channel to reconnect with side channels and the floodplain more generally and allow meandering processes to return to more natural patterns. Construction of in-channel wood would create local hard points and instream roughness that could induce local bar deposition and migration of the thalweg in the direction of the opposite bank, or force channel splits depending on structure placement location and size.

Suitable sites for riprap removal would be upstream of ~RM 9.7 and downstream of Haskell Slough (~RM 3.5), subject to evaluation of avulsion potential using Plates 4-9 and landowner willingness to reengage floodplain channels. Within these sub-reaches, the river meandered historically and side channels are more prominent. Between RM 3.5-9.7, the river may be too channelized and side channels too limited in presence for small scale riprap removal to have much effect on channel form, although a few opportunities may exist to selectively reengage side channels combined with floodplain protection and riparian restoration measures such as flood fencing. Riprap removal in the channelized sub-reach should be at locations where upstream-downstream sediment transport rate imbalances between adjacent analysis segments are calculated to be minor to negligible (classes 3-5, Table 2) to minimize potential for significant relocation of the mainstem channel.

Suitable sites for in-channel structures would be located where there are large upstream-downstream sediment transport rate imbalances and a strong aggradation tendency such that a structure could be constructed to facilitate local deposition and set up conditions favoring channel migration away from the deposition location, or split the flow and increase flood flow in a perched side channel. In addition, there should be a relatively high avulsion risk into the

channel (i.e., it should be engaged preferentially at the 2 year flood), which are likely to be locations deemed most feasible according to land ownership and farmland preservation goals.

For riprap removal, the following analysis segments have reach scale conditions favoring controlled reconnection with side channels that could potentially provide habitat subject to landowner concurrence, additional restoration measures improving connectivity and riparian conditions, and/or implementation of suitable grade controls where needed to control avulsion risk:

- Segment 6
- Segment 17
- Segment 31
- Segment 38 (Haskell Slough)
- Segment 56

For instream structures, the following analysis segments potentially have reach scale conditions favoring structures inducing channel splits, including a locally aggradational setting and existing perched side channels that could lead to longer term restored side channel habitat:

- Segment 21 (for right bank channel)
- Segment 44
- Segment 51
- Segment 57
- Segment 62

Segments 7 and 11 also feature heads of perched side channels but are associated with a neutral aggradation/degradation tendency, thus the effectiveness of constructing structures to engage the side channels is less certain.

4.2.2 Instream Habitat Complexity Projects

The recovery plan indicates the need for side channel habitat complexity for juvenile salmonids. Structures providing cover should be located in relatively persistent and prominent side channels that are in contact with groundwater and potentially even flowing during the summer. The heads of such channels should be located in analysis segments with relatively neutral aggradation/degradation tendency so that the effective lifespan of the structures is maximized. In addition, avulsion potential should be relatively low in the vicinity of each structure where private

property concerns exist. Accordingly, the geomorphic analysis results are interpreted to suggest the following suitable locations:

- Groeneveld Slough (Segments 3-7)
- Segments 12-16, right channel
- Haskell Slough (if reconnected with mainstem through riprap removal)

4.2.3 Mainstem Spawning Habitat

Gravels are most suitable for Chinook salmon spawning in the mainstem upstream of ~RM 9.7 and downstream of Haskell Slough (~RM 3.5). Given the relatively confined nature of the river and abundant gravel at various locations, no measures are suggested at this time to physically increase the quantity and quality of spawning gravel. However, given the general paucity of instream habitat structure, construction of smaller log structures or boulder fields could provide cover near suitable spawning locations. Suitability for such instream structures would be highest in the sub-reaches noted above where grain sizes are most suitable for Chinook spawning, in analysis segments where aggradation/degradation potential is generally neutral and where spawning surveys indicate most extensive use. The meandering planform sub-reach upstream of ~RM 9.7 appears to be most appropriate. The results from this analysis can be compared accordingly with redd surveys to identify suitable locations.

4.2.4 Maintain Island Splits

A persistent island/split channel morphology is limited in the lower Skykomish River in part because of the relatively channelized and trained nature of most of the river. This morphologic unit type provides habitat diversity, especially during high flow and it appears beneficial to fish to preserve islands where they exist. This can be accomplished by constructing apex jams at the upstream end of islands, subject to the constraint that the locations are not associated with a strong degradation or aggradation tendency where, respectively, the structure might fail or private land might become affected by increased flooding. Two locations identified in the analysis reach generally meet these criteria and may be suitable for this type of project. Jams or flood fence structures could be placed specifically at the following locations:

- Segment 11
- Segment 62

4.3 Level of Confidence in Analysis and Results

The longitudinal profiles of channel gradient, grain size, sediment transport analysis predictions of aggradation/degradation potential, flow depth channel migration rates, and size and extent of

side channel changes over time, all consistently point to the five geomorphic sub-reaches outlined above. More site specific analysis and design will be required to evaluate erosion risk for specific projects and management actions, but the results presented here provide a quantitative estimate of reach scale hydraulic and erosion processes that will affect general suitability of specific measures. The information can be used to infer relative risk associated with different restoration activities (e.g., channel and floodplain connectivity, instream/bank stabilization structures, channel migration training, and bank revetment removal), with respect to whether projects would work against or with natural sedimentation and channel forming processes.

The level of uncertainty about each individual analysis varies depending on the type of data, and can be inferred in many cases from the scatter of data depicted in the graphs above. Specific cases are identified below:

- The flood level and sediment transport predictions should not be used to precisely delineate lateral flood extents and predict actual bed elevation changes. Limited field surveyed flood level data were used to calibrate the HEC-RAS model that involved approximately bankfull flood levels. Overbank flows were not calibrated.
- Typical sediment transport rate prediction errors range within an order of magnitude. However, the relative differences in sediment transport potential predicted for successive transects should be preserved and not meaningfully affect the results presented in Figure 8, or erosion risk determinations based on those results.
- The river has changed course variably at different locations since the LiDAR data were collected; all channel planform, flood level estimation, and sediment transport predictions are presented here based on earlier topography. The 2007 aerial photographs and 2003 LiDAR and 2007 channel elevation data are among the most recent physical data available (2009 photographs are now available at time of writing). It does not appear feasible to redo the analyses reported here every time the channel moves, but the general trends seen here at the sub-reach scale should be preserved in the foreseeable future, possibly within the next 20-50 years.
- The channel migration traces are generally accurate for the main channel and major side channels. Smaller side channels not visible in the aerial photographs were delineated as part of the avulsion risk analysis using the LiDAR data. The collective digitized channel traces for the present and avulsion risk analyses should provide for a reasonable delineation of the channel migration zone.

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APPENDIX A

Summary of Hydraulic Calibration

(1) Introduction

This appendix summarizes hydraulic modeling of the Skykomish River. The model reach extended from the confluence with the Snoqualmie River (RM 0) to RM 29.2. **Figure 1** shows the longitudinal channel thalweg profile of the study reach. The lower section where $RM < 15.7$ (below the Wallace River mouth) has a mild channel slope of $S_o = 0.12\%$, the upper part from $RM > 22.9$ (above the High Bridge) has a relatively steep slope of 0.69% . The middle section of the river has a channel slope of 0.26% .

(2) Hydraulic Models

There were two HEC-RAS models developed by R2 and NHC. The NHC model extended from RM 0.0 (Snoqualmie River confluence) to RM 22. The R2 model extended from RM 9.7 to RM 29.2. The NHC model had been previously calibrated up to about RM 9.7. The R2 model was calibrated to high water marks (HWMs) surveyed for floods occurring in 1990, 2006, and 2008. **Table 1** lists the flows of each of the floods at three different locations on the Skykomish River, including the USGS gage near Gold Bar (#12134500), below the Wallace River, and below the Sultan River.

Figure 2 depicts the Manning's n coefficient of the calibrated R2 model along the main channel for the three flood flows. The HWMs of 1990 and 2006 floods were calibrated together using the same channel roughness because their flows were similar, while the 2008 flood was calibrated in a separate model, as shown in **Figure 2**. **Table 2** summarizes the model calibration results for the three floods. The calibration errors are equal to the calibrated WSE minus the HWM elevation. For the majority of HWMs, the calibration errors are well within 0.5 ft, the error permitted by FEMA (Federal Emergency Management Agency). However, a few points have errors greater than 2 ft. Those points were considered outliers and excluded from model calibration because their WSEs were hydraulically impossible to achieve with reasonable channel roughness and the existing geometry setup. The HWMs and simulated WSEs of 1990/2006 floods are plotted in **Figure 3.1** through **Figure 3.5**, and 2008 flood simulation results are plotted in **Figure 4.1** through **Figure 4.5**.

The NHC model was calibrated previously up to about RM 9.7. The two HEC-RAS models were merged, where NHC cross-sections were used below RM 9.7 and R2 cross-sections above RM 9.7.

(3) Estimate of Flow in Sloughs and Overtopping Levees

The NHC model was originally developed for unsteady flow simulation and the geometry of the model configuration had to be modified to facilitate steady flow simulations as part of the geomorphic sediment transport analysis. Haskell and Riley sloughs were removed from the

model geometry and replaced with corresponding flow change locations. In addition to the sloughs, water was also modeled to leave or enter the Skykomish River by overtopping levees during floods. To quantify the flows in the sloughs and/or overtopping the levees during high flows, the original NHC unsteady model was employed to simulate the hydraulics of the 1975, 1980, 1986, and 1990 storms. The storm hydrographs and boundary conditions were derived from the accompanying DSS files of the NHC model. The simulated hydrographs of the four storms at different locations along the Skykomish River were analyzed to determine the flow change relationship under various high flow conditions due to the presence of sloughs and levees.

A total of 8 locations were selected estimate flow changes, including just u/s of Riley Slough (RM 6.5), just u/s of Haskell Slough (RM 6.01), Monroe (RM 4.85), SR-203 Bridge (RM 3.96), just below where Haskell Slough returns (RM 3.09), RM 2.07, RM 0.92, and RM 0.16. Those locations were set as flow change points in the mainstem, with outflows to sloughs and levee overtopping, and inflows from slough outlets.

Figure 5.1 through **Figure 5.4** show the simulated hydrographs at those locations for each of the four storms. **Table 3.1** through **Table 3.4** list the flows read off from **Figure 5.1** through **Figure 5.4**, respectively, and each table summarizes the flows at different times from the beginning of each storm. **Figure 6.1** through **Figure 6.4** plot the flow variations for **Table 3.1** through **Table 3.4**, respectively.

In order to compare the same flow starting from below the Sultan River and varying in the downstream direction, the analysis needed to take average water particle travel time into account. Travel time from the confluence with the Sultan River (RM 13.07) to Riley Slough (RM 6.50) was estimated to be about two hours, and an additional 1 hour from Riley slough to the outlet of Haskell Slough. For simplicity, two hours of travel time (relative to Sultan River confluence at RM 13.07) was applied to the river reach between RM 6.5 and RM 3.09, and three hours of travel time was applied for the locations below RM 3.09.

The flow variations in **Table 3.1** through **Table 3.4** were then converted to percent of flow change with respect to the discharge of the upstream flow changing locations. The results are summarized in the **Table 4.1** through **Table 4.4**, in which Column 1 and Column 2 are, respectively, the time and the starting flow below the Sultan River (RM 13.07) directly from the NHC model output. Column 3 is percent of flow change above Riley Slough (RM 6.5) relative to flow below the Sultan River. Column 4 is the percent of flow leaving Skykomish River into Riley Slough relative to the flow below the Sultan River. Column 5 is the percent of flow entering Haskell Slough (RM 6.01) relative to the flow just upstream. Column 6 is the percent of flow leaving Skykomish River between Monroe (RM 4.85) and SR-203 Bridge (RM 3.96)

relative to the flow at Monroe. Column 7 is the percent of flow returning from Haskell Slough (RM 3.09) relative to the flow at the SR-203 bridge. Column 8 is the percent of flow leaving Skykomish River between RM 3.09 and RM 2.07 relative to the flow just below where Haskell Slough flow returns. Column 9 is the percent of flow leaving the Skykomish River between RM 0.92 and RM 2.08 relative to the flow at RM 2.08. Column 10 is the percent of flow leaving the Skykomish River between RM 0.92 and RM 0.16 relative to the flow at RM 0.92.

Figure 7.1 through **Figure 7.8** plot the percentages in **Table 4** versus flow below the Sultan River. Each of the eight plots in **Figure 7** contains the percentages from **Table 4.1** through **Table 4.4** for each of the four storms. A composite regression line was fit to the percentage data in each plot to describe first-order variation in the percent change.

Figure 7.1 plots the percent of flow increase between the Sultan River and Riley Slough (Column 2 in Table 2) and the plot shows little correlation among the points, with the majority of points falling within $\pm 4\%$. Because no significant tributaries or distributaries exist between the Sultan River and Riley Slough, it was assumed that the flows at these two locations would be approximately the same and 0% was assigned for all flows, as shown in the figure.

Figure 7.2 plots the percentage of flow entering Riley Slough (Column 3 in Table 2), and the graph shows that the percentage generally increases with increasing flow in the Skykomish River. A composite curve P was developed to fit the percentage data for the entire range of flows, per the following equations:

- (1) $Q \leq 30,000\text{cfs}$: $P=0\%$
- (2) $30,000\text{cfs} \leq Q \leq 100,000\text{cfs}$: $P=3\%*(Q-30,000)/70,000$
- (3) $Q \geq 100,000\text{cfs}$: $P=3\%+5%*(Q-100,000)/40,000$

Figure 7.3 plots the percentage of flow entering Haskell slough (Column 4 in Table 2), and the plot shows the percentage generally increases with increasing flow in the Skykomish River. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 8,000\text{cfs}$: $P=0\%$
- (2) $8,000\text{cfs} \leq Q \leq 40,000\text{cfs}$: $P=11%*(Q-8,000)/32,000$
- (3) $Q \geq 40,000\text{cfs}$: $P=11\%+13%*(Q-40,000)/100,000$

Figure 7.4 plots the percentage of flow leaving the Skykomish River between Monroe and the SR-203 bridge (Column 5 in Table 2). The plot shows the percentage generally decreases with increasing flow in the Skykomish River. A negative percent value indicates more flow is

entering than leaving the Skykomish River between Monroe and SR-203 Bridge. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 8,000\text{cfs}$: $P=0\%$
- (2) $8,000\text{cfs} \leq Q \leq 24,000\text{cfs}$: $P=6\%*(Q-8,000)/16,000$
- (3) $24,000\text{cfs} \leq Q \leq 80,000\text{cfs}$: $P=6\%$
- (4) $Q \geq 80,000\text{cfs}$: $P=6\%-19%*(Q-80,000)/60,000$

Figure 7.5 plots the percent of flow returning from Haskell Slough (Column 6 in Table 2), and the plot shows the percentage generally increases with increasing flow in the Skykomish River. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 12,000\text{cfs}$: $P=0\%$
- (2) $12,000\text{cfs} \leq Q \leq 52,000\text{cfs}$: $P=5\%+16%*(Q-12,000)/40,000$
- (3) $48,000\text{cfs} \leq Q \leq 100,000\text{cfs}$: $P=21\%$
- (4) $Q \geq 100,000\text{cfs}$: $P=21\%+14%*(Q-100,000)/40,000$

Figure 7.6 plots the percentage of flow leaving the Skykomish River between RM 3.09 and RM 2.07 (Column 7 in Table 2), and the plot shows the percentage generally increases with increasing flow in the Skykomish River. The percent values are always positive, suggesting there are generally more flows leaving than entering the Skykomish River within this reach during high flows. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 12,000\text{cfs}$: $P=0\%$
- (2) $12,000\text{cfs} \leq Q \leq 80,000\text{cfs}$: $P=20%*(Q-12,000)/68,000$
- (3) $Q \geq 80,000\text{cfs}$: $P=20\%+5%*(Q-80,000)/40,000$

Figure 7.7 plots the percentage of flow leaving the Skykomish River between RM 0.92 and RM 2.08 (Column 8 in Table 2), and the plot shows the percentage increases with flows less than 40,000 cfs, and decreased with increasing flows greater than 100,000cfs. The percentage is always positive, suggesting the flows are generally leaving the Skykomish River within this reach during high flows. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 8,000\text{cfs}$: $P=0\%$
- (2) $8,000\text{cfs} \leq Q \leq 40,000\text{cfs}$: $P=2\%+54%*(Q-8,000)/32,000$
- (3) $40,000\text{cfs} \leq Q \leq 100,000\text{cfs}$: $P=56\%$
- (4) $Q \geq 100,000\text{cfs}$: $P=56\%-36%*(Q-100,000)/40,000$

Figure 7.8 plots the percentage of flow leaving the Skykomish River between RM 0.92 and RM 0.16 (Column 9 in Table 2), and the plot shows the percentage generally decreases with increasing flows in the Skykomish River. The percentage values are mostly negative, suggesting the Skykomish River receives flows from the Snoqualmie River during high flows. A composite curve P was developed to fit the percent data, per the following equations:

- (1) $Q \leq 12,000\text{cfs}$: $P=0\%$
- (2) $12,000\text{cfs} \leq Q \leq 20,000\text{cfs}$: $P=5\%*(Q-12,000)/8,000$
- (3) $20,000\text{cfs} \leq Q \leq 40,000\text{cfs}$: $P=5\%$
- (4) $40,000\text{cfs} \leq Q \leq 80,000\text{cfs}$: $P=5\%-37%*(Q-40,000)/40,000$
- (3) $Q \geq 80,000\text{cfs}$: $P=-32\%$

(4) Estimating Sediment Transport Simulation Flows

After the percentage of flow change at each of the 8 locations was determined, flows at those locations could be estimated for any given steady flow level. Eleven simulation flows were modeled for the sediment transport analysis ranging from the 5% exceedance flow to the 50-yr return period flood at Gold Bar, as listed in **Table 5**. Also listed are the flows below the Wallace and Sultan rivers (see nhc 2008 hydrology memo). **Table 6** summarizes the estimated flows at each of the selected locations on the Skykomish River, after applying the equations above in **Figure 7.1** through **Figure 7.8**. **Figure 8** graphically shows the flows along the Skykomish River for the 11 simulation flows in **Table 6**.

Table 1: Flows for the 1990, 2006, and 2008 floods

Location	Flow (cfs)		
	Nov 1990 Flood	Nov 2006 Flood	Nov 2008 Flood
Skykomish River near Gold Bar	102000	129000	67500
Skykomish River below Wallace River	105070	129700	68350
Skykomish River below Sultan River	127270	132890	72220

Table 2. Hydraulic calibration summary for the HWMs of 1990, 2006, and 2008 floods

Flood	HWM Numbering	River Distance		HWM Elev (ft)	Modeled WSE	Calib Error (ft)
		(ft)	(RM)			
1990 Flood	1990-12	53064	10.05	97.99	98.185	0.20
	1990-13	60403	11.44	103.29	103.2	-0.09
	1990-14	62040	11.75	104.49	104.55	0.06
	1990-15	64838	12.28	105.29	110.14	4.85
	1990-16	70488	13.35	112.09	114.57	2.48
	1990-17	72442	13.72	116.29	115.91	-0.38
	1990-18	74501	14.11	118.59	118.76	0.17
	1990-19	75346	14.27	120.09	119.9	-0.19
	1990-20	78408	14.85	123.49	123.59	0.10
	1990-21	83054	15.73	135.19	135.13	-0.06
	1990-22	120226	22.77	235.09	235.15	0.06
2006 Flood	2006-5	57974	10.98	96.67	101.07	4.40
	2006-8	71333	13.51	113.96	113.64	-0.32
	2006-9	71333	13.51	116.52	116.13	-0.39
	2006-7	72125	13.66	114.89	114.84	-0.05
	2006-6	72125	13.66	114.6	114.84	0.24
	2006-10	79939	15.14	129.05	128.68	-0.37
	2006-11	81206	15.38	129.24	129.70	0.46
	2006-12	96413	18.26	158.57	162.62	4.05
	2006-13	107237	20.31	194.63	194.90	0.27
	2006-14	123130	23.32	248.26	252.63	4.37
	2006-15	128357	24.31	279.91	280.18	0.27
	2006-16	141187	26.74	351.25	351.53	0.28
	2006-17	153806	29.13	450.17	450.15	-0.02
2008 Flood	2008-7	50925	9.64	89.86	89.88	0.02
	2008-18	68524	12.98	107.84	109.79	1.95
	2008-19	68524	12.98	107.67	109.79	2.12
	2008-5	80250	15.20	127.14	127.21	0.07
	2008-4	84620	16.03	136.06	136.01	-0.05
	2008-14	122619	23.22	242.53	242.84	0.31
	2008-13	122709	23.24	242.89	243.19	0.30
	2008-3	123378	23.37	244.5	244.16	-0.33
	2008-1	123568	23.40	244.88	245.18	0.30
	2008-2	123748	23.44	245.7	246.15	0.45
	2008-11	128801	24.39	276.48	276.49	0.01
	2008-10	134177	25.41	304.02	304.19	0.17
	2008-9	154463	29.25	453.2	453.22	0.02
	2008-8	154608	29.28	453.21	453.46	0.25

Table 3.1 Simulated flows (cfs) of Nov, 1975 flood at different locations on the Skykomish River where flows are changed due to sloughs and/or levees. Estimated travel times from Sultan River to each location are also indicated.

Location	below Sultan R.	u/s of Riley	u/s of Haskel	at Monroe	at SR-203 Bridge	below Haskel	RM-2	RM-1	RM-0
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
Time	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/30/1975 12:00	3,078	2,209	2,126	1,989	2,393	2,818	2,668	2,513	2,403
12/1/1975 0:00	15,240	15,349	15,253	14,475	14,013	15,291	15,028	12,419	12,179
12/1/1975 12:00	33,969	33,107	32,971	29,580	27,425	32,907	31,780	15,842	15,153
12/2/1975 0:00	53,760	53,489	53,287	46,632	44,094	53,694	47,608	21,561	25,166
12/2/1975 4:00	68,243	66,735	66,018	56,237	53,278	66,517	55,419	25,715	32,712
12/2/1975 8:00	88,580	88,026	86,856	72,114	70,922	85,964	68,576	35,578	47,790
12/2/1975 12:00	102,296	100,773	98,169	80,118	81,692	97,222	75,765	50,841	67,592
12/2/1975 20:00	80,626	82,380	82,260	69,325	70,958	82,527	64,839	68,991	90,186
12/3/1975 5:00	97,324	97,895	95,926	78,799	81,243	95,660	71,406	79,677	102,109
12/4/1975 0:00	74,509	75,718	75,676	64,225	64,784	76,197	58,215	76,895	99,549
12/4/1975 8:00	87,218	88,035	87,385	72,931	74,325	87,378	65,767	76,526	98,560
12/5/1975 0:00	40,072	42,341	42,559	38,243	37,375	43,432	38,826	54,256	74,287

Table 3.2 Simulated flows (cfs) of Dec, 1980 flood at different locations on the Skykomish River where flows are changed due to sloughs and/or levees.
Estimated travel times from Sultan River to each location are also indicated.

Location	below Sultan R.	u/s of Riley	u/s of Haskel	at Monroe	at SR-203 Bridge	below Haskel	RM-2	RM-1	RM-0
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
12/23/1980 1:00	14,127	14,386	14,419	14,126	13,777	14,591	14,684	12,251	12,361
12/23/1980 8:00	12,411	12,726	12,740	12,535	12,384	13,196	13,234	11,467	11,595
12/23/1980 9:00	12,278	12,589	12,601	12,405	12,268	13,080	13,113	11,400	11,515
12/23/1980 11:00	12,044	12,364	12,374	12,195	12,074	12,862	12,892	11,278	11,378
12/23/1980 13:00	11,866	12,179	12,186	12,020	11,896	12,679	12,705	11,166	11,244
12/24/1980 0:00	13,311	13,739	13,701	13,276	13,303	14,323	14,229	12,033	11,960
12/24/1980 20:00	35,706	35,295	35,177	31,386	29,506	35,745	34,099	15,988	15,681
12/25/1980 0:00	43,032	42,670	42,350	37,271	35,547	44,185	40,349	18,732	19,168
12/25/1980 2:00	52,804	51,132	50,475	43,669	41,369	52,710	46,104	20,343	21,911
12/25/1980 5:00	74,851	72,491	71,307	59,782	57,071	72,359	58,835	24,693	29,896
12/25/1980 7:00	90,131	89,546	87,621	72,054	70,299	87,965	69,076	28,479	36,831
12/25/1980 11:00	113,185	111,352	106,449	84,968	88,008	106,941	81,494	38,899	51,826

Table 3.3 Simulated flows (cfs) of Nov, 1986 flood at different locations on the Skykomish River where flows are changed due to sloughs and/or levees. Estimated travel times from Sultan River to each location are also indicated.

