

MIDDLE PILCHUCK RIVER ASSESSMENT

Geomorphic Report

Prepared for

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Prepared by

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Table of Contents

List of Figures	ii
List of Tables	ii
1 Executive Summary.....	1
2 Introduction	3
2.1 Assessment Goals	3
2.2 Assessment Area	3
2.3 Assessment Stages	5
3 Methods	6
3.1 Objective and Guiding Questions	6
3.2 Analysis Methods	6
3.2.1 Reach Delineation	7
3.2.2 Sediment Transport Methodology.....	7
3.2.3 Hydrologic Analysis	9
3.2.4 Historical Channel Mapping.....	12
4 Results	14
4.1.1 Reach Delineation	14
4.1.2 Hydrologic Analysis	15
4.1.3 Sediment Transport Analysis	16
4.1.4 Historical Channel Mapping.....	18
5 Discussion.....	21
5.1.1 Geomorphic characteristics	21
5.1.2 Geomorphic processes favorable and / or unfavorable to project performance	21
5.1.3 Comparison with 2003 Tulalip report	22
6 References	23
Appendix A.....	24

List of Figures

Figure 2-1. Assessment workflow	3
Figure 2-2. Map of assessment area, reaches and cross section locations.	4
Figure 3-1. Example of digitized channel-bank traces, cut lines and segments used for channel movement analysis.	13
Figure 4-1. Middle Pilchuck River longitudinal profile	14
Figure 4-2. Distribution of sediment sizes for selected cross sections in reaches 1, 2 and 3.....	16
Figure 4-3. Calculated and observed median particle size.	17
Figure 4-4. BEI values within analysis segments of the Pilchuck River in Reaches 1-3, 1947 to 1955.	24
Figure 4-5. BEI values within analysis segments of the Pilchuck River in Reaches 1-3, 1955 to 1978.	24
Figure 4-6. BEI values within analysis segments of the Pilchuck River in Reaches 1-3, 1978 to 1991.	24
Figure 4-7. BEI values within analysis segments of the Pilchuck River in Reaches 1-3, 1991 to 2001.	24
Figure 4-8. BEI values within analysis segments of the Pilchuck River in Reaches 1-3, 2001 to 2009.	24

List of Tables

Table 2-1. Assessment Reaches	5
Table 3-1. Geomorphic assessment questions, indicators, data collection information, and outputs.....	6
Table 3-2. Pilchuck River stream gages.....	9
Table 3-3. Regression coefficients used to transpose discharges to ungaged locations.....	12
Table 3-4. Bank Erosion Index classification for assessing channel planform changes.	13
Table 4-1. Reach delineation data.	14
Table 4-2. Results of flood frequency analyses (Bulletin 17B) and regression analyses for USGS gages...	15
Table 4-3. Results of discharge simulations.....	15
Table 4-4. Discharges transposed from USGS gages to ungaged locations using Equation 1.	16
Table 4-5. Results from shear stress and median particle size calculations.....	17
Table 4-6. Estimated and calculated discharges.....	18
Table 4-7. Frequency of Bank Erosion Index (BEI) values by analysis time period.....	19
Table 4-8. Spatial and temporal variation in channel movement tendencies within analysis segments of the Pilchuck River.....	20

1 Executive Summary

The Pilchuck River, a tributary to the Snohomish River, has been identified as a high priority watershed for the recovery of salmonids in the Snohomish River basin. The overall goals of the Middle Pilchuck River Assessment are to identify opportunities to address salmonid habitat deficiencies through restoration activities and to develop preliminary designs for capital projects at three high priority sites. Salmon recovery priorities previously recommended for this sub-basin strategy group include preservation (along focus reaches), reconnection of off-channel habitats, restoration of shoreline conditions, riparian enhancement, and enhancement of in-stream structure (SBSRF, 2005). This geomorphic assessment focused on describing the river processes that help inform these preservation and restoration objectives.

The habitat assessment completed for this project (Snohomish County, 2012) identified three primary categories of project types to be considered in the geomorphic assessment, consisting of: pool creation, side channel and floodplain channel connectivity, and restoration of the riparian zone. These actions are primarily intended to increase juvenile rearing habitat availability, considered to be the primary factor limiting Chinook salmon production in the Middle Pilchuck River.

The geomorphic assessment area encompassed a ten-mile section of the Pilchuck River divided into three river reaches, extending upstream from the confluence with Dubuque Creek at OK Mill Road (RM 8.6) to the upstream end of reach three (RM 18.32) near the City of Granite Falls. This ten-mile stretch of the river was selected for the geomorphic assessment for the following reasons: it is the core spawning and rearing area for Chinook salmon within the sub-basin; it encompasses all mainstem restoration project concepts identified for the sub-basin in the 2003 Savery and Hook report and the 2005 Snohomish River Basin Salmon Conservation Plan; and, it is characterized by significant human interaction with river processes.

Data generated by the geomorphic assessment include information on historical discharge levels, channel characteristics, and sediment transport processes. The computed critical-to-observed median grain size ratios indicate that the three reaches exhibit sufficient transport capacity to meet and exceed supply. In other words, the river appears to be capable of transporting fine sediment downstream without significant risk of aggradation in most locations. Project types that will improve Chinook rearing habitat are recommended and should be constructed in areas that work in concert with geomorphic processes and positively impact landowners. The following project types are recommended:

- Pool creation could be facilitated through techniques such as construction of in-stream structures and facilitation of lateral channel movement, with some locations better suited for these types of projects than others;
- Reconnection of side channels and floodplain channels would likely be most successful in the vicinity of river segments where the channel movement analysis results depicted in Table 4-7 indicate moderate to large channel movement rates during any time period (it should be noted that channel and floodplain connectivity projects are only feasible according to land ownership, and bank armoring should be absent or able to be removed or modified consistent with landowner goals); and
- Restoration of the riparian zone is generally advisable wherever it is feasible.

After potential project sites are selected for preliminary designs, more detailed hydraulic and sediment transport analyses must be conducted to evaluate project feasibility and risk at each site.

Recommendations for habitat improvement projects from this assessment are consistent with the 'general suggestions for enhancement' in the Tulalip report (Savery and Hook, 2003). Project types recommended in the Tulalip report include reducing bank hardening, increasing floodplain connectivity, decreasing pool spacing by adding roughness elements such as large woody debris, and replanting the riparian zone with a mix of hardwood and conifer species. Site-specific recommendations resulting from this assessment may vary somewhat from the Tulalip recommendations

2 Introduction

2.1 Assessment Goals

The goals of the Middle Pilchuck River Assessment (assessment) are to identify opportunities to address salmonid habitat deficiencies through restoration activities and to develop preliminary designs for capital projects at three high priority sites. The following steps were proposed to meet these goals:

- 1) Compile existing data and collect new data on habitat conditions.
- 2) Evaluate habitat data to identify habitat limiting factors.
- 3) Complete a geomorphic assessment of habitat forming processes.
- 4) Identify and prioritize opportunities for habitat restoration.
- 5) Complete public outreach to evaluate and build support for projects.
- 6) Select three high priority sites for near-term work.
- 7) Complete 30% designs for the three sites and generate cost estimates.
- 8) Prepare a final assessment report.

This Geomorphic Report documents step 3 and summarizes how data was collected and analyzed for the geomorphic assessment in the Middle Pilchuck sub-basin. The geomorphic assessment provides information on how habitat-forming geomorphic processes in the assessment area can support the development of sustainable projects that address limiting factors for listed salmonid populations. The workdischarge for the overall assessment is shown below in Figure 2-1.

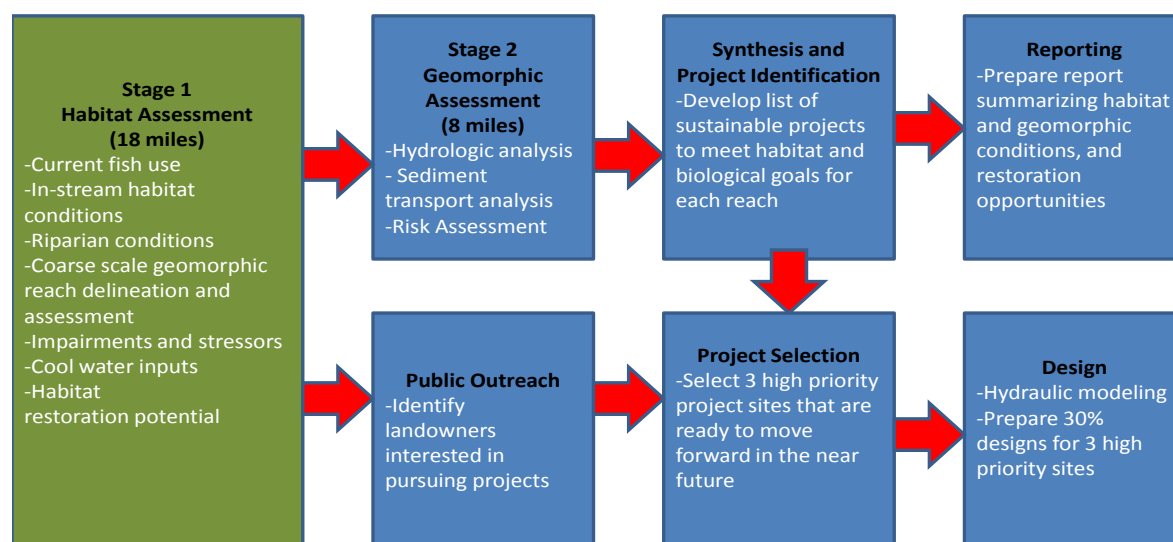


Figure 2-1. Assessment Workflow

2.2 Assessment Area

The overall assessment area encompasses an eighteen-mile section of the Pilchuck River in the Middle Pilchuck sub-basin (Figure 2-2). This portion of the river stretches upstream from the confluence with Dubuque Creek (RM 8.60) to an area just below the City of Snohomish diversion dam (RM 26.44).

