100 PERCENT DESIGN REPORT

HABITAT RESTORATION OF THE CHELAN RIVER REACH 4 AND TAILRACE

Prepared for

Public Utility District Number 1 of Chelan County

327 North Wenatchee Avenue

Wenatchee, Washington 98801

Prepared by

Anchor Environmental, L.L.C.

1423 Third Avenue, Suite 300

Seattle, Washington 98101

Chinook Engineering

Watershed GeoDynamics

Waterfall Engineers

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1 INTRODUCTION

As part of the Public Utility District Number 1 of Chelan County's (the District's) new Federal Energy Regulatory Commission license and settlement agreement for the Lake Chelan Hydroelectric Project (Project), the District will provide additional spawning and rearing habitat in the Chelan River Reach 4 and tailrace of the powerhouse to support Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) populations. As part of this commitment to provide additional habitat, the District will provide as much as 320 cubic feet per second (cfs) into Reach 4 through flow releases from the dam and pumped water from the tailrace. The District hired a consultant team led by Anchor Environmental, L.L.C. (Anchor) to design the Reach 4 and tailrace habitat restoration elements. The Anchor Team also includes Chinook Engineering, Waterfall Engineering, and Watershed GeoDynamics. The habitat restoration design elements include the following:

- New habitat side channel to be created in Reach 4 near the right bank when facing downstream
- Hydraulic Control Structure (HCS; weir) just upstream of the new habitat channel to direct low flows into the new habitat channel and high flows away from the new habitat channel
- Spawning terrace in the powerhouse tailrace
- Canal to convey water from a pump station at the tailrace (being designed by CH2M Hill) to the upper portion of Reach 4
- Outlet structure of canal to introduce pumped water into Reach 4 at suitable velocities

The design approach implemented is to create additional spawning and rearing habitat using generally accepted stream restoration techniques to provide and maintain gravel areas for spawning, create pools, increase channel sinuosity, and maintain moderate water velocities.

This *90 Percent Design Report* (Design Report) describes the analysis conducted during the habitat restoration design to advance the understanding of the site conditions and support the project design. A separate *Design Memorandum* prepared at the outset of the design efforts (Anchor et al. 2007) describes the restoration objectives and design criteria that are being used to guide the design of the habitat restoration elements. All elevations contained in this document are reported in National Geodetic Vertical Datum of 1929 (NGVD29).

2 RELICENSING AGREEMENT – CHELAN RIVER FLOW REQUIREMENTS AND HABITAT OBJECTIVES

Under the terms of the settlement agreement and as part of the new license, instream flow releases from the dam will provide a minimum of 80 cfs to the lower Chelan River, with additional flow for spawning and incubation provided to Reach 4 by either water pumped from the tailrace during specified months or spilled from the dam (Table 1 and Figure 1).

Table 1
Fish Flows Provided into Reach 4 under New License

Flow Provided By	Dry Year	Average Year	Wet Year
Dam outlet or spill	80 cfs spilled all months	80 cfs spilled July 16 to May 14	80 cfs spilled July 16 to May 14
		200 cfs spilled May 15 to July 15	320 cfs spilled May 15 to July 15
Pumped water from tailrace	Additional 240 cfs pumped March 15 to May 15 and October 15 to November 30	Total of 320 cfs (combined spill plus pumped flow) March 15 to May 15 and October 15 to November 30	Total of 320 cfs (combined spill plus pumped flow) March 15 to May 15 and October 15 to November 30

Note:
Source: *Lake Chelan Comprehensive Plan*, Chapter 7, Table 7-3 (District 2003)

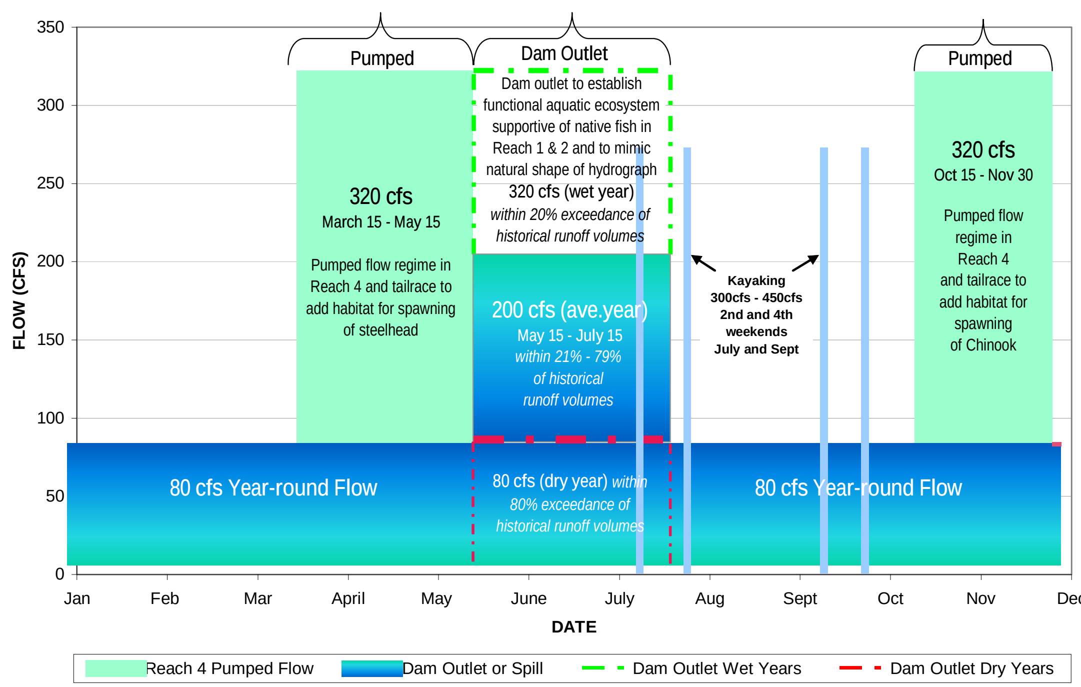


Figure 1
Flows in Reach 4 under New License Settlement Agreement

The primary objective of the habitat restoration efforts in Reach 4 and the tailrace is to provide additional or enhanced spawning and rearing habitat for summer steelhead and fall Chinook. The new license and settlement agreement include the objectives of creating approximately 2 acres of useable spawning and rearing habitat in Reach 4 and 1 to 2 acres of useable spawning and rearing habitat in the tailrace. Habitat restoration will be in accord with generally accepted stream restoration techniques to provide and maintain gravel areas for spawning, create pools, increase channel sinuosity, and moderate velocities. To the maximum extent practicable, spawning gravel in created or enhanced spawning areas will be located at an elevation below the minimum operation of the Chelan tailrace elevation and the Lake Entiat pool elevation.

3 HYDROLOGY

Under past normal operating conditions, flow was released into the Chelan River below the dam during spill conditions, when the lake level was high and inflow exceeded the turbine capacity. Normal turbine flows are 2,200 cfs; maximum capacity is approximately 2,300 cfs.

In addition to the planned releases described in Section 2, spill will also occur under the new license when lake levels are high and inflow exceeds turbine capacity. In the past, spills occurred occasionally during winter rain-on-snow events and almost every year during spring runoff conditions. Under the new license, new reservoir operating guidelines will likely result in fewer and lower magnitude spring spills. However, the precise outcomes of changes under the new license are unknown. Therefore, an analysis of past spills was conducted to provide information on high flow magnitudes and frequencies.

3.1 Methods

Flow records available for the Chelan River downstream of the dam include:

- U.S. Geological Survey (USGS) Gage 12452500 (Chelan River at Chelan, Washington)
    - Period of Record – (1903 to 2006) Includes mean daily flow and instantaneous peak flows (peak flow record began with 2004 water year)
    - Remarks – Includes flow through turbines (up to 2,300 cfs), flow through two irrigation pipes that divert water from the penstocks just above the turbines, and spill discharge; the Project began diverting flows in 1928
- Actual Spill records
    - Period of Record – (1974 to 2003) Mean daily flows (not instantaneous peak flows)
    - Remarks – Spill records provided by the District

3.1.1 Mean Daily Flow Analysis

Actual Spill records were entered into a Microsoft Excel spreadsheet to calculate monthly flow exceedance statistics (see Appendix A).

3.1.2 Peak Flow Analysis

Instantaneous peak flow records from the USGS Gage were run through the USGS peak flow analysis program PKFQWin 5.0 to provide peak flow recurrence statistics (Flynn et al. 2005). Analyses were run for the following cases:

- USGS Gage, Period of Record (this includes flow through the turbines)
- USGS Gage, 1928 to 2006 (period of Project operation; includes flow through turbines)
- Estimated Spill (i.e., Chelan River flow) – USGS Gage minus 2,200 cfs (the normal turbine flow), 1928 to 2006 (represents likely spill from dam during peak flow measurement)

3.2 Results

3.2.1 Mean Daily Flow Analysis

Spill into the Chelan River downstream of the dam occurs most years during the spring runoff season and occasionally during large fall/winter rain or rain-on-snow events. The 10 percent, 25 percent, and 50 percent mean daily reported spill exceedances for each month were plotted with month on the x-axis and flow on the y-axis (Figure 2). Flow exceedance refers to the percentage of days during each month that a particular flow is exceeded. For example, a 10 percent flow exceedance of 1,402 cfs during May means that for a 30-year analysis period on 10 percent of the days during May, or on average 3 days in May, the mean daily flow was greater than 1,402 cfs (conversely, 90 percent of the days' flows was less than 1,402 cfs). Flow exceedance values for mean daily recorded spills shows a monthly 50 percent exceedance value of 200 cfs in June and 544 cfs in July (Figure 2 and Appendix B). Note that this analysis groups all days of each month together (e.g., all June days for the 30 years of record are treated as a population, a total of 900 days).

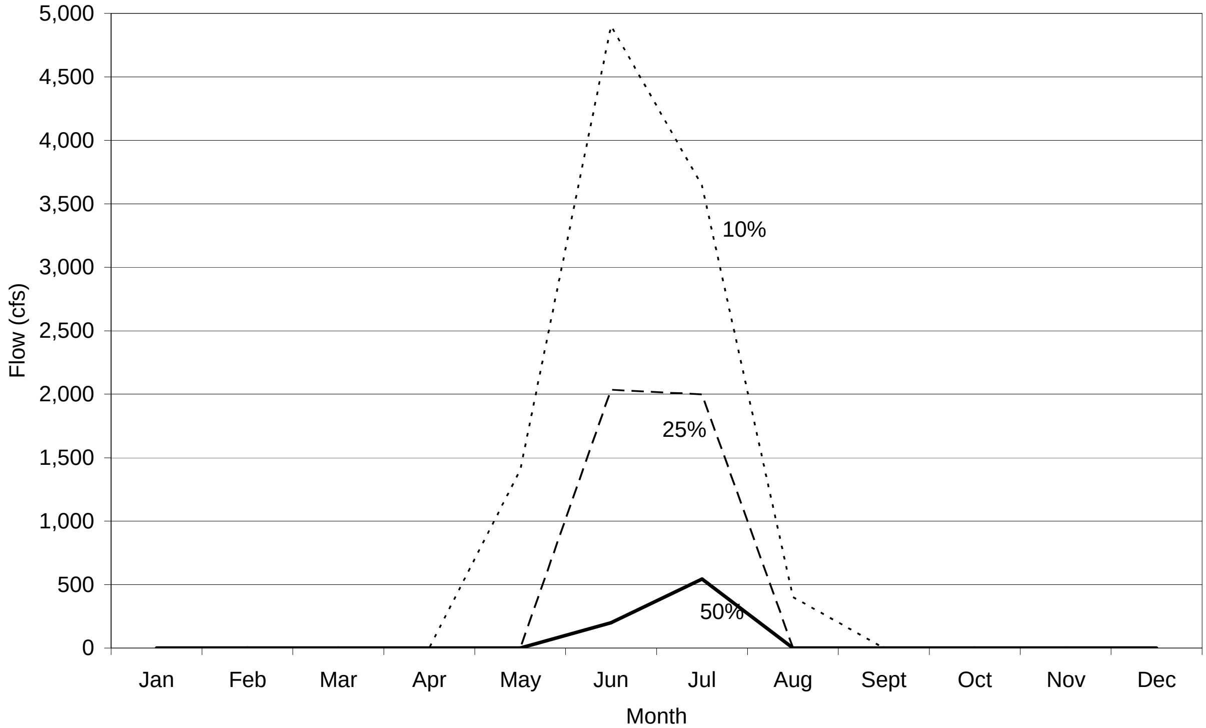


Figure 2
Historic Chelan River Spill Exceedance – 1974 to 2003

To provide additional detail on the likelihood and magnitude of spill during any given year, the percent of days over the period of spill records (30 years) that actually had spill was calculated for each day of the year (Figure 3; daily spill data provided in Appendix A). This analysis is not grouped by month, but by each day of the year (e.g., the population for June 1 is the flow on June 1 during each of the 30 years, a total of 30 days). Likelihood of spill is low during the fall, winter, and early spring. On more than 10 percent of years, the days between mid-May and mid-August had spill. On more than 60 percent of the years, days between mid-June and mid-July had spill, with median (50 percent exceedance) spill magnitudes between 250 to 1,400 cfs, and an average spill of 1,000 to 2,000 cfs. There was some spill during 26 of the 30 years of spill record.