Location	below Sultan R.	u/s of Riley	u/s of Haskel	at Monroe	at SR-203 Bridge	below Haskel	RM-2	RM-1	RM-0
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/20/1986 1:00	9,237	9,457	9,458	9,420	9,942	10,531	10,456	9,619	9,582
11/20/1986 8:00	19,216	19,107	18,609	16,778	16,422	20,199	19,022	13,937	12,514
11/20/1986 10:00	29,717	28,473	28,170	24,798	23,247	27,857	26,117	16,319	15,523
11/20/1986 14:00	38,990	38,778	38,682	34,475	32,537	38,999	36,796	16,840	15,975
11/21/1986 0:00	25,827	26,884	26,974	25,124	24,381	27,924	28,252	15,668	16,227
11/22/1986 0:00	14,455	14,904	14,932	14,562	14,401	15,264	15,342	13,112	13,221
11/23/1986 0:00	12,161	12,401	12,396	12,187	11,972	12,793	12,781	11,200	11,237
11/23/1986 12:00	39,387	38,072	37,742	33,168	31,425	38,921	35,919	16,050	14,893
11/23/1986 16:00	63,610	61,081	59,855	50,742	47,691	62,202	51,990	20,648	21,883
11/23/1986 18:00	81,848	79,798	78,318	64,908	62,317	79,233	63,169	24,571	29,347
11/23/1986 21:00	93,929	94,458	92,888	76,693	79,077	94,126	73,859	30,461	40,441
11/24/1986 17:00	40,504	43,851	44,128	39,562	39,888	45,966	40,209	58,389	78,453

Table 3.4 Simulated flows (cfs) of Nov, 1990 flood at different locations on the Skykomish River where flows are changed due to sloughs and/or levees. Estimated travel times from Sultan River to each location are also indicated.

Location	below Sultan R.	u/s of Riley	u/s of Haskel	at Monroe	at SR-203 Bridge	below Haskel	RM-2	RM-1	RM-0
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/22/1990 1:00	7,043	7,142	7,118	7,032	7,126	7,491	7,410	7,014	6,980
11/22/1990 8:00	14,703	14,887	14,505	13,296	12,359	15,067	14,089	11,569	10,827
11/22/1990 9:00	20,353	19,171	18,633	16,735	15,492	19,035	17,746	13,363	12,321
11/22/1990 11:00	30,246	28,352	28,069	24,801	22,572	26,942	25,323	16,322	15,296
11/22/1990 13:00	35,424	33,885	33,692	30,059	27,650	33,188	31,751	16,354	15,377
11/23/1990 0:00	43,065	43,191	43,193	38,489	36,052	43,161	40,362	19,050	20,956
11/23/1990 20:00	44,762	43,933	43,574	38,324	35,644	44,682	40,474	27,602	36,488
11/24/1990 0:00	75,912	72,792	71,267	59,480	55,387	72,027	58,142	33,084	44,393
11/24/1990 2:00	96,508	94,976	92,344	75,402	72,948	92,240	71,320	38,763	52,118
11/24/1990 5:00	120,438	121,734	114,254	89,534	94,547	118,271	87,580	51,906	68,072
11/24/1990 6:00	126,607	128,201	119,408	91,973	99,759	123,430	91,040	57,301	74,522
11/24/1990 9:00	133,408	133,996	124,271	94,326	104,954	127,074	93,065	72,508	92,552

Table 4.1 Estimated flow percentage leaving or entering Skykomish River for the Nov 1975 storm at selected locations where flows would change in the HEC-RAS model.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
	Flow (cfs)	% of low change relative to flow below Sultan R.	% of flow out to Riley Slough relative to flow below Sultan R.	% flow out to Haskel Slough relative to flow above Haskell	% of overtopping outflow relative to flow at Monroe	% of return flow from Haskel relative to flow at SR-203 Bridge	% of overtopping outflow relative to flow below where Haskel returns	% of overtopping outflow relative to flow at RM=2.07	% of overtopping outflow relative to flow at RM 0.92
Location	below Sultan	u/s of Riley	u/s of Haskel	at Monroe	at SR-203 Bridge	bl Haskel returns	RM-2	RM-1	RM-0
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/30/1975 12:00	3,078	-28.2%	2.7%	6.4%	-20.3%	34.7%	5.3%	5.8%	4.4%
12/1/1975 0:00	15,240	0.7%	0.6%	5.1%	3.2%	5.8%	1.7%	17.4%	1.9%
12/1/1975 12:00	33,969	-2.5%	0.4%	10.3%	7.3%	12.1%	3.4%	50.1%	4.4%
12/2/1975 0:00	53,760	-0.5%	0.4%	12.5%	5.4%	16.0%	11.3%	54.7%	-16.7%
12/2/1975 4:00	68,243	-2.2%	1.1%	14.8%	5.3%	19.3%	16.7%	53.6%	-27.2%
12/2/1975 8:00	88,580	-0.6%	1.3%	17.0%	1.7%	19.5%	20.2%	48.1%	-34.3%
12/2/1975 12:00	102,296	-1.5%	2.5%	18.4%	-2.0%	20.9%	22.1%	32.9%	-32.9%
12/2/1975 20:00	80,626	2.2%	0.1%	15.7%	-2.4%	18.6%	21.4%	-6.4%	-30.7%
12/3/1975 5:00	97,324	0.6%	2.0%	17.9%	-3.1%	20.8%	25.4%	-11.6%	-28.2%
12/4/1975 0:00	74,509	1.6%	0.1%	15.1%	-0.9%	18.5%	23.6%	-32.1%	-29.5%
12/4/1975 8:00	87,218	0.9%	0.7%	16.5%	-1.9%	19.4%	24.7%	-16.4%	-28.8%
12/5/1975 0:00	40,072	5.7%	-0.5%	10.1%	2.3%	13.9%	10.6%	-39.7%	-36.9%

Table 4.2 Estimated flow percentage leaving or entering Skykomish River for the Dec 1980 storm at selected locations where flows would change in the HEC-RAS model.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
	Flow (cfs)	% of low change relative to flow below Sultan R.	% of flow out to Riley Slough relative to flow below Sultan R.	% flow out to Haskell Slough relative to flow above Haskell	% of overtopping outflow relative to flow at Monroe	% of return flow from Haskell relative to flow at SR-203 Bridge	% of overtopping outflow relative to flow below where Haskell returns	% of overtopping outflow relative to flow at RM=2.07	% of overtopping outflow relative to flow at RM 0.92
Location	below Sultan	u/s of Riley	u/s of Haskell	at Monroe	at SR-203 Bridge	bl Haskell slough	RM-2	RM-1	RM-0
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
12/23/1980 1:00	14,127	1.8%	-0.2%	2.0%	2.5%	3.4%	-0.6%	16.6%	-0.9%
12/23/1980 8:00	12,411	2.5%	-0.1%	1.6%	1.2%	5.3%	-0.3%	13.4%	-1.1%
12/23/1980 9:00	12,278	2.5%	-0.1%	1.6%	1.1%	5.5%	-0.3%	13.1%	-1.0%
12/23/1980 11:00	12,044	2.7%	-0.1%	1.4%	1.0%	5.5%	-0.2%	12.5%	-0.9%
12/23/1980 13:00	11,866	2.6%	-0.1%	1.4%	1.0%	5.5%	-0.2%	12.1%	-0.7%
12/24/1980 0:00	13,311	3.2%	0.3%	3.1%	-0.2%	7.9%	0.7%	15.4%	0.6%
12/24/1980 20:00	35,706	-1.2%	0.3%	10.8%	6.0%	14.8%	4.6%	53.1%	1.9%
12/25/1980 0:00	43,032	-0.8%	0.7%	12.0%	4.6%	19.4%	8.7%	53.6%	-2.3%
12/25/1980 2:00	52,804	-3.2%	1.2%	13.5%	5.3%	21.9%	12.5%	55.9%	-7.7%
12/25/1980 5:00	74,851	-3.2%	1.6%	16.2%	4.5%	22.0%	18.7%	58.0%	-21.1%
12/25/1980 7:00	90,131	-0.6%	2.1%	17.8%	2.4%	22.6%	21.5%	58.8%	-29.3%
12/25/1980 11:00	113,185	-1.6%	4.3%	20.2%	-3.6%	25.0%	23.8%	52.3%	-33.2%

Table 4.3 Estimated flow percentage leaving or entering Skykomish River for the Nov 1986 storm at selected locations where flows would change in the HEC-RAS model.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
	Flow (cfs)	% of low change relative to flow below Sultan R.	% of flow out to Riley Slough relative to flow below Sultan R.	% flow out to Haskell Slough relative to flow above Haskell	% of overtopping outflow relative to flow at Monroe	% of return flow from Haskell relative to flow at SR-203 Bridge	% of overtopping outflow relative to flow below where Haskell returns	% of overtopping outflow relative to flow at RM=2.07	% of overtopping outflow relative to flow at RM 0.92
Location	below Sultan	u/s of Riley	u/s of Haskell	at Monroe	at SR-203 Bridge	bl Haskell slough	RM-2	RM-1	RM-0
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/21/1986 1:00	24,890	2.4%	0.0%	0.4%	-5.5%	11.2%	0.7%	8.0%	0.4%
11/21/1986 8:00	21,519	-0.6%	2.6%	9.8%	2.1%	20.8%	5.8%	26.7%	10.2%
11/21/1986 10:00	20,383	-4.2%	1.0%	12.0%	6.3%	13.2%	6.2%	37.5%	4.9%
11/21/1986 14:00	18,134	-0.5%	0.2%	10.9%	5.6%	13.9%	5.6%	54.2%	5.1%
11/22/1986 0:00	14,455	4.1%	-0.3%	6.9%	3.0%	11.5%	-1.2%	44.5%	-3.6%
11/23/1986 0:00	12,161	3.1%	-0.2%	2.5%	1.1%	4.9%	-0.5%	14.5%	-0.8%
11/24/1986 0:00	89,552	2.0%	0.0%	1.7%	1.8%	5.1%	0.1%	12.4%	-0.3%
11/24/1986 12:00	54,737	-3.3%	0.8%	12.1%	5.3%	18.3%	7.7%	55.3%	7.2%
11/24/1986 16:00	42,605	-4.0%	1.9%	15.2%	6.0%	24.0%	16.4%	60.3%	-6.0%
11/24/1986 18:00	38,499	-2.5%	1.8%	17.1%	4.0%	23.0%	20.3%	61.1%	-19.4%
11/24/1986 21:00	33,424	0.6%	1.7%	17.4%	-3.1%	22.0%	21.5%	58.8%	-32.8%
1/0/1900 0:00	00,000	8.3%	-0.7%	10.3%	-0.8%	16.1%	12.5%	-45.2%	-34.4%

Table 4.4 Estimated flow percentage leaving or entering Skykomish River for the Nov 1990 storm at selected locations where flows would change in the HEC-RAS model.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Travel Time	+ 0 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 2 hr	+ 3 hr	+ 3 hr	+ 3 hr	+ 3 hr
	Flow (cfs)	% of low change relative to flow below Sultan R.	% of flow out to Riley Slough relative to flow below Sultan R.	% flow out to Haskell Slough relative to flow above Haskell	% of overtopping outflow relative to flow at Monroe	% of return flow from Haskell relative to flow at SR-203 Bridge	% of overtopping outflow relative to flow below where Haskell returns	% of overtopping outflow relative to flow at RM=2.07	% of overtopping outflow relative to flow at RM 0.92
Location	below Sultan	u/s of Riley	u/s of Haskell	at Monroe	at SR-203 Bridge	bl Haskell slough	RM-2	RM-1	RM-0
Time / RM	RM 13.07	RM 6.5	RM 6.01	RM 4.85	RM 3.96	RM 3.09	RM 2.07	RM 0.92	RM 0.16
11/22/1990 1:00	7,043	1.4%	0.3%	1.2%	-1.3%	6.4%	1.1%	5.3%	0.5%
11/22/1990 8:00	14,703	1.2%	2.6%	8.3%	7.0%	14.3%	6.5%	17.9%	6.4%
11/22/1990 9:00	20,353	-5.8%	2.6%	10.2%	7.4%	14.8%	6.8%	24.7%	7.8%
11/22/1990 11:00	30,246	-6.3%	0.9%	11.6%	9.0%	9.5%	6.0%	35.5%	6.3%
11/22/1990 13:00	35,424	-4.3%	0.5%	10.8%	8.0%	11.3%	4.3%	48.5%	6.0%
11/23/1990 0:00	43,065	0.3%	0.0%	10.9%	6.3%	13.0%	6.5%	52.8%	-10.0%
11/23/1990 20:00	44,762	-1.9%	0.8%	12.0%	7.0%	17.8%	9.4%	31.8%	-32.2%
11/24/1990 0:00	75,912	-4.1%	2.0%	16.5%	6.9%	22.7%	19.3%	43.1%	-34.2%
11/24/1990 2:00	96,508	-1.6%	2.7%	18.3%	3.3%	23.1%	22.7%	45.6%	-34.5%
11/24/1990 5:00	120,438	1.1%	6.2%	21.6%	-5.6%	30.4%	25.9%	40.7%	-31.1%
11/24/1990 6:00	126,607	1.3%	6.9%	23.0%	-8.5%	31.5%	26.2%	37.1%	-30.1%
11/24/1990 9:00	133,408	0.4%	7.3%	24.1%	-11.3%	31.2%	26.8%	22.1%	-27.6%

Table 5. Simulation flows for sediment transport study.

Flow Scenario	Flow % Exceedance (Return Period)	Flow (cfs)		
		near Gold Bar	below Wallace River	below Sultan River
1	5	10600	11635	13325
2	1	18500	20109	22379
3	0.5	24500	26699	29939
4	0.4	26400	28737	32117
5	0.3	28800	31408	35298
6	0.2	34300	37557	42707
7	0.14 ($Q_{2\text{yr}}$)	40900	42500	47000
8	0.1	41100	45470	53250
9	0.03 ($Q_{10\text{yr}}$)	77000	82900	97900
10	0.01 ($Q_{25\text{yr}}$)	97500	103000	120000
11	0.005 ($Q_{50\text{yr}}$)	113000	119200	139200

Table 6. Estimated flows at flow changing points on the Skykomish River for the 11 sediment transport simulation flow scenarios.

Flow % Excd (Return period)	Flow (cfs)										
	bl Sultan River	above Riley	above Haskell	@ RM 5.48	@ Monroe	@ SR-203	bl Haskell return	@ RM 2.07	@ RM 1.51	@ RM 0.92	@ RM 0.16
RM	13.09	6.5	6.01	5.48	4.85	3.96	3.09	2.07	1.51	0.92	0.16
5	13325	13325	13325	13081	13081	12820	13529	13476	12755	11996	11896
1	22379	22379	22379	21273	21273	20126	21968	21297	18573	15703	14918
0.5	29939	29939	29939	27681	27681	26020	29188	27648	22395	16859	16016
0.4	32117	32117	32088	29428	29428	27662	31271	29421	23304	16859	16016
0.3	35298	35298	35218	33708	31913	29998	34294	31944	24467	16590	15760
0.2	42707	42707	42474	40271	37653	35394	41511	37762	27464	16615	16200
0.14 (Q _{2yr})	47000	47000	46658	44119	41101	38635	45975	41242	29996	18147	18414
0.1	53250	53250	52719	49655	46012	43251	52334	45985	33445	20233	21702
0.03 (Q _{10yr})	97900	97900	95051	87005	77441	77184	93393	72625	52820	31955	42180
0.01 (Q _{25yr})	120000	120000	113400	102312	89132	95075	121695	91272	74382	56588	74697
0.005 (Q _{50yr})	139200	139200	128203	114206	97568	110004	148198	107592	96736	85299	112594

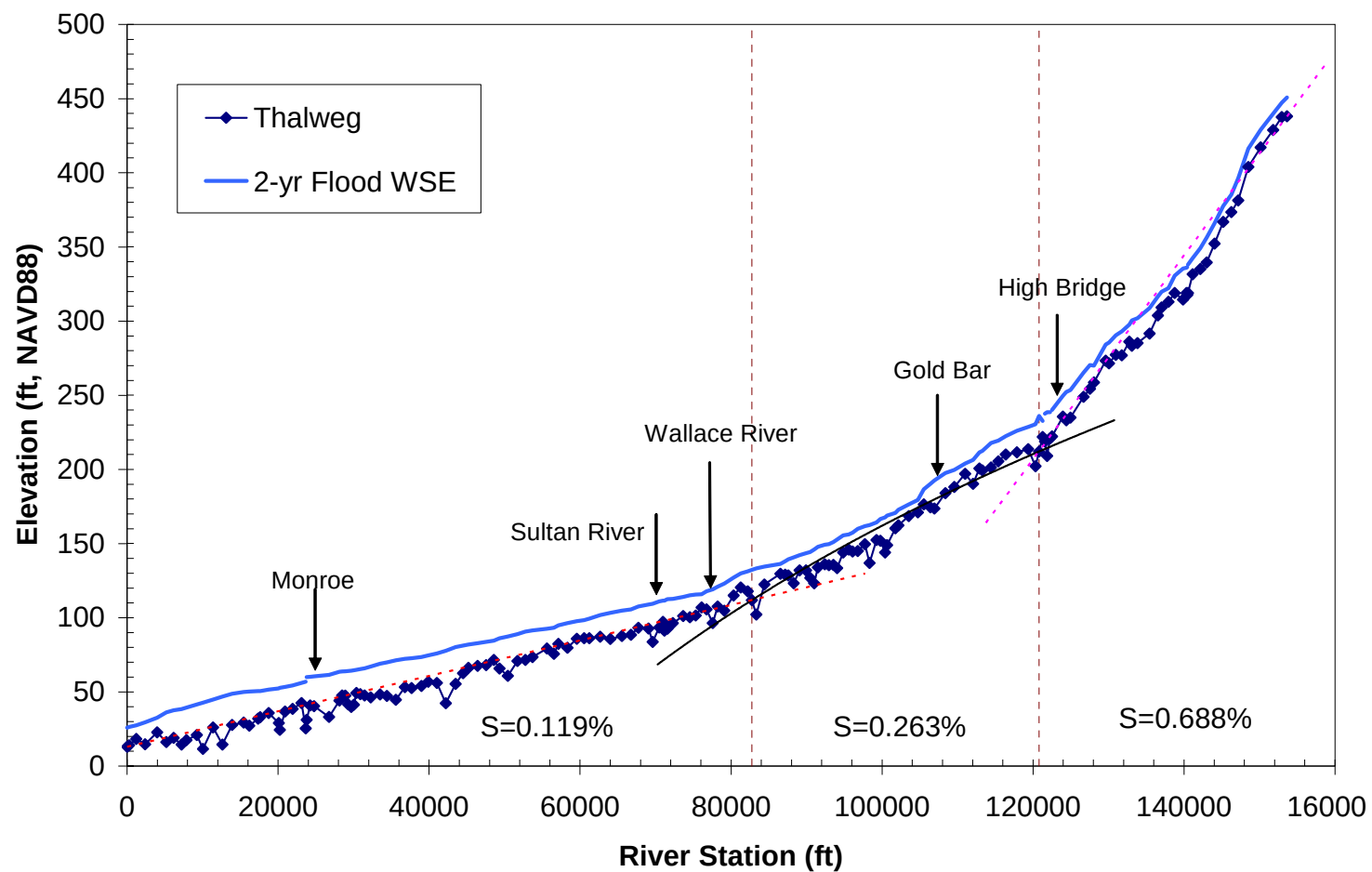


Figure 1. Skykomish River main channel thalweg profile and large scale channel longitudinal gradients.

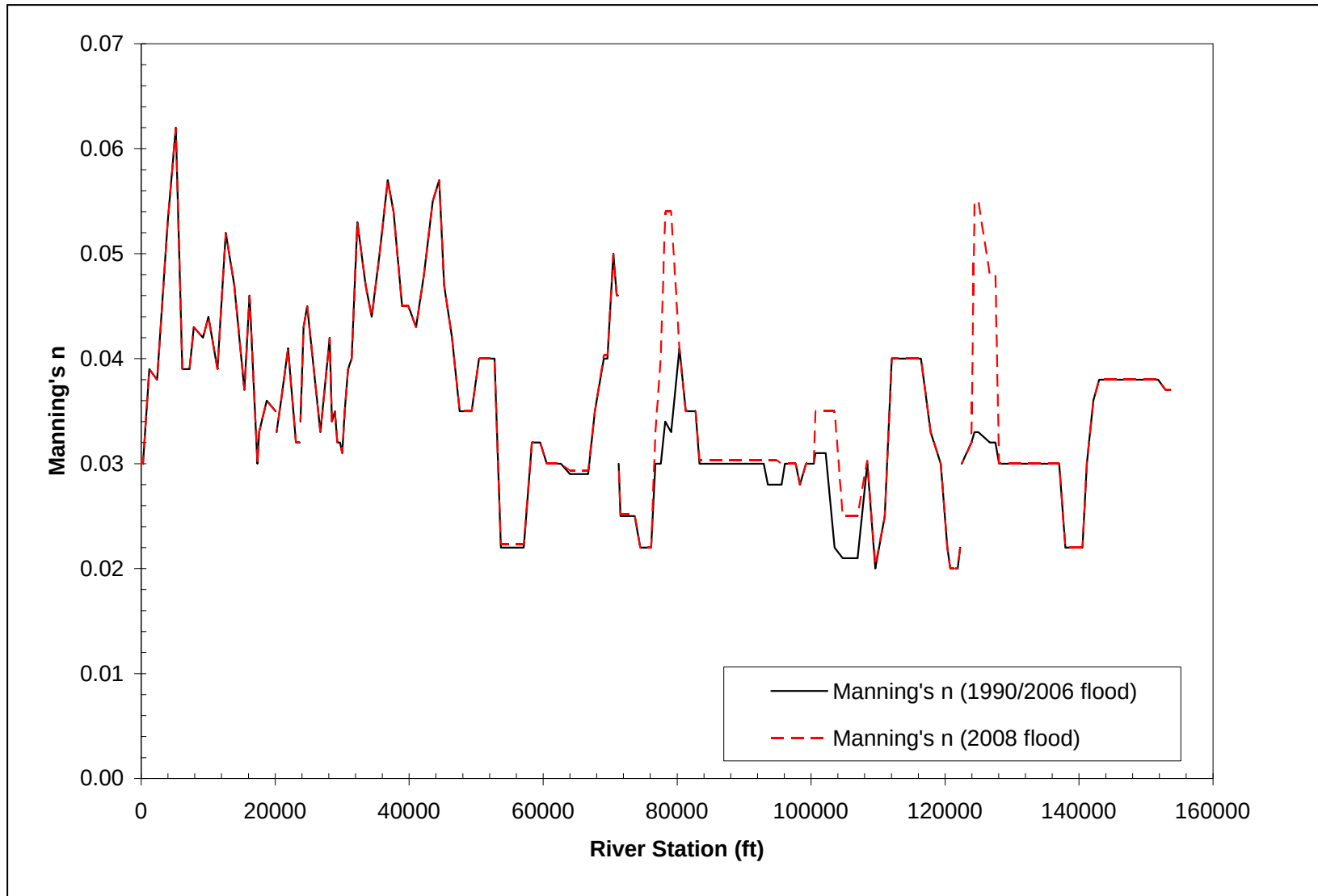


Figure 2. Calibrated channel roughness coefficients for the Skykomish River main channel, per HWMs of 1990, 2006, and 2008 floods.

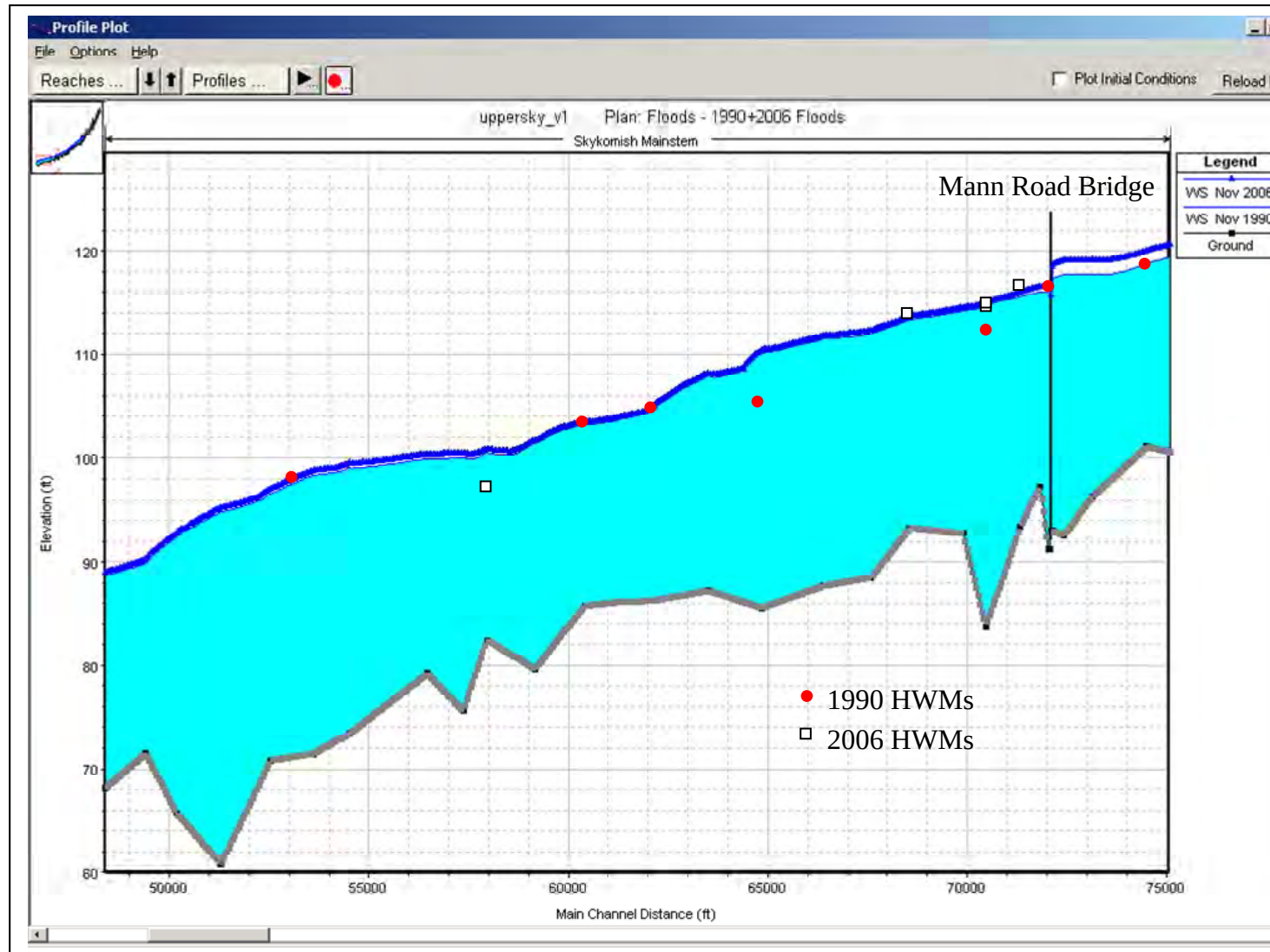


Figure 3.1 Skykomish River WSE calibration for 1990 and 2006 flood flows. River distance = 50000ft (RM 9.47) ~ 75000ft (RM 14.20). Circles and squares are the HWMs of 1990 flood and 2006 flood, respectively.