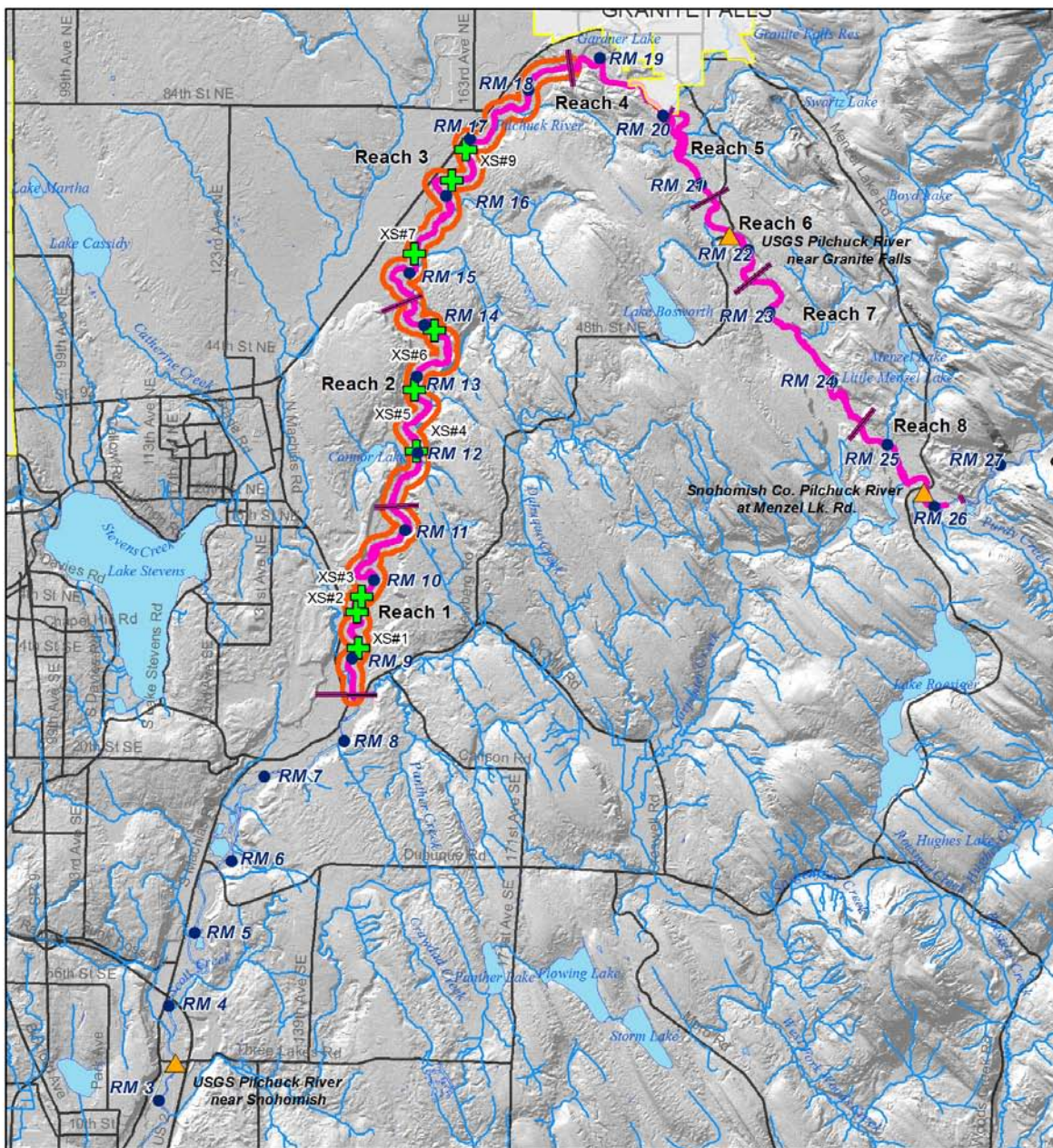


Figure 2-2. Map of Assessment Area, Reaches, and Cross Section Locations.



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Figure 2-2. Map of assessment area, reaches and cross section locations.

The assessment area was divided into eight reaches based on channel slope, floodplain width, and channel constraints. These reaches are listed in Table 2-1 below.

Table 2-1. Assessment Reaches

Reach	River Mile		Length (mi.)
	Start	End	
1	8.60	11.38	2.78
2	11.38	14.45	3.07
3	14.45	18.32	3.86
4	18.32	20.12	1.80
5	20.12	21.29	1.17
6	21.29	22.52	1.23
7	22.52	24.79	2.27
8	24.79	26.44	1.65

2.3 Assessment Stages

The overall assessment was completed in two stages. For stage 1, a habitat assessment was conducted for the entire eighteen-mile assessment area. This assessment included a coarse-scale geomorphic element, which is described in the Habitat Report. Data produced by the habitat assessment was used to evaluate existing habitat conditions within the eight assessment reaches listed in Table 2-1.

For stage 2, a geomorphic assessment was completed for the lower ten miles (reaches 1 – 3) of the assessment area. Also referred to as the geomorphic assessment area, this area stretches from the confluence with Dubuque Creek (RM 8.60) to the upstream end of reach three (RM 18.32) near the City of Granite Falls. This ten-mile stretch of the river was selected for the geomorphic assessment for the following reasons: it is the core spawning and rearing area for Chinook salmon within the sub-basin; it encompasses all mainstem restoration project concepts identified for the sub-basin in the 2003 Savery and Hook report and the 2005 Snohomish River Basin Salmon Conservation Plan; and, it is characterized by significant human interaction with river processes. Data generated by the geomorphic assessment includes information on historical discharge levels, channel characteristics, and sediment transport processes. This information will be used in conjunction with the habitat assessment data to identify and prioritize opportunities for habitat restoration.

This assessment differs somewhat from previous river assessments conducted in Snohomish County. In lieu of developing a reach-wide hydraulic model (e.g., HEC-RAS) and completing detailed sediment transport calculations, a screening level analysis was performed. The local balance between sediment supply and transport capacity was quantified at locations distributed along the length of the geomorphic assessment reach. A more detailed sediment transport analysis is recommended for design of projects selected for the preliminary designs.

3 Methods

3.1 Objective and Guiding Questions

The objective of the geomorphic assessment was to define the primary geomorphic processes that influence fish habitat creation and the selection of habitat restoration projects in the Middle Pilchuck sub-basin. The geomorphic assessment included collection of data pertaining to slope, confinement, and floodplain connectivity for all eight assessment reaches. Channel movement and sediment transport characteristics were also analyzed for the geomorphic assessment area (reaches 1 – 3). The assessment was designed to answer the two questions listed in Table 3-1.

Table 3-1. Geomorphic assessment questions, indicators, data collection information, and outputs

Geomorphic Assessment Question	Indicators	Data Collection Activities and Protocols	Outputs
1. <u>Coarse-scale:</u> What are the geomorphic characteristics of each reach?	- Channel slope - Confinement - Floodplain connectivity	<u>Remote sensing</u> of channel elevation, confinement, and side channel connectivity.	Identify reach scale geomorphic differences.
2. <u>Fine-scale:</u> What are the geomorphic processes favorable and/or unfavorable to project performance?	- Channel size and shape - Channel movement - Grain size distribution	<u>Mapping</u> of historical channels using aerial photographs. <u>Field survey</u> of channel cross sections and grain size distribution. <u>Analysis</u> of sediment transport.	Project types and locations compatible with natural flooding and sedimentation processes.

3.2 Analysis Methods

Geomorphic assessment data was collected and analyzed between June 2010 and May 2011. Major data sources for the assessment included:

- Review of remote sensing information including aerial photos and topographic data;
- Review of available hydrologic data and supplemental discharge measurements; and,
- Field surveys of channel cross sections, high water marks and grain size distribution.

Remote sensing information was used in combination with field surveys (Section 3.2.2) to collect data for the geomorphic assessment. Data was generated on confinement, elevation changes, and channel planform in order to characterize the large scale geomorphic setting that reflects channel processes.

3.2.1 Reach Delineation

Reaches were delineated using channel slope and confinement as the primary determinants. Major reach breaks were identified based on slope breaks and major changes in valley width.

Channel Slope

A longitudinal profile of water surface was developed for the entire assessment area to evaluate if there are large scale slope changes that influence sediment transport and deposition patterns. Slope was calculated by sampling elevations along the centerline of the river channel alignment from the 2005 LiDAR Digital Elevation Model (DEM). Elevations were sampled every 100 feet and represent the water surface at the time of the LiDAR survey. The profile was plotted and separated into the following slope classes (DOE, 2010):

- < 2% -- low gradient
- 2 - 4% -- moderate gradient
- > 4% -- high gradient

Confinement

Confinement was used as input for delineating large scale reach breaks for the assessment area. Confinement is defined as the ratio of active channel width to valley width and was visually estimated using available maps and topographic data

3.2.2 Sediment Transport Methodology

Sediment transport analysis was used to assess the effectiveness of the types of restoration projects recommended to address limiting factors. In lieu of developing a reach-wide hydraulic model (e.g., HEC-RAS) and completing detailed sediment transport calculations, a screening level analysis was performed. The sediment transport analysis method previously applied to large rivers was modified to better fit the smaller Pilchuck River system. Surveying cross sections at the density required for the more detailed sediment transport analysis would have been cost prohibitive.

For the screening level analysis, the local balance between sediment supply and transport capacity was quantified at locations distributed along the length of the geomorphic assessment reach. This was accomplished by comparing the ratio of the median grain size predicted to mobilize when the discharge reaches the bankfull level (D_{50c}) at representative cross section locations to the median grain size (D_{50}) observed in distinct bar deposits nearby.

The first step in determining the median grain size predicted to mobilize when the discharge reaches the bankfull level was to generate an estimate for the bankfull water surface elevation. This was done using cross sections that were surveyed in straight, relatively prismatic channels, at locations where a clear bankfull elevation could be discerned visually in the field on at least one side of the channel. Channel cross sections were surveyed (reaches 1 – 3) using a combination of Global Positioning System (GPS) and traditional survey methods. Local channel slope was also determined by surveying channel bed elevation approximately 50 meters upstream and downstream of each cross section. Data collection, processing, and quality control for the cross section survey were completed by the Snohomish County Public Works department under the supervision of a licensed surveyor. The elevation of bankfull

discharge was identified on the cross section profile plots as the point beyond which the profile clearly flattened, which corresponds to a break point in plots of wetted perimeter vs. discharge.