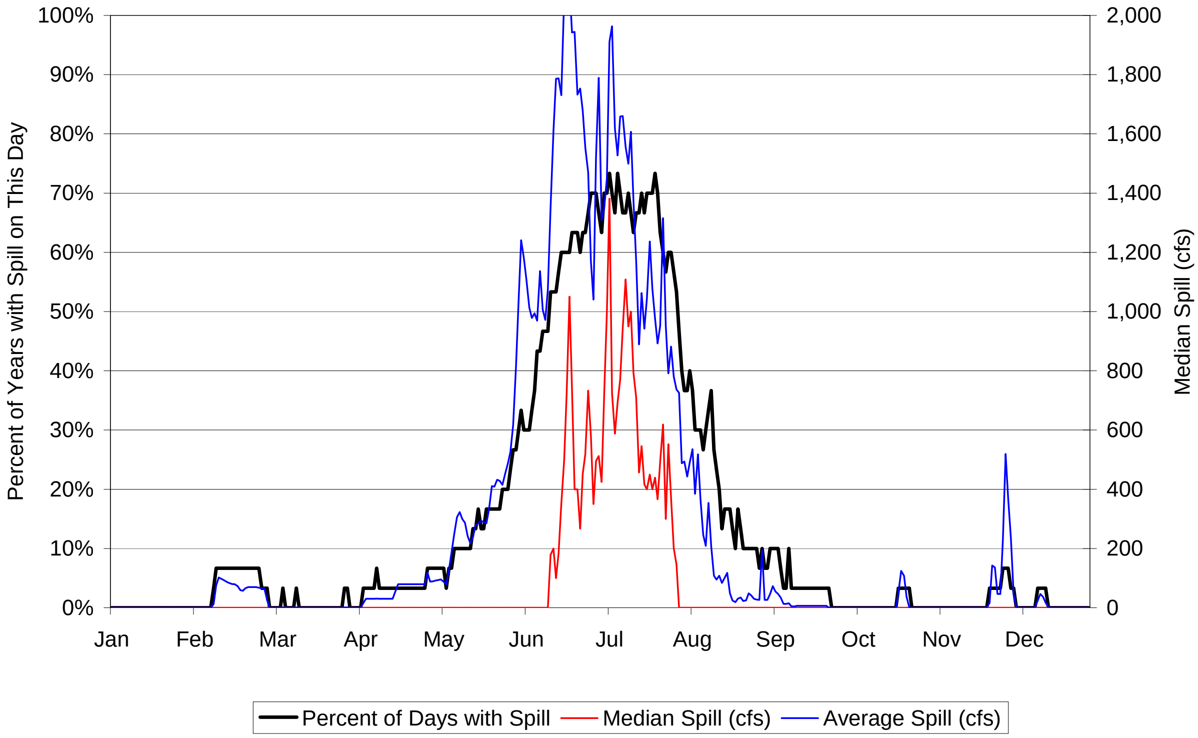


Figure 3
Historic Chelan River Days with Average and Median Spill Magnitude – 1974 to 2003

3.2.2 Peak Flow Analysis

Peak instantaneous flows were used to calculate peak flow recurrence intervals (Table 2). These data were based on the USGS peak instantaneous flow record. Instantaneous flows are higher than mean daily flows. The estimated with-Project 5-year spill peak is 10,960 cfs; the 100-year spill peak is 22,400 cfs. This estimate is based on subtracting powerhouse flows (2,200 cfs) from each annual peak flow (which includes spill and powerhouse flow) for the 1928 to 2006 period and computing recurrence intervals based on this modified flow record (Estimated Spill column). This produces different flows than just subtracting 2,200 cfs from the results of the analysis of reported USGS flows (USGS Gage columns) due to the statistical method the flow recurrence uses to fit the flow distribution.

Table 2
Peak Flow Recurrence

Recurrence Interval (Years)	USGS Gage Period of Record (1904 to 2006) (cfs)	USGS Gage Period of Project Operation (1928 to 2006) (cfs)	Estimated Spill[a] (1928 to 2006) (cfs)
1.5	6,431	6,319	3,949
5	11,530	12,140	10,960
10	13,550	14,600	14,210
25	15,770	17,390	17,900
50	17,200	19,260	20,300
100	18,480	20,960	22,400

Note:
a = Estimated Spill is the estimated flow down the Chelan River.

Note that the 100-year Estimated Spill peak is higher than the full USGS Gage flow (with powerhouse flow included) peak. This is the result of the probability distribution method used to calculate peak flows, and it points out the fact that the absolute magnitude of longer return interval flows is uncertain. The computed 95 percent confidence limit on the 100-year flood is +/-3,000 to 5,000 cfs. Therefore, there is statistically no difference between the estimated 100-year flood among the three flow scenarios.

The District has suggested that it may be possible to manage spills to keep them below approximately 6,000 or 8,000 cfs. Under past spill operations, 6,000 cfs had approximately a 2-year peak flow recurrence interval; 8,000 cfs had approximately a 3.1-year peak flow recurrence interval.

4 HYDRAULIC MODELING

Hydraulic modeling was conducted to support the design of the new habitat channel and tailrace. This modeling was conducted to investigate the following issues:

1. Verify that no significant increase in flooding or excessive backwater against the powerhouse occurs in the tailrace reach after construction of the spawning and rearing terrace in the tailrace and after construction of the new habitat channel in Reach 4
2. Assess flow distributions in Reach 4 between the existing channel and new habitat channel during various flow conditions
3. Verify that habitat design criteria are satisfied in the new habitat channel and the tailrace, specifically a minimum hydraulic depth of 1 foot, and target velocities between 1 and 2.5 feet per second (fps) in the Reach 4 channel and between 1 and 2 fps in the tailrace. An evaluation of the extent of these conditions will be reported
4. Provide input to geomorphologic and sediment analysis

4.1 Methods

Hydraulic modeling was conducted using the one-dimensional flow model HEC-RAS Version 4.0 (U.S. Army Corps of Engineers [Corps] 2002 and 2006). This model was used both in steady and unsteady mode. All elevations contained in this document are reported in NGVD29.

Hydraulic modeling was conducted for two scenarios: existing conditions and proposed conditions. The existing condition topographic survey was provided by the District. The survey included the tailrace channel, the Chelan River Reach 4 channel, and Chelan River reach downstream of Reach 4 near where it meets the Columbia River. The proposed conditions include the tailrace channel modified and re-graded for a spawning and rearing terrace, Reach 4 channel modified with the new habitat channel and HCS, and the Chelan River reach downstream of Reach 4 that included limited grade changes.

4.1.1 HEC-RAS Modeling – Existing Conditions

The upstream end of the Chelan River Reach 4 is in the canyon 2,850 feet upstream of the tailrace reach. The upstream end of the tailrace reach is just downstream of the powerhouse. The downstream end of the model is in the Chelan River Entiat Pool of Lake Entiat, 540 feet downstream of the Reach 4 confluence with the tailrace.

The maximum flow modeled entering the tailrace Reach from the Chelan Powerhouse is 2,200 cfs. Flows above 2,200 cfs are spilled over Chelan Dam into Reach 1 and are conveyed into the upstream end of Reach 4 of the model. A portion of the 2,200 cfs in the tailrace consisting of 240 cfs will be pumped from the tailrace to a receiving pool in Reach 4 just above the new habitat channel at STA 22+00 of the HEC-RAS alignment. The HEC-RAS model assumes no additional flow contributions. The model does not account for any losses via infiltration or subsurface flow.

For downstream conditions at the Chelan River Entiat Pool, several conditions were assumed, consistent with previous hydrology data:

- Water surface elevation at 706.1 feet NGVD29, consistent with low flows and 99 percent exceedance, normal low water surface elevation
- Design water surface elevation at 707.7 feet NGVD29, consistent with average flows and 50 percent exceedance
- Water surface elevation at 709.5 feet NGVD29, consistent with high flows and 2 percent exceedance, normal high water surface elevation
- Water surface elevation at 716.7 feet NGVD29, consistent with the historical maximum observed elevation, design flood

Model geometry was developed utilizing the topography. Model cross-sections were placed every 25 feet along Reach 4 and every 25 to 50 feet along the tailrace reach. Details on the county road bridge and railroad bridge, downstream of the tailrace, were obtained using Washington State Department of Transportation (WSDOT) plans and specifications. Details of the adjacent county road bridge were estimated from aerial photos and measured during the field visit. Both bridges have low chords that are high above the water surface elevations associated with the highest flows, so only bridge piers interfere with the flow under the bridge. The highway bridge is located between sections 320 and 350 of the downstream reach; the width of the four bridge piers was estimated at 8 feet each. The railroad bridge is located between sections 230 and 260 of the downstream reach; the width of the three bridge piers was measured to be 10 feet each. Both bridges affect the gravel transport locally and shape the gravel bar created mostly from Entiat pool backwater effects.

Representative hydraulic roughness was determined based on aerial photography and photographic documentation, field visits, and pebble counts throughout the site. For Reach 4, a hydraulic roughness of 0.04, consistent with a river channel with gravel- to boulder-size material and with little vegetation, was used for the main low flow channel, and hydraulic roughness of 0.05 was used for floodplain terrace and side overflow channels. For the tailrace reach and the Reach 4 downstream reach, a hydraulic roughness of 0.03 was used for the main river section, and 0.06 to 0.07 was used for the adjacent floodplain terrace.

Model simulations showed that flow splits from the main channel into the new habitat channel on the right and a high left bank overflow channel downstream of Section 12+00 of the Reach 4 channel during modeled flows in the river greater than 500 cfs. Flow areas in the left overbank channel and other high side channels were considered flooded, but ineffective (with zero velocity) during model simulation. The model simulation focused on the hydraulics in the main channel and did not simulate split-flows in the side channels.

The model was calibrated to the water surface elevations measured during high spill flows in the Reach 4 channel between April 24 and May 2, 2007. The calibration was conducted by adjusting Manning roughness to 0.04 in the main channel. Calibration was not conducted in the tailrace reach or downstream of the confluence. However, the Rocky Reach Pool was close to the average water surface elevation of 707.7 feet NGVD29 during the monitoring period. Correct representation of hydraulic roughness in Reach 4 was important, as this reach channel geometry is significantly modified in proposed conditions.

4.1.2 HEC-RAS Modeling – Proposed Conditions

The upstream and downstream boundary conditions were set identical to the boundary conditions in the existing conditions of the HEC-RAS model. The existing model geometry was adjusted in Reach 4 and in the tailrace reach to reflect the design for the new habitat channel changes and the construction of the tailrace spawning and rearing terrace. In Reach 4, the new habitat channel will be constructed along the right bank (looking downstream) of the existing channel of the delta. The channel will be 2,200 feet long and will consist of six pools and six riffles. The riffles will have 2.5 percent design slope and will be moderately V-shaped to mimic a natural riverbed form. The pools will have 3.4- to 4.5-foot depth at the maximum channel design flow of 320 cfs. The new habitat channel will be modeled to determine conditions of depth and velocity when flows are greater than 320 cfs and range up to 500 cfs.

4.2 Results of Proposed Conditions

Model results for the proposed conditions have been used iteratively for the design process and are continuing through the final design stages of the project. The results for the tailrace, new habitat channel, and HCS include velocity and depth values that are used in design with consideration of meeting criteria for fish and geomorphology requirements.

4.2.1 Tailrace Spawning and Rearing Terrace

Results indicate that there is a maximum of approximately 0.2 foot of increased water depth in the tailrace from the existing conditions and the proposed terrace construction. The terrace will be constructed by filling the tailrace full width approximately 300 lineal feet upstream of the existing paddlers boat launch and no farther upstream than a line drawn outward from the restrooms in the park. Excavation of some material will occur adjacent to the paddlers boat launch to form the terrace at an elevation that is below the low design elevation of 706 feet NGVD29 and always covered with water. This will create approximately 1.5 acres of suitable spawning substrate gravels with depths and rearing areas that meet fish production criteria.

The fish criteria goal in this area was to establish a spawning and rearing area in excess of 1 acre and less than 2 acres that would have depths that range from 2 to 4 feet and may range up to 7 feet with target velocities of 2 fps. Figures 4 and 5 show the resulting depths and velocity, respectively, along a profile of the tailrace that intersects various depths. The criteria goal was met as modeled and used as the driving design criteria during design detailing and preparation of contract documents.