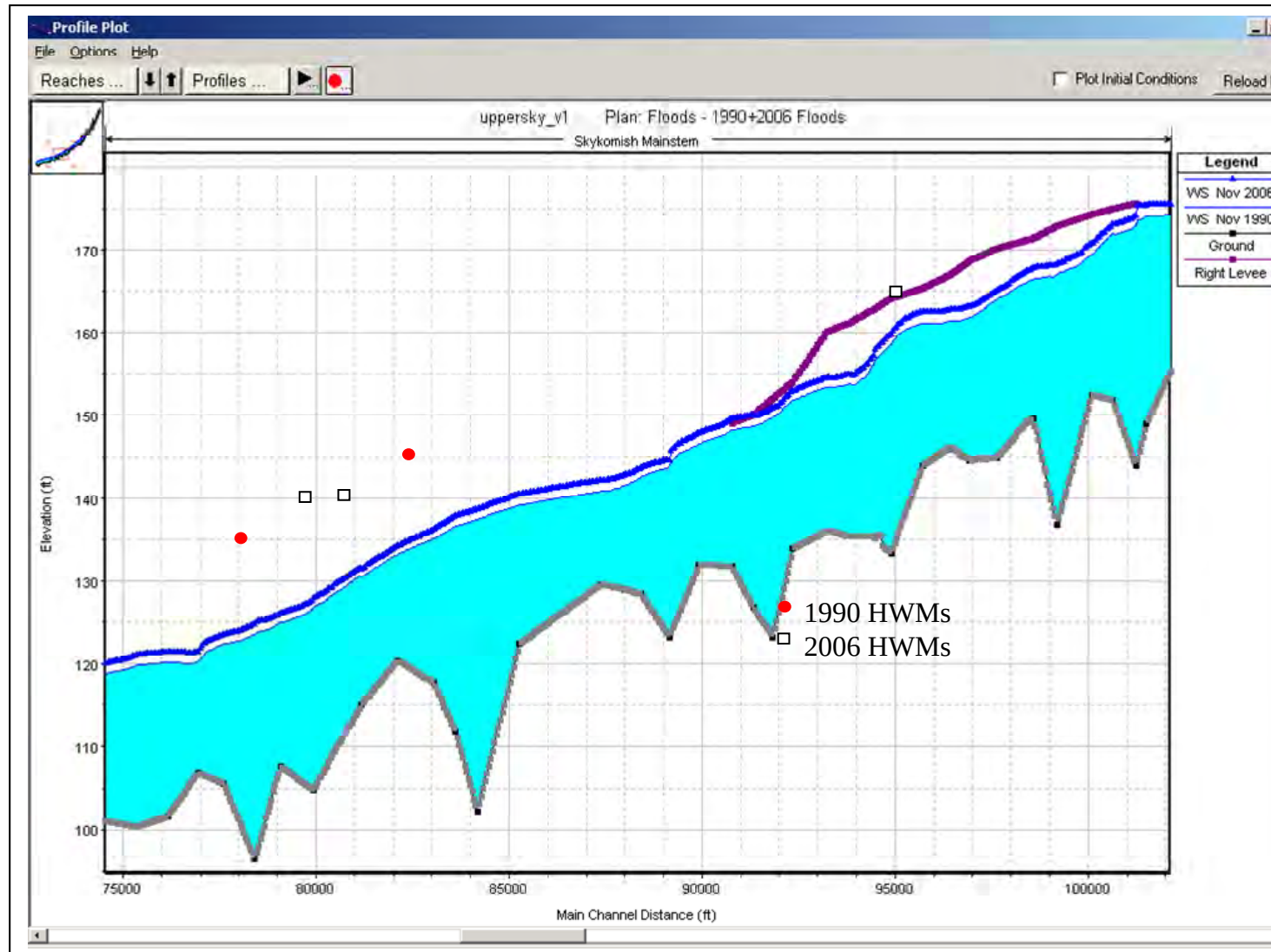


Figure 3.2 Skykomish River WSE calibration for 1990 and 2006 flood flows. River distance = 75,000ft (RM 14.20) ~ 100,000ft (RM 18.94). Circles and squares are the HWMs of 1990 flood and 2006 flood, respectively.

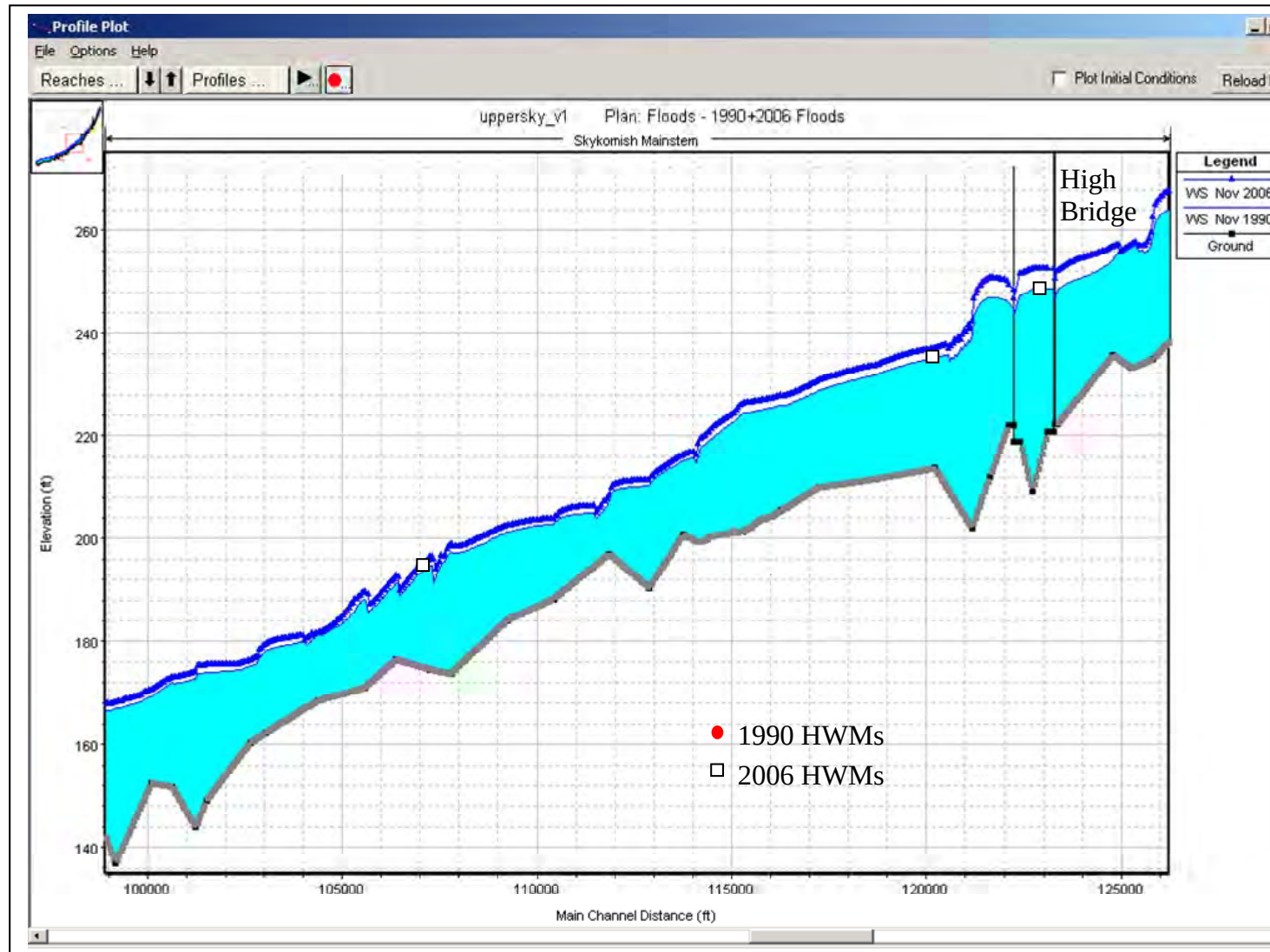


Figure 3.3 Skykomish River WSE calibration for 1990 and 2006 flood flows. River distance = 100,000ft (RM 18.94) ~ 125,000ft (RM 23.67). Circles and squares are the HWMs of 1990 flood and 2006 flood, respectively.

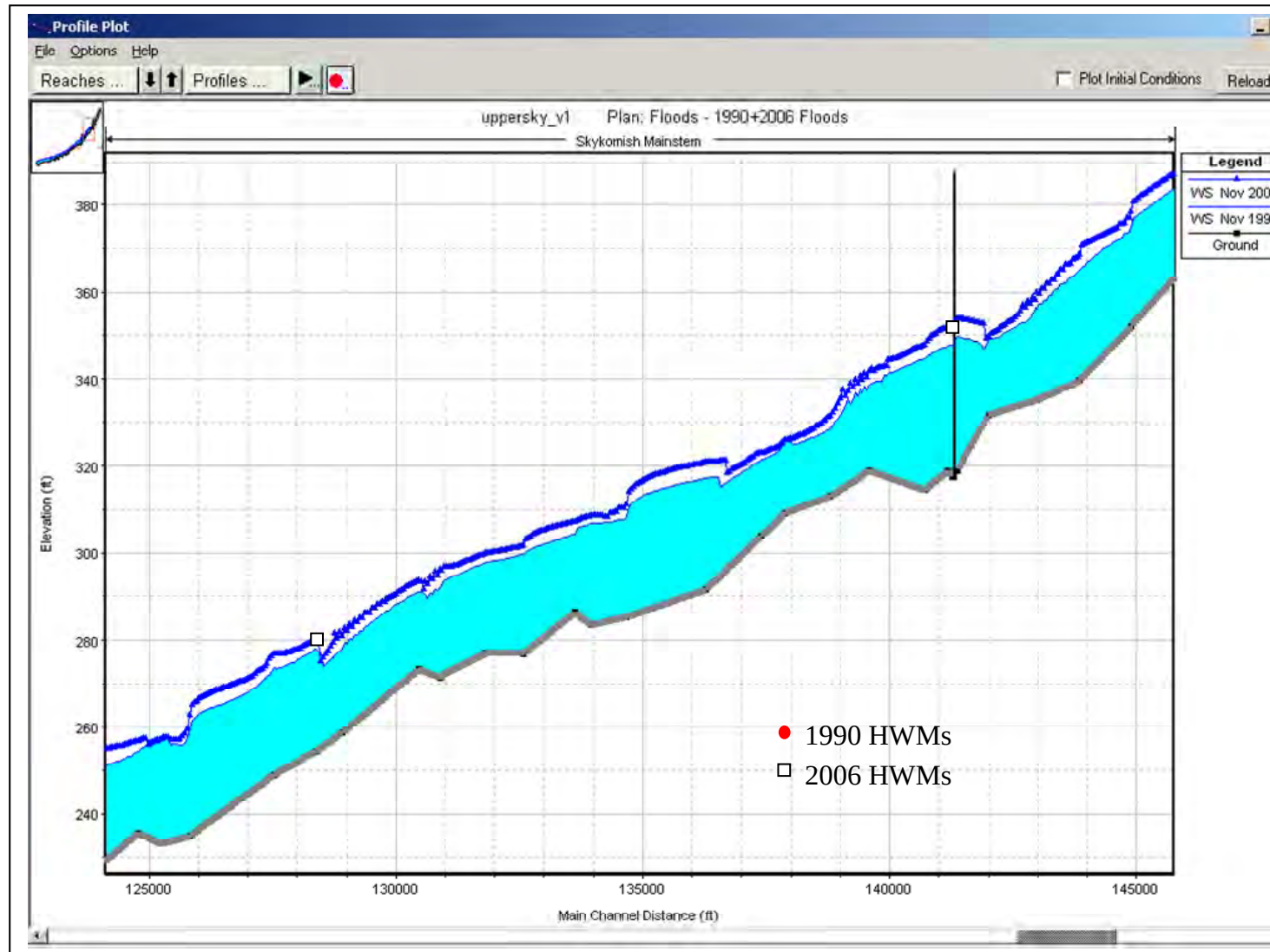


Figure 3.4 Skykomish River WSE calibration for 1990 and 2006 flood flows. River distance = 125,000ft (RM 23.67) ~ 145,000ft (RM 27.46). Circles and squares are the HWMs of 1990 flood and 2006 flood, respectively.

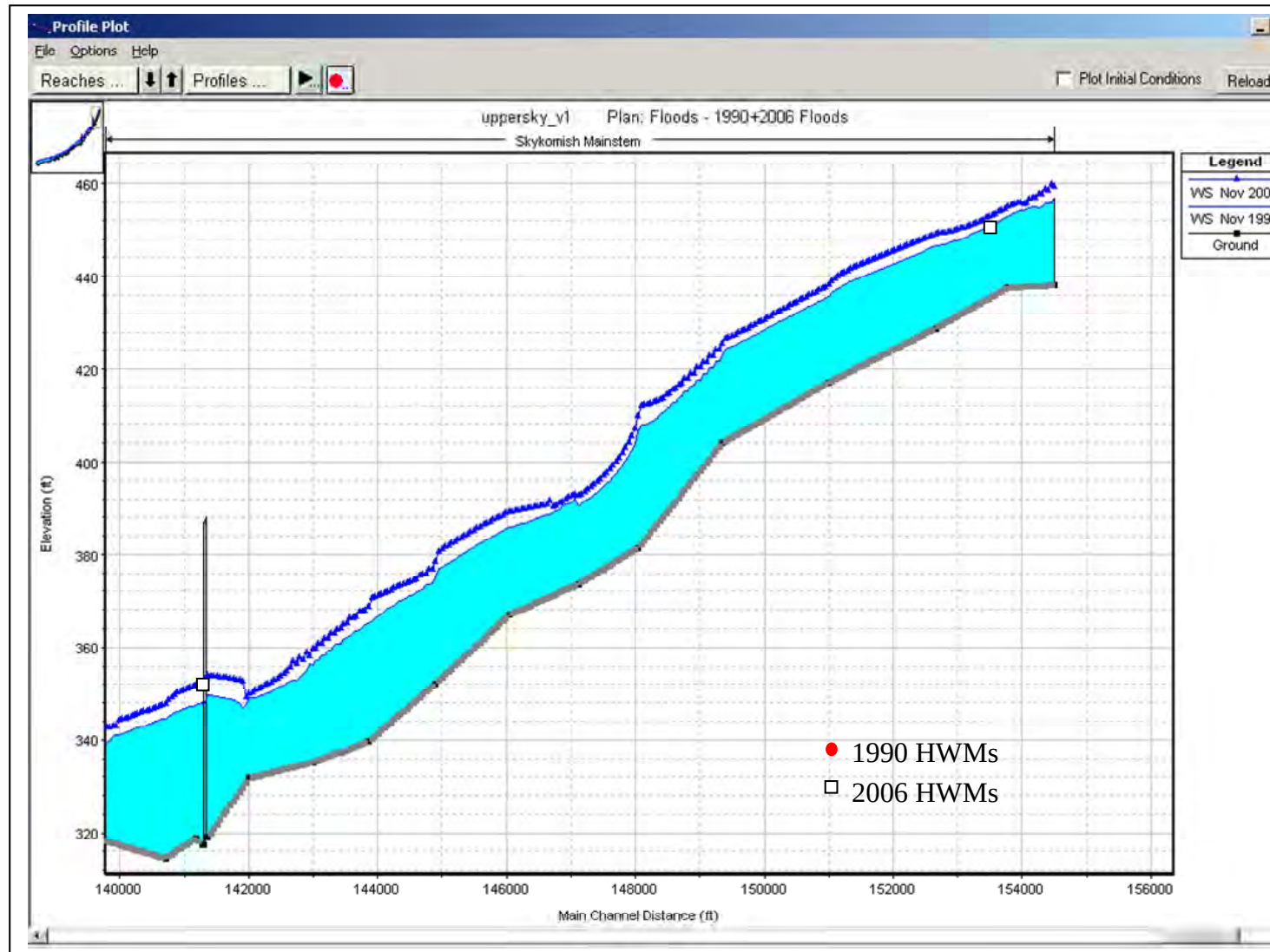


Figure 3.5 Skykomish River WSE calibration for 1990 and 2006 flood flows. River distance > 140,000ft (RM 26.52). Circles and squares are the HWMs of 1990 flood and 2006 flood, respectively.

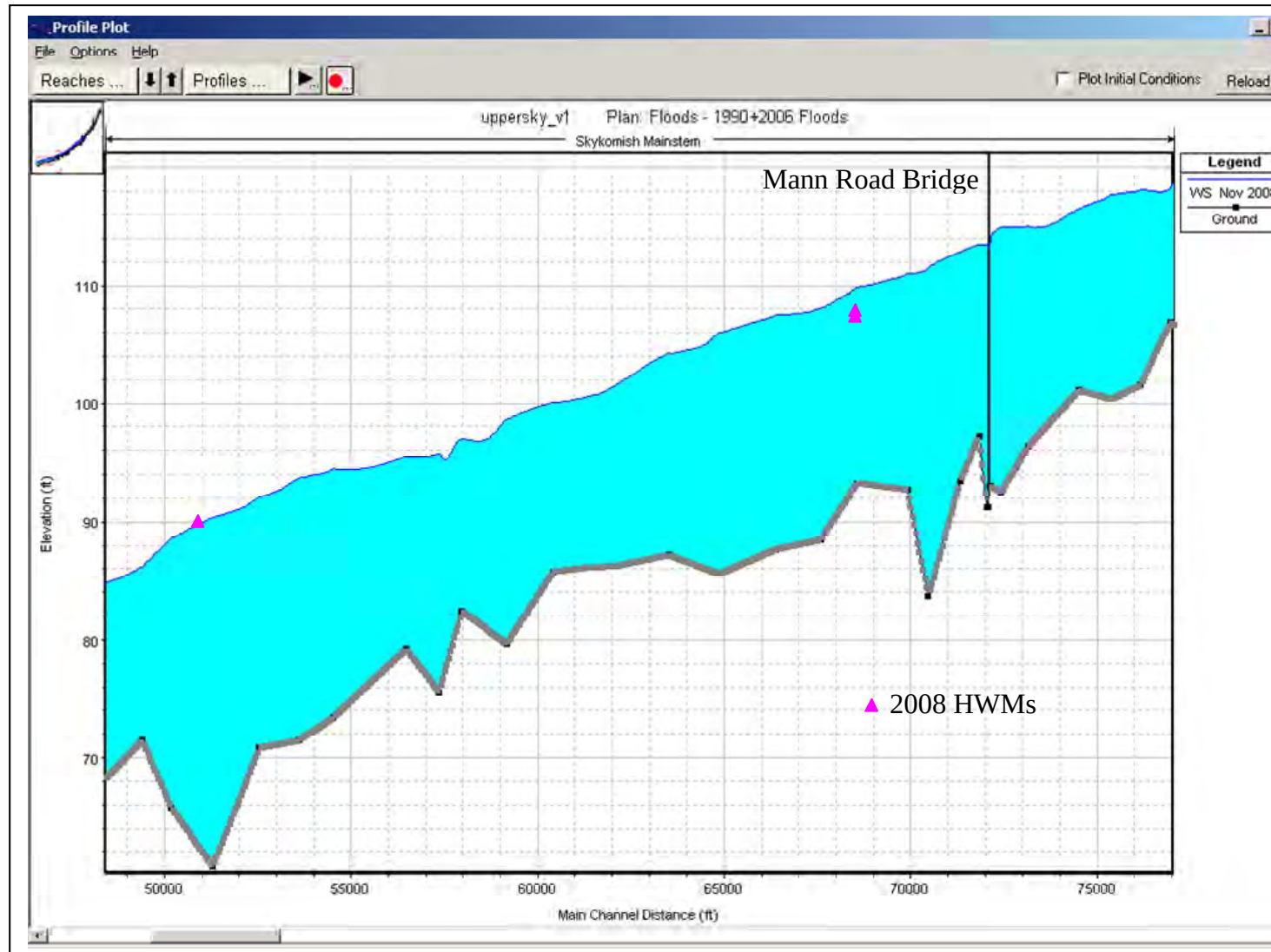


Figure 4.1 Skykomish River WSE calibration for the 2008 flood flow. River distance = 50,000ft (RM 9.47) ~ 75,000ft (RM 14.20). Triangles indicate the HWMs of 2008 flood.

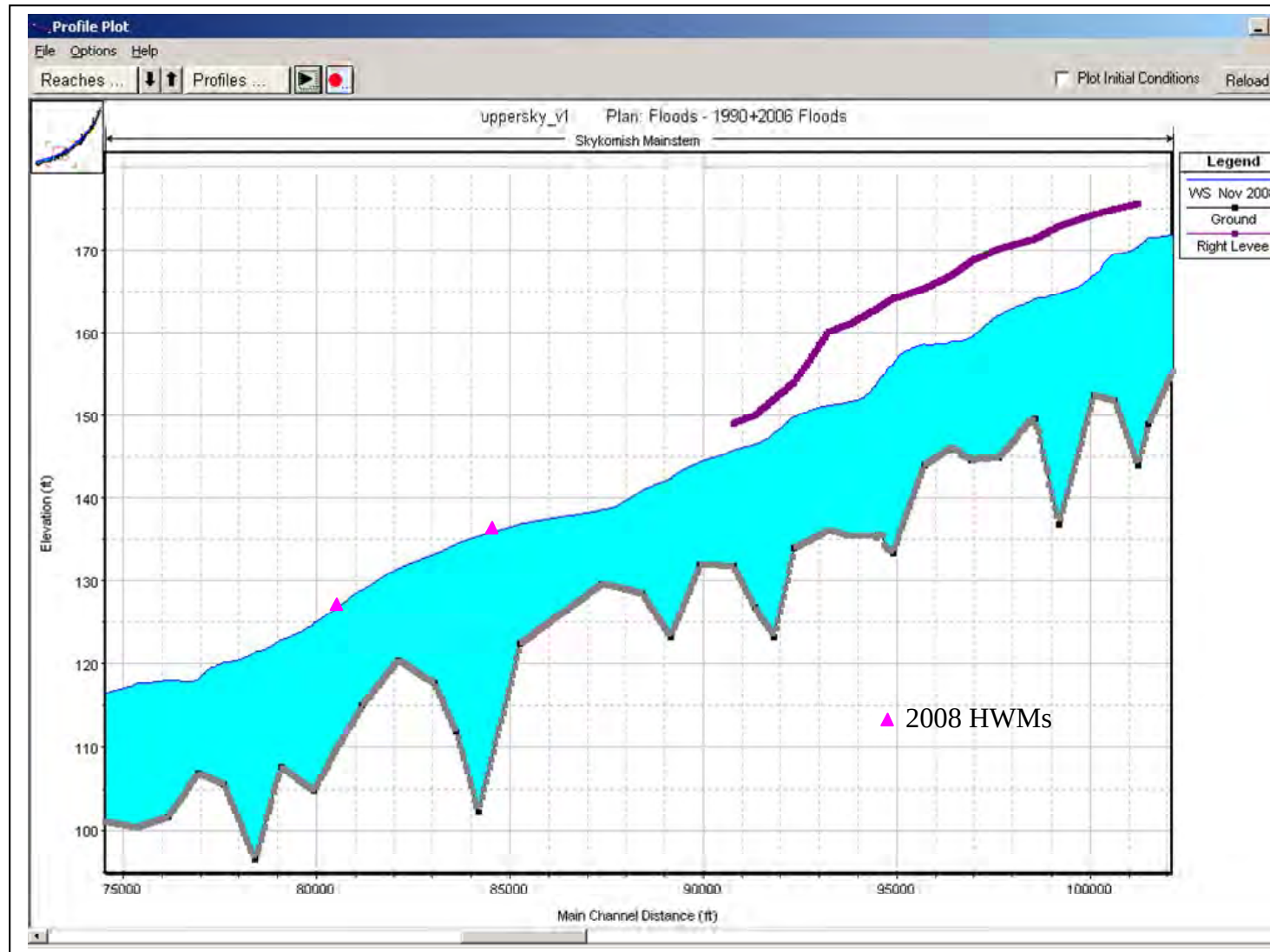


Figure 4.2 Skykomish River WSE calibration for 2008 flood flow. River distance = 75,000ft (RM 14.20) ~ 100,000ft (RM 18.94). Triangles indicate the HWMs of 2008 flood.