For a fluid to begin transporting sediment that is at rest, the shear stress at the bed must exceed the critical shear stress for the initiation of motion of the bed sediments. The second step in the analysis was to calculate bankfull area, wetted perimeter, and the resulting hydraulic radius for the surveyed cross sections. The hydraulic radius and channel slope were then used to calculate the critical shear stress for each cross section using equation 1, the uniform channel approximation for shear stress.

$$\text{Equation 1: } \tau_o = \gamma RS$$

- τ_o = Shear stress at the bed (N/m²)
- $\gamma = \rho g$
- ρ = Density of water (kg/m³)
- g = gravity (m/s²)
- R = Hydraulic radius at bankfull discharge (m)
- S = Channel slope (m/m)

The third step in the analysis was to calculate the critical median grain size (D_{50c}) for each representative cross section using the Shields parameter in the form shown in equation 2. The critical Shields parameter was set at 0.045, a typical value for alluvial streams and bedload transport equations (Leopold et al., 1995).

$$\text{Equation 2: } \theta_c = \frac{\tau_o}{(\rho_s - \rho)gD_{50c}}$$

- θ_c = Critical Shields parameter
- τ_o = Shear stress at the bed (N/m²)
- ρ_s = Density of material (kg/m³)
- D_{50c} = Critical median grain size (m)

In order to increase confidence in the estimate of bankfull parameters and resulting estimate of critical median grain size (D_{50c}), the bankfull discharge estimated using the cross section data was compared against hydrologic estimates of the two year flood discharge. Relatively close correspondence between the bankfull-derived estimate and hydrologic estimate of the two year flood, which should generally equal or exceed bankfull discharge in alluvial channels (Leopold et al., 1995), would indicate that the bankfull discharge parameters derived from the cross section profile plots are approximately correct. Manning's equation, expressed in equation 3, was used to estimate the bankfull discharge. The channel roughness coefficient, Manning's n , was estimated from field indicators of flood level and validated using discharge measurements.

$$\text{Equation 3: } Q_{BF} = A \left(\frac{1.49}{n} \right) R^{2/3} S^{1/2}$$

- Q_{BF} = Calculated bankfull discharge (cfs)
- A = Channel area at bankfull discharge (ft²)
- n = Channel roughness coefficient (0.033)
- R = Hydraulic radius at bankfull discharge (ft)
- S = Channel slope (ft/ft)

A total of 32 pebble counts were completed to characterize upstream-downstream variation in grain size distribution for the entire assessment area (reaches 1 – 8). This information was used to gain an understanding of the distribution of sediment sizes that are being actively transported through the assessment area. The final step in the analysis was to calculate median observed grain size (D_{50}) for the pebble count located nearest to each surveyed cross section. The ratio of critical-to-observed median grain size was computed for each cross section. This ratio is indicative of the river's transport capacity relative to the sediment that is currently being supplied for transport through the geomorphic reach.

A more detailed sediment transport analysis is recommended for design of projects selected for the preliminary designs. The following elements should be applied to evaluate project feasibility and risk at each proposed project site:

- Complete hydraulic modeling (HEC-RAS) to interpret the relationships between water surface elevation, floodplain inundation and current/potential discharge pathways.
- Complete detailed sediment transport analysis to identify zones of active aggradation and degradation to aid in project site selection and design.

3.2.3 Hydrologic Analysis

The hydrologic analysis focused on estimating the approximate 2 year flood discharges at different locations along the Pilchuck River. This information was used to assess reach scale variation in sediment transport potential. The analysis evaluated stream gage data, discharge measurements, and regional regression predictions to arrive at a reasonable estimate of flood magnitudes for the Pilchuck River. Two methods for determining flood discharges at cross section locations were considered: (1) estimating discharges using USGS regression equations, and (2) calculating discharges using flood frequency analysis at gaged locations and transposing the calculated discharges to the ungaged locations using drainage area and precipitation statistics.

Gage Data

The three stream gages that have operated on the Pilchuck River collecting stage and discharge data for various periods are listed in Table 3-2. Two stream gages have been installed on the Pilchuck River by USGS. They are the Pilchuck River near Granite Falls gage (12152500) and the Pilchuck River near Snohomish gage (12155300). A third gage was recently installed in the upper watershed by Snohomish County near the City of Snohomish Water Treatment Plant on Menzel Lake Road for flood warning purposes.

Table 3-2. Pilchuck River stream gages.

Gage Location (USGS Gage #)	Period of Record	Drainage Area (square mi.)	Peak Discharge (cfs) / Date
Pilchuck River near Granite Falls (USGS 12152500)	Recording Gage 1944 – 1957 Crest Gage 1957 - 1980	54.5	10,500 cfs 25 Oct. 1945
Pilchuck River near Snohomish (USGS 12155300)	Recording Gage 1992 – Present	127	13,900 cfs 8 Jan. 2009
Pilchuck River at Menzel Lake Rd.	Stage Gage 2008 – Present	43.6	9,900 cfs (est.) 8 Jan. 2009

The USGS gage near Granite Falls was installed in 1911 and operated for a period of three months. It was then re-established in 1943 and operated continuously through 1957. The gage was maintained as a peak-stage gage from 1957 through 1980. There are 37 years of published peak discharge data for this gage. The record instantaneous peak discharge for the gage of 10,500 cfs occurred in October 1945. This is approximately a 100-year flood based on frequency analysis of the 37 year period of record.

The USGS gage near Snohomish has been in operation since 1992. There are 18 years of published peak discharge data for this gage. The record peak discharge for the gage occurred in January 2009. The USGS investigated and determined that the instantaneous peak discharge was 13,900 cfs at the Snohomish gage (Kimbrough, 2011). This is approximately a 25-year flood based on frequency analysis of the 18 year period of record.

The Snohomish County gage on Menzel Lake Road was installed in 2008 and has been operated as a stage-only flood warning gage. Several discharge measurements have been made and an initial rating curve developed for a limited range of discharges. The short period of record for this gage does not allow for reliable frequency analysis to be performed.

Discharge Measurements

Several discharge measurements were made by Snohomish County for use in the hydrologic and sediment transport analyses. Measurements attempted to capture the peak discharge of a bankfull discharge event that occurred on March 30, 2011 and a lower magnitude event on March 14, 2011, with estimated recurrence intervals of 2 and 1.2 years at the Snohomish gage respectively. A measurement was attempted for the bankfull event at Bridge 581 located on 64th St. in the middle of reach 3. The discharge measurement was unsuccessful due to turbulence caused by the bridge piers; however, a measurement was made successfully from the bridge on March 14. Discharge measurements for both events were made at the Menzel Lake Rd. gage located at the upstream end of reach 8. Discharge measurements were made using acoustic doppler current profile instruments and processed using WinRiver (v2) software.

High Water Marks

High water mark data were collected following the December 2010 and March 2011 floods. The recurrence intervals for the floods were estimated at 4 and 5-years respectively using data from the gage near Snohomish. Marks for the December 2010 event were identified by a field team at publicly accessible locations and surveyed by the County Surveyor. Marks for the March 2011 event were identified by a field team at each cross section location for use in the sediment transport analysis.

Regression Analysis

Regression-analysis based estimates of discharges generated for each of the ungaged cross section locations using StreamStats (USGS, 2011). In order to develop the regression equations used in StreamStats, USGS analyzed peak-discharge records of 527 gaging stations on unregulated streams in Washington to obtain discharges with recurrence intervals of 2, 10, 25, 50, 100 and 500-years (Sumioka et al., 1998). The results of the frequency analysis were combined with physical and climatic basin characteristics values to develop equations that can be used to compute peak discharges for ungaged streams. Basin characteristics shown to be important in estimating flood discharge include contributing drainage area and mean annual precipitation.

Gage Analysis

Analysis of annual peak discharge data was used to generate the most accurate estimate of flood magnitudes possible. The period of record for the two USGS gages on the Pilchuck River do not overlap, therefore no direct comparison between the gages is possible, nor is it possible to extend the period of record using a two-station comparison. The gage analysis for this assessment utilized a method for transposing gage based peak discharges from gaged locations to nearby ungaged locations. This was accomplished by using the ratio of the discharges for a given recurrence interval estimated using the USGS regression equation parameters. The reason for using this method of transposition was that transposition using only the ratio of basin areas tended to result in large errors in peak discharge when compared to frequency analysis of gaged records at the same locations. It was also noted that the USGS regression equations tended to under predict peak discharges at gaged locations in the Pilchuck River basin.

Transposing gaged data to ungaged locations relies on the assumption of similar topography, geology, vegetation, rainfall, drainage area and other characteristics that may affect flood magnitude. Peak discharges for an ungaged site on a gaged stream can be computed by using an equation if the drainage area of the ungaged site is between 50 and 150 percent of the drainage area of the gaged site (Sumioka, 2001). Drainage area statistics and estimates of mean annual precipitation for the two USGS gage locations on the Pilchuck River were retrieved from USGS. The drainage area of the representative cross sections ranged from 50 to 56 percent of the drainage area for the Snohomish gage and from 118 to 131 percent of the Granite Falls gage.

The 2-, 10-, 25-, 50-, and 100-yr discharges were calculated from annual peak discharge data for the Pilchuck River gages near Snohomish and Granite Falls using methods described in the Interagency Advisory Committee on Water Data Guidelines for determining flood frequency, Bulletin 17B (IACWD, 1981). Discharges computed for the Pilchuck River at Snohomish gage were transposed to ungaged locations using equation 4 (IACWD 1982, Sumioka et al. 1998).

$$\text{Equation 4: } Q_u = Q_g \left(\frac{A_u}{A_g} \right)^a \left(\frac{P_u}{P_g} \right)^b$$

- Q_u = peak discharge at the ungaged location for a specific recurrence interval (cfs),
- Q_g = peak discharge at the gaged location determined by frequency analysis for a specific recurrence interval (cfs),
- A_u = contributing drainage area at the ungaged site (sq. mi.),
- A_g = contributing drainage area at the gaged site (sq. mi.),
- a = area exponent for Region 2 (Sumioka, 2001)
- P_u = mean annual precipitation in inches, for the ungaged site,
- P_g = mean annual precipitation, in inches, for the gaged site, and
- b = mean annual precipitation area exponent for Region 2 for a specific recurrence interval (Sumioka, 2001, Table 2)

Table 3-3. Regression coefficients used to transpose discharges to ungaged locations (Sumioka 1998, Table 4, Region 2).

	Recurrence Interval				
	2-yr	10-yr	25-yr	50-yr	100-yr
Area coefficient (a)	0.877	0.868	0.864	0.862	0.861
Precip. coefficient (b)	1.51	1.57	1.59	1.61	1.62

Discharge measurements were used to validate estimates from gage analysis. A discharge measurement was made at Bridge 581 on March 14, 2011 at the peak of a small flood. The corresponding peak discharge from the Pilchuck River near Snohomish gage was transposed to the discharge measurement location using equation 4. These values were then multiplied by the ratio of the 2-year discharges estimated using the regression equation to approximate the discharge that would be estimated from the Granite Falls gage if the gage were still in operation.