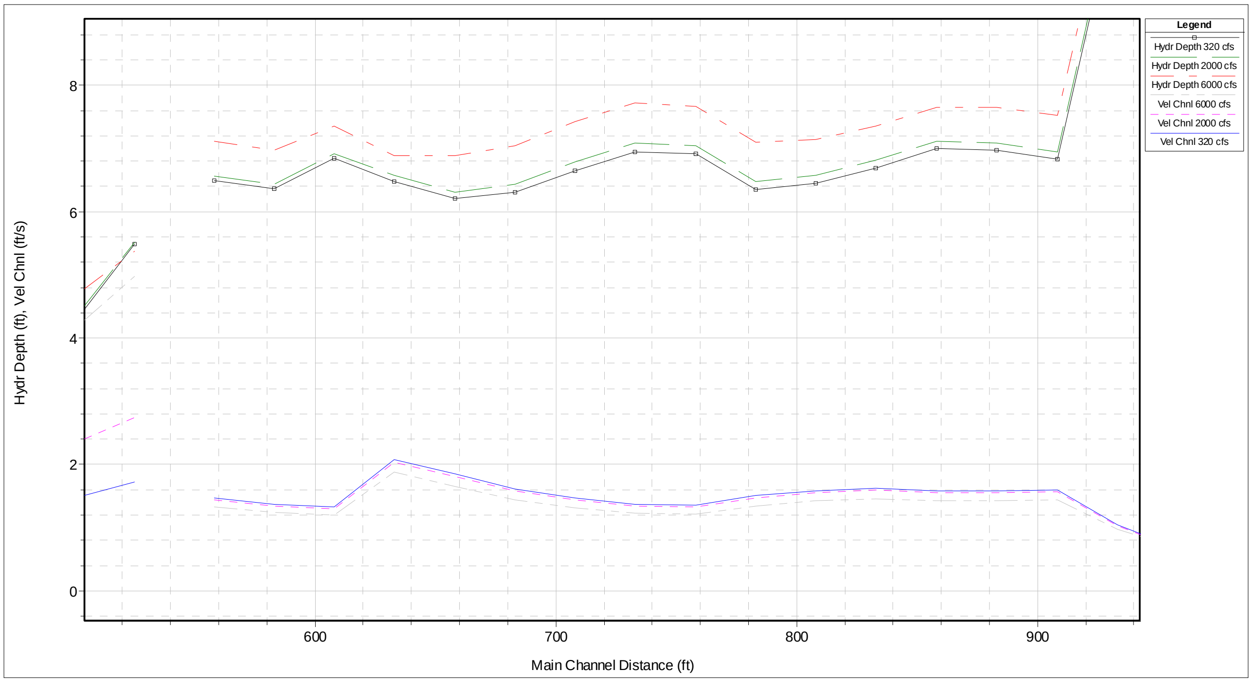


Figure 4
Proposed Tailrace Spawning Terrace Depths and Velocity at 320; 2,000; and 6,000 cfs in New Habitat Channel and 2,200 cfs Flow in Powerhouse
(Note: Terrace is located from Main Channel Distance STA 5+50 to STA 8+50)

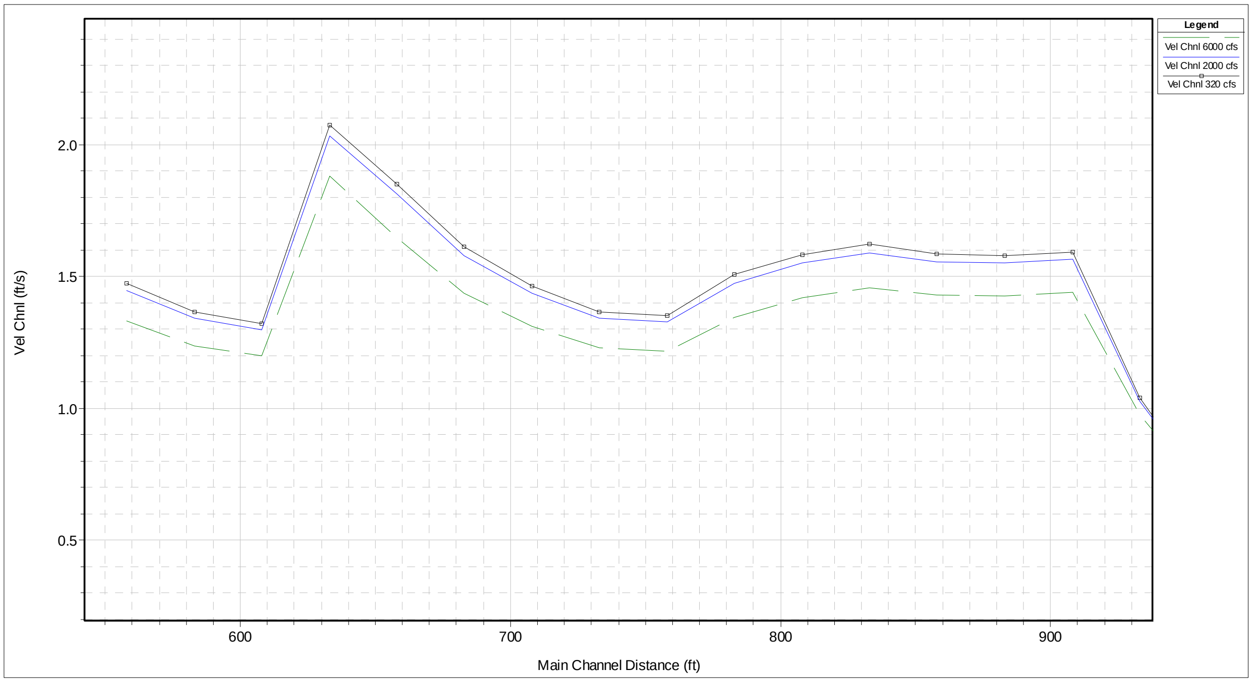


Figure 5
Proposed Tailrace Spawning Terrace Velocity at 320; 2,000; and 6,000 cfs in New Habitat Channel and 2,200 cfs Flow in Powerhouse
(Note: Terrace is located from Main Channel Distance STA 5+50 to STA 8+50)

4.2.2 New Habitat Channel

Results from the HEC-RAS model output of the new habitat channel indicate that criteria for fish and geomorphology are met. The area of the channel also meets the required approximate 2-acre goal as established. Results show that the depth criteria of 1 to 3 feet (which includes Chinook criteria of 1 to 3 feet of depth and the steelhead criteria of 1 to 1.7 feet of depth) are met (Figure 6). The results also reveal that the intersection of these depths with the velocity criteria for Chinook of 1.2 to 2.2 fps and steelhead of 2 to 3.2 fps are met in the correct quantity and distributed along the length of the habitat channel.

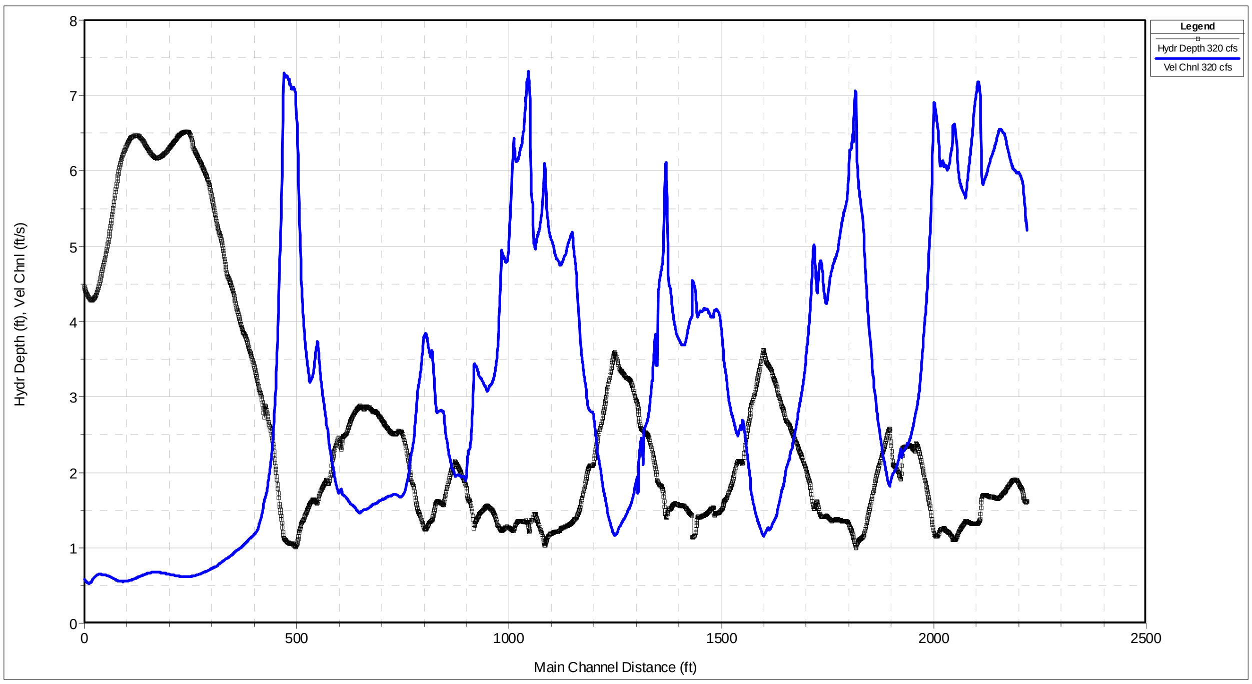


Figure 6
New Habitat Channel Velocity and Depths at 320 cfs along the Channel Centerline

4.2.3 Hydraulic Control Structure (HCS)

Resultant water velocities across the HCS are significant for upstream fish passage, human safety, and design for high flows. Figure 7 presents water velocities over a wide range of flows. Results show that during low flows, fish passage opportunity does exist, and during extreme high flows, velocities are manageable for scour and erosive forces on the HCS. Figure 8 shows the stage discharge curve for the water surface elevations in the pool above the HCS and at the same position as the outlet structure centerline. This is shown through a range of flows in Reach 4 from 80 to 22,400 cfs.

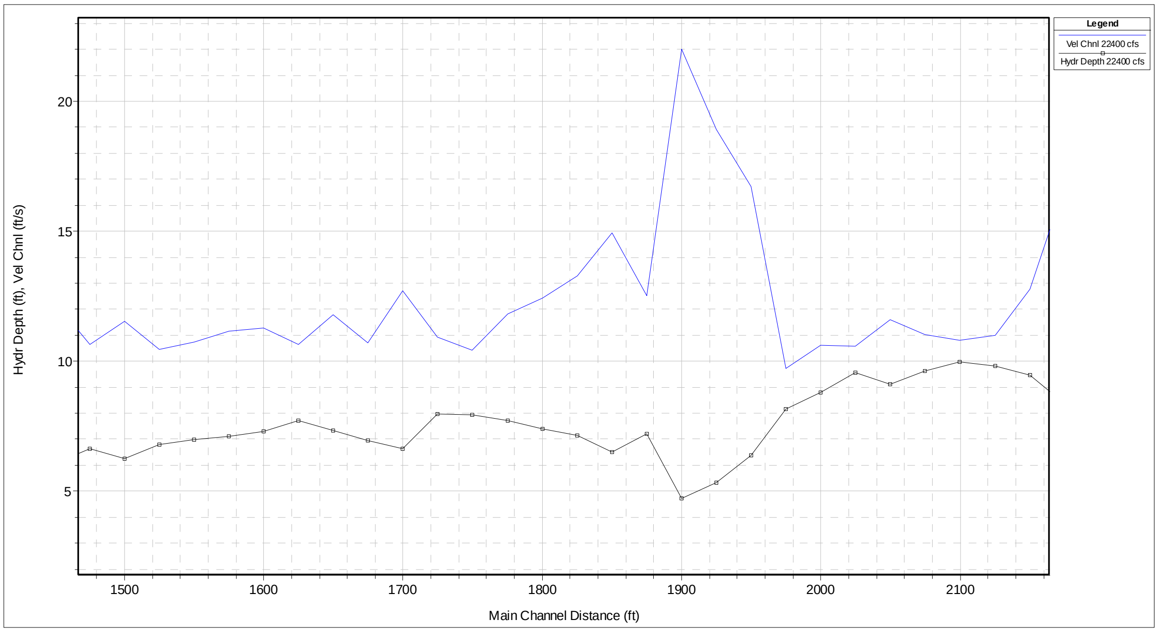


Figure 7
Channel Velocity and Depths at 22,400 cfs along the Channel Centerline and across the HCS (100-year Event)
(Note: HCS is located at Station 21+25 on the main channel distance in feet)