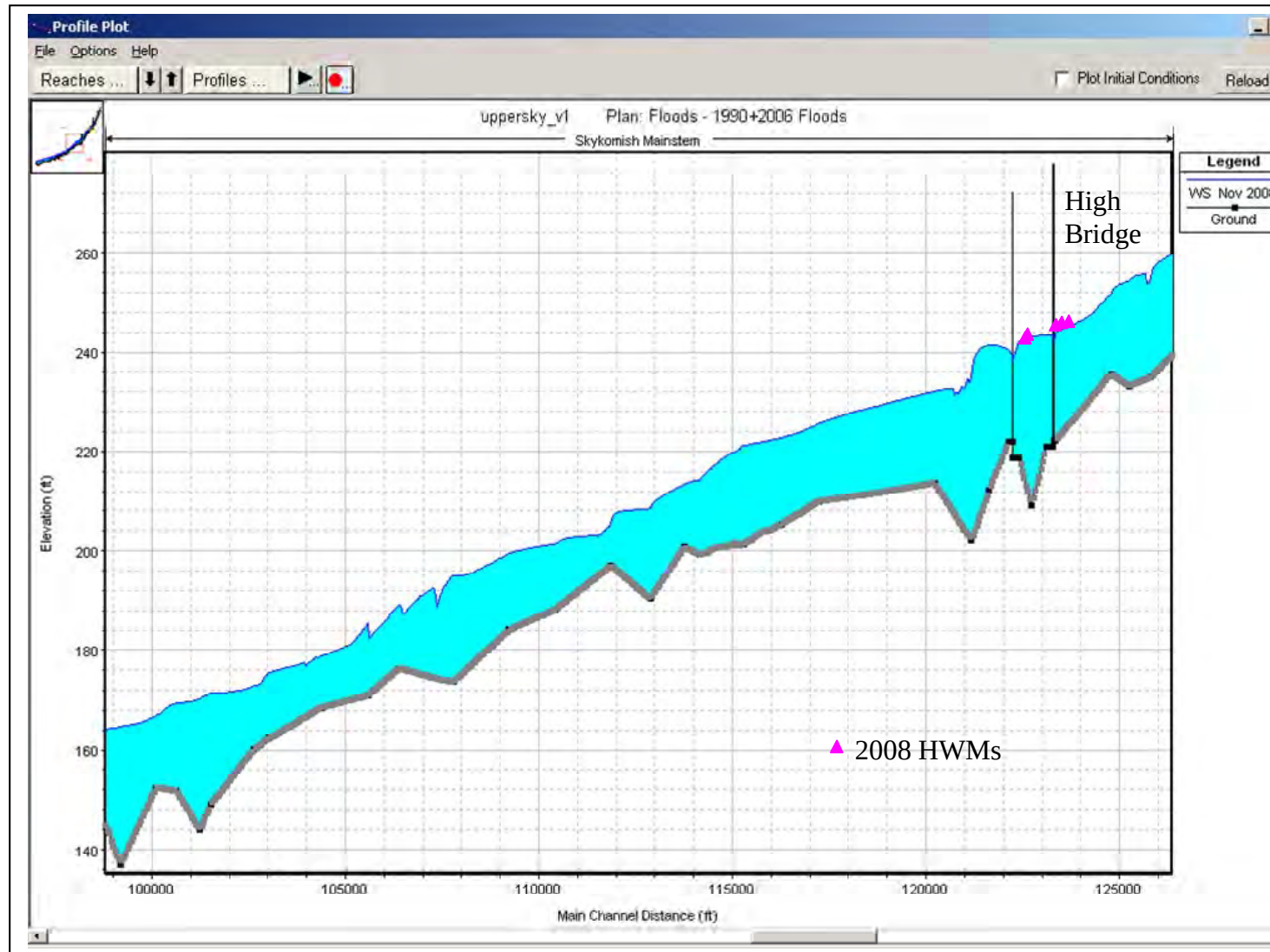


Figure 4.3 Skykomish River WSE calibration for 2008 flood flow. River distance = 100,000ft (RM 18.94) ~ 125,000ft (RM 23.67). Triangles indicate the HWMs of 2008 flood.

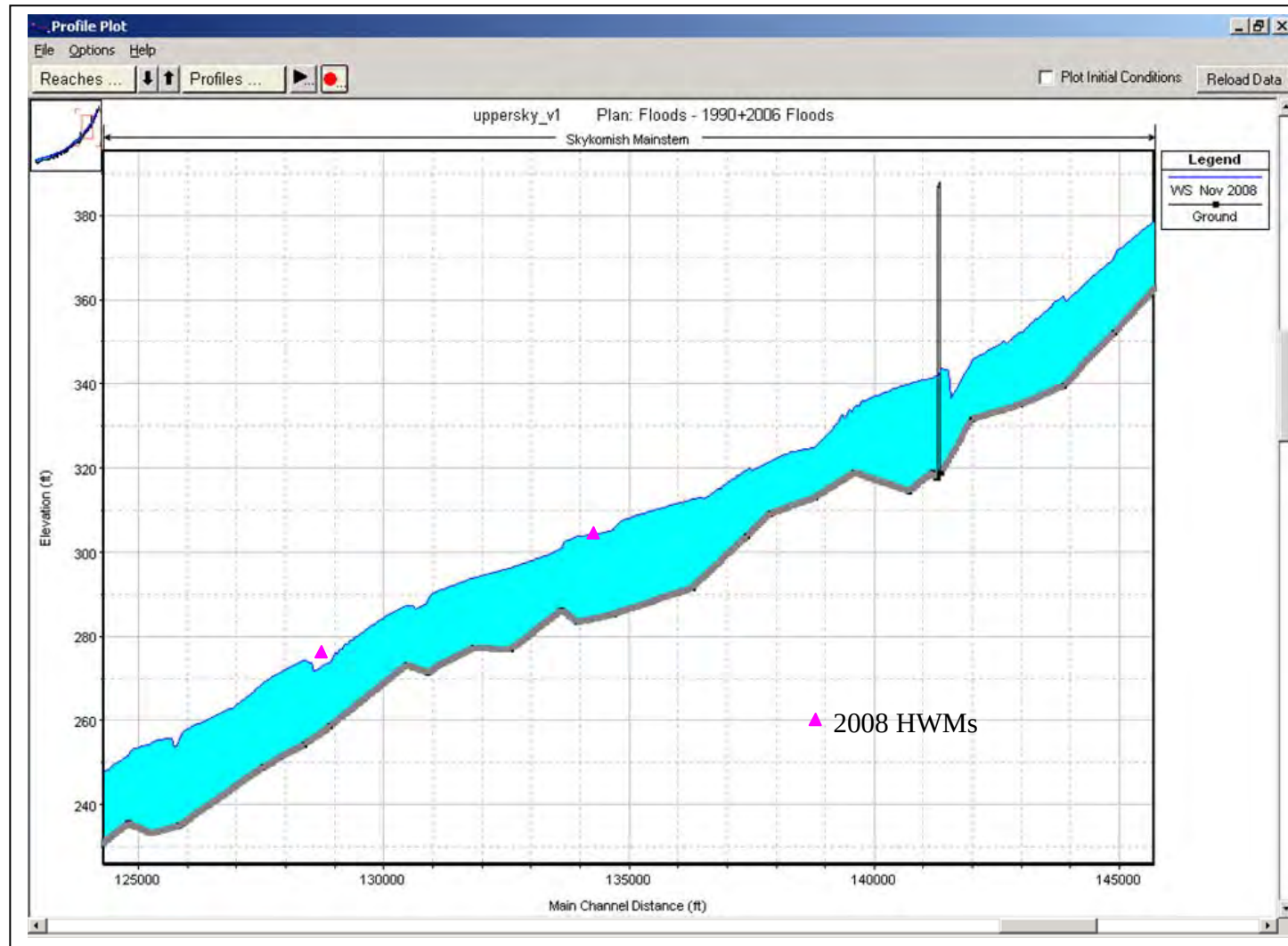


Figure 4.4 Skykomish River WSE calibration for 2008 flood flow. River distance = 125,000ft (RM 23.67) ~ 145,000ft (RM 27.46). Triangles are the HWMs of 2008 flood.

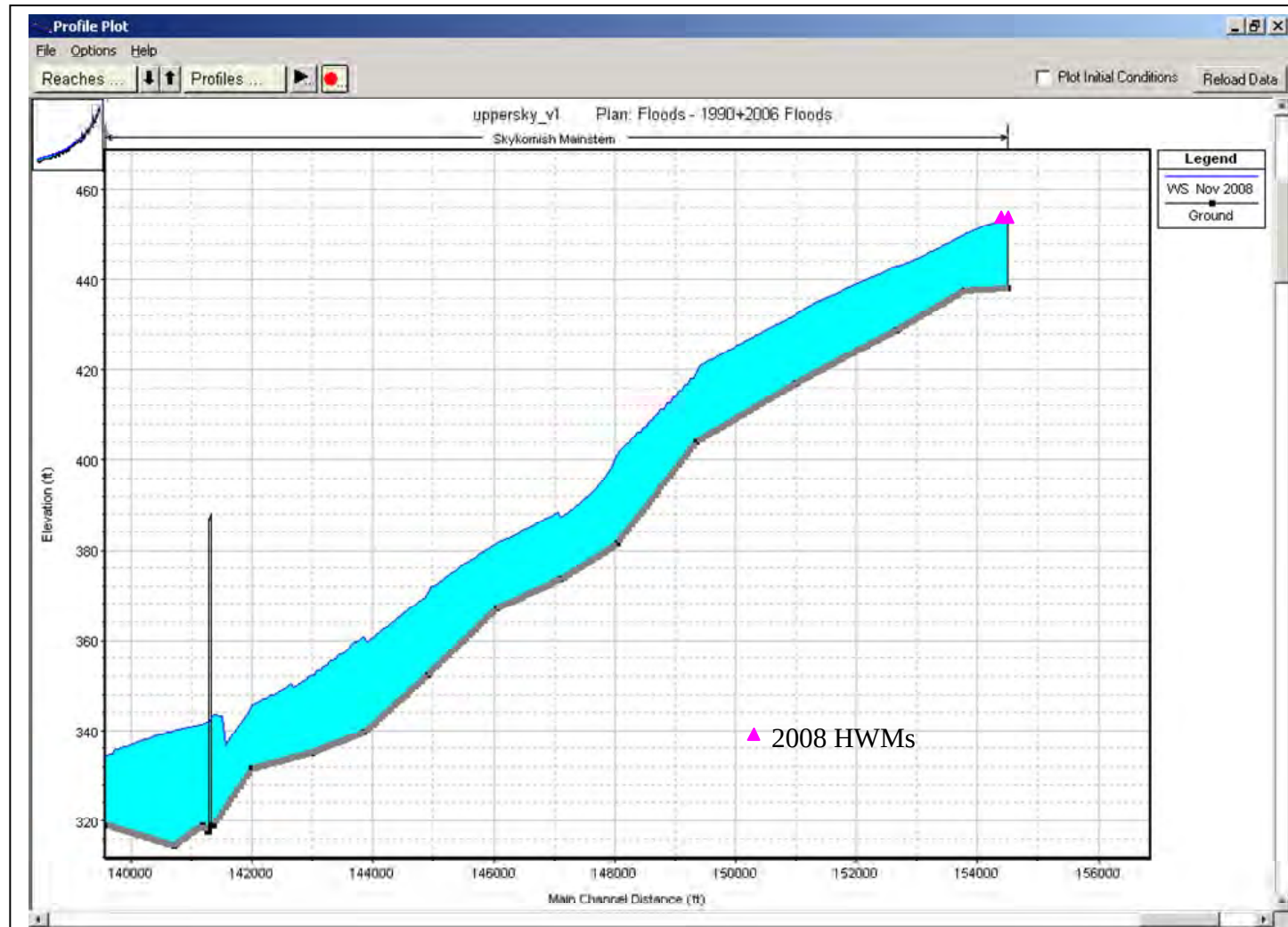


Figure 4.5 Skykomish River WSE calibration for 2008 flood flow. River distance > 140,000ft (RM 26.52). Triangles are the HWMs of 2008 flood.

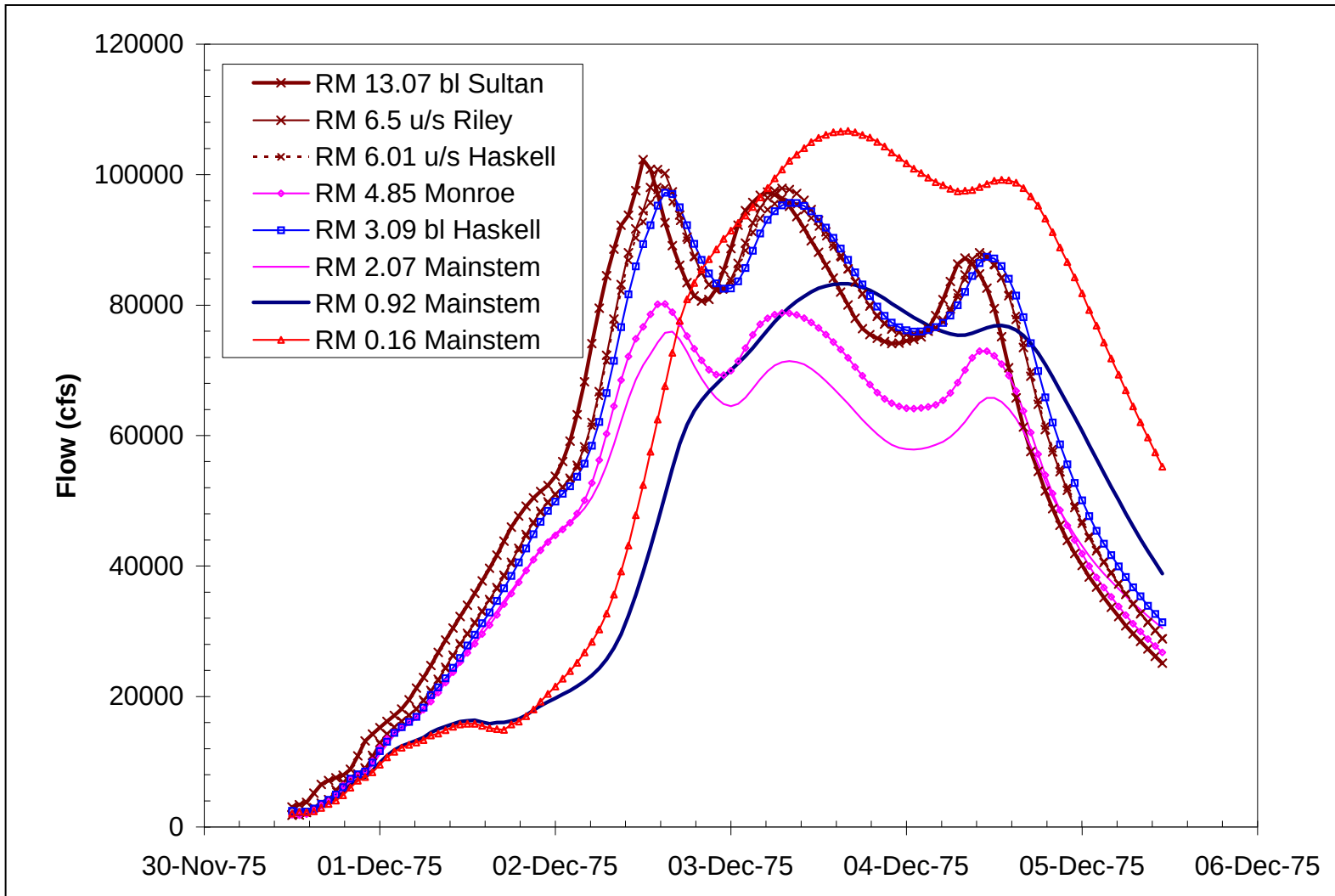


Figure 5.1 Simulated hydrographs at different locations on the Skykomish River for the Nov, 1975 storm.

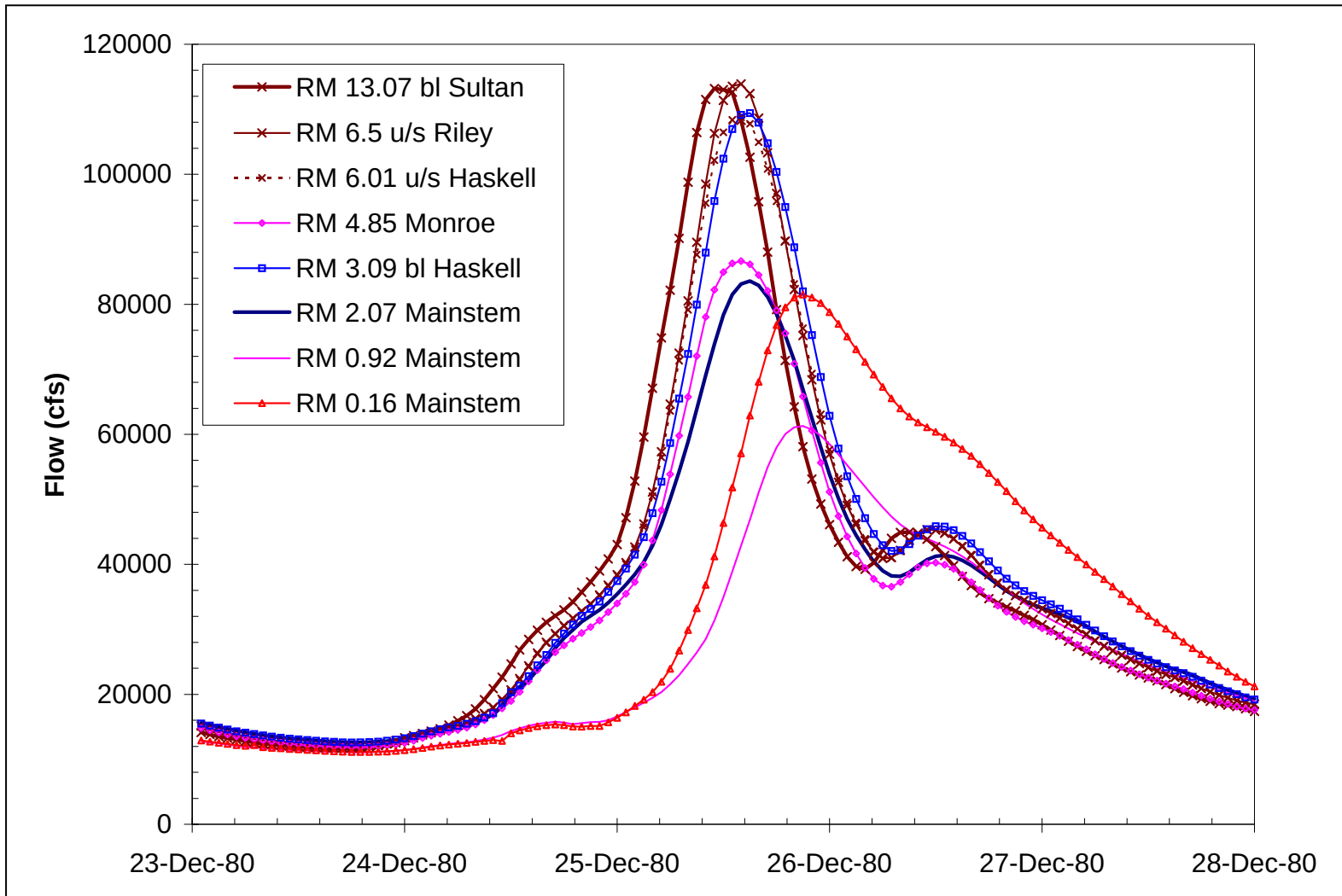


Figure 5.2 Simulated hydrographs at different locations on the Skykomish River for the Dec, 1980 storm.

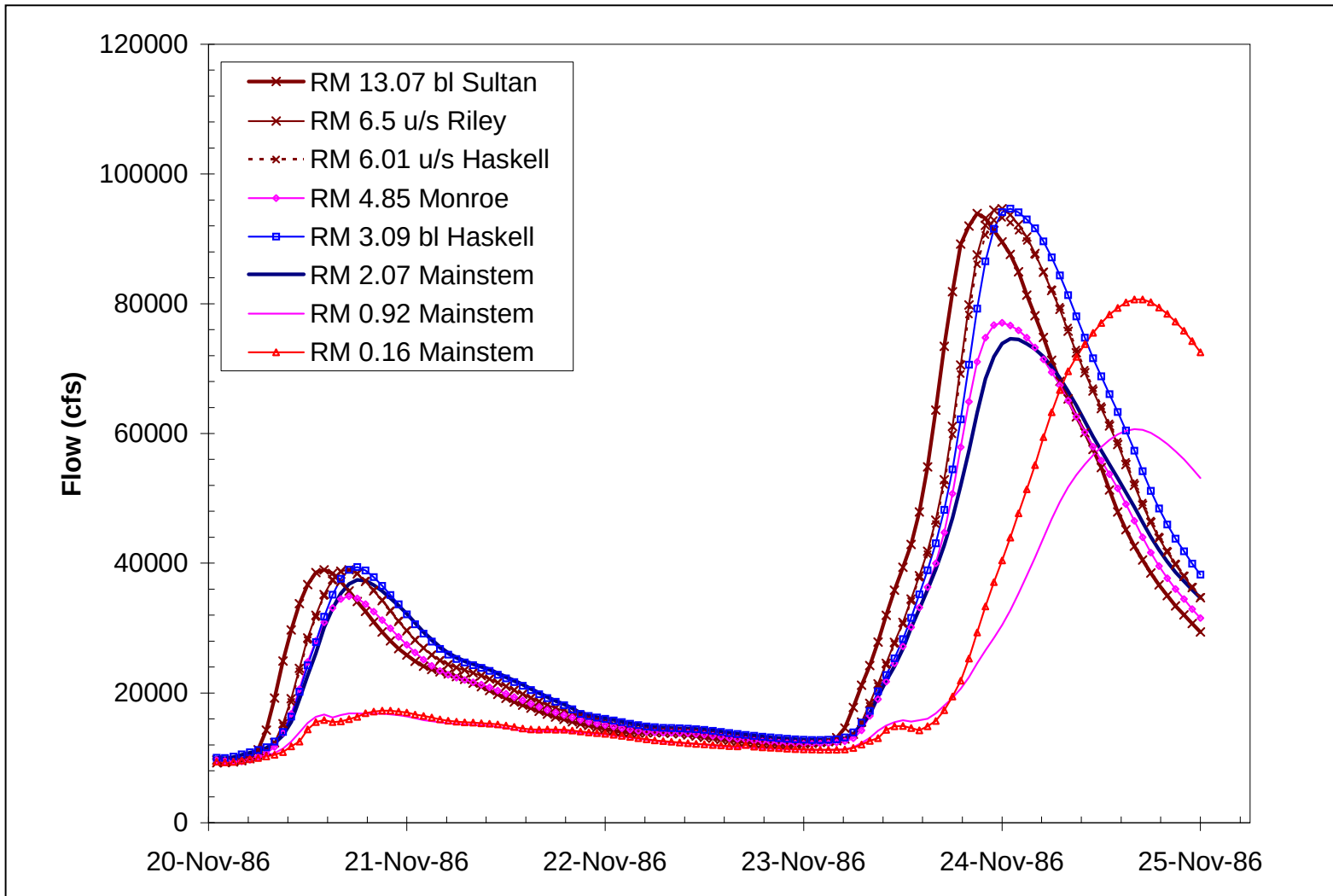


Figure 5.3 Simulated hydrographs at different locations on the Skykomish River for the Nov, 1986 storm.

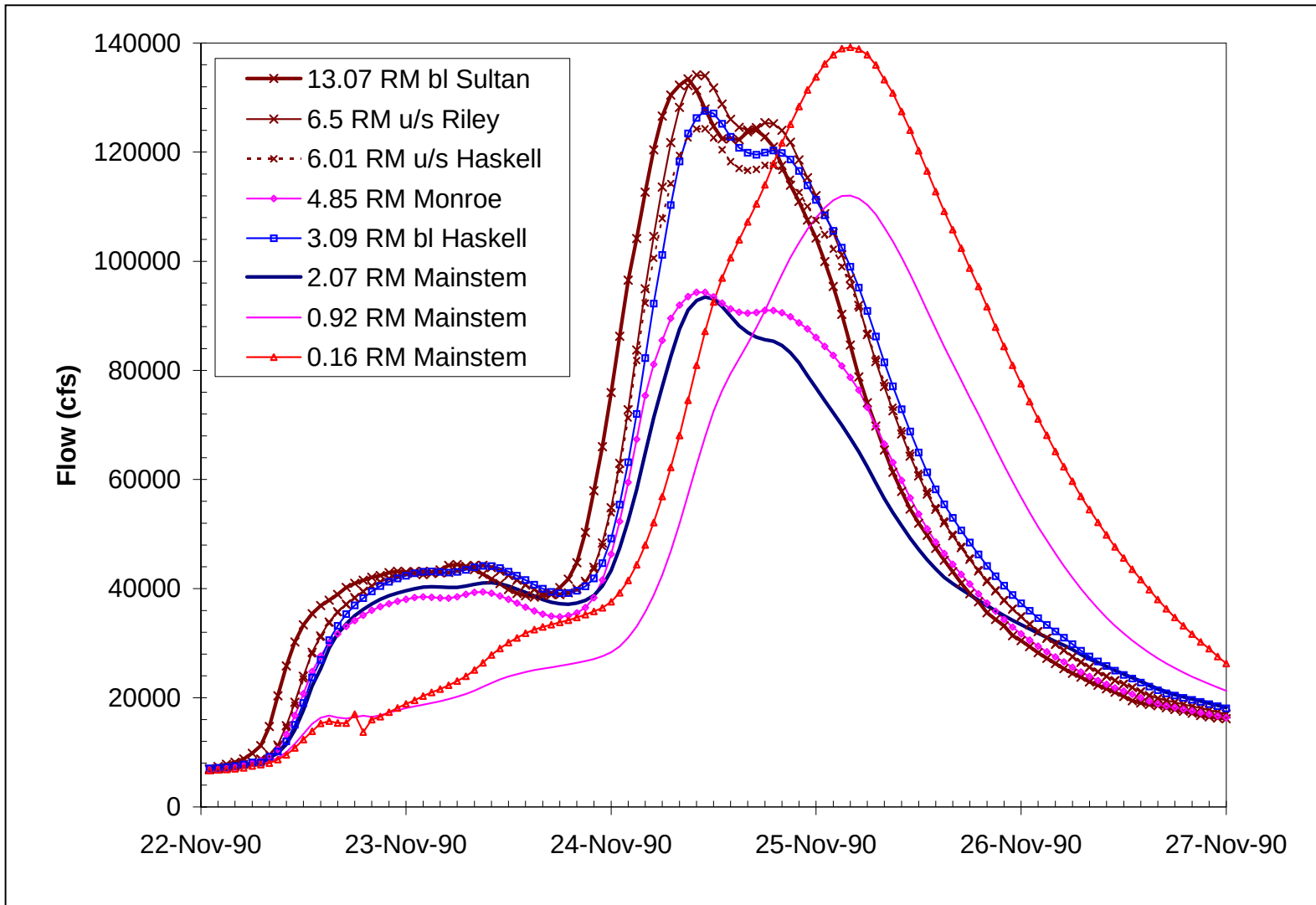


Figure 5.4 Simulated hydrographs at different locations on the Skykomish River for the Nov, 1990 storm.