3.2.4 Historical Channel Mapping

Mapping of historical channel locations was used to determine the maximum and average annual bank erosion rates and assess patterns of channel movement. Active channel bank lines were digitized for the geomorphic assessment area (reaches 1 – 3) from seven sets of historical aerial photographs. Photo years ranged from 1947 to 2009.

Color aerial orthophoto mosaics acquired in 2003, 2006, 2007 and 2009 were available in GIS format. Historical black and white aerial photographs for photo years 1947, 1955, 1965, 1978, 1991, 1998 and 2001 were retrieved from County digital archives. The images were georeferenced using ArcGIS georeferencing tools, using the Snohomish County 2007 1-foot orthophotos as the registration source. Originals were 9" x 9", but were not available for scanning. The County digital archives had previously been scanned and enlarged to approximately 11" x 17". Resulting distortion varied greatly across the image with the least in the center and most on the edges. Lens distortion was unquantifiable and irregular because the fiducial marks were missing and because the photos were cut from the originals resulting in lens distortion irregularly distributed from photo to photo. Overall accuracy was estimated at approximately three feet. Channel movement rates less than this value were considered within measurement error for the analysis.

Right and left river bank locations were digitized for the main channel and for visible side channels by SWM GIS staff, for each year of photographs at a scale of 1:5000. The resulting digitized poly lines were overlaid chronologically and locations compared between consecutive sets of photographs (Fig. 3-1). Average channel movement rates were estimated for 700 ft long analysis segments. This length was selected to reflect typical channel unit spacing in meandering alluvial channels, or approximately 7 channel widths (Leopold et al. 1995).

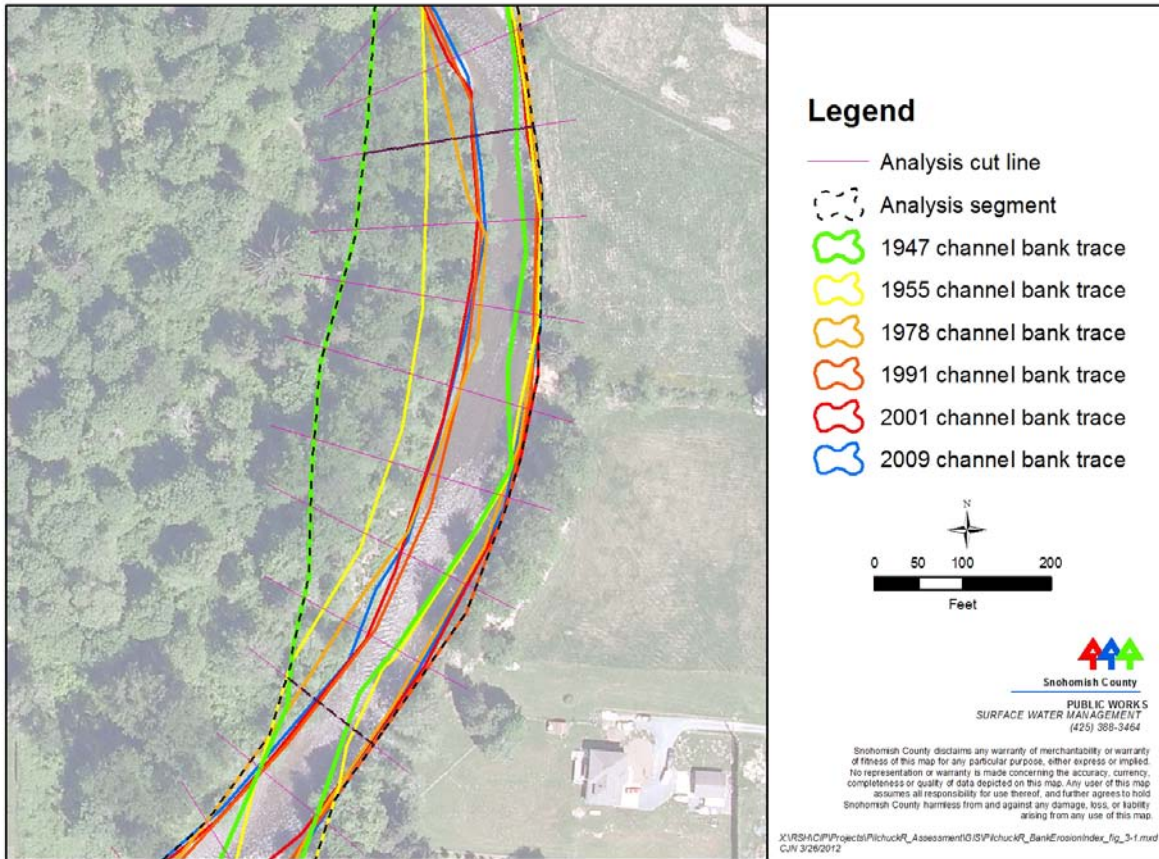


Figure 3-1. Example of digitized channel-bank traces, cut lines and segments used for channel movement analysis.

Channel movement distance was measured in GIS using cut lines spaced at 100 ft increments along and perpendicular to the river centerline. Channel movement distance was computed as the distance between successive main channel river bank traces where they intersected a cutline. The average movement distance was computed for the downstream analysis segment boundary cut line and the six cut lines upstream. An average annual migration rate was computed by dividing the average movement distance by the number of years between the two sets of photographs. The average annual movement rates were used as the basis for classifying analysis segments according to planform changes using Bank Erosion Index (BEI) rates in Table 3-4. Professional judgment was used to define the BEI threshold levels defined in Table 3-4. Movement may have occurred in either left or right bank direction. The riverbank with the greater average annual movement rate was used to classify a segment.

Table 3-4. Bank Erosion Index classification for assessing channel planform changes.

Bank Erosion Index (BEI)	Average Movement Rate (ft/yr, one or both banks)
0	< 3 (within measurement error)
1	3-6 (minor change)
2	6-12 (moderate change)
3	> 12 (large change)

4 Results

4.1.1 Reach Delineation

The assessment area was divided into 2 slope classes based on significant slope breaks (Fig. 4-1) and further divided into 8 reaches based on confinement. This division resulted in identifying reaches where large scale geomorphic processes should be generally similar as they influence project function and performance.

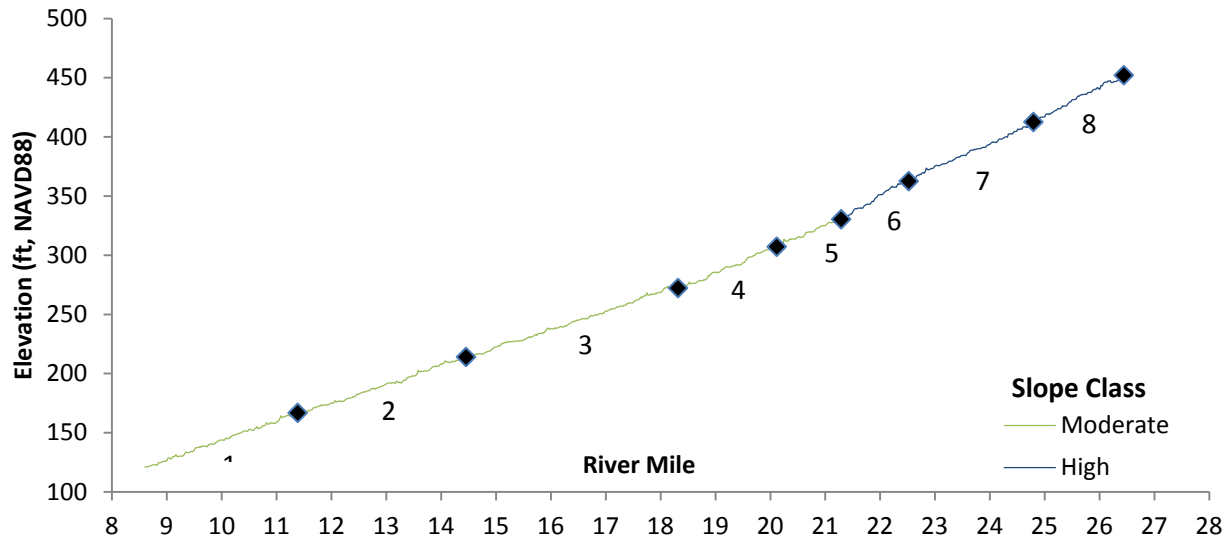


Figure 4-1. Middle Pilchuck River longitudinal profile.

The average channel slope for the reaches ranged from 0.29 to 0.52 percent. Reach average slopes are provided in Table 4-1, which are characteristic of gravel-bed rivers with typical sizes in the gravel to cobble range.

Table 4-1. Reach delineation data.

Reach	River Mile		Length (mi.)	Elevation (ft.)		Slope		Confinement
	Start	End		Start	End	%	Class	Class
1	8.60	11.38	2.78	121.00	166.78	0.31	Moderate	Unconfined
2	11.38	14.45	3.07	166.78	214.01	0.29	Moderate	Unconfined
3	14.45	18.32	3.86	214.01	272.28	0.29	Moderate	Unconfined
4	18.32	20.12	1.80	272.28	307.19	0.37	Moderate	Confined
5	20.12	21.29	1.17	307.19	330.39	0.38	Moderate	Moderately Confined
6	21.29	22.52	1.23	330.39	362.61	0.50	High	Confined
7	22.52	24.79	2.27	362.61	412.61	0.41	High	Moderately Confined
8	24.79	26.44	1.65	412.61	452.14	0.45	High	Moderately Confined

4.1.2 Hydrologic Analysis

Discharge estimates generated for the Pilchuck River gages near Snohomish and Granite Falls are listed in Table 4-2. The 2-, 10-, 25-, 50-, and 100-yr discharges were calculated using annual peak discharge data (17B) and compared to USGS regression estimates for the gage locations.

Table 4-2. Results of flood frequency analyses (Bulletin 17B) and regression analyses for USGS gages.