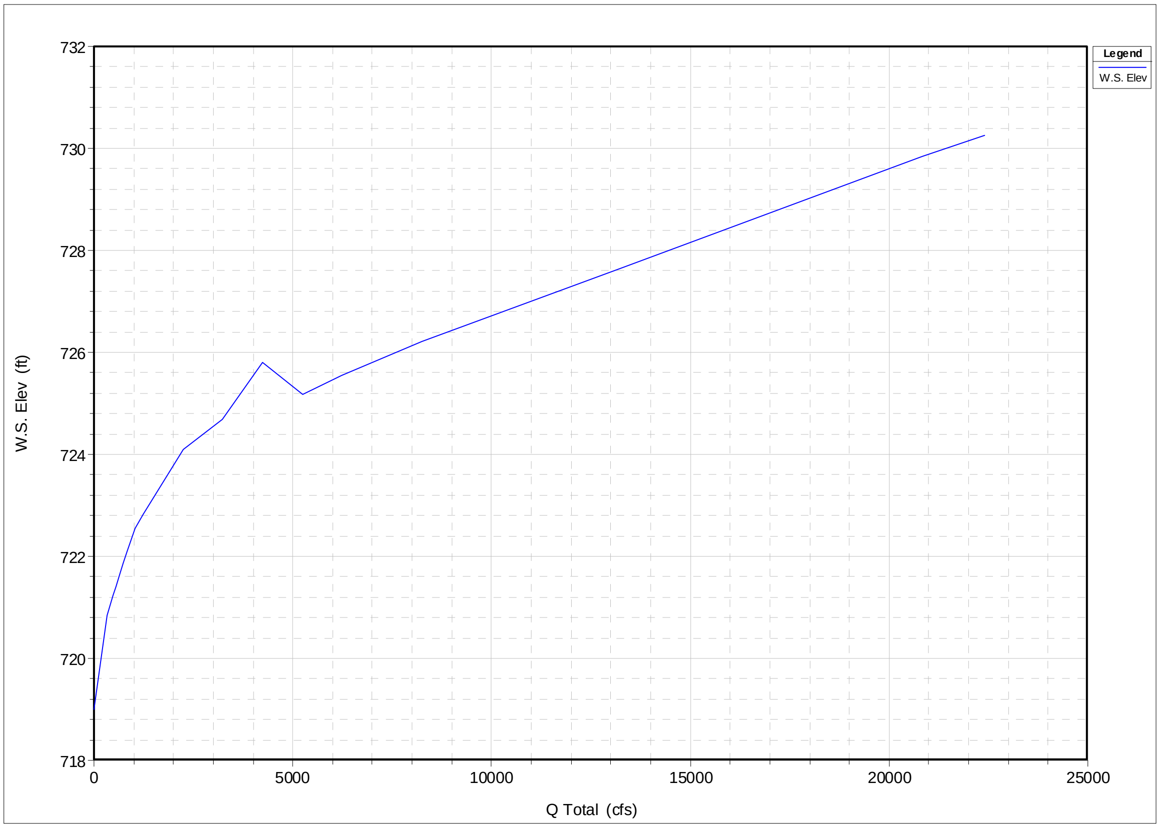


Figure 8
Reach 4 Stage Discharge Curve at the Location of the Outlet Structure from 0 to 22,400 cfs (100-year Event) along the Channel Centerline

4.2.4 Conveyance and Distribution across HCS

Results from the HEC-RAS model indicate that the HCS will split the flows in the river as a side channel in a river would naturally do. During low flow conditions in which spill flow rates are 80 cfs and the pump station delivers 240 cfs, the total flow of 320 cfs will flow down the habitat channel by filtering through the log jam at the upstream end (entrance) of the habitat channel.

During total flows in excess of 320 cfs, a split flow regime will occur such that water will flow down both the habitat channel and left bank high flow channel in Reach 4. The HCS crest elevations are lowest along the far left bank. As a result, the portion of the total flows over 320 cfs that will flow through the left bank high flow channel will occur along the far left bank of Reach 4. As total flows increase, the water stage along the HCS increases and the entire HCS is overtopped when the center high point of the HCS is overtopped at 724 feet NGVD29. At this stage, water will be flowing into the habitat channel as well as over the entire HCS crest. The design high flow for the HCS and habitat channel split flow regime has been established at 6,000 cfs. At this level of flow, the water stage will be approximately at 724.6 feet NGVD29 and the center high point of the HCS is overtopped. Water will flow down the habitat channel through the entrance log jam as well as over the left bank high flow channel in a proportion that is determined by the hydraulic slope, bottom roughness, wetted perimeter, and available flow areas.

HEC-RAS was used to estimate the flow split between the habitat channel and left bank high flow channel (i.e., remainder of Reach 4 delta) at flows between 320 cfs and 6,000 cfs. This modeling analysis was conducted using the cross-section extending through the upstream end of the habitat channel and the HCS. The estimated flow split between the habitat channel and the left bank of Reach 4 is shown in Table 3. With increasing total flows, the habitat channel will convey an increasing flow rate but decreased percentage of the total flow. At 1,000 cfs total flow, approximately 780 cfs (78 percent of total flow) will enter the habitat channel. At 6,000 cfs total flow, approximately 1,440 cfs (24 percent of total flow) will enter the habitat channel.

Table 3
HEC-RAS Estimates of Flow Split over Range of Flows

Total Flow (cfs) Entering Reach 4	Estimated Percentage of Total Flow (%)		Estimated Flow (cfs)	
	Habitat Channel	Left Bank of Reach 4	Habitat Channel	Left Bank of Reach 4
80	100	0	80	0
320	100	0	320	0
1,000	78	22	780	220
3,000	33	67	990	2,010
6,000	24	76	1,440	4,560

4.2.5 River Flows through Conveyance Canal and Outlet Structure

The purpose of the conveyance canal and outlet structure at the upstream end is to convey pumped water from the Project tailrace to the top of the habitat channel to meet the flow requirements described in Section 2. During time periods when pumped water is not being conveyed, the canal and outlet structure are designed to allow some river water into and out of the canal. Through the use of stop logs, the outlet structure will prevent water from entering the canal until a water stage of 723 feet NGVD29 is achieved at the top of the habitat channel and HCS. This stage corresponds to a total flow of approximately 3,000 cfs. The purpose of allowing water in at that stage (rather than building up the outlet structure to prevent all flows from entering) is to prevent canal "uplift" through increased groundwater surface level in the area.

The downstream end of the canal at the pump station is not designed to allow outflow of water during these high flow events. Rather, a single drain will be installed near the pump station, which will be used to drain the canal after a period of pumping water or after river flows recede and no water enters the canal at the outlet structure. To transport high flow water out of the canal, a 300-foot-long section (canal STA 1+00 to STA 4+00) of the outboard berm of the canal (i.e., the canal bank separating it from the habitat channel) will have a lowered crest elevation of 723 feet NGVD29 compared to 725 feet NGVD29 along adjacent canal bank sections. In this way, the canal bank will form a spillway between STA1+00 and STA 4+00. The flow over the spillway will start when river flows exceed 3,000 cfs and would be up to 1 foot deep when river flows reach 6,000 cfs (stage of 726 feet NGVD29 at outlet structure). Water from the canal will be directed toward the habitat channel by contouring the slopes along flowpaths. The water will be directed to flow to either side of the log jam at habitat channel STA 12+50.

5 SEDIMENT

The Chelan River is comprised of four geomorphic zones based on channel slope (gradient) and confinement. Figure 9 shows the geomorphic zones and profile of the Chelan River from the Chelan Dam to its confluence with the Columbia River at the railroad bridge.

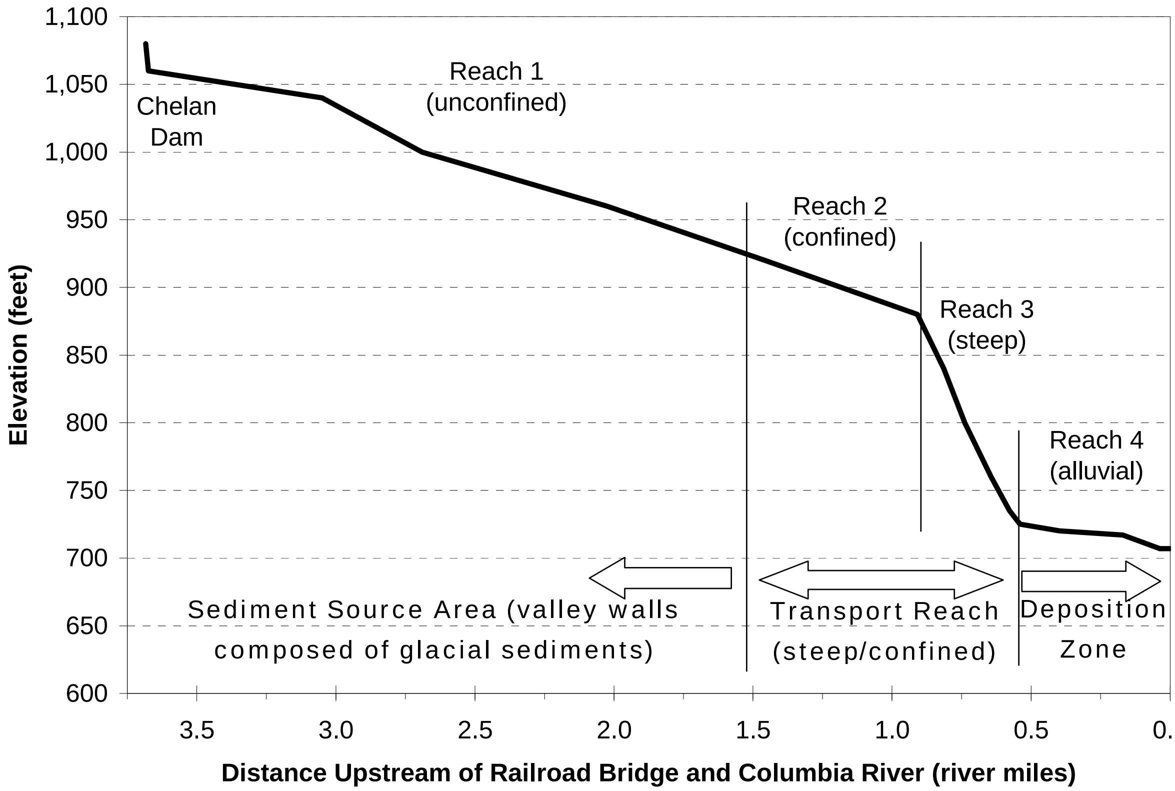


Figure 9
Chelan River Geomorphic Zones and Profile

Reach 1 extends from Chelan Dam downstream for 2.3 miles. This reach is relatively low gradient (1 percent) and moderately confined by steep slopes of glacial moraine deposits. The glacial deposits are easily eroded, providing the river with a large source of boulders, cobbles, gravel, and sand when flows are high enough to erode the valley walls. Reach 2 has a similar low gradient but is within the upper portion of the narrow bedrock canyon. Reach 3 is the high gradient portion of the bedrock canyon. This reach is very steep (9 percent) and confined; sediment supplied from upstream reaches is transported quickly through this reach. Reach 4 is a very low gradient (0.4 percent), and is a relatively unconfined reach. Because of the extreme transition in gradient from Reach 3 to Reach 4, all the boulders, cobbles, gravel, and sand from upstream reaches are deposited in Reach 4.

The geomorphic setting of Reach 4 is an aggrading delta (i.e., delta is building upward). This setting presents several challenges to the design of the proposed habitat improvements, particularly with the goal of making natural, stable, spawning and rearing habitat. River deltas are not naturally stable systems, but rather they aggrade, and channels often change position during large storm events. The sediment-related issues that need to be recognized and addressed in the design include:

- Likelihood of continued Reach 4 aggradation (the current delta is between 10 to 17 feet higher than in the mid-1970s)
- Multiple, shifting channels throughout Reach 4 with shifts occurring during high flow conditions
- High flows during spill events could transport spawning-sized substrate out of the constructed channel improvement reach

To improve the understanding of these issues, the following specific items were identified as needing additional study during the design process:

- Estimate timing and volume of sediment inputs into Reach 4
- Determine timing and volume of sediment deposition in the pool upstream of the proposed Reach 4 HCS and in the remainder of Reach 4
- Assess stability of substrate placed in the new spawning/rearing channel under high flow conditions

These items were investigated through a review of historic documentation, modeling using HEC-RAS, and field investigations. Following is a description of the methods and findings of these investigations.

5.1 Identification of Sediment Sources

Through an initial assessment of conditions in the Chelan River, it is apparent that the primary source of sediment to Reach 4 is from the erosion of banks in Reach 1. As described at the beginning of Section 4, Reach 1 is moderately confined by steep slopes of unconsolidated glacial deposits (boulders, cobbles, gravel, and sand) that are easily eroded if the river impinges upon them at high flows. Reaches 2 and 3 comprise a narrow bedrock canyon, which contributes limited or no gravel to the river system. Thus, the identification of sediment sources focused on Reach 1.

5.1.1 Analysis of Historic Aerial Photographs

5.1.1.1 Methods

The location, timing, and extent of terrace and valley wall erosion in Reach 1 was estimated by comparing bank and channel positions in a series of historic aerial photographs (Table 4). A subset of these photographs from 1966 to 1990 was the primary information source used in this analysis. Table 4 also presents the date and peak estimated flow for all spill events greater than 12,000 cfs. Spill events of this magnitude likely cause severe bank erosion of the scale that can be detected in an analysis of historic aerial photographs.

Channel and bank positions were marked on acetate sheets, reduced or enlarged to a common scale, and overlain on subsequent aerial photographs to determine position and timing of eroding banks. Average length and width of eroded banks were measured, and bank heights were estimated from the USGS topographic map to determine eroded volume.