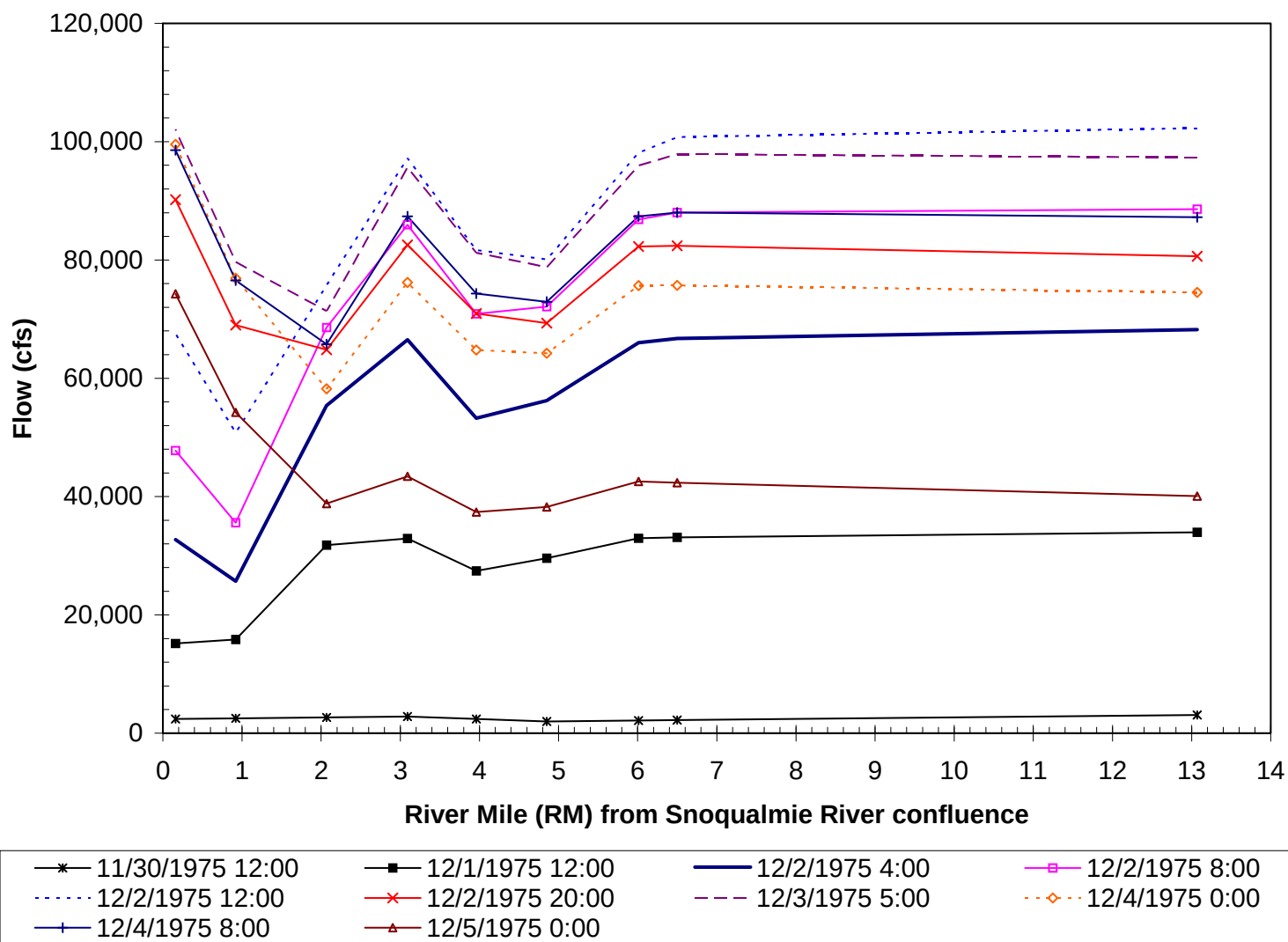


Figure 6.1 Nov, 1975 storm hydrograph. The time for each legend indicates the initial time of the flow starting from below the Sultan River. The flow on each curve represents the discharge of the starting flow as it moves downstream.

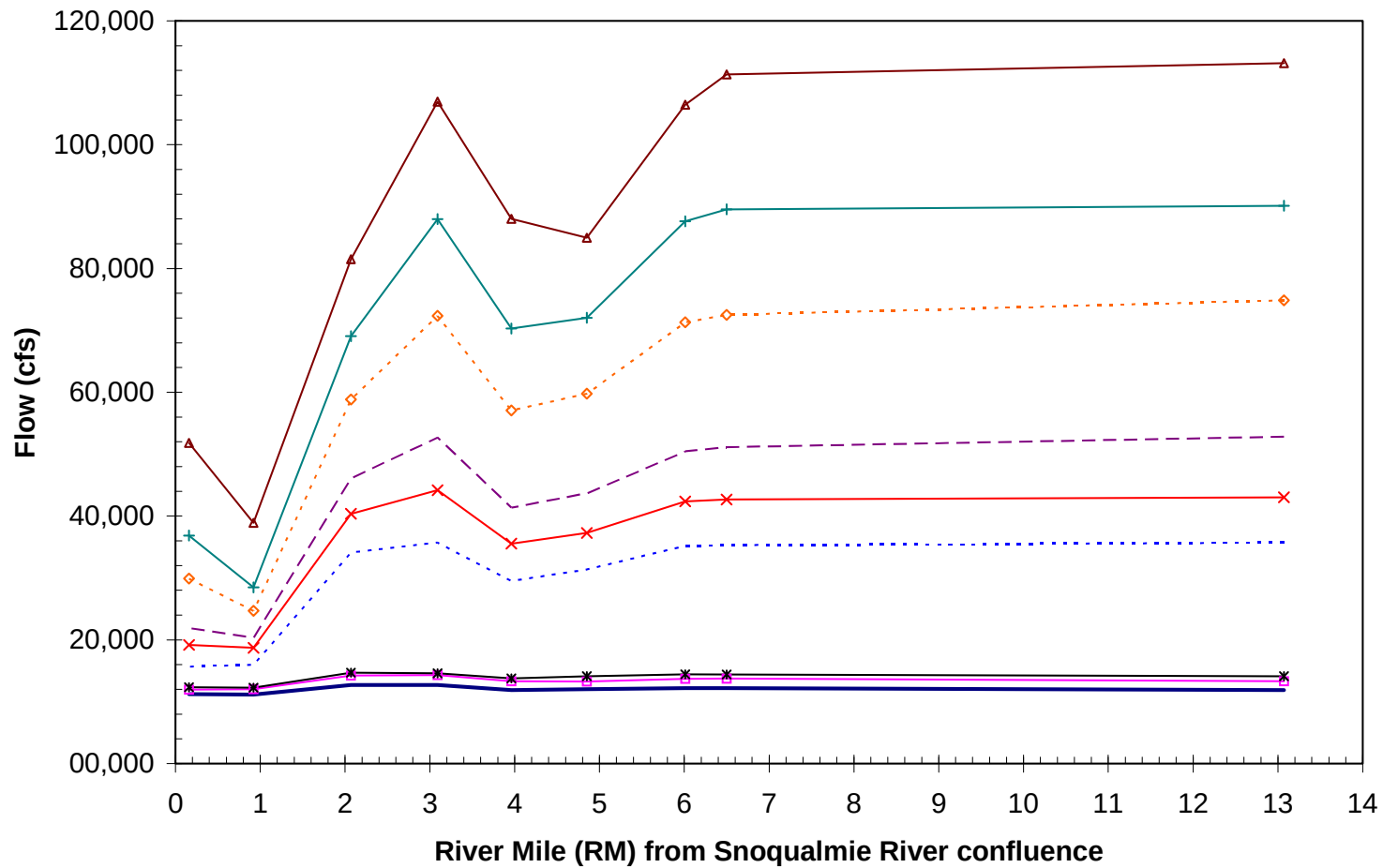


Figure 6.2 Dec, 1980 storm hydrograph. The time for each legend indicates the initial time of the flow starting from below the Sultan River. The flow on each curve represents the discharge of the starting flow as it moves downstream.

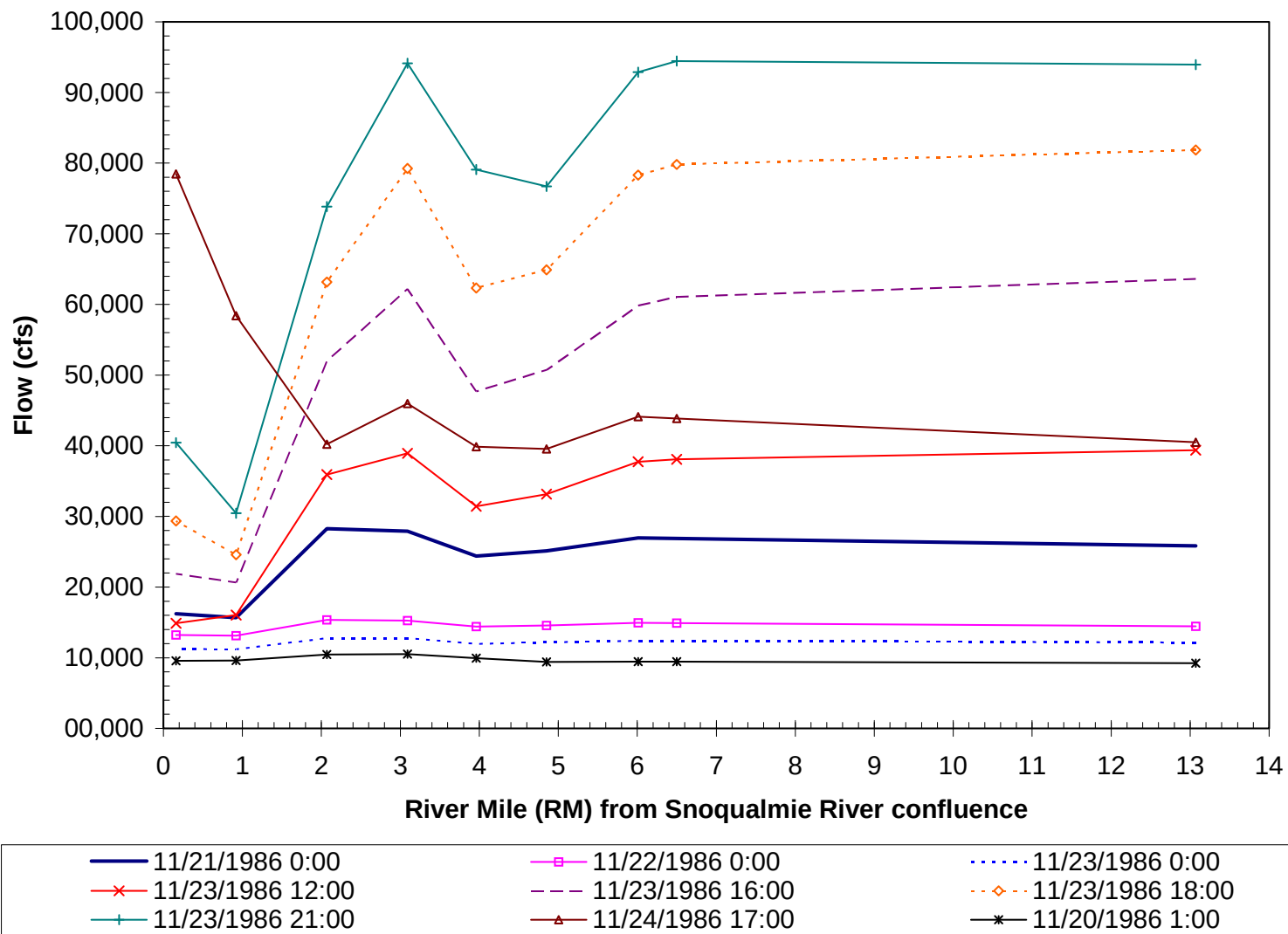


Figure 6.3 Nov, 1986 storm hydrograph. The time for each legend indicates the initial time of the flow starting from below the Sultan River. The flow on each curve represents the discharge of the starting flow as it moves downstream.

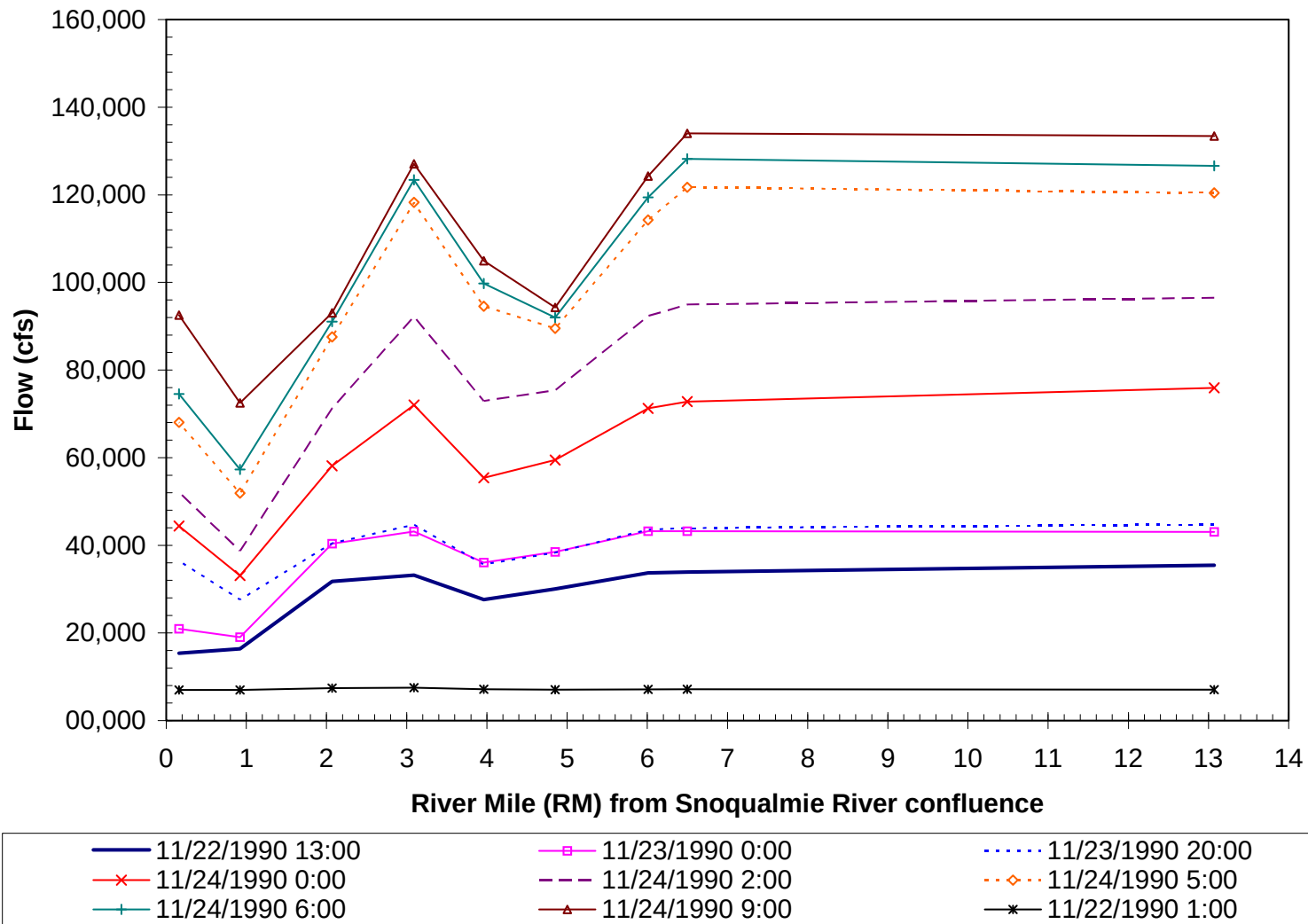


Figure 6.4 Nov, 1990 storm hydrograph. The time for each legend indicates the initial time of the flow starting from below the Sultan River. The flow on each curve represents the discharge of the starting flow as it moves downstream.

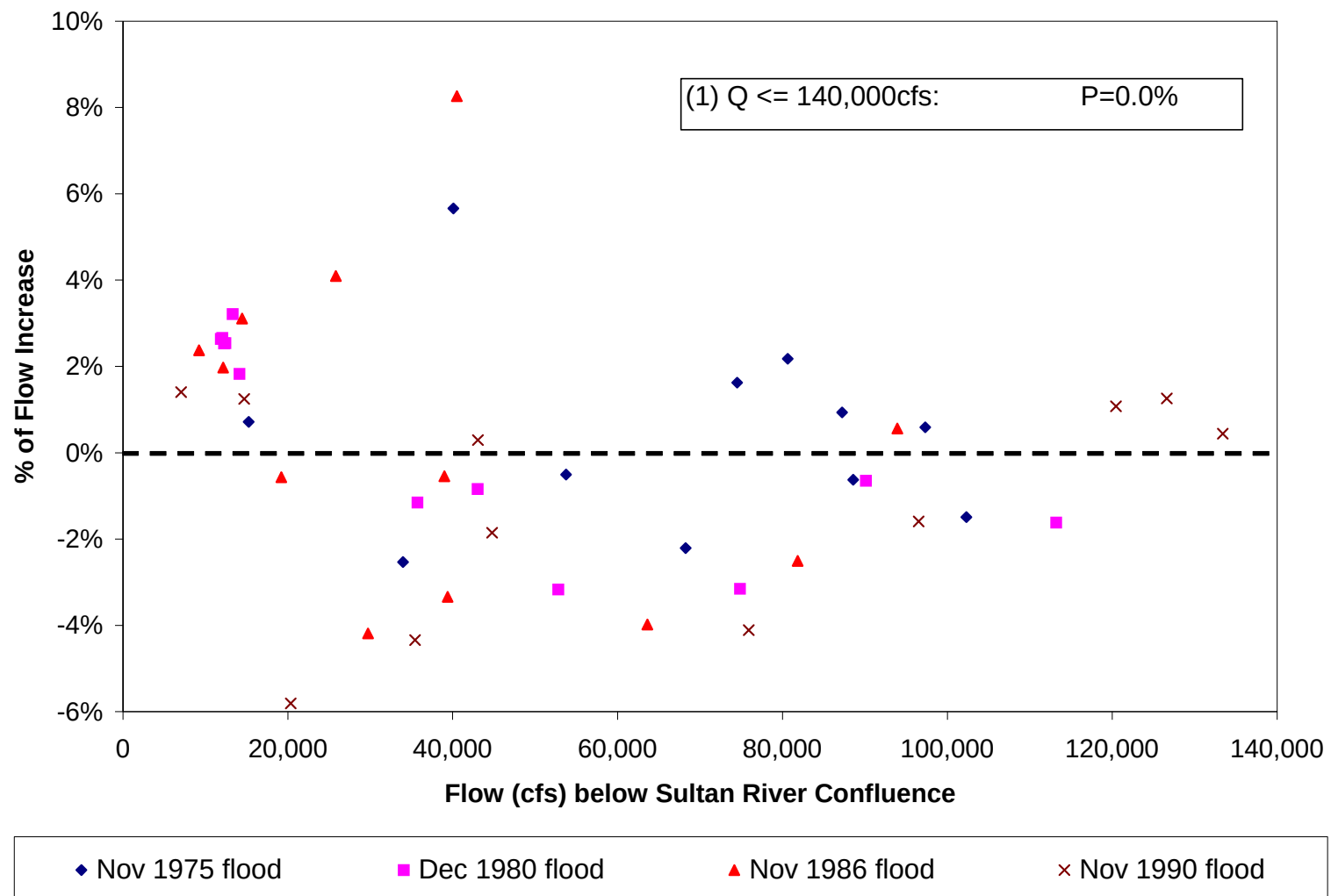


Figure 7.1 Percentage of Q change from below Sultan River (RM 13.07) to above Riley Slough (RM 6.50) relative to flow below the Sultan River.

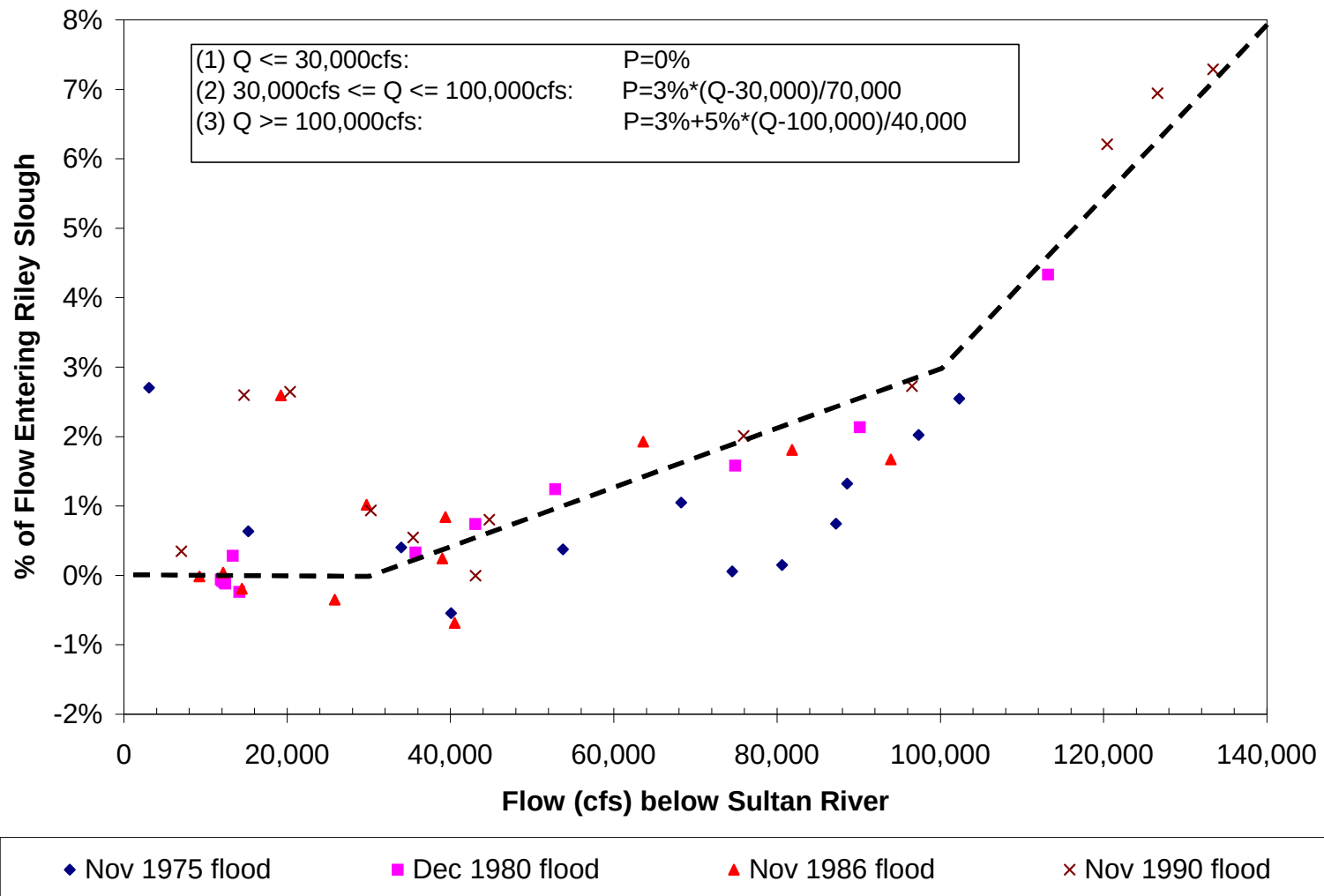


Figure 7.2 Percentage of Q entering Riley Slough at RM 6.50 relative to the flow d/s of Sultan River (RM 13.07).