Pilchuck River		Peak Discharges (cfs)				
	Method	2-yr	10-yr	25-yr	50-yr	100-yr
At Gage Near City of Granite Falls	17B	5101	7759	9006	9903	10777
	Regression	1640	2920	3580	4210	4720
At Gage Near City of Snohomish	17B	5776	10923	13710	15851	18042
	Regression	2480	4310	5250	6120	6850

The results of the analyses in Table 4-2 show that the regression-based estimates are significantly lower than the discharges computed using frequency analysis of gage data. Standard error estimates reported by USGS for the regression estimates ranged from +53% to -56%. The difference between the regression estimates and the frequency analyses exceeded this error range. The large difference may be due to the fact that Pilchuck River has a relatively steep gradient and is fairly confined as compared to lower gradient rivers with broad floodplains such as the Snohomish River, that were included in the representative set of data used to generate the regression equation coefficients.

This observation led to an approach which made use of the frequency analysis data from both USGS gages to determine discharges at ungaged locations. The results are listed in Table 4-3. Using the gage near Snohomish data resulted in under-prediction of the measured discharge, while using the gage near Granite Falls data resulted in over-prediction of the measured discharge. Averaging the results from both gages resulted in a discharge estimate that was slightly higher than measured.

Table 4-3. Results of discharge simulations.

Method	Gage near Snohomish	Gage near Granite Falls	Average of Snohomish & Granite Falls gages
Equation 1	-10.2%	19.7%	4.7%

Estimated flood discharges using this approach are listed for each representative cross section location in Table 4-4. The discharges, based on comparison of results at gaged locations, appear to be slightly larger than discharges measured. Overall the 2-year discharges calculated using this method were determined to be reasonable for use in estimating bankfull discharge levels.

Table 4-4. Discharges transposed from USGS gages to ungaged locations using Equation 1.

	Cross Section (locations shown in Fig. 2-2)								
	1	2	3	4	5	6	7	8	9
Drainage Area (sq mi)	71.8	71.4	71.4	69.7	69.1	68.5	66.5	64.6	64.4
Mean Annual Precipitation (inches)	60.5	60.6	60.6	61.1	61.2	61.4	61.9	62.4	62.5
Recurrence interval	Average of discharges transposed from Pilchuck R. nr. Snohomish and Pilchuck R. nr. Granite Falls gages using Equation 1 (cfs)								
2-yr	5086	5073	5073	5029	5004	4990	4922	4857	4856
10-yr	8602	8582	8582	8511	8468	8446	8334	8227	8225
25-yr	10408	10385	10385	10299	10248	10222	10088	9960	9958
50-yr	11770	11743	11743	11648	11590	11562	11411	11268	11266
100-yr	13130	13100	13100	12995	12931	12899	12732	12574	12571

4.1.3 Sediment Transport Analysis

The classification of material within the bed stretched from the “large cobble” to “fine gravel” classification (Strum, 2001). A particle distribution plot is shown in Figure 4-2 to display the representation of material visually.

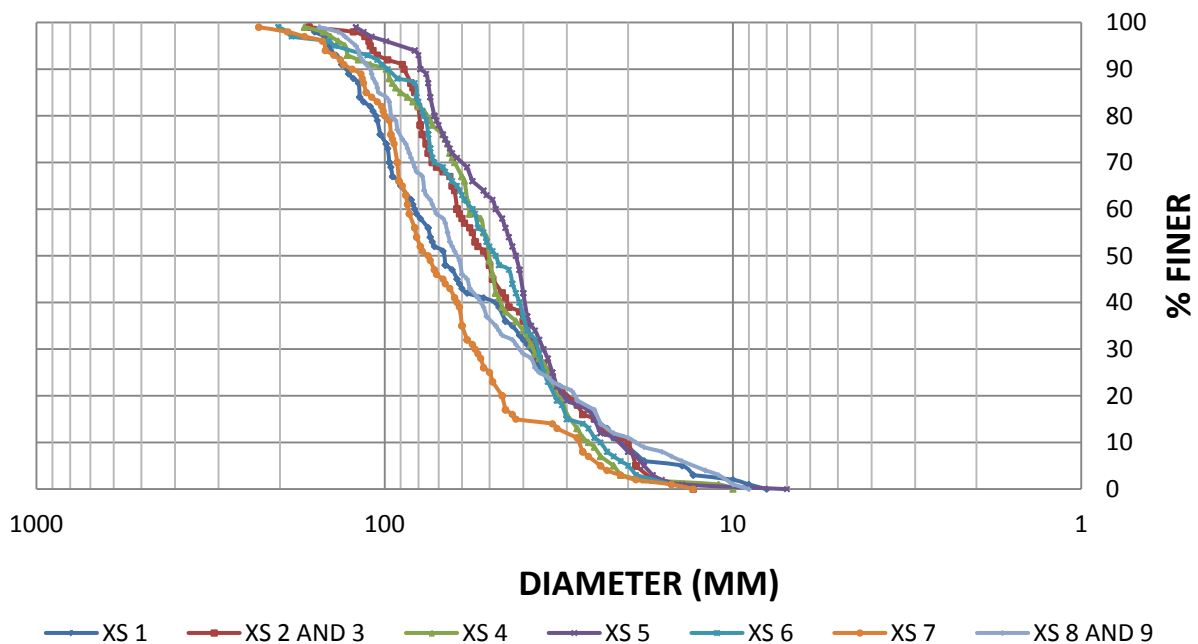


Figure 4-2. Distribution of sediment sizes for selected cross sections in reaches 1, 2 and 3.

Table 4-5. Results from shear stress and median particle size calculations.

Reach	Cross-Section ¹	River Mile (mi.)	τ_o (N/m^2)	D ₅₀ – Calc. (mm)	D ₅₀ – Obs. (mm)	D _{50 C} / D _{50 OBS}
1	1	9.12	4.58	6	50	0.126
1	2	9.60	35.45	49	50	0.973
1	3	9.79	5.87	8	50	0.161
2	4	12.08	15.24	21	50	0.375
2	5	12.91	28.61	39	42	0.935
2	6	13.85	19.69	27	48	0.563
3	7	15.22	12.86	18	75	0.235
3	8	16.37	25.52	35	62	0.565
3	9	16.85	53.07	73	62	1.175

1. Cross section locations shown in Fig. 2-2

The computed critical-to-observed median grain size ratios indicate that the three reaches exhibit sufficient transport capacity to meet and exceed supply. In other words, the river appears to be capable of transporting fine sediment downstream without significant risk of aggradation in most locations (Table 4-5; Figure 4-3). The results for cross-sections 1 and 3 may not be wholly representative because they are associated with a substantially lower estimated bankfull discharge than the rest of the reach (Table 4-6), which suggests that an accurate bankfull indicator was not discerned at those locations. The results for cross-sections 2 and 5 suggest that the transport to supply balance is closer to equilibrium. In those locations, sediment sorting could be enhanced with an in-stream project, or channel movement could be re-activated with a floodplain connectivity treatment. From Figure 4-3 it is also apparent that the reach closest to being in a state of equilibrium ($D_{50 CR} / D_{50 OBS} = 1$) is reach 2. This figure shows an increase in particle size with upstream travel, a trend typical of most river systems.

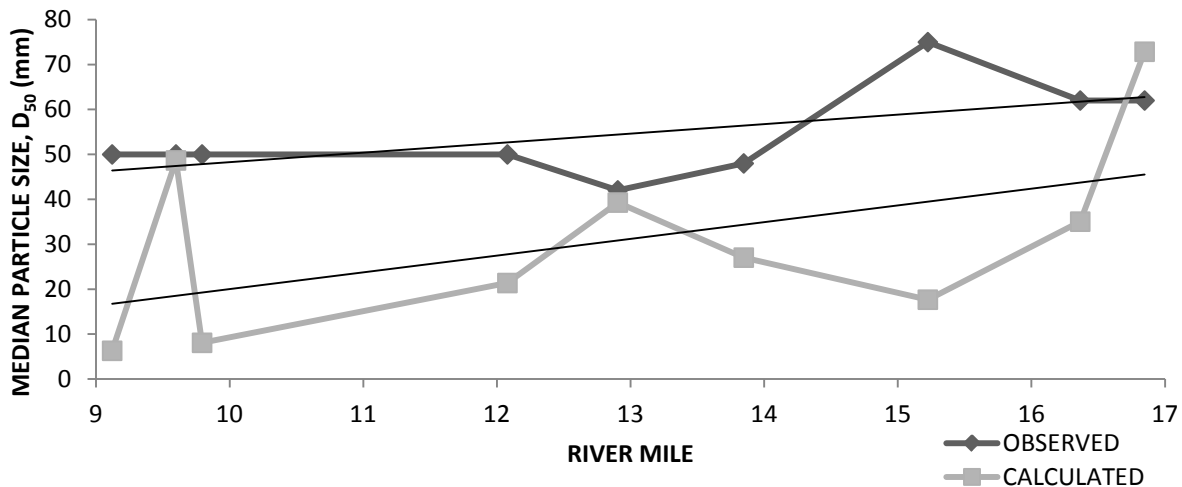


Figure 4-3. Calculated and observed median particle size.

Table 4-6. Estimated and calculated discharges. [2-Year Hydrologic Q = Estimated discharge based on Snohomish and Granite Falls gages; Bankfull Q = Calculated discharge from estimated bankfull elevation and cross section geometry]

Cross-Section ¹	River Mile (mi.)	Bankfull Elev. (ft.)	Area (ft ²)	W.P. (ft)	R (ft)	2-Year Hydrologic Q (FT ³ /s)	Bankfull Q (FT ³ /s)	% Diff.
1	9.1205	132.77	381.22	103.65	3.68	5086	837	143
2	9.5982	144.69	819.04	146.28	5.60	5073	5365	6
3	9.7934	142.59	229.83	101.04	2.27	5073	527	162
4	12.0785	177.31	169.93	104.08	1.63	5029	5029	0
5	12.9045	194.65	651.13	140.98	4.62	5004	3711	30
6	13.8471	209.04	502.67	132.98	3.78	4990	2299	74
7	15.2248	231.05	536.73	115.77	4.64	4922	2053	82
8	16.3653	247.72	635.81	138.68	4.58	4857	3418	35
9	16.8472	257.08	760.19	151.41	5.02	4856	5984	21

1. Cross section locations shown in Fig. 2-2

4.1.4 Historical Channel Mapping

Historical channel movement analysis was completed by tracing bank lines from successive series of geo-referenced aerial photographs. The channel movement rates were classified using Bank Erosion Index (BEI) threshold values from Table 3-4. A summary table showing the frequency of each BEI category for each interval of time analyzed is presented in Table 4-7. This table provides an overall picture of how active this section of the Pilchuck River was during the time periods analyzed. Results of the historical channel movement analysis using are presented by analysis segment and time period in Table 4-8. This table displays spatial and temporal variation in channel movement patterns. Planform change index values are color coded to enable visual identification of channel movement patterns using the following color scheme:

- 0 (blank) = within measurement error (< 3 ft.);
- 1 (yellow) = minor change (3-6 ft.);
- 2 (orange) = moderate change (6-12 ft.);
- 3 (red) = large change (>12 ft); and,
- shaded boxes indicate segments where bank erosion rates appear to have decreased since 1978.