It was assumed that all sediment eroded from banks was a net input of sediment and was transported through Reach 1, 2, and 3 and into Reach 4. These are reasonable assumptions since the eroded banks that were included in the analysis were the high valley walls composed of glacial deposits or historic river terraces (erosion of current, low river banks was not counted since bank erosion on the outside of meander bends is normally offset by deposition on the inside of the meander). The steep gradient, confined channel, and lack of gravel deposits in Reach 2 and 3 are consistent with the assumption that sediment eroded from Reach 1 is transported through Reach 2 and 3 to Reach 4.

Table 4
Aerial Photographs Used to Investigate Sediment Input from Reach 1
(The dates of all spill events larger than 12,000 cfs are also presented)

Date	Photograph	Flight	Source
9/20/26	Pre-Project survey and boreholes	Not applicable	District
Spill: 5/30/48 – 13,800 cfs			
4/27/65	Black and white air photographs 1:3,000 (Reach 1 and 2 only)	CHEL-65	WSDOT (University of Washington Library)
5/23/66	Black and white air photographs 1:24,000	0409	WSDOT
Spill: 6/21/67 – 13,700 cfs			
Spill: 6/3/68 – 16,200 cfs			
7/9/73	Black and white air photographs 1:63,600	CDS-H	WSDOT (University of Washington Library)
Spill: 6/22/74 – 12,100 cfs			
8/26/78	Color air photographs 1:6,000	CF-78	WSDOT (University of Washington Library)
Spill: 6/3/82 – 16,200 cfs			
1986	Black and white orthophotograph 1:24,000	SC-H-86	Washington Department of Natural Resources (University of Washington Library)
9/11/90	Black and white air photographs 1:24,000	CHELAN BL	WSDOT
Spill: 11/30/95 – 14,800 cfs			
Approximately 2002	Color mosaic (photographs are from different flights)	Digital	District

5.1.1.2 Results

Bank erosion rates measured from aerial photographs should be treated as estimates due to errors associated with the small widths being measured at the scale of the photographs and the fact that the photographs are not ortho-rectified. The majority of bank erosion in Reach 1 occurred in the 0.5-mile area just upstream of the entrance to the gorge, between river mile (RM) 1.9 and RM 2.4. Three areas of erosion were noted in this stretch, with 300 to 400 feet of bank retreat between 1966 and 1990 along much of the bank length. One other very high valley wall (approximately 200 feet high) is also eroding near RM 3.2. However, bank retreat over the period was not large enough to be measured at the scale of the aerial photographs. It was assumed that a total of 1 foot of bank retreat occurred along this bank over the measurement period.

The total estimated volume of sediment erosion in Reach 1 between 1966 and 1990 was 860,000 cubic yards (cy). If it were assumed that this material eroded during peak flows greater than 12,000 cfs, an average of 214,000 cy would have eroded during each of the four peak flows greater than 12,000 cfs that occurred during this period. Grain size samples of valley walls sediments were not taken. However, based on visual observations, the material consists of a mix of sand, gravel, and cobble material with occasional boulders.

Several of the eroding banks have been stabilized by placement of riprap during recent years. This should reduce the frequency and magnitude of erosion in Reach 1 in the future and reduce the amount of sediment transported into Reach 4.

5.1.2 Reach 1 Painted Rock Study

An opportunity to test the level of flow that initiates bank erosion in Reach 1 and substrate erosion/deposition in Reach 4 (presented in Section 5.3.2) occurred during May and June 2007. Lake levels and inflows were high enough that spill was required at the Chelan Dam. A painted rock study was conducted during a series of planned spills to determine the flow level that resulted in bank erosion in Reach 1. The basic premise of a painted rock study is to place painted rocks at selected locations in the river's study area and to observe whether the rocks are transported away during known flow rates (spill tests).

5.1.2.1 Methods

All unarmored streambank locations in Reach 1 that had shown evidence of past erosion in the aerial photograph analysis were surveyed and marked. Five banks (numbers 3 through 7) were selected for monitoring (Figure 10). The banks with marked rocks were classified as either primarily fine-grained (Banks 3 and 4) or coarse-grained (Banks 5, 6, and 7). The fine-grained banks had a mantle of silty/sandy sediment over the underlying glacial deposits. The coarse-grained banks had a mantle of cobble/gravel over the underlying glacial deposits.

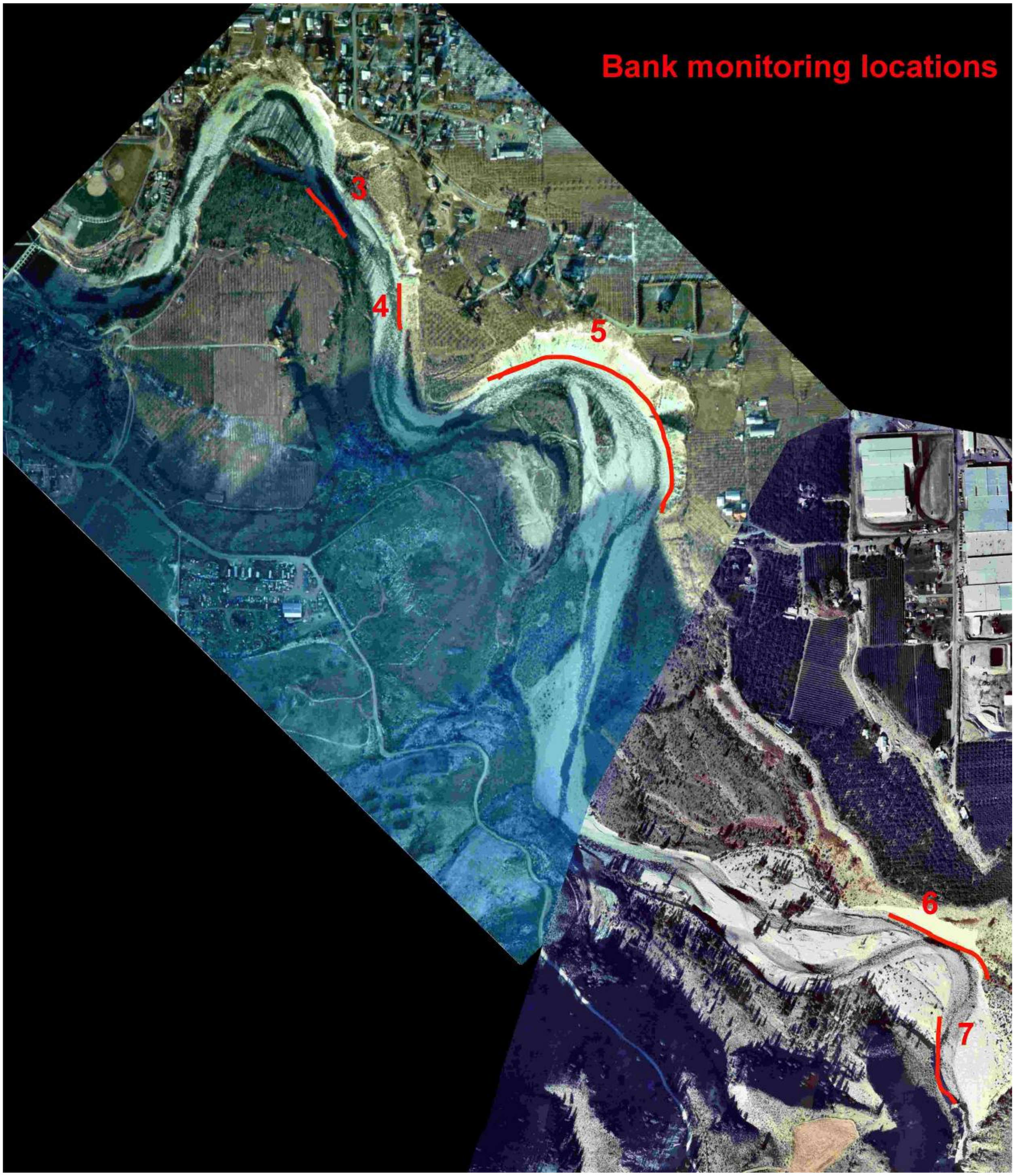


Figure 10
Chelan River Reach 1 Streambank Erosion Test Locations

Along each of the banks, a series of representative-sized rocks at or just above the estimated high water level was painted bright orange (Figure 11). Painted rocks were spaced 10 feet apart in a line along the target elevation. The location of each marked rock was also surveyed by District personnel using global positioning system (GPS). The length of the bank painted varied between locations and ranged from 200 feet to 1,800 feet.

A series of six spills were released in April, May, and June 2007 from the Chelan Dam:

- 1,850 cfs – Approximately 12 hours
- 3,250 cfs – Approximately 17 hours
- 4,780 cfs – Approximately 17 hours
- 6,710 cfs – Approximately 18 hours
- 8,000 cfs – Approximately 12 hours
- 10,000 cfs – Approximately 10 hours

The spills were released in increasing order. Between each target spill, flows were reduced to allow the monitoring locations to be re-visited to determine if erosion or gravel movement had taken place. The number of missing rocks at each monitoring location was noted, and the banks were photographed. In the event a spill washed away all painted rocks at a monitoring location, then new rocks were painted to allow further investigation at higher flows. Often the remaining rocks that are painted after a washout are larger; therefore, only limited comparisons can be made between flows before and after re-painting. Re-painting was necessary at Banks 3 and 4 following the 6,710 cfs spill event and at Bank 7 following the 8,000 cfs spill event.

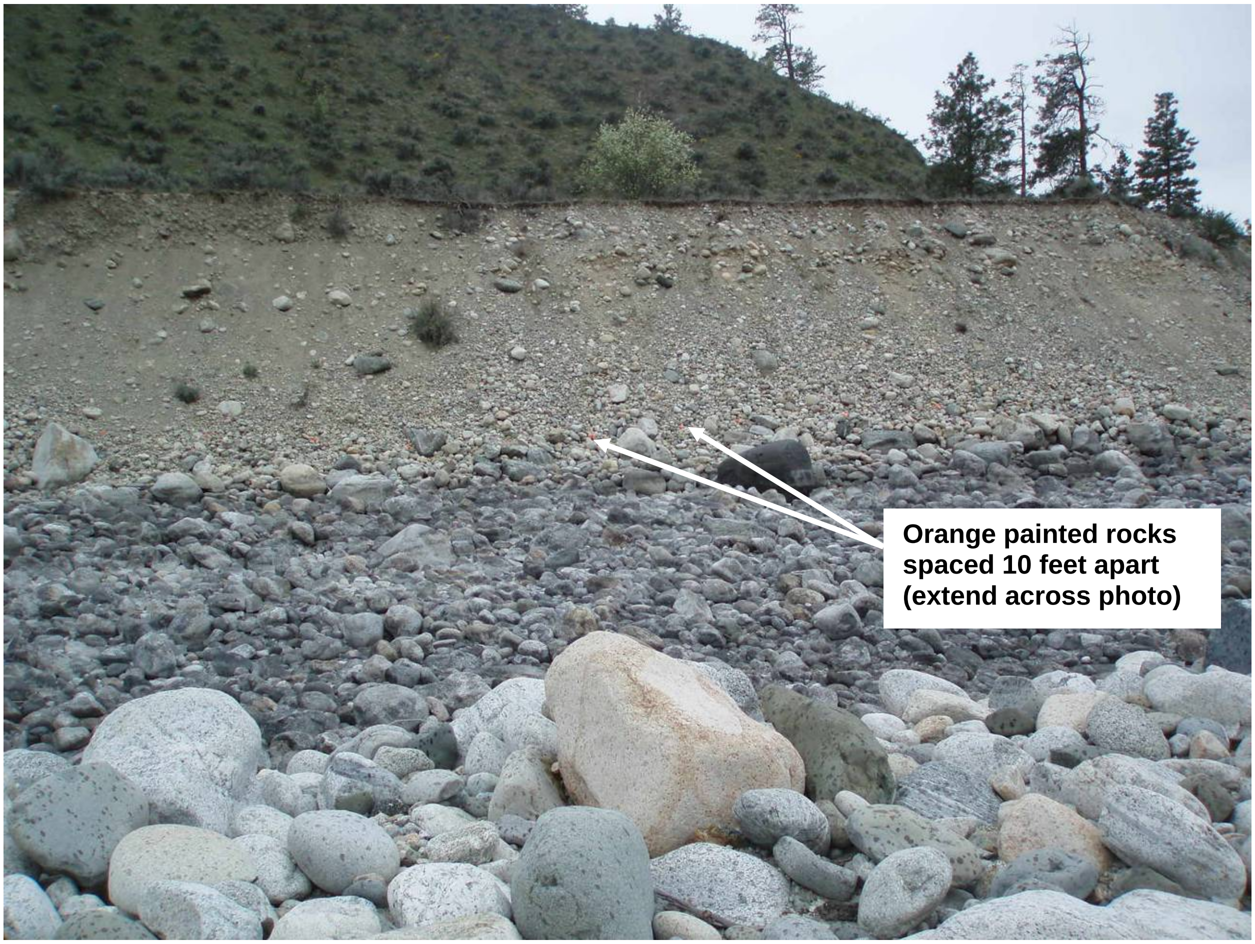
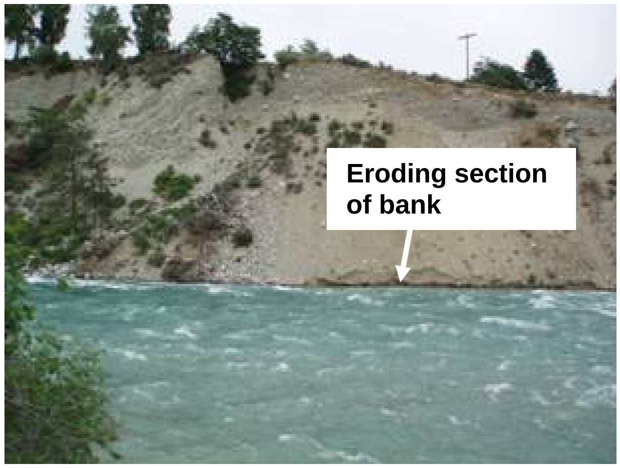


Figure 11
Bank 7 (Reach 1) Marked Rocks Prior to Spill

5.1.2.2 Results

The data sheets from the Reach 1 painted rock study are included in Appendix C. In general, the fine-grained banks (Banks 3 and 4) had more erosion at lower flows than the coarse-grained banks (Banks 5, 6, and 7) (Figures 12, 13, and 14; Table 5).