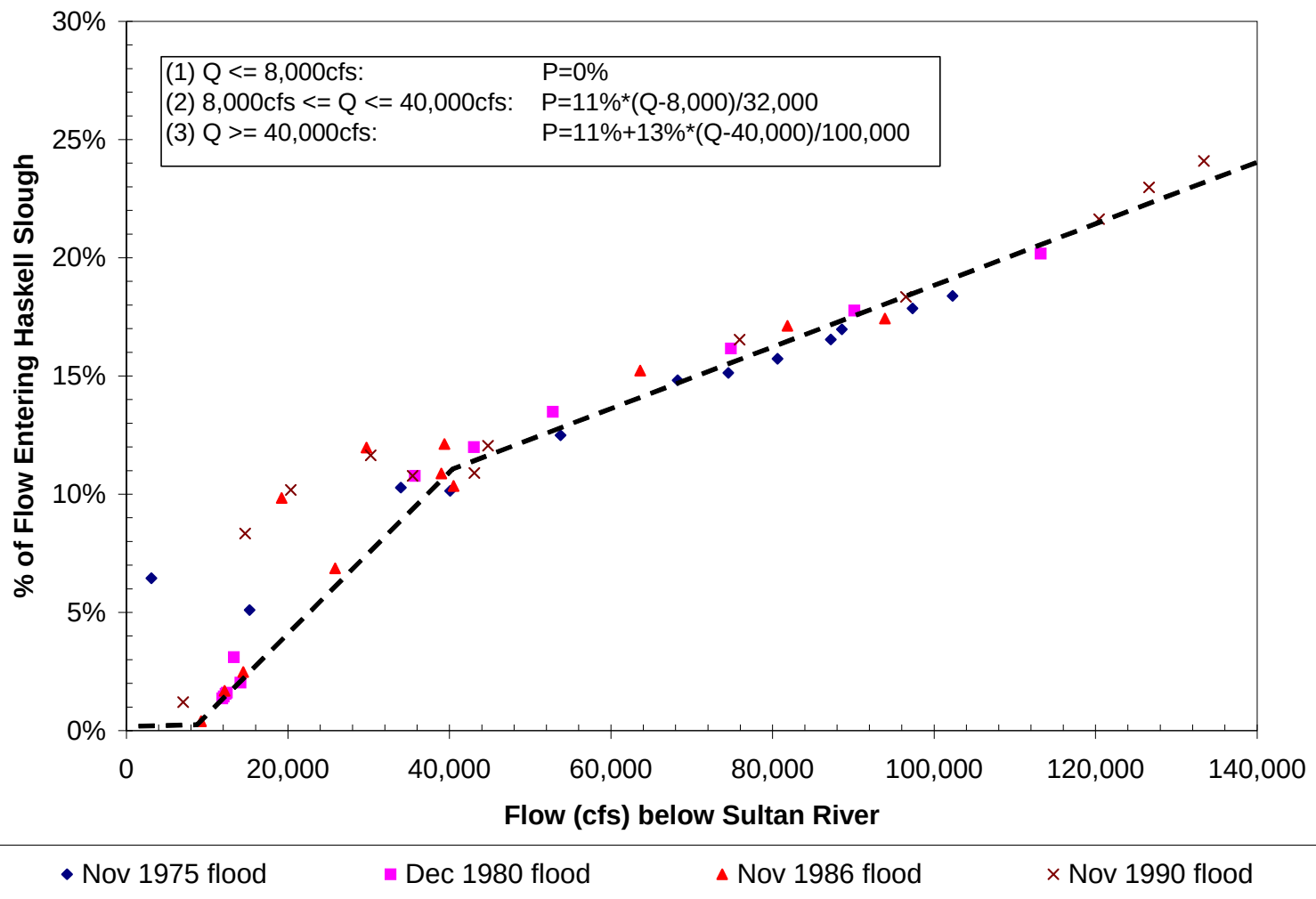


Figure 7.3 Percentage of flow entering Haskell Slough relative to flow u/s of Haskell Slough.

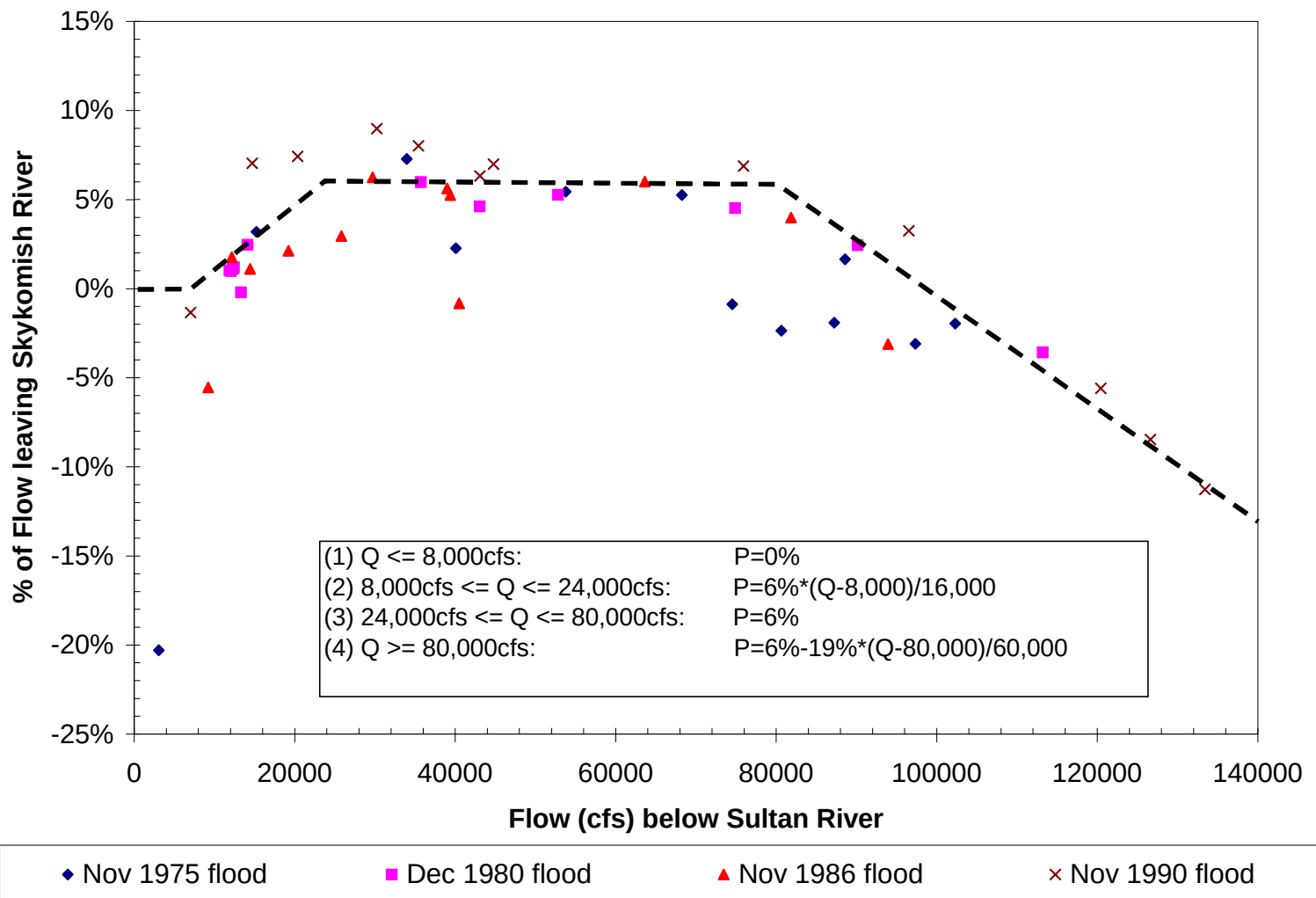


Figure 7.4 Percentage of flow leaving Skykomish River between SR203 Bridge and Monroe (RM 4.85) relative to the flow at Monroe. A negative percentage indicates flow entering Skykomish River.

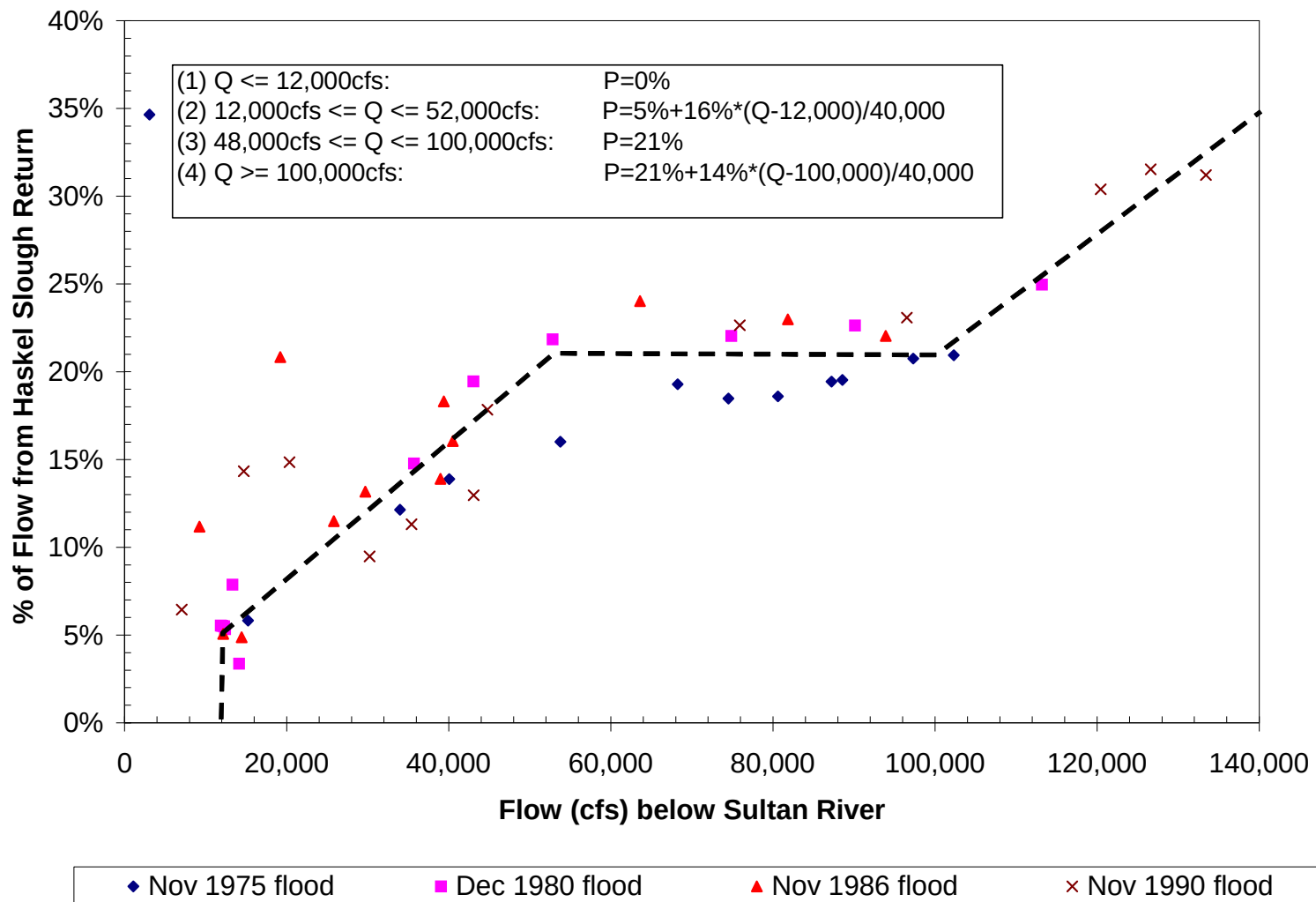


Figure 7.5 Percentage of return flow from Haskel Slough relative to the flow at SR-203 Bridge.

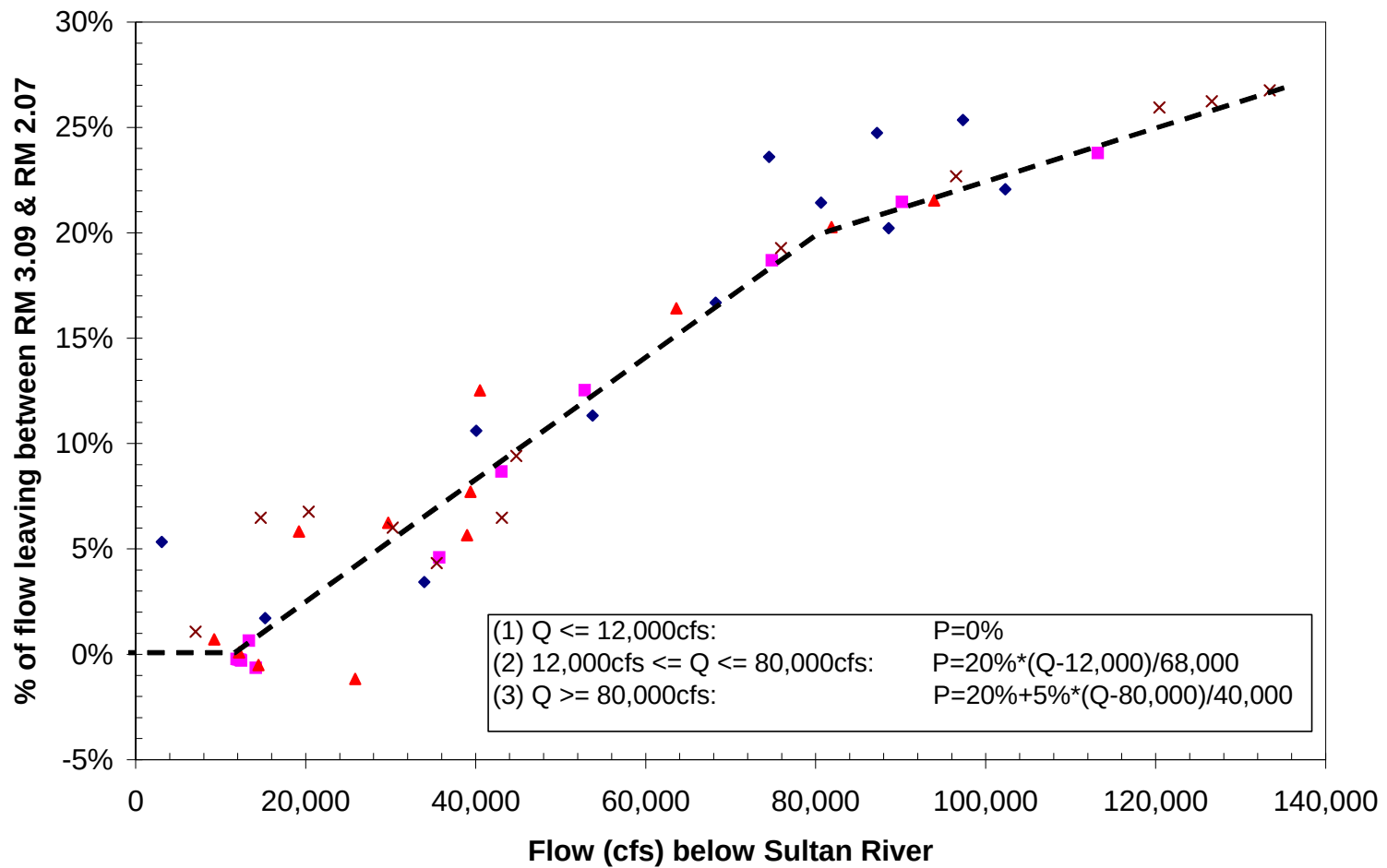


Figure7.6 % of overtopping outflow between RM 3.09 and RM 2.07 relative to the flow just below where Haskel Slough returns (RM 3.09).

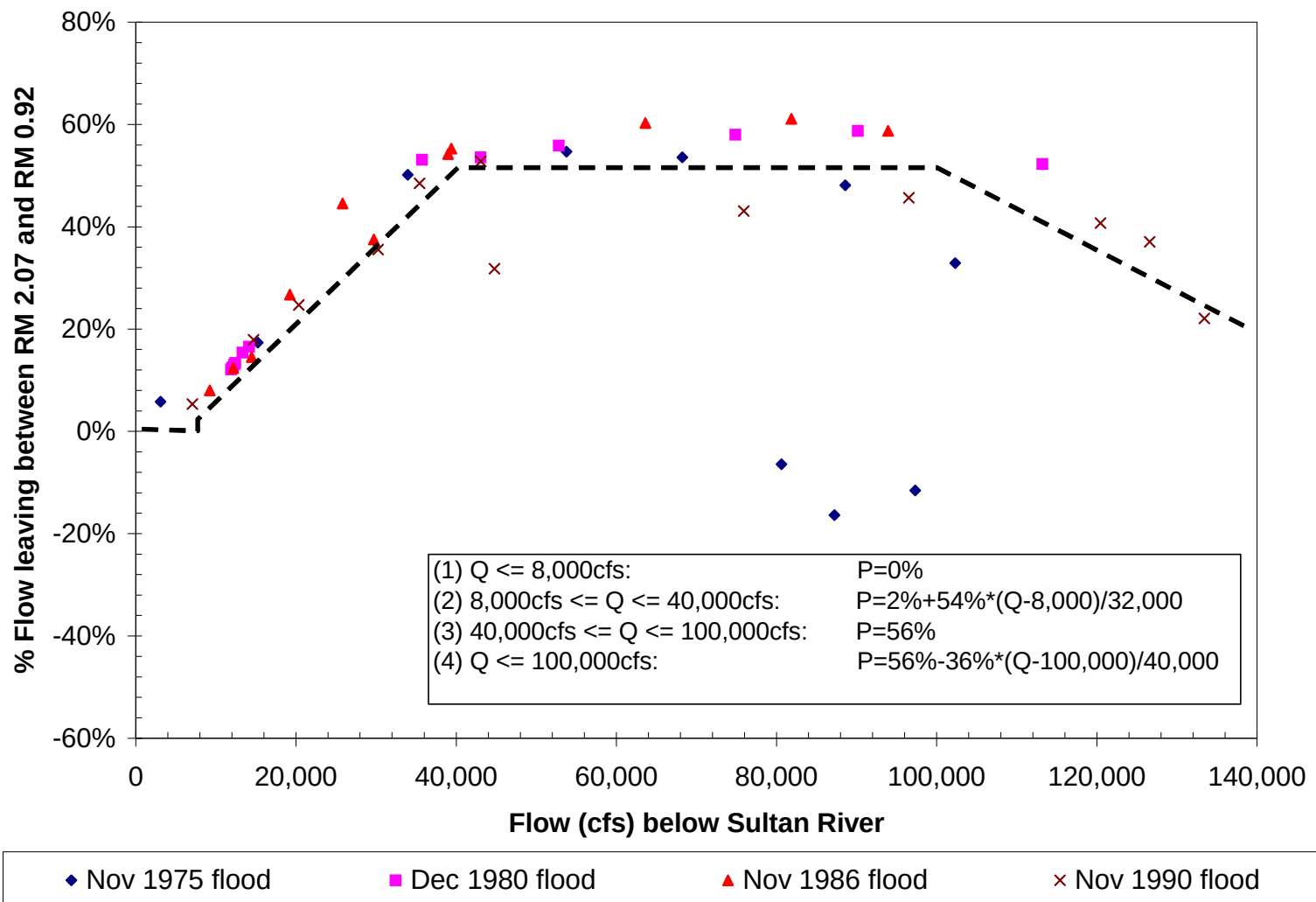


Figure 7.7 % of flow leaving Skykomish River between RM 2.07 and RM 0.92 relative to the flow at RM 2.07.

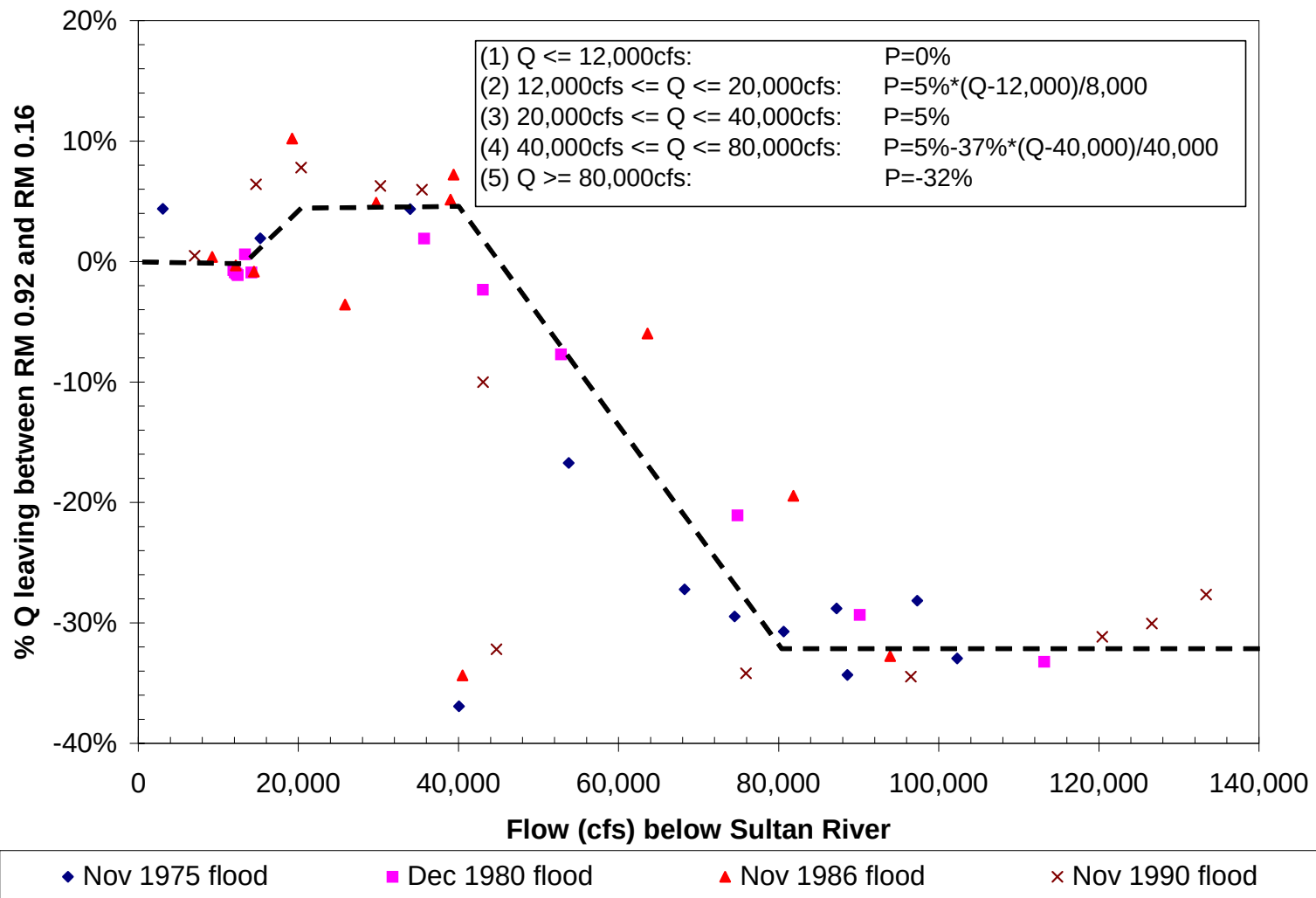


Figure 7.8 % of flow leaving Skykomish River between RM 0.92 and RM 0.16 relative to the flow at RM 0.92. A negative percentage indicates flow entering Skykomish River.