Segments where there was a noticeable increase in channel stability after the 1978 photos are shaded. This reflects extensive revetment construction during the 1960's. Channel instability can be inferred from minor in blank and yellow cells, to moderate in orange cells, and large in red cells. In some locations there has been an apparent shift in instability moving in the downstream direction over time, whereas in others the zone of instability has remained in roughly the same general location. Some segments were relatively stable between 1978 and 2001, and appear more recently to have become more unstable again. This could result from increased erosion due to the recent flooding, lack of maintenance of river training structures, or from translation of river meanders in the downstream direction. Bank Erosion Index values are mapped for each time period in Figures 4-4 through 4-8 located in Appendix A - Maps.

Table 4-7. Frequency of Bank Erosion Index (BEI) values by analysis time period.

BEI Value	Avg. Annual Channel Movement Rate (ft.)	1945-1955	1955-1978	1978-1991	1991-2001	2001-2009
0	< 3	26	50	52	39	42
1	3 – 6	21	22	19	27	23
2	6 – 12	26	10	12	10	12
3	> 12	13	4	3	10	9

Table 4-8. Spatial and temporal variation in channel movement tendencies within analysis segments of the Pilchuck River, as indicated by successive series of geo-referenced aerial photographs.[Planform change index values: 0 (blank) = within measurement error (< 3 ft.); 1 (yellow) = minor change (3-6 ft.); 2 (orange) = moderate change (6-12 ft.); 3 (red) = large change (>12 ft); shaded boxes indicate segments where bank erosion rates appear to have decreased since 1978].

Segment ID	Bank Erosion Index					Segment ID	Bank Erosion Index				
	1945-1955	1955-1978	1978-1991	1991-2001	2001-2009		1945-1955	1955-1978	1978-1991	1991-2001	2001-2009
1-1						2-44			3	3	2
1-2	1					2-45		1	2	3	
1-3			1	2		3-46		2			
1-4			1	2		3-47					
1-5	2					3-48			1		
1-6	1					3-49	2		1	1	2
1-7	2	1				3-50	1			1	2
1-8	3	2		1		3-51					
1-9	2	1			1	3-52					
1-10	2				1	3-53	2		1		
1-11						3-54	2	1			1
1-12	1			1	1	3-55	2			1	3
1-13	3	1	2	2	3	3-56	2	1	1	1	1
1-14	3		2	3	3	3-57			2	2	2
1-15	2		1	1	1	3-58	1			1	2
1-16	2	1	2	2		3-59	2	1	1	1	1
1-17	2	1	3	1		3-60	1			1	1
1-18	2	1			1	3-61	3				1
1-19	1	2	1	1	2	3-62	1			1	
1-20			3	2	2	3-63					
1-21	3	1	1	1	1	3-64				1	
1-22	2	2	2	3	3	3-65	1				
2-23	1		2	3		3-66	2				
2-24	1			1		3-67				1	1
2-25	3	3	1	1	2	3-68	1			1	1
2-26	3	3	2	3	1	3-69	2	2	1	1	1
2-27	3	3		1		3-70	2	2		1	2
2-28	1	3	1		3	3-71	2			2	3
2-29	3	1			3	3-72	1		1		1
2-30	1	1	1		2	3-73	1	1		1	1
2-31	1	1		2		3-74					
2-32	2		1	3		3-75					
2-33	2	2	2	3	1	3-76					
2-34	1	1		3		3-77	1		1		
2-35						3-78	2	2	1	1	1
2-36	1					3-79	3			1	1
2-37	2	1			1	3-80	2	1		1	
2-38	1				2	4-81					
2-39	2	1	1	1	3	4-82					
2-40	3		2	2	3	4-83					
2-41	3	1	2	3	2	4-84					
2-42	3	2	2	2	1	4-85		1		1	
2-43	2	1			1	4-86					

5 Discussion

Results are discussed below as they pertain to the questions and key indicators in Table 2-1 that formed the basis of the data collection and analysis methodology.

5.1.1 Geomorphic characteristics

Geomorphic properties for each reach are presented in Table 4-1, including channel slope and the level of channel confinement.

5.1.2 Geomorphic processes favorable and / or unfavorable to project performance

Results are discussed below as they pertain to the questions and key indicators in Table 2-1 that formed the basis of the data collection and analysis methodology. This discussion employs the results from the sediment transport analysis to assess the effectiveness of different types of restoration projects within reaches one, two, and three. The habitat assessment results indicate three primary categories of project types that should be considered: pool creation, side channel and floodplain channel connectivity, and restoration of the riparian zone. These actions are primarily intended to increase juvenile rearing habitat availability in the lower three reaches.

Pool creation

The geomorphic assessment results suggest that pool creation could be facilitated through techniques such as construction of in-stream structures. The sediment transport analysis results indicate that this technique could be viable in all three reaches, with some locations better suited than others. The lowest risk for scouring or deposition around in-stream structures is in sub-reaches 1-3, 2-4, 3-3 and 3-4 where transport and supply appear to be in approximate balance (cf. Figure 4-3). These locations may also be conducive to sorting of spawning gravels in the vicinity of structures. The other sub-reaches could also be suitable locations for construction of in-stream structures, although with a greater transport potential relative to supply, design measures would need to include greater consideration against scouring and structure loss.

Fine sediment deposition is not suggested by the analysis to be a significant problem in the geomorphic assessment area (reaches 1 – 3). The fine sediments observed visually throughout the length of the three lower reaches appear to be composed mainly of coarse sand. Fine silts and clays that originate from several high eroding cliffs appear to be readily transported downstream during floods as washload, the relatively fine material in near-permanent suspension which is transported downstream without deposition. The volume of fines within these size ranges being introduced annually through bank collapse appears to be small relative to the more prevalent sand-sized sediments. The river appears to process sand-sized and larger sediments through periodic storage in bars and remobilization during floods.

Higher concentrations of fine sediments leading to substrate embeddedness were found in limited areas throughout the assessment area where the dominant substrate size category was 2-16 mm and where the local water surface slope appeared to be controlled by larger riffles with larger gravel size. A number of plane bed sections of the channel appear to have high embeddedness values. The analysis suggests that this problem would be relatively easily corrected by installing structures that facilitate sediment sorting, and through facilitation of lateral channel movement.

Pools could also be created through facilitation of lateral channel movement. Approximately 40% of all log jams (23 total) in reaches 1 -3 were located in 6 segments (out of 87), each of which had an erosion index value of 2 or 3. There were more wood formed pools and more backwater pools in these active segments. Among all 87 segments, those with BEI values of 3 (most instability) contained 2.6 jams on average. Segments with BEI values of 0 contained 0.16 jams on average.

Side channel and floodplain connectivity

Reconnection of side channels and floodplain channels would likely be most successful in the vicinity of river segments where the channel movement analysis results depicted in Table 4-7 indicate moderate to large channel movement rates during any time period (i.e., with bank erosion index values of 2 and 3). Structures could be constructed at locations selected to promote local deposition, thereby setting up conditions favoring channel movement away from the deposition location. Alternatively, a structure could be placed at the head of an existing or proposed channel split to create a hard point at locations where more active channel movement has occurred historically.

The best locations for side channel reconnection are where there is a relatively high avulsion risk that could create new or additional discharge pathways resulting from increased instability. However, it should be noted that channel and floodplain connectivity projects are only feasible according to land ownership, and bank armoring should be absent or able to be removed or modified consistent with landowner goals.

Riparian restoration

Restoration of the riparian zone is generally advisable wherever it is feasible. The species selected should reflect the relative stability indicated by the channel movement analysis. Fast growing, disturbance-adapted species are recommended at locations where channel movement into the riparian zone is higher. A key plant for this situation is cottonwood (*Populus* sp.). At other locations, planting of conifers should be focused in more stable areas so they have a chance to grow to a size that will provide shade, bank stability, and future fish habitat.

5.1.3 Comparison with 2003 Tulalip report

Recommendations for habitat improvement from this assessment are consistent with the ‘general suggestions for enhancement’ in the Tulalip report (Savery and Hook, 2003) that include reducing bank hardening, increasing floodplain connectivity, decreasing pool spacing by adding roughness elements such as large woody debris, and replanting the riparian zone with a mix of hardwood and conifer species. However, site-specific recommendations resulting from this assessment may vary somewhat from the Tulalip recommendations.

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Appendix A

Maps:

Figure 4-4. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1947 to 1955.

Figure 4-5. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1955 to 1978.

Figure 4-6. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1978 to 1991.

Figure 4-7. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1991 to 2001.

Figure 4-8. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 2001 to 2009.