Prior to spill



During 6,710 cfs spill

Following 8,000 cfs spill

Following 10,000 cfs spill

Figure 12
Bank Erosion at Bank 4 (Fine-grained Bank)

Prior to spill

During 6,710 cfs spill

During 8,000 cfs spill

Following 10,000 cfs spill

Figure 13

Bank Erosion at Bank 6 (Coarse-grained Bank)

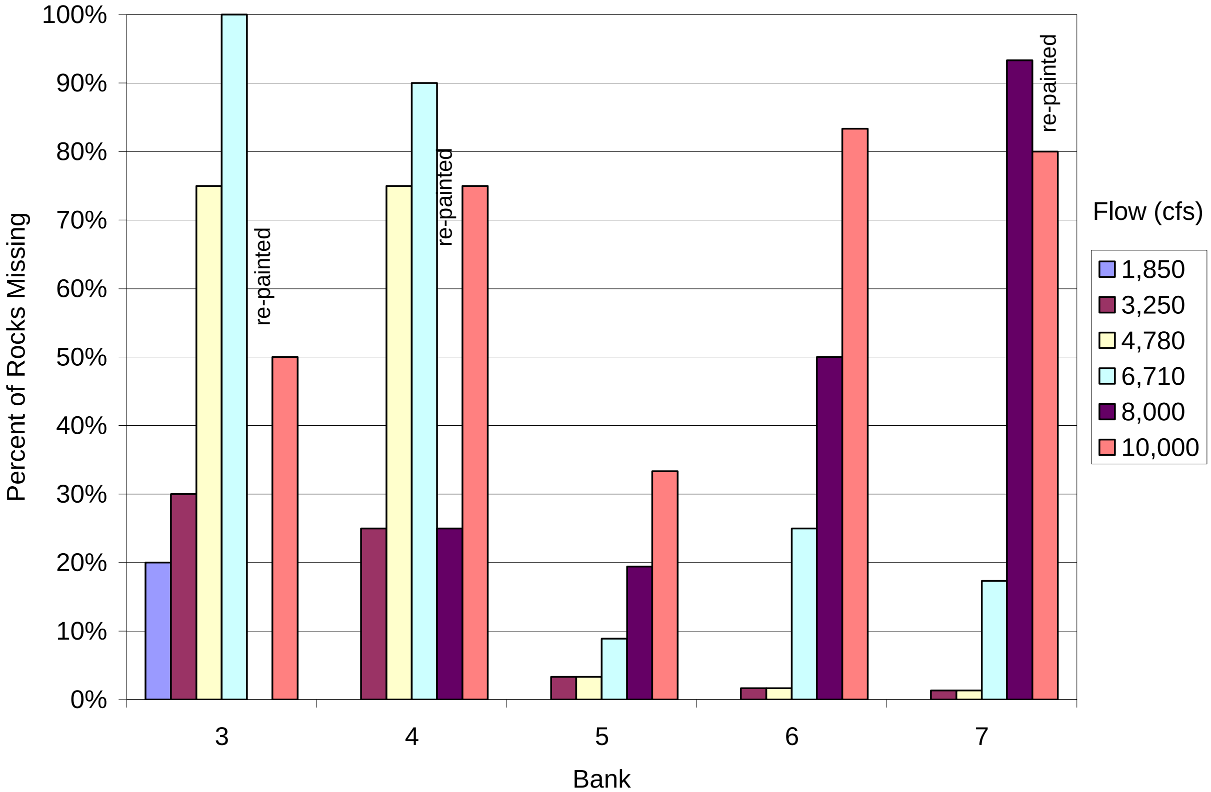


Figure 14
Summary of Bank Erosion in Reach 1

Table 5
Length of Bank Erosion (Feet) in Reach 1 During Test Spills

	Bank 3	Bank 4	Bank 5	Bank 6	Bank 7
Length of Monitoring Location (ft)	**200**	**200**	**1,800**	**600**	**750**
Fine-grained or coarse-grained?	**Fine-grained**	**Fine-grained**	**Coarse-grained**	**Coarse-grained**	**Coarse-grained**
1,850 cfs spill	40	0	0	0	0
3,250 cfs spill	60	50	60	10	10
4,780 cfs spill	150	150	60	10	10
6,710 cfs spill	200	180	160	150	130
8,000 cfs spill	0[a]	50[a]	350	300	700
10,000 cfs spill	100	150	Approximately 600	500	600[a]

Note:
a = New paint applied to replace previously washed away rocks
ft = feet

At 1,850 cfs, the lowest flow tested, only Bank 3 showed any signs of erosion (see Table 5). Painted rocks along 40 feet of the 200-foot-long Bank 3 monitoring location (i.e., 20 percent) had moved at 1,850 cfs. During the 3,250 cfs flow, approximately 25 to 30 percent of the rocks on Banks 3 and 4 moved following the 3,250 flow, while only 1 to 3 percent of Banks 5, 6, and 7 eroded. At 4,780 cfs, 75 percent of the painted rocks had moved from Banks 3 and 4, while no additional erosion was documented at Banks 5, 6, and 7. Nearly the entire length of Banks 3 and 4 had experienced erosion following the 6,710 cfs flow, while only 10 to 25 percent of the coarse-grained banks had erosion following that flow.

The rocks on Banks 3 and 4 were re-painted following the 6,710 cfs flow because the majority of the bank was eroded. The underlying rocks that were painted were coarser-grained (cobble/gravel) than the original painted rocks. Limited erosion occurred along Banks 3 and 4 at the 8,000 flows, but 50 to 75 percent of the banks eroded during the 10,000 cfs flows. These results suggest that the underlying glacial deposits on Banks 3 and 4 will begin to erode at flows of approximately 10,000 cfs.

The coarse-grained Banks (5, 6, and 7) eroded more at flows of 8,000 and 10,000 cfs than at the lower flows. Bank 5, which has been riprapped, encountered the least erosion. Bank 6 has also had some riprap work done, which should prevent erosion from progressing into the bank. However, Bank 6 is actively eroding above the riprap and the eroded material has covered the riprap. During the high spills, the eroded material covering the riprap was eroded from the riprap face of Bank 6. Bank 7 encountered nearly complete erosion of painted rocks during spills of 8,000 and 10,000 cfs.

The volume of sediment eroded at different spill levels was estimated based on measured height and depth (into the bank) that was eroded at each of the monitored banks (Table 6). Note that these volumes were eroded over a relatively short spill length (10 to 18 hours). A larger volume could be eroded if the spill continued for a longer period of time, particularly the higher magnitude spills (8,000 to 10,000 cfs).

The estimated volume of material was summed for each spill event (Total for Spill Event column in Table 6); however, this sum does not include the material washed away at previous, lower spill events, so it is not necessarily representative of the total volume that would be eroded during a spill of that magnitude. The last column in Table 6 (Cumulative Total) shows the cumulative volume eroded and is more representative of the volume that would be eroded if a spill of that magnitude occurred without previous spill. As mentioned earlier, these sediment volumes show the amount eroded during spills of relatively short period of time; more sediment would presumably be eroded if spills lasted for a longer period of time, particularly the higher magnitude (8,000 to 10,000 cfs) spills.

Table 6
Estimated Volume (cy) of Sediment Eroded at Different Spill Levels

Spill Rate (cfs)	Bank					Total for Spill Event	Cumulative Total
	3	4	5	6	7		
1,850	10	0	0	0	0	10	10
3,250	20	10	20	Less than 10	10	60	70
4,780	40	40	20	Less than 10	10	110	180
6,710	50	50	60	40	100	330	510
8,000	0[a]	10[a]	130	140	550	830	1,340
10,000	30	40	220	230	470[a]	990	2,330

Note:
a = New paint applied to replace rocks previously washed away.

The banks in Reach 1 are comprised of glacial outwash and till deposits—a heterogeneous mix of sand, gravel, cobble, and boulders. The majority of the cobble and finer-grained sediment eroded from banks in Reach 1 would be transported through the higher gradient Reaches 2 and 3 and delivered to Reach 4 where the sand, gravel, and larger sediments would be deposited in the pool upstream of the control weir. This pool has a volume of approximately 3,400 cy (350 feet long, 75 feet wide, and average 3.5 feet deep). During spills over approximately 7,000 to 8,000 cfs, when appreciable amounts of sediment would be supplied from the banks in Reach 1, boulder, cobble, and gravel sediment would be deposited in the pool, along with some portion of the finer-grained sediments in lower-velocity zones along the pool margins. It is estimated that 50 percent of the sediment supplied from the banks in Reach 1 consist of gravel and larger sediment. Thus, a 10- to 18-hour spill of 8,000 cfs is estimated to fill approximately 20 percent of the pool volume. A 10 to 18-hour spill of 10,000 cfs is estimated to fill approximately 35 percent of the pool volume. Longer duration or higher magnitude spills would fill the pool faster and would require more frequent cleaning of the deposited sediments to maintain proper functioning of the control weir.

5.2 Sediment Deposition in Reach 4

5.2.1 Review of Historic Sediment Deposition Documentation

5.2.1.1 Methods

Timing and volume of sediment deposition in Reach 4 was estimated based on comparison of historic maps and aerial photographs (see Table 4), observations made by powerhouse operators, and changes in channel depth measurements recorded during construction and subsequent inspection of the Chelan Falls Road Bridge. In the absence of detailed historic topography, a calculation of the volume of sediment deposited was estimated based on the assumption that deposition filled in the average width (500 feet) and length (2,000 feet) of the delta to an average depth.

5.2.1.2 Results

Existing surficial sediments in Reach 4 are predominantly boulder and cobble in the main flow channel, and cobble to boulder in overbank areas. Construction of the fill for the railroad and road right-of-way across the mouth of the Chelan River in the mid-1970s and the backwater effect of the Rocky Reach Pool in the Columbia River further exacerbate aggradation in this reach. Observations by the powerhouse operators suggest the channel has aggraded 8 feet in the past 15 years. This is consistent with bathymetric measurements made for the Chelan County Public Works Department on the Chelan Falls Road Bridge (No. 805A), which show "significant aggradation of the channel, as much as 17 feet between Piers 2 and 3" between 1975 and 2002 (HPA Engineers 2002). Pre-Project topographic mapping of Reach 4 is not very detailed but suggests the channel was 10 to 15 feet lower than at present (map dated Sept. 20, 1926, titled Chelan Station Powerhouse Sites, Location of Exploration Holes). Comparison of historic oblique photographs during Project construction (1920s) and aerial photographs from 1966, 1973, 1978, 1990, and 2002 also show an aggrading, shifting channel. The long-term aggradation rates in Reach 4 are between 0.5 and 0.6 foot per year based on the different sources of data. However, sediment transport in gravel-, cobble-, and boulder-bedded rivers is not gradual but occurs episodically during peak flows. Powerhouse operators report deposition occurs in Reach 4 during flows greater than about 12,000 cfs. Lower flows are reported as clear water, with flows between about 4,000 cfs and 12,000 cfs cutting channels into the deposited sediments. Since the Project was constructed in 1928, six flows over 12,000 cfs have occurred (Table 4).

Based on an average aggradation depth of 10 feet between 1974 and 2000, an estimated 370,000 cy of sediment accumulated in Reach 4. During this period, three peak flows over 12,000 cfs occurred. If it were assumed that sediment was transported primarily during these flow events, an average of 123,000 cy of sediment (approximately 3 feet of deposition) would have occurred during each of the three high flows.