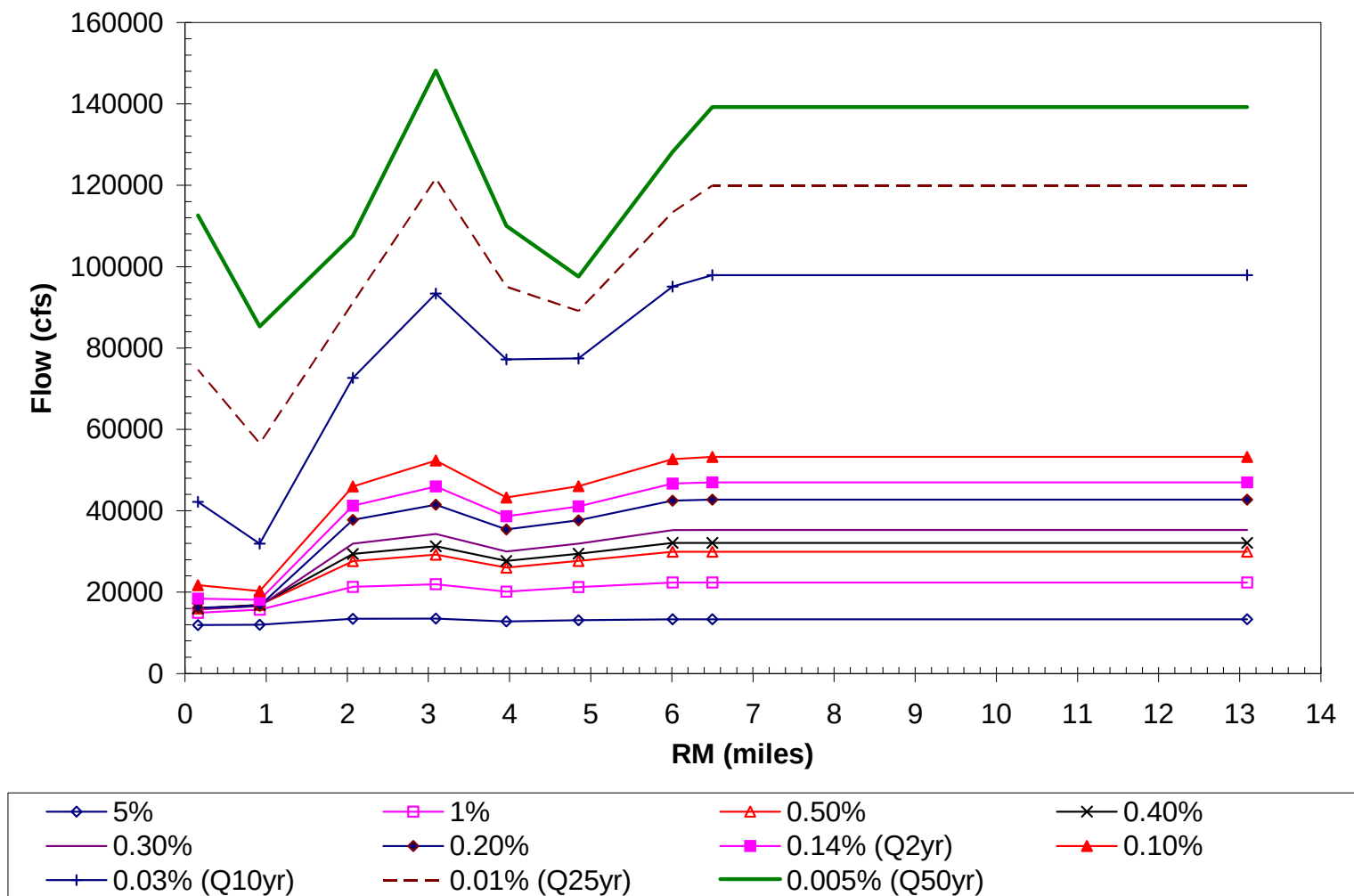
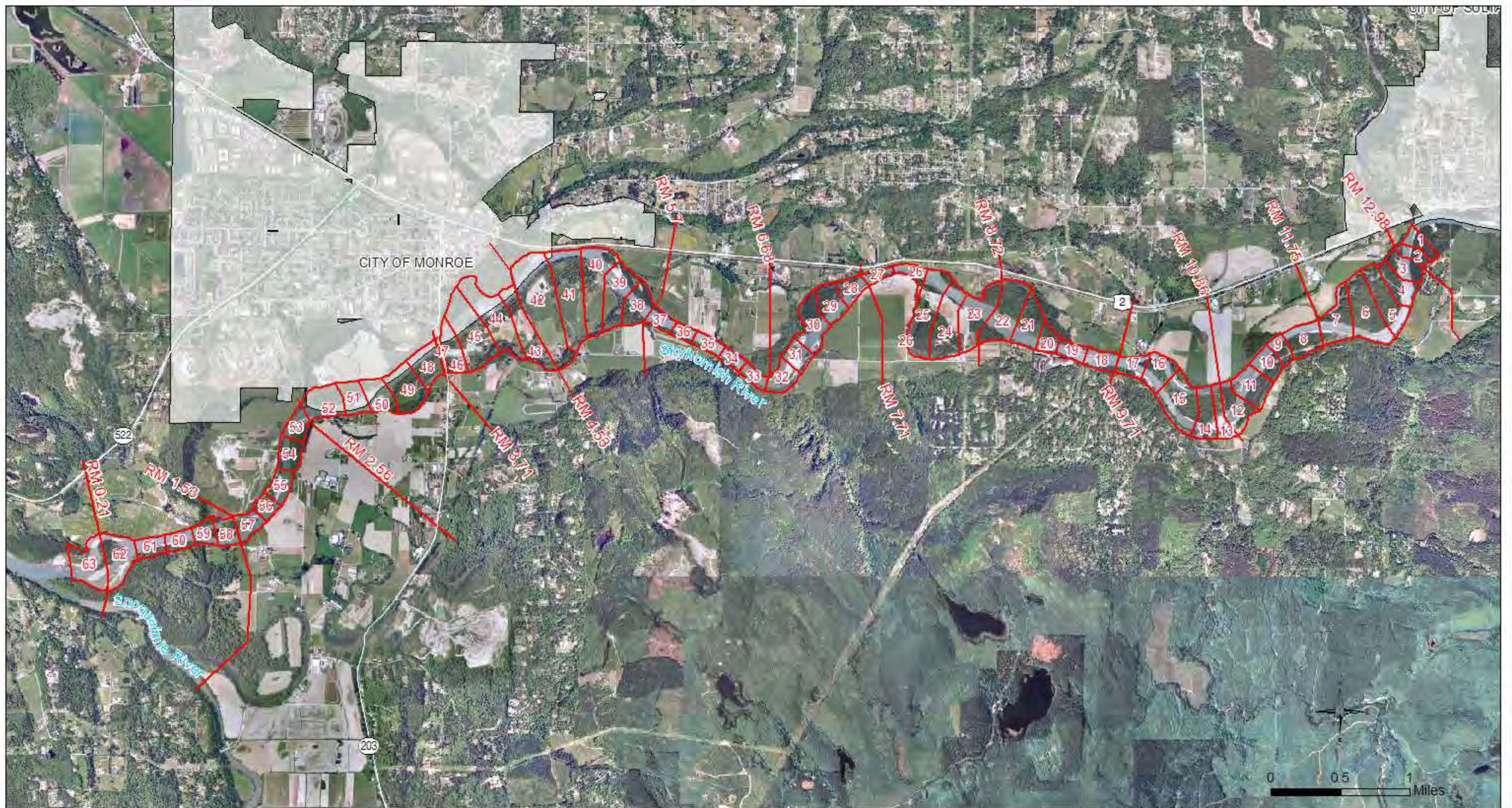


Figure 8 Flow variations along the Skykomish River from Sultan River confluence to Snoqualmie River junction. The flows range from 5% exceedance flow to 50-yr return period flood.



- Analysis Segment
- Cross Section
w/ River Mile

Plate 1: Lower Skykomish River Analysis Segments

Location of analysis segments established to evaluate and present GIS data for the lower Skykomish River geomorphic reach analysis.

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Aerial Photo: 2007 & 2009



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Key

■	< -1.0 ft/yr	Erosion
■	-1.0 to -0.20 ft/yr	
■	-0.20 to -0.05 ft/yr	
■	+/- 0.05 ft/yr	Negligible
■	0.05 to 0.20 ft/yr	Deposition
■	0.20 to 1.0 ft/yr	
■	> 1.0 ft/yr	

Plate 2: Lower Skykomish River Aggradation/Degradation Potential

Spatial variation in erosional and depositional trends in the lower Skykomish River analysis reach as suggested by sediment transport modeling using Parker's (1990) bedload transport equation; classifications are as defined in Table 2. Lateral extent depicted is based on the extent of historic channel delineation.

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Aerial Photo: 2007 & 2009

Lower Skykomish River Main Channel Tracings

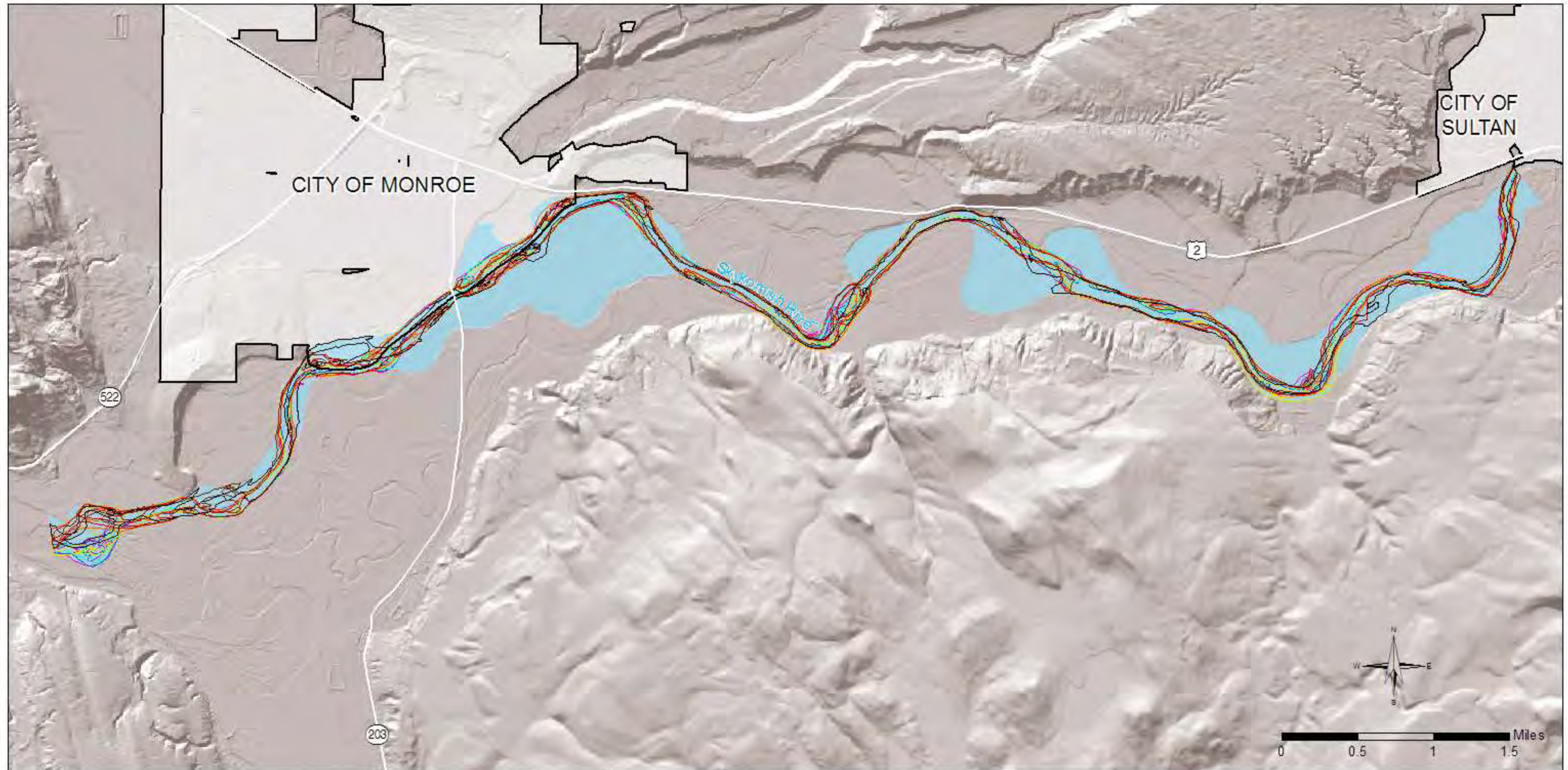
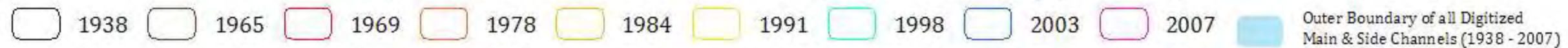
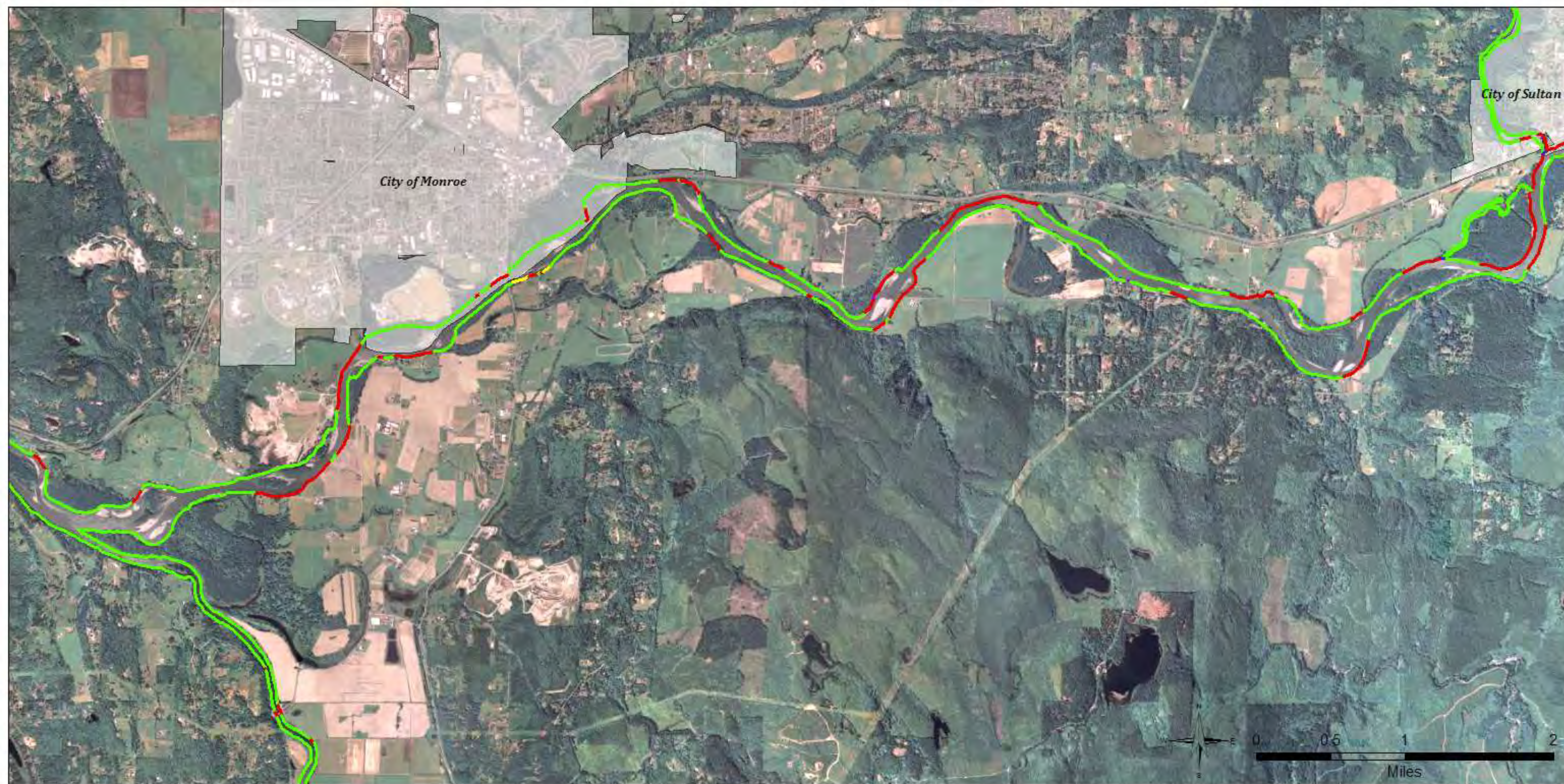


Plate 3: Main Channel Tracing by Year

Locations of main and side channels of the lower Skykomish River analysis reach as digitized from georeferenced aerial photographs.
Mapped extent of main and side channel locations over the period of record is indicated by light blue shading.



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Legend

Type

- Break
- Earth/Natural
- Rip Rap (GT 256 mm)
- Rubble (LT 256 mm)
- Structural

Plate 4: Lower Skykomish Bank Condition

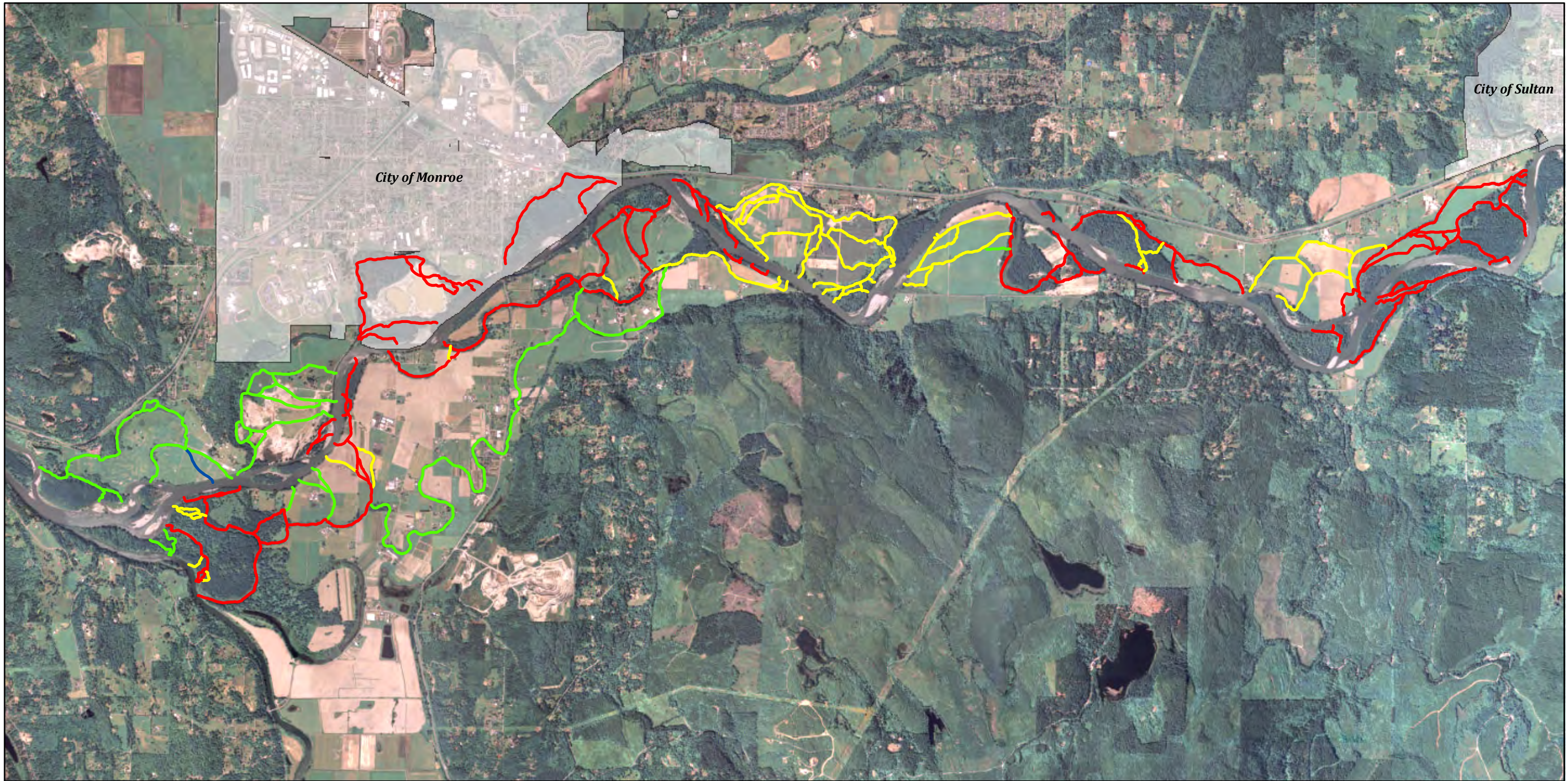
Results of bank condition survey of the lower Skykomish River performed by Snohomish County Surface Water Management in 2006.



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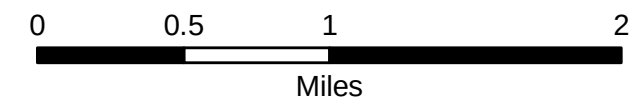
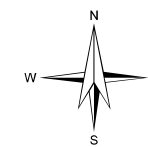
Legend
Recurrence Interval

- 2
- 10
- 100
- > 100

Plate 5

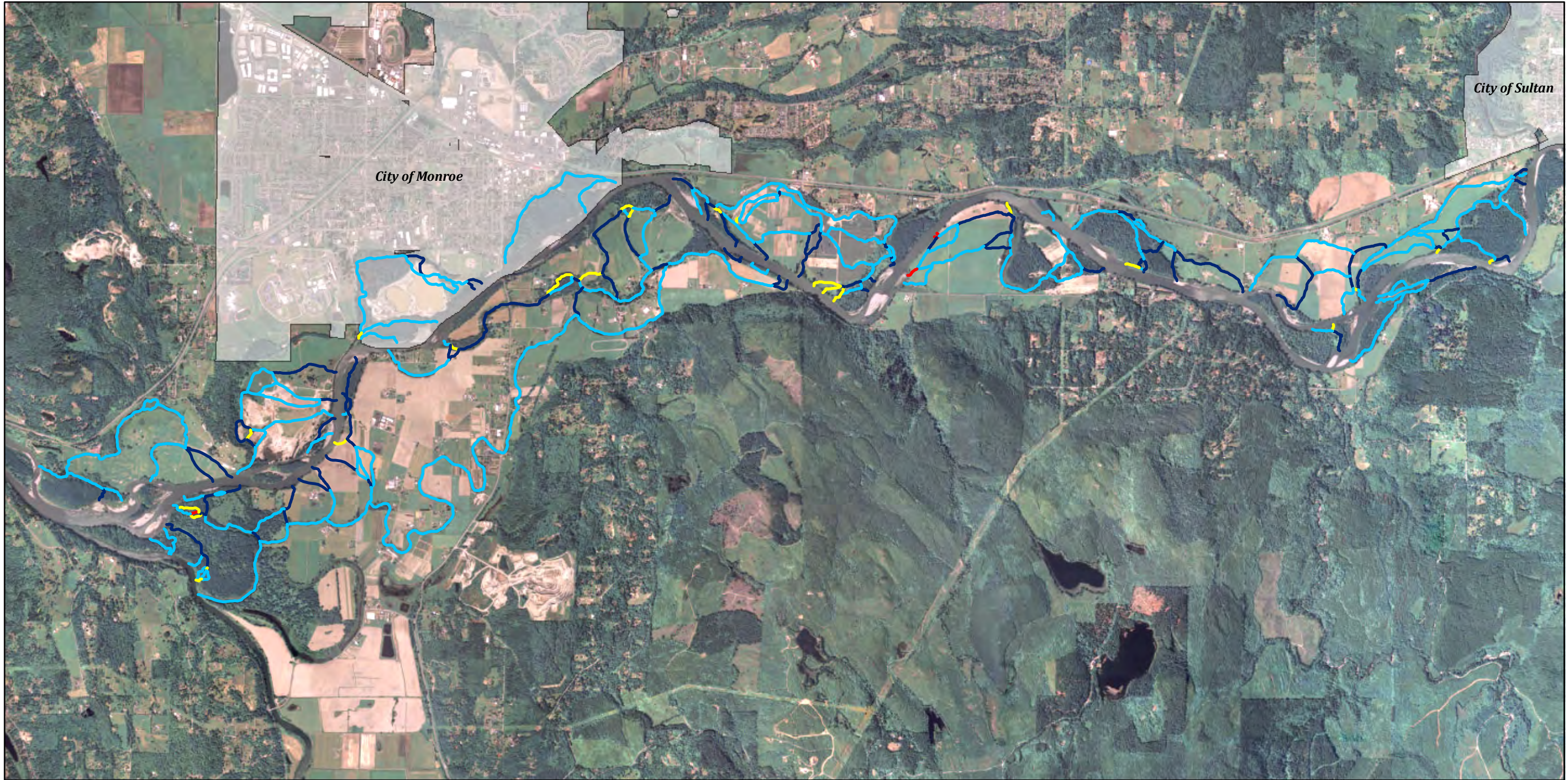
Risk ratings of potential avulsion pathways characterized according to lowest of three flood levels (2-, 10- and 100-year recurrence intervals) at which floodplain or off-channel flow may occur. Tracings and ratings were based on 2006 topography. GIS Data available from Snohomish County Surface Water Management.

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Legend

Slope

- <0%
- >0 - <=1%
- >1 - <=3%
- >3%

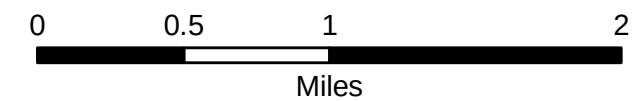
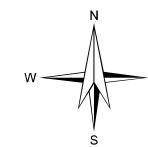
Plate 6

Risk ratings of potential avulsion pathways characterized according to average gradient along each pathway segment.

Tracings and ratings were based on 2006 topography.