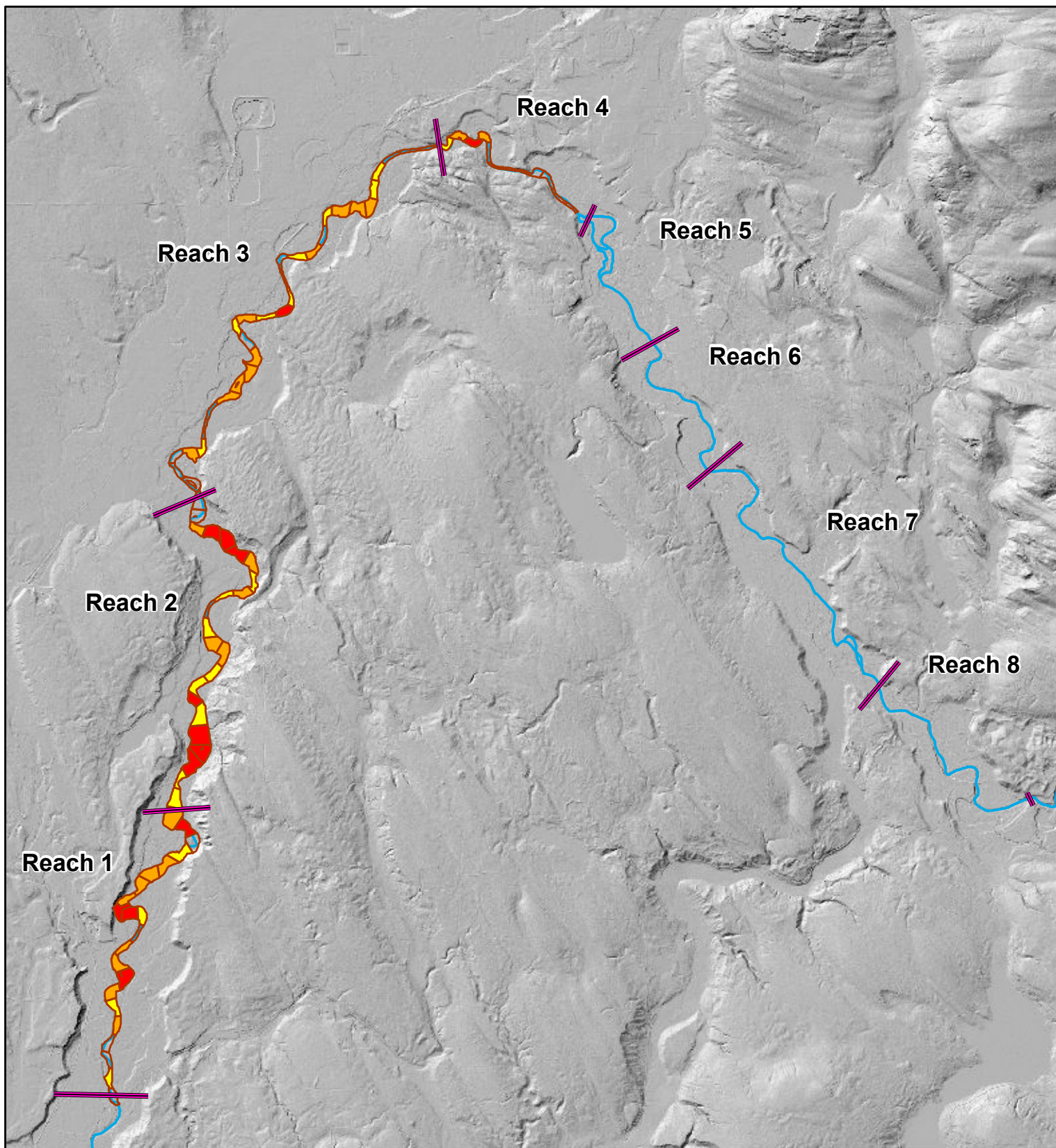
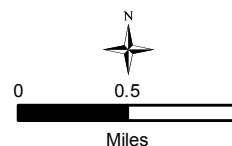
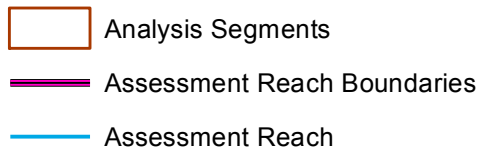
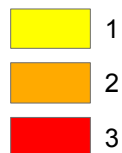


Figure 7-1. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1945 to 1955.

Bank Erosion Index



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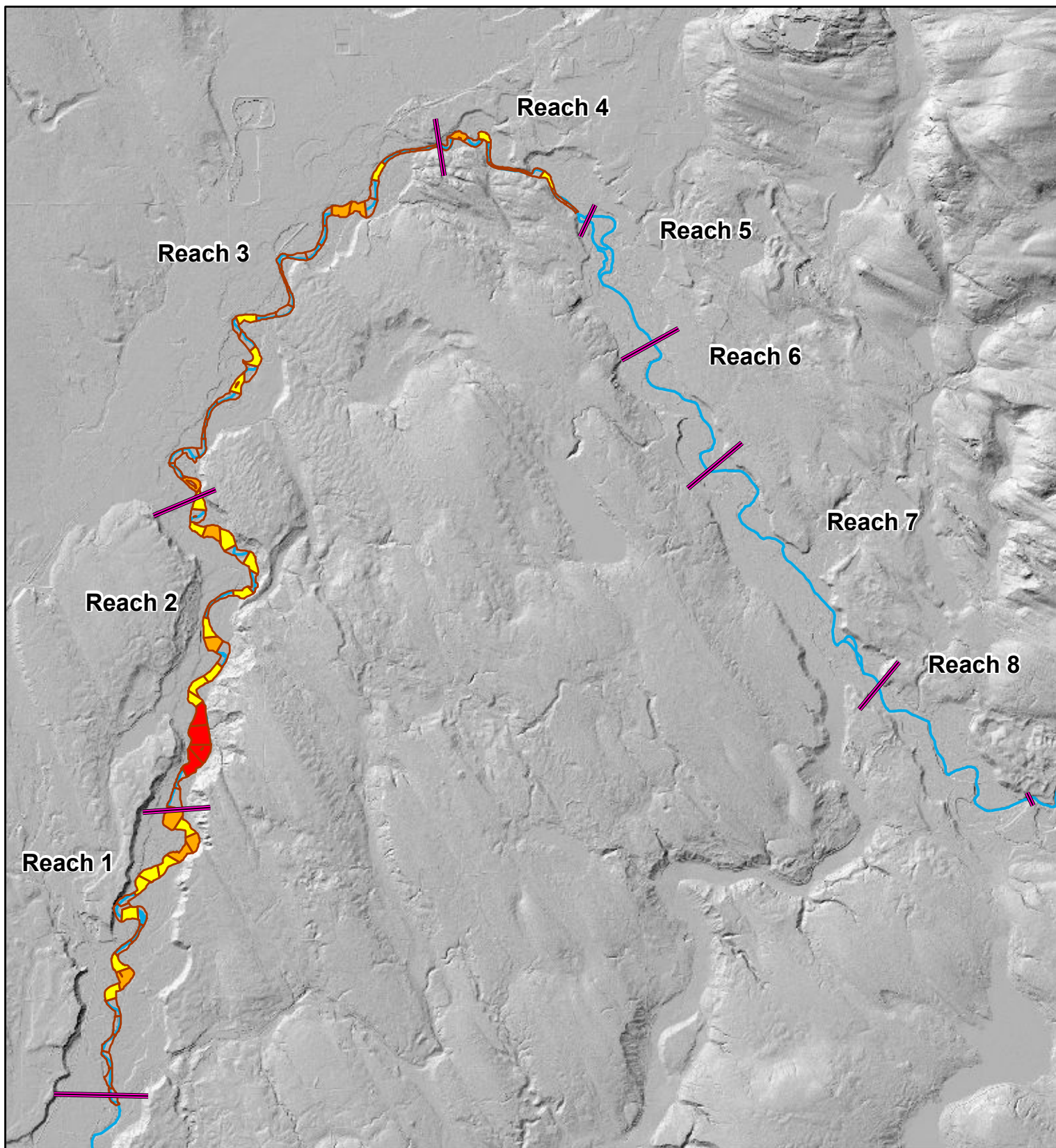
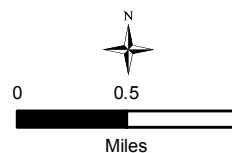
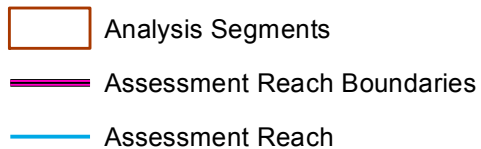
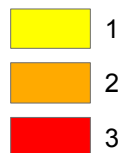


Figure 7-2. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1955 to 1978.

Bank Erosion Index



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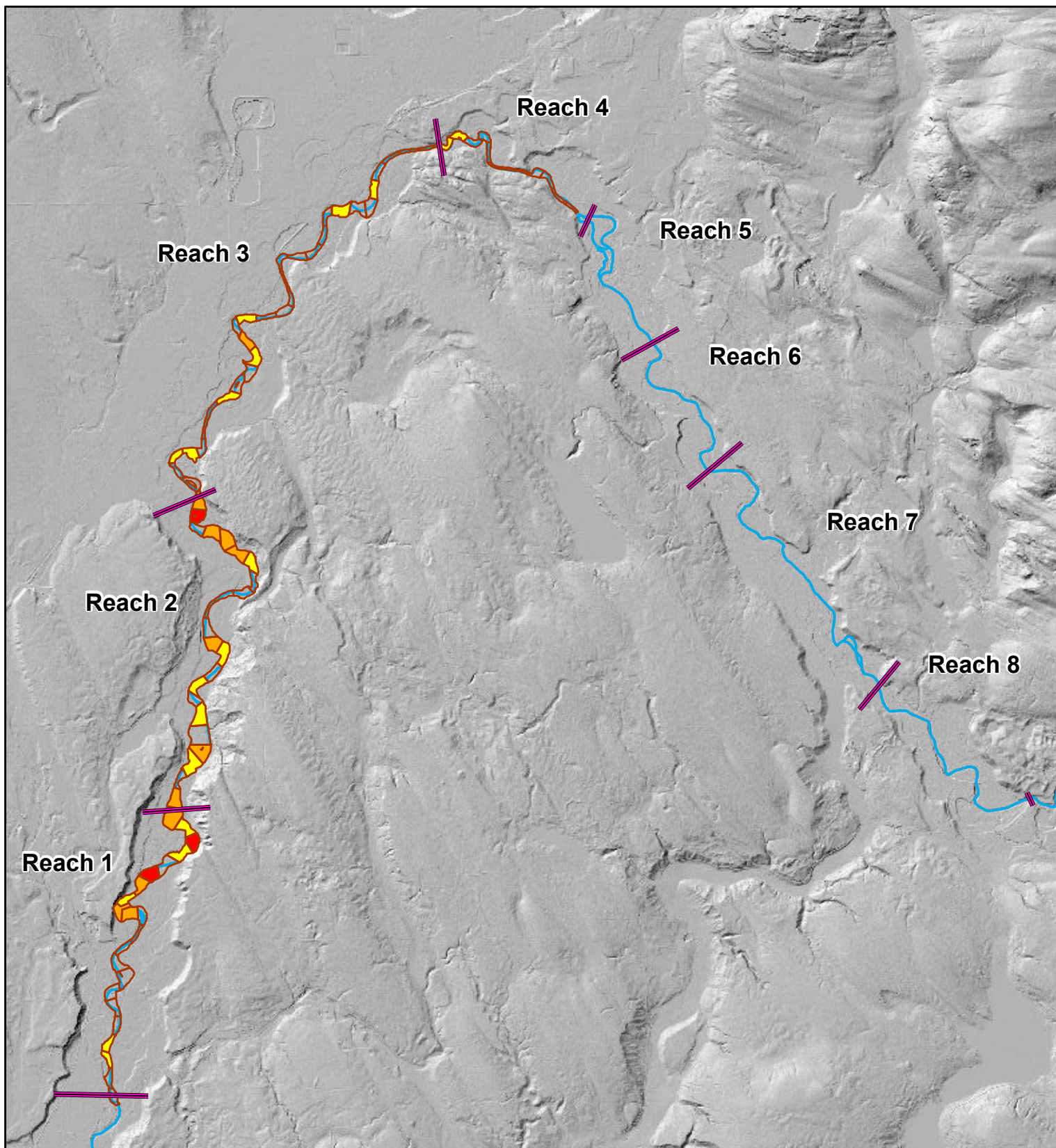
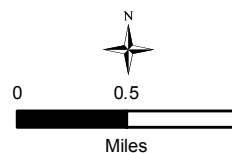
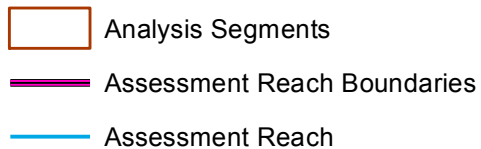
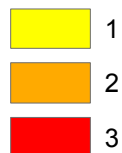


Figure 7-3. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1978 to 1991.