Note that the estimated erosion from Reach 1 was approximately 214,000 cy per event, and deposition in Reach 4 was approximately 123,000 cy per event. The difference between these two estimates is due in part to the errors in estimating sediment volumes and in part to the fact that material eroded in Reach 1 includes a mix of sand, gravel, cobble, and boulder material, while the sediment deposited in Reach 4 includes primarily the gravel-, cobble-, and boulder-size fractions with a smaller percentage of sand. Much of the sand and finer-grained material eroded from Reach 1 is transported through Reach 4 and into the Columbia River.

5.2.2 Modeling of Sediment Deposition

5.2.2.1 Methods

Outputs of HEC-RAS modeling were used to estimate sediment deposition in Reach 4, both upstream and downstream of the proposed HCS. The criteria for determining if sediment that is already moving as bedload (e.g., moving through Reach 3 and into Reach 4) will continue to be transported or will settle out on the bed of the river is different from the criteria used to determine entrainment. Deposition of sediment in the pool upstream of the boulder weir and in Reach 4 was estimated using the Meyer-Peter Mueller bedload equation (Meyer-Peter and Muller 1948):

$$Q_{bj} = (39.25\ q^{2/3}\ S - 9.95\ d_j)^{1.5}$$

where Q_{bj} = bedload flux of the j grain size per unit width of river (pound per second per foot) q = specific water discharge (cfs/foot of channel width)

S = water surface gradient

d_j = diameter of the j grain size (feet)

Sediment in each grain size class was assumed to drop out of transport and deposit on the bed when the bedload flux of that grain size equaled zero. The HEC-RAS output (discharge, width, and gradient) was used to determine the size of sediment that would drop out of transport at each cross-section under the different flow scenarios.

5.2.3 Reach 4 Grain Size Distribution

5.2.3.1 Methods

Subsurface and surface sediment samples were analyzed to characterize the size distribution of sediments in Chelan River Reach 4. This grain size information is needed for use in the sediment transport analysis and to determine the suitability of material for use as substrate for salmon spawning and rearing in the new habitat channel.

Subsurface sediment samples were collected from each of the six pump test pits dug in January 2007 (see Section 6 and Figure 18). These grab samples were taken from the subsurface deposits during digging of each of the pits. A 5-gallon bucket of sediment was taken from each pit using a shovel. Each bucket was labeled and transported to a sediment lab for grain size analysis by dry sieving and testing of Atterberg Limits.

Surface pebble counts were taken at 11 sites in Reach 4. Pebble count sites were designated based on the stationing marked on the ground by survey stakes[1]:

- STA 24+00
- STA 21+00
- STA 18+56
- STA 17+00

[1] Note that these station numbers are different than those used in the HEC-RAS model; HEC-RAS stations are approximately 232 feet higher than corresponding survey locations.

- STA 15+50
- STA 14+00
- STA 12+00
- STA 10+00
- STA 9+00
- STA 8+00
- STA 4+50

Surface sediment size data were collected using the Wolman pebble count method. Pebble counts of 100 particles were measured at each site by walking heel to toe in the sample area and selecting the particle at the toe of the surveyor's boot. Using a gravelometer, the diameter of each particle was classified into one of the following categories:

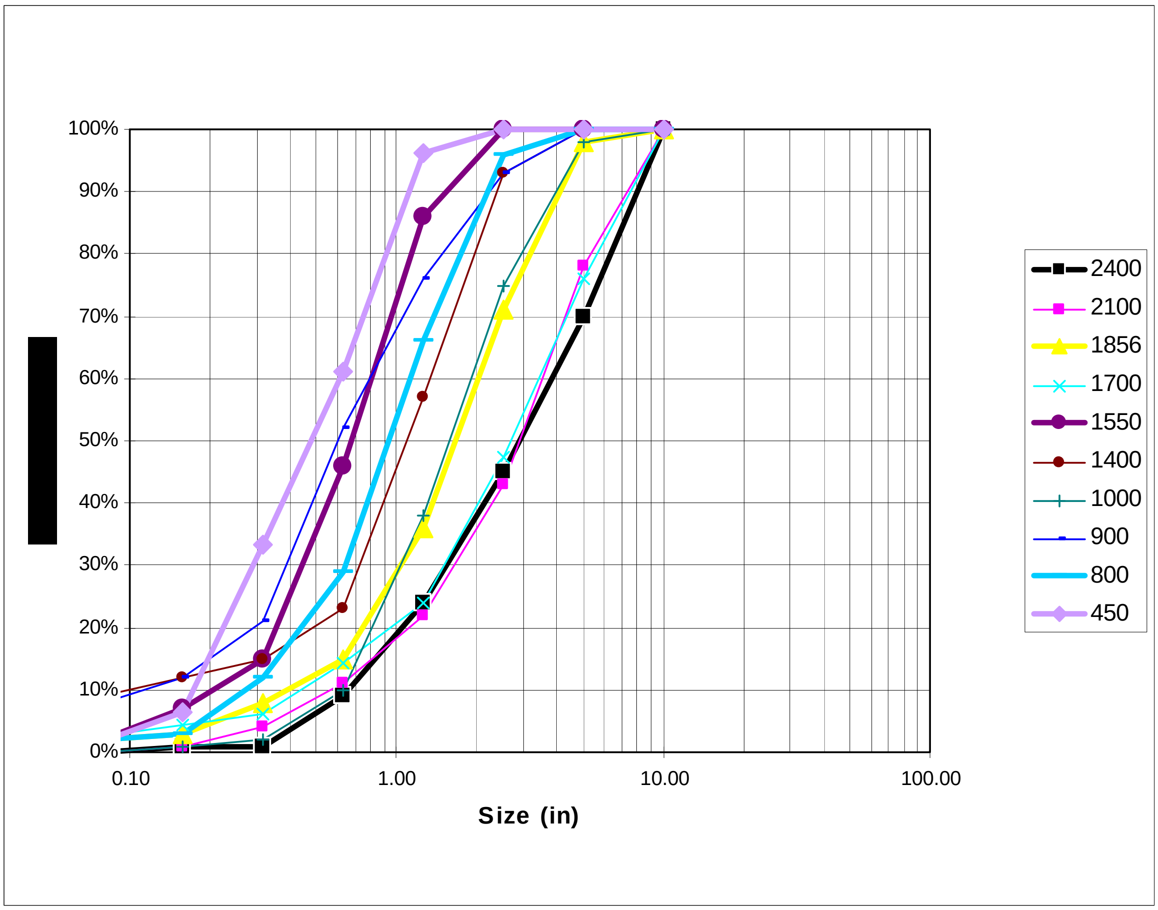
- Less than 2 millimeters (mm)
- 2 to 4 mm
- 4 to 8 mm
- 8 to 16 mm
- 16 to 32 mm
- 32 to 64 mm
- 64 to 128 mm
- 128 to 256 mm
- 256 to 512 mm
- 512 to 1024 mm

A gravelometer is a metal template with square holes corresponding to each of the noted grain size classes. Data were entered into a spreadsheet for graphing.

5.2.3.2 Results

Surface pebble counts and sub-surface sediment sample data summary sheets with graphs are provided in Appendix D. Surface pebble count grain size distributions are summarized in Figure 15. Note that the information in Figure 15 is converted to grain size in inches. Graphs and data are in mm, the standard unit used for pebble counts and sieving.

Median particle size of surface layer samples ranged from 77 mm (3 inches) in diameter near the top of Reach 4 to 12 mm (0.5 inch) in diameter near STA 4+50. Median particle size of the sub-surface samples ranged from 15 mm (0.6 inch) to 40 mm (1.5 inches) in diameter. Note that the sub-surface layers did not include particles larger than 10 inches due to sampling constraints.



Note:

The station locations described here do not correspond to station locations used in the hydraulic modeling. The hydraulic modeling of the new habitat channel design adjusted the station positioning by approximately 232 feet. As a result, STA 4+00 in the test pit analysis corresponds to location 6+32 in the hydraulic modeling analysis.

Figure 15
Surface Sediment Pebble Count Grain Size Distribution

5.3 Transport of Spawning Size Sediment from Reach 4

5.3.1 Modeling of Sediment Entrainment

5.3.1.1 Methods

Erosion of substrate in Reach 4 under peak flow conditions was estimated for peak flows of 4,000; 6,000; 8,000; 11,000; and 14,000 cfs. These peak flows correspond to flows with a recurrence interval of 1.5, 2, 3.1, 5, and 10 years respectively. The HEC-RAS model output was used to determine water depth and shear stress (τ) in the main channel and left and right overbank at each of the HEC-RAS stations for each of the flows. Shear stress at each cross-section was compared to critical shear stress (τ^*_c) for each flow to determine the particle size that could be entrained by the flow.

The Shields' Criterion was used to determine the critical shear stress for initiation of substrate movement:

$$\tau^*_c = a(\gamma_s - \gamma_w)d_{50}$$

where τ^*_c = critical Shields stress for mobility of particle size d_{50}

a = constant, 0.039 for this analysis due to type of river and sediment

γ_s and γ_w are the specific weights of sediment and water, respectively

d_{50} = median particle size at threshold of mobility

5.3.1.2 Results

The potential for erosion of substrate placed in the new habitat channel was determined based on Shields' Criterion and HEC-RAS hydraulic output at each cross-section. Substrate placed in the new spawning/rearing channel is planned to be gravel- and cobble-sized (0.5 to 6 inches in diameter). In the current Reach 4 setting, substrate larger than approximately 1.5 inches in diameter is calculated to be stable at all cross-sections downstream from HEC-RAS STA 21+00 at flows up to 8,000 cfs, and at most cross-sections at flows up to 14,000 cfs. When the spawning channel is constructed, the berm separating it from the main channel of Reach 4 will further reduce the likelihood of scour of spawning size substrates in the new habitat channel.

5.3.2 Reach 4 Painted Rock Study

5.3.2.1 Methods

During the painted rock study of sediment sources in Reach 1 (Section 5.1.2), a painted rock study was also conducted in Reach 4 to test the flow that caused erosion or deposition of the existing substrate and rocks representative of the "fish mix" (0.5- to 4-inch-diameter substrate) planned to be placed in the new habitat channel. Painted rocks were also deployed at six monitoring locations in Reach 4 (Figure 16). At each of these locations, a 3- to 4-foot-diameter circle of yellow was painted on the existing substrate.

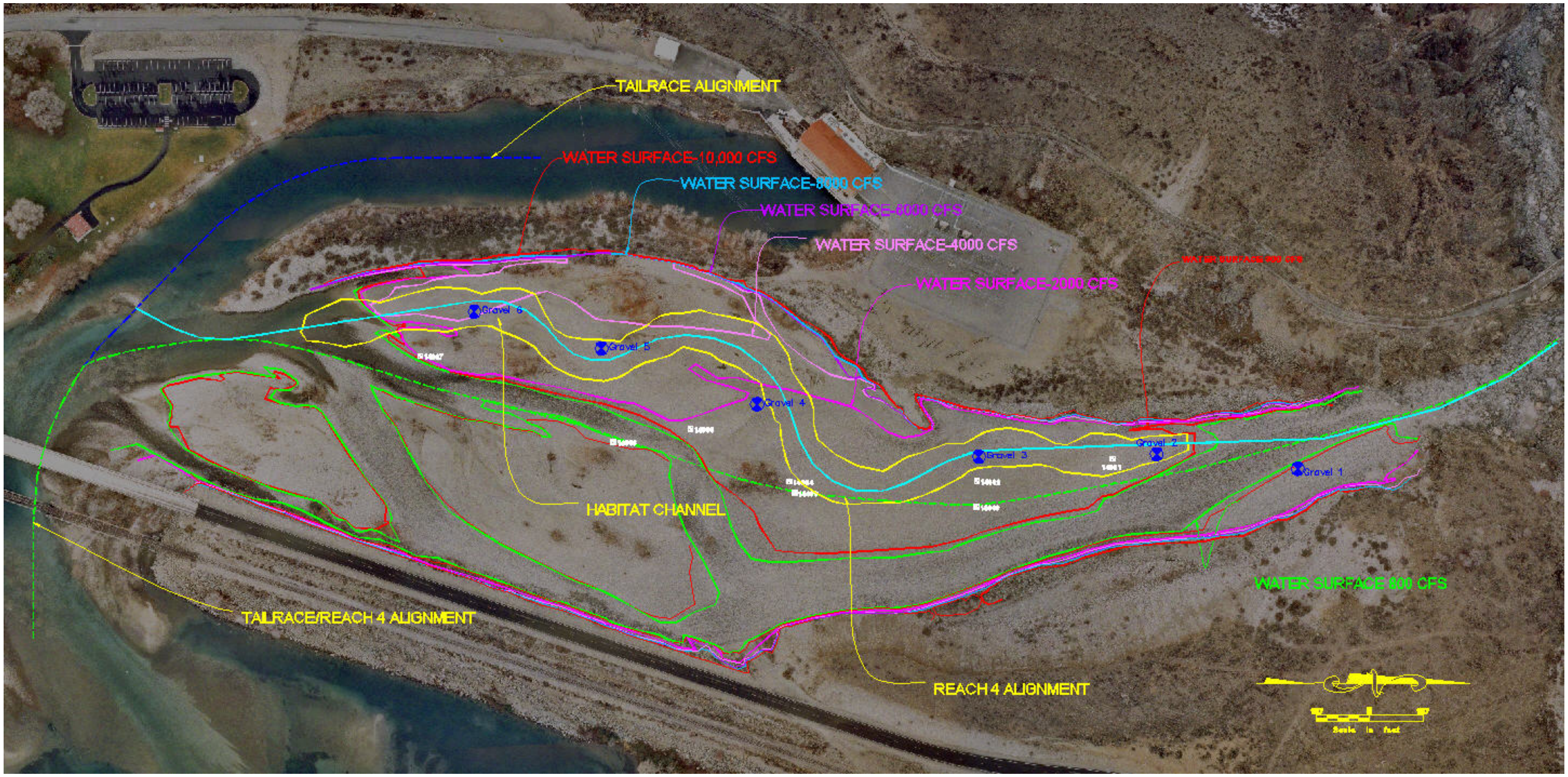


Figure 16
Reach 4 Substrate Erosion Test Locations

Twelve orange rocks representative of the fish mix size range were placed on top of the yellow painted substrate in a 3 x 4 grid pattern (Figure 17). Rock spacing along each row and column of the grid was approximately 1 foot. Each row in the grid contained a different size rock. The largest rocks were placed at the downstream end, with incrementally smaller rocks placed in upstream rows. This rock placement design ensured that the larger orange rocks did not shield the smaller orange rocks from oncoming flow. Each orange rock was placed in the substrate by removing a similarly sized existing rock and replacing it with the orange rock to mimic exposure on the bed of the river.