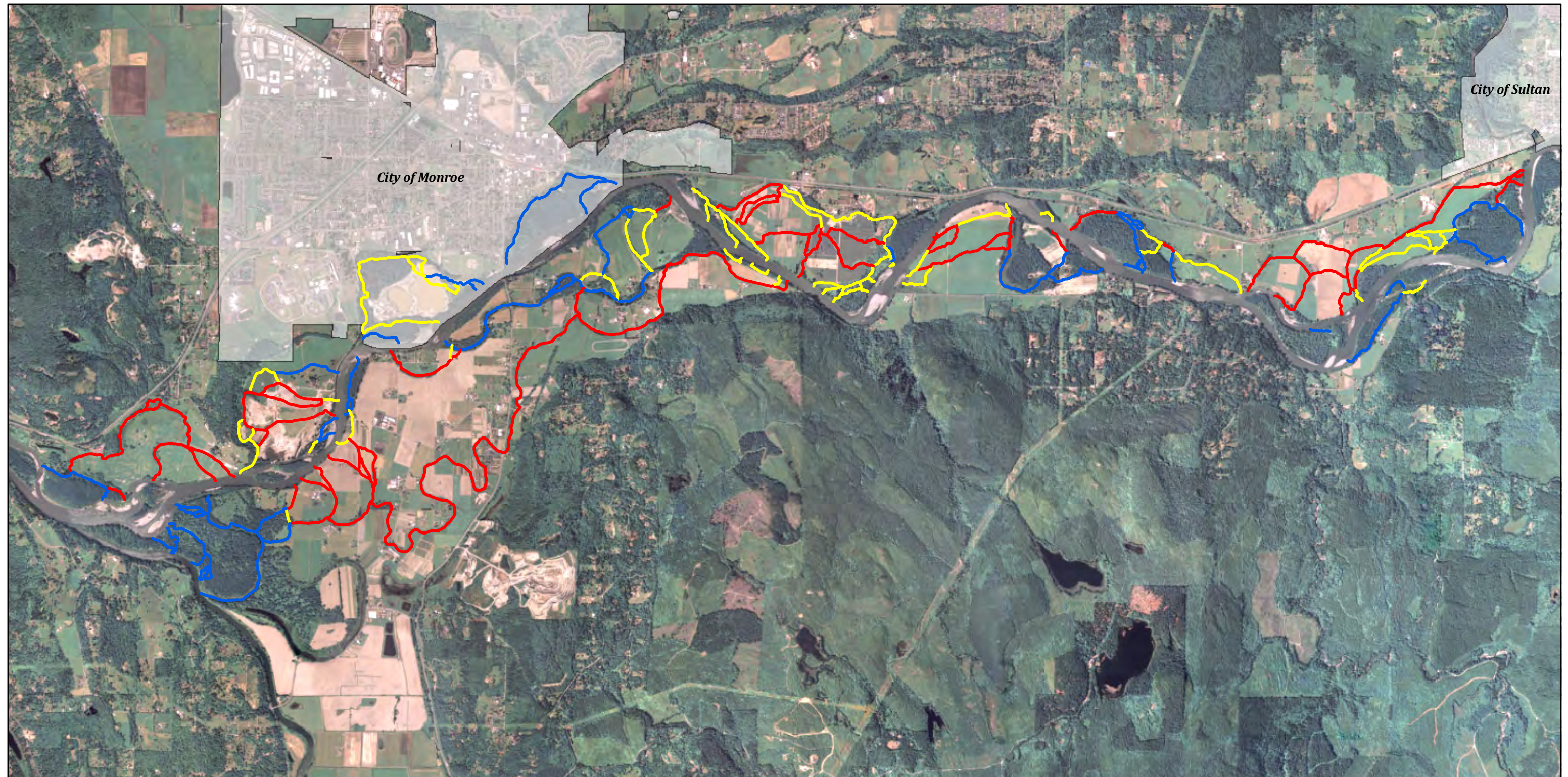
GIS Data available from Snohomish County Surface Water Management.

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Legend

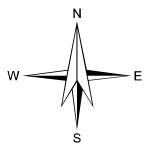
Soil Class

- 1 Higher Erosivity
- 2 Moderate Erosivity
- 3 Lower Erosivity

Plate 7

Risk ratings of potential avulsion pathways characterized according to floodplain soil Kw erodibility factors.
GIS Data available from Snohomish County Surface Water Management.

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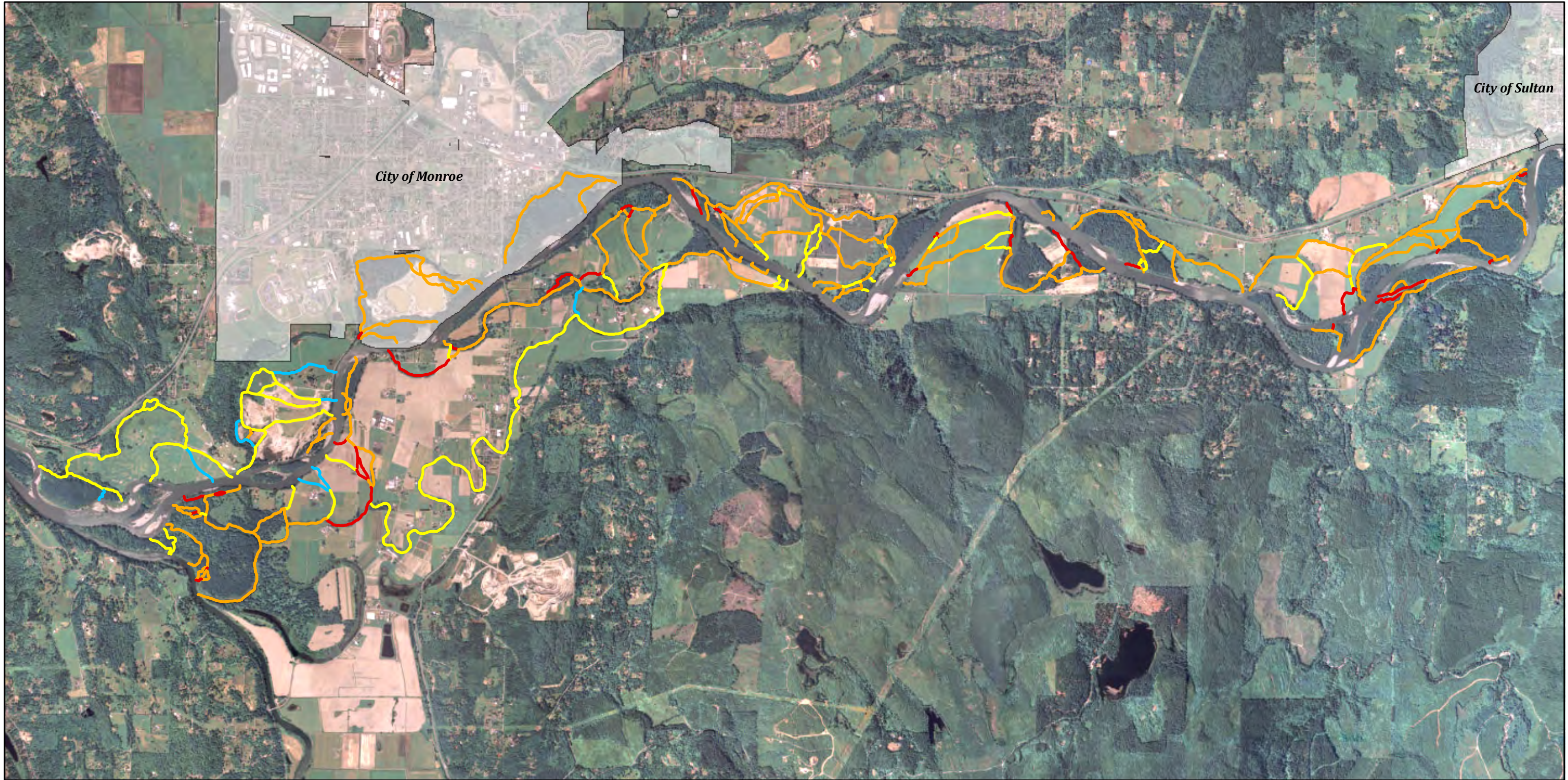
0
0.5
1
2

Miles



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- Legend**
Risk Class
- 1 Highest
 - 2
 - 3
 - 4 Lowest

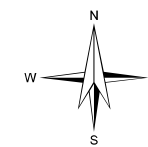
Plate 8

Joint avulsion risk ratings of potential avulsion pathways characterized according to weighted sums of flood flow level, longitudinal gradient, and floodplain soil Kw erodibility factor ratings depicted in Figures 1-3.

Tracings and ratings were based on 2003 topography.

GIS Data available from Snohomish County Surface Water Management.

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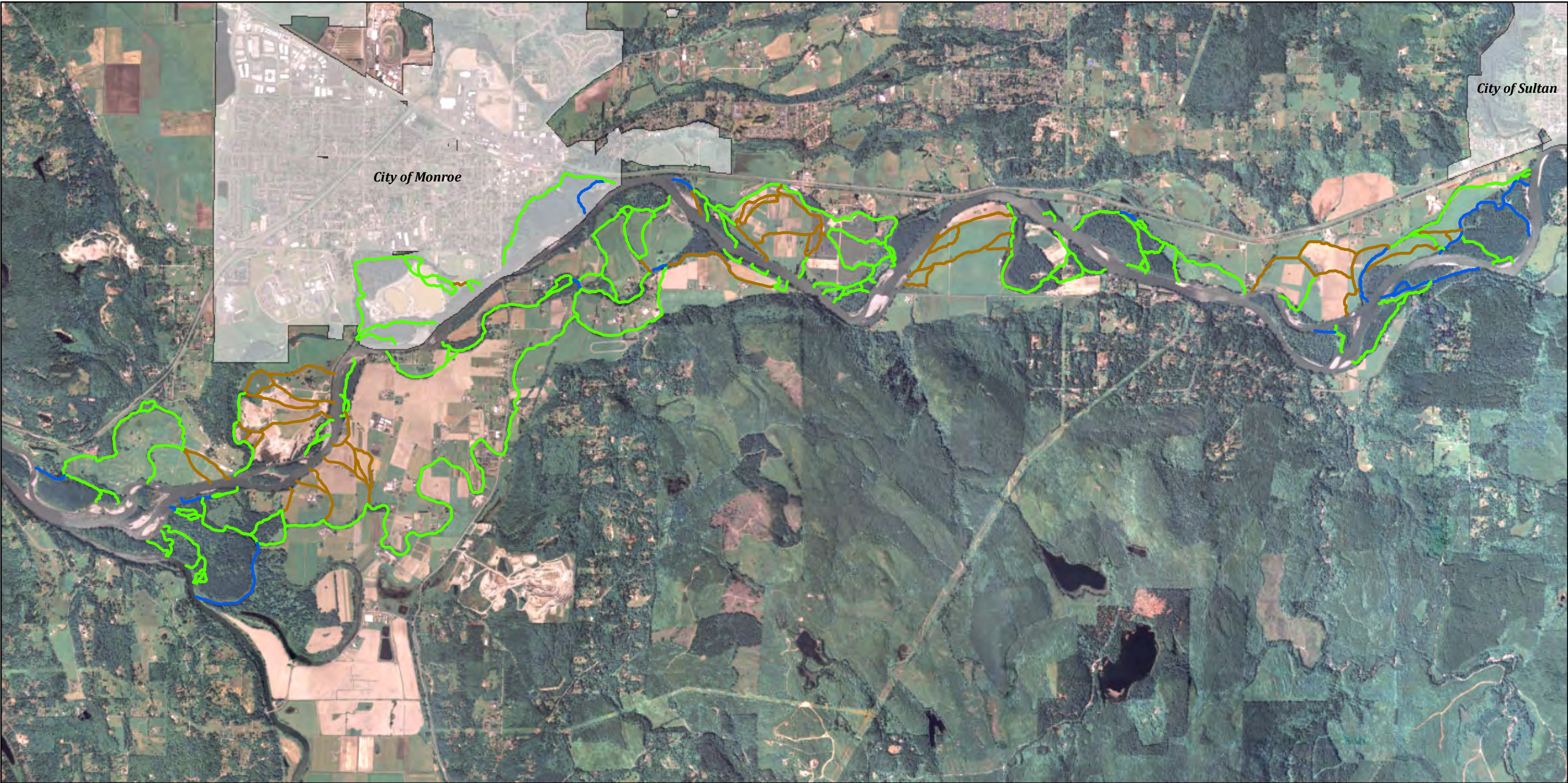


0 0.5 1 2
Miles



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Legend

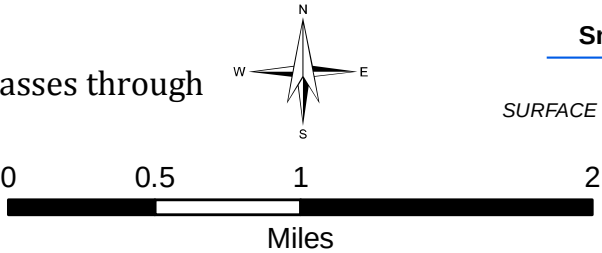
Vegetation

- Forested (Partially or Fully)
- Nonforested
- Open Water

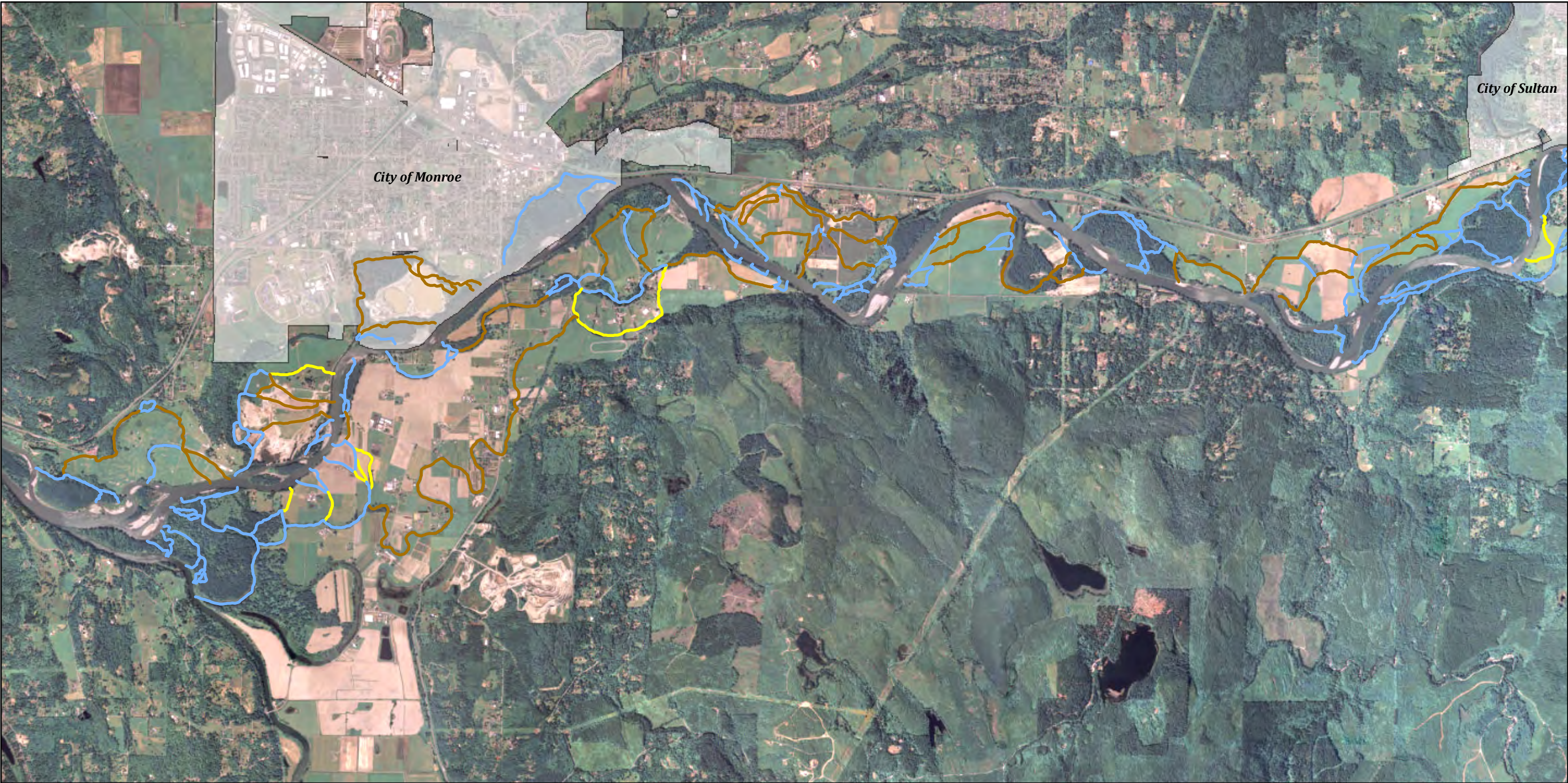
Plate 9

Avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment passes through forested land. GIS Data available from Snohomish County Surface Water Management.

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Legend

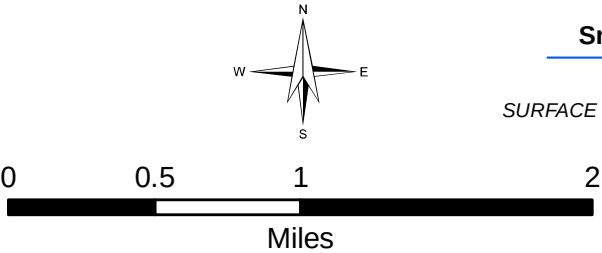
Roads

- Road Crossings not Identified
- Gravel/ Dirt Roads
- Paved Roads

Plate 10

Avulsion risk mitigation ratings of potential avulsion pathways characterized according to whether a segment is intersected by a paved or gravel surfaced road. GIS Data available from Snohomish County Surface Water Management. Road coverage may be incomplete and should be evaluated on a site-specific basis.

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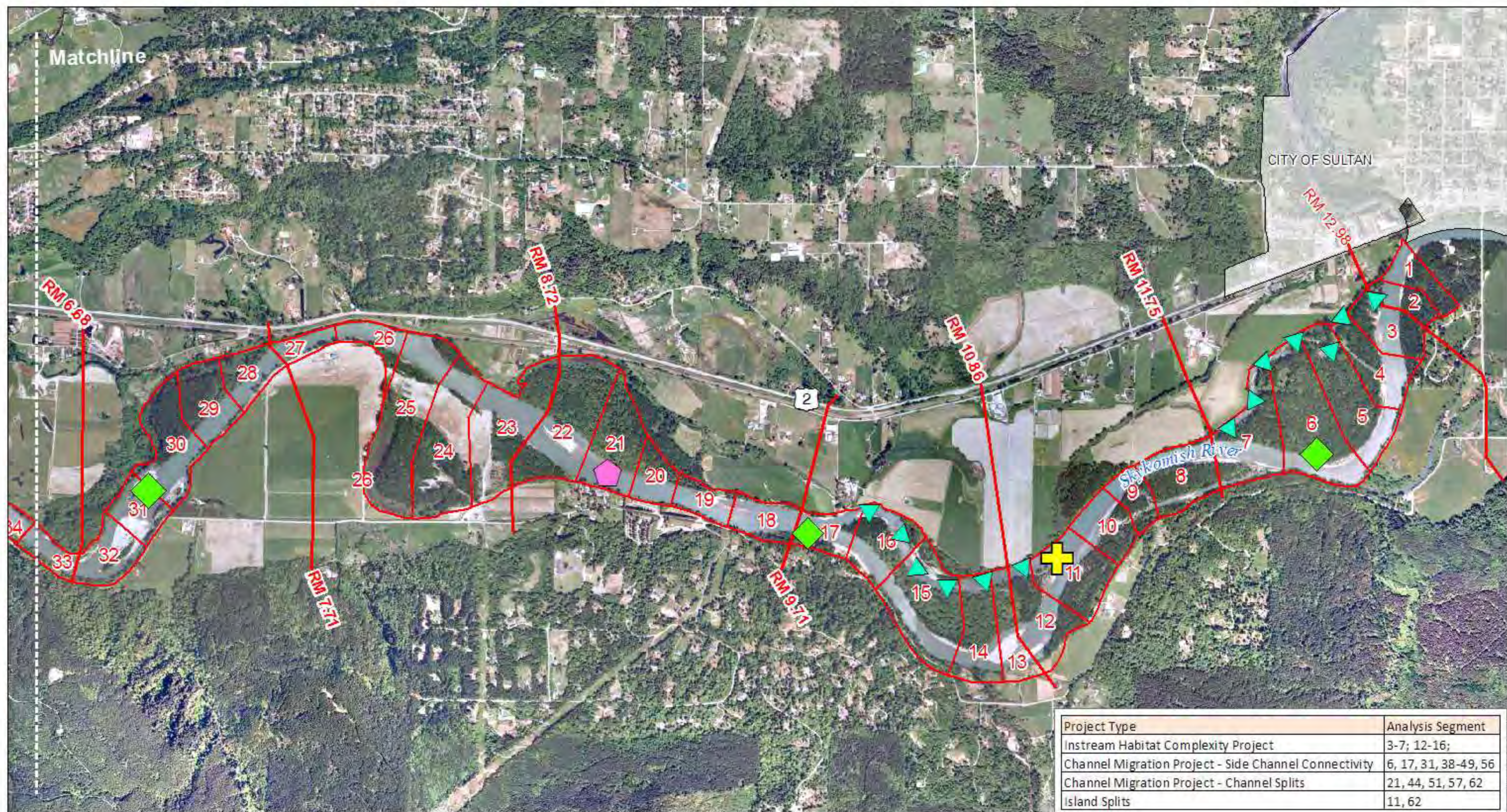
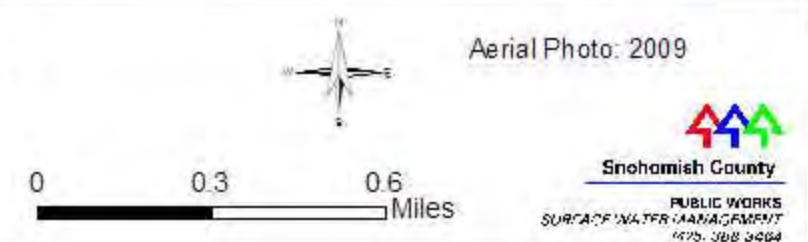
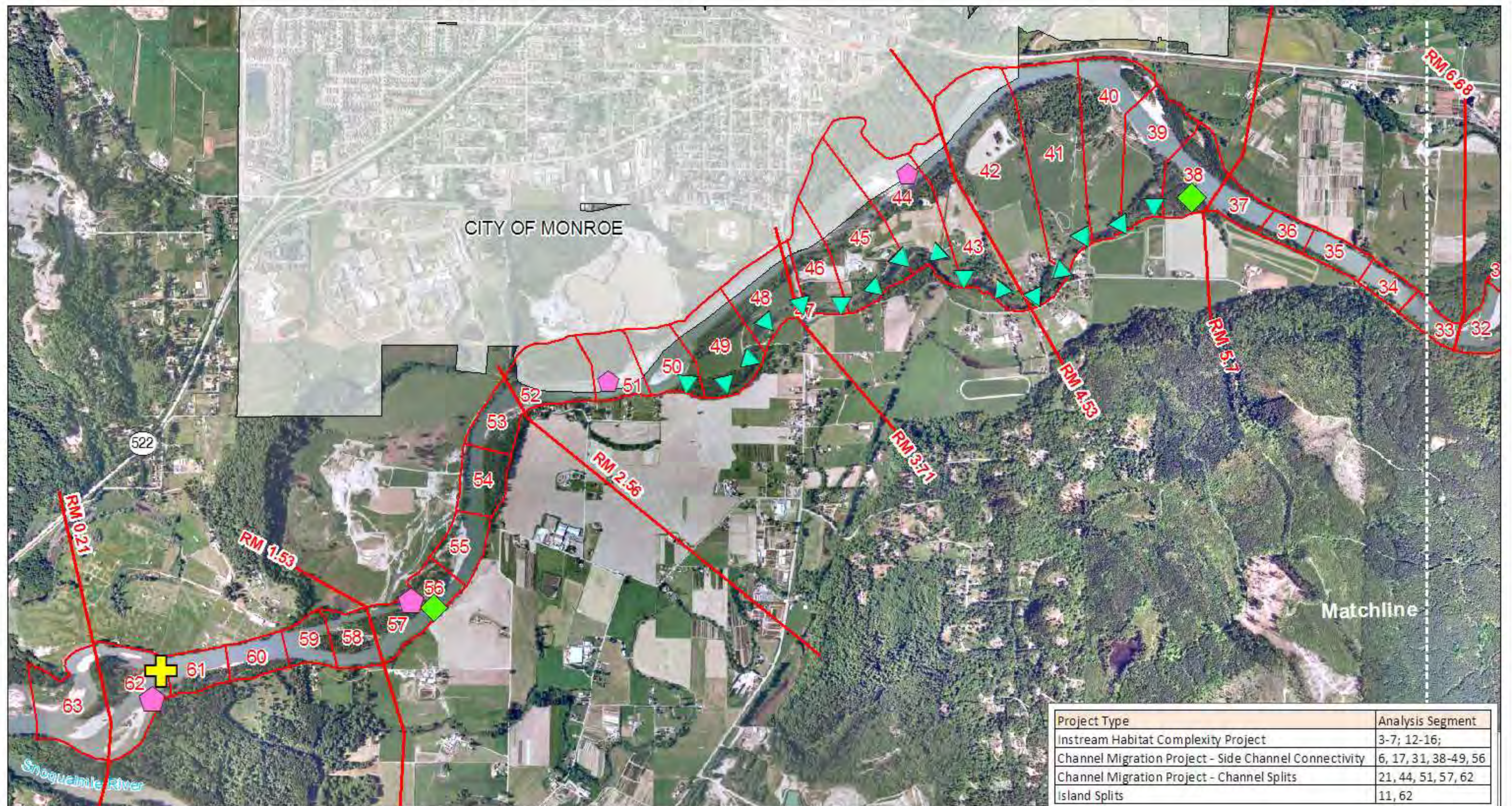


Plate 11A: Locations of restoration projects identified in this assessment that address the Snohomish River Recovery Plan goals and that are consistent with natural processes in the lower Skykomish River

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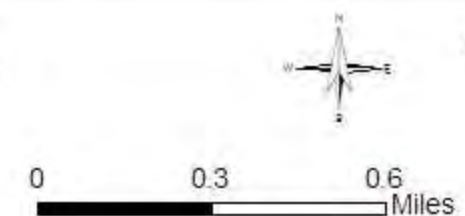




- Analysis Segment
- ~ Cross Section w/ River Mile
- + Island Split
- ▲ Instream Habitat Complexity Project
- ◆ Channel Migration Project-Side Channel Connectivity
- ⬠ Channel Migration Project-Channel Splits

Plate 11B: Locations of restoration projects identified in this assessment that address the Snohomish River Recovery Plan goals and that are consistent with natural processes in the lower Skokomish River

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