Bank Erosion Index



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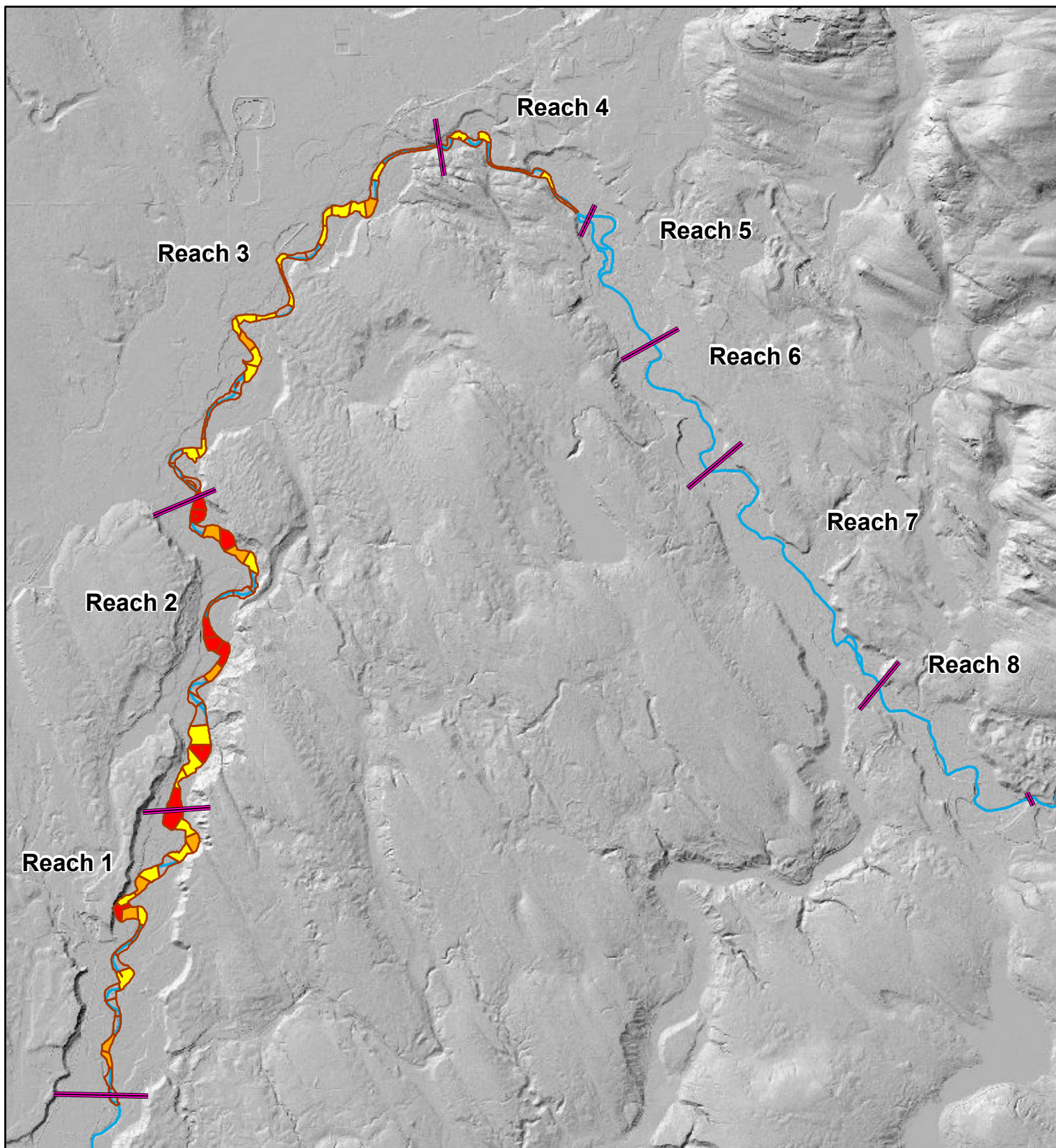
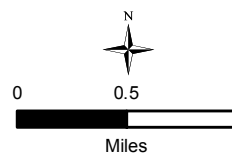
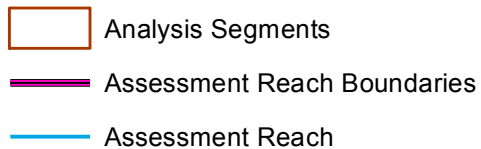
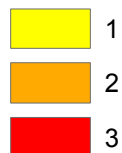


Figure 7-4. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 1991 to 2001.

Bank Erosion Index



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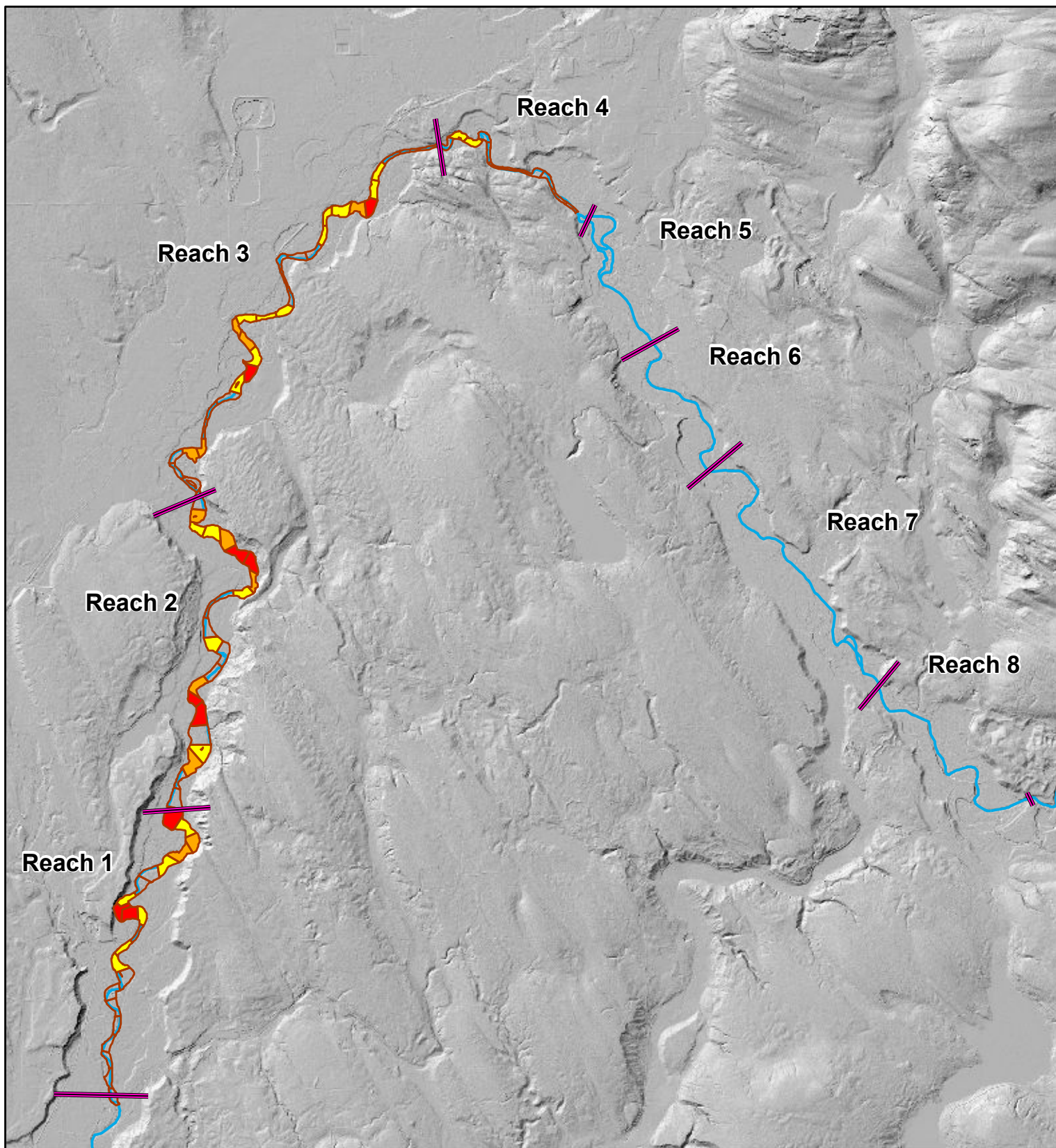
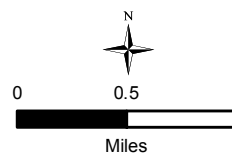
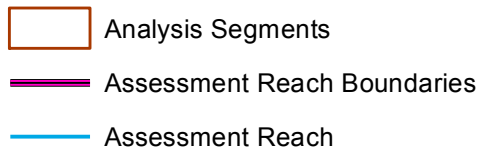
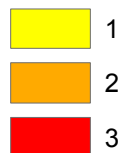


Figure 7-5. Bank Erosion Index within analysis segments of the Pilchuck River in Reaches 1-3, 2001 to 2009.

Bank Erosion Index



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