Figure 17
Gravel Test Site 1 (Reach 4) Prior to Spill
(Note: Flow is from bottom of photograph to top of photograph.)

As described in Section 5.1.2, painted rock movement was studied during a series of six spill events from the Chelan Dam: 1,850; 3,250; 4,780; 6,710; 8,000; and 10,000 cfs. Rock movement was assessed following each spill event.

5.3.2.2 Results

The painted rock study investigated the substrate sizes that would be entrained by known spill flow rates in the current configuration of Reach 4. The construction of the new habitat channel and associated berm to keep high flows out of the channel will reduce the entrainment potential described in this study.

Table 7 lists the median diameter of particles that remain at each of the test locations following each flow (painted rocks were sized 1 to 2 inches, 2 to 3 inches, and 3 to 4 inches in diameter). All sites were inundated at flows of 3,250 cfs and higher. At Sites 3 through 6, which were positioned in the new habitat channel alignment, no substrate movement was documented at flows of 4,780 cfs and lower.

At 8,000 cfs, almost all fish mix spawning size substrate would be transported away in the current Reach 4 configuration.

Table 7
Substrate Size (Diameter) Eroded from Reach 4 at Different Spill Levels

Spill Rate (cfs)	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
1,850	No movement	No movement	No movement	No movement	No movement	No movement
3,250	No movement	No movement	No movement	No movement	No movement	No movement
4,780	Smaller than 6 inches	Smaller than 3 inches	No movement	No movement	No movement	No movement
6,710	Smaller than 12 inches	Smaller than 8 to 10 inches	Minor movement	Smaller than 2 to 4 inches	Minor movement	Minor movement
8,000	All painted rocks eroded	All painted rocks eroded	Smaller than 3 to 4 inches	Smaller than 3 to 4 inches	n/d	Smaller than 3 to 4 inches
10,000	All painted rocks eroded	All painted rocks eroded	All painted rocks eroded	Smaller than 4 inches	Smaller than 4 inches	All painted rocks eroded

Note:
n/d = No data because the site could not be relocated

5.3.3 Grain Size at Downstream End of Reach 4

The District contracted with Hammond Collier Wade Livingstone (Hammond Collier) to investigate sediment grain size at the downstream end of Reach 4 near the road and railroad bridges (Appendix E). Sediment in the area of investigation will be available for use in the habitat restoration project. In an analysis of grain size distributions in five test pits dug to a maximum depth of 5 feet, Hammond Collier estimate that approximately 50 to 70 percent of the material is gravel between 3/16 inch and 3 inches in diameter. Much of this material was found below a cobble armor layer on the gravel bar.

5.4 Conclusions

Based on the sediment erosion and deposition analyses described above, the following conclusions can be drawn about the new habitat channel modifications in Reach 4:

1. *Timing and volume of sediment inputs into Reach 4* – In the past, sediment has been eroded from river banks in Reach 1 and transported into Reach 4 when flow in the Chelan River is greater than approximately 12,000 cfs. An estimated 370,000 cy of sediment has accumulated in Reach 4 over the past 30 to 40 years. This accumulation likely occurred during three peak flow events larger than 12,000 cfs that have occurred in this time period. Sediment accumulations in Reach 4 should be at a lower rate in the future as a result of armoring of several of the eroding banks in Reach 1 and implementing new operating guidelines that will help limit the magnitude and frequency of spills. Based on the results of the Reach 1 painted rock study (Section 5.1.2), limiting spill events greater than 10,000 cfs would also reduce future bank erosion. However, it should be anticipated that some peak flows over 12,000 cfs will occur during the new license period (likely recurrence interval 8 to 10 years) that will result in aggradation and/or channel shifting in Reach 4. Channel shifting could affect the new habitat channel.
2. *Timing and volume of sediment deposition in the pool upstream of the HCS* – Particles larger than 3 to 4 inches in diameter are calculated to deposit in the pool during peak flow events large enough to substantially erode streambanks in Reach 1. Smaller sized particles would also likely accumulate in lower velocity zones within the pool. A 10- to 18-hour spill of 8,000 cfs is estimated to fill approximately 20 percent of the pool volume. A 10- to 18-hour spill of 10,000 cfs is estimated to fill approximately 35 percent of the pool volume. Longer duration or higher magnitude spills would fill the pool faster and would require more frequent cleaning of the deposited sediments to maintain proper functioning of the weir.

3. *Stability of substrate placed in the new spawning/rearing channel under high flow conditions* – Substrate in the greater than 1- to 6-inch-size range should be stable under high flow conditions if the main flow channel remains separate from the new habitat channel. There will likely be winnowing of some particles smaller than 1 inch in diameter and local scouring of larger particle sizes. If aggradation or a large peak flow occurs and the main channel migrates or switches into the new habitat channel, erosion of substrate will occur.

6 PUMP TEST

Field and laboratory testing of surface water percolation rates was conducted to evaluate the ability of the restored channel to hold water at surface.

6.1 Methods

On January 16, 2007, test pits and pumping tests were conducted at the Reach 4 channel. The weather was cold (10 to 20 degrees Fahrenheit) and the top 16 inches of substrate was frozen. Six stations distributed throughout Reach 4 were sampled (Figure 18). Station reference is relative to the original Anchor, drawing and channel alignment that was staked in the field by the District[2]. Station references start with STA 0+00 at the downstream end of Reach 4 and increase in number reference moving upstream. Table 8 identifies the tests conducted at each station. Additional tests relevant to sediments were conducted at each station and are reported in Section 4.

Table 8
Tests Conducted at Each Station

Station	Falling Head Test		Pump Test
	Field	Lab	
STA 4+00		✓	
STA 8+00	✓		
STA 9+00	✓		
STA 12+00	✓		✓
STA 15+50	✓	✓	
STA 18+50	✓		

Test holes were dug 3 to 5 feet deep with a track mounted excavator. Hole radius at the bottom ranged from 5 to 7 feet. Water was pumped into the holes from the powerhouse tailrace to provide a water level. The pump was then shut off and the rate of falling water recorded. At STA 12+00, a pump test was conducted at a pumping rate of 200 gallons per minute (gpm).

[2] The station locations described for the test pits do not correspond to station locations used in the hydraulic modeling. The hydraulic modeling of the proposed channel design adjusted the station positioning by approximately 232 feet. As a result, STA 4+00 in the test pit analysis corresponds to location 6+32 in the hydraulic modeling analysis.

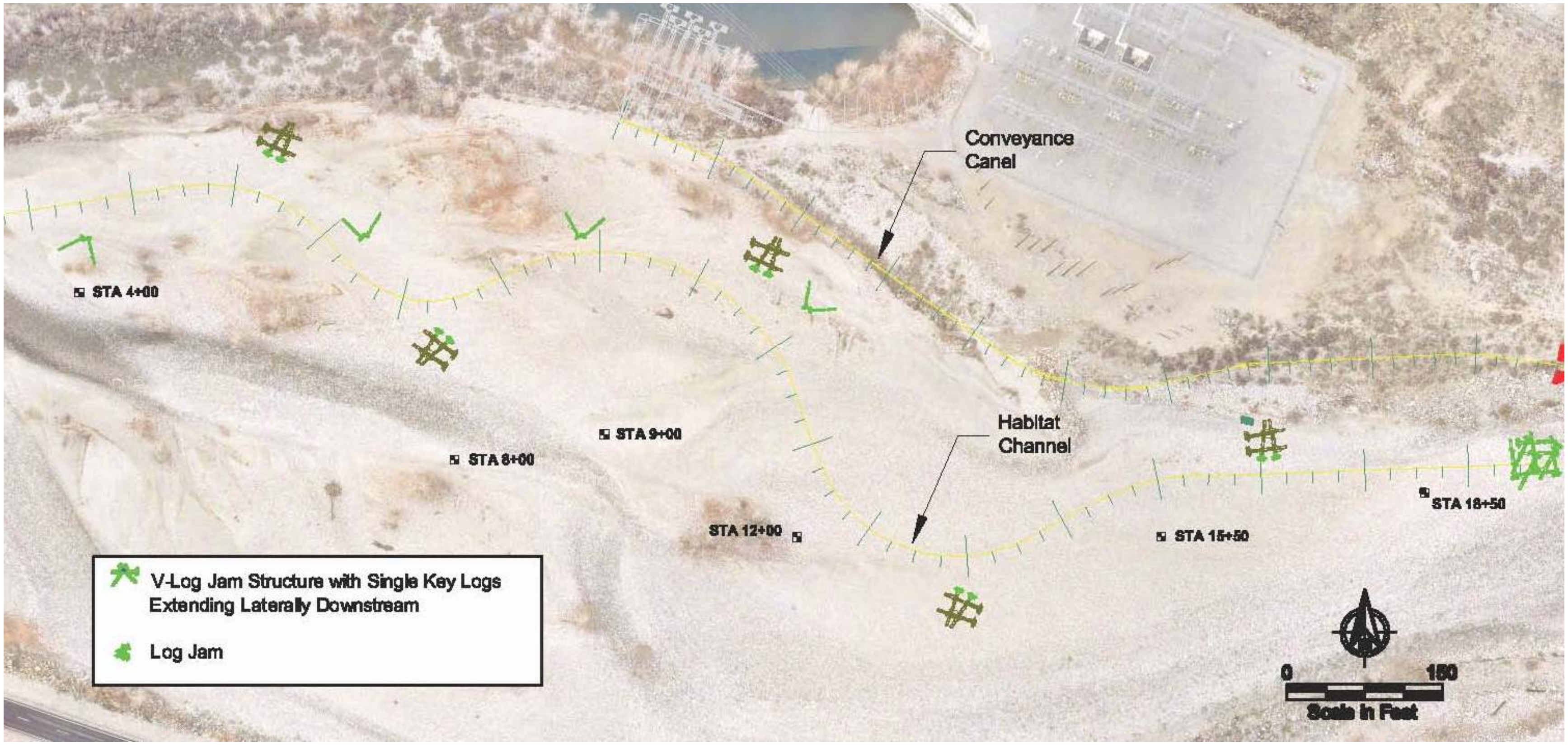


Figure 18
Test Pit Locations
(Note: Habitat channel alignment and log jam configurations do not represent final design alignments.)

6.2 Results

Table 9 is a summary of data collected from the falling head tests. Groundwater was not found in any of the excavation areas. The deepest point of excavation was elevation 704.3 feet at STA 15+50 and 704.7 feet at STA 8+00. Both of these elevations are below the Chelan River tailrace water surface elevation (WSEL) of 709.1 feet at the time of testing. In a separate investigation, CH2M Hill reports finding groundwater at one deep excavation along the flume alignment (CH2M Hill 2007).

Table 9
Summary of Falling Head and Pump Test Data

Station	Rising Time (min)	Falling Time (min)	Pump Rate (gpm)	Hole Volume				Rising Rate (gpm)	Falling Rate in Field (gpm)	Falling Rate in Field (in/hr)	Falling Rate in Lab (in/hr)
				Depth (ft)	Radius (ft)	Volume (cf)	Bottom Elevation (ft)				
STA 4+00											70
STA 8+00		6.7		2.5	5.5	950	704.7		1,114	269	
STA 9+00		9.79		2.8	7.1	1,773	706.1		762	253	
STA 12+00	6	8	200	2	6.3	997	710.6	1,243	933	93	
STA 15+50		12.78		2.72	5.2	924	704.3		584	152	423
STA 18+50		22.37		2.96	6.4	1,523	715.4		334	95	

Notes:
cf = cubic feet
ft = feet
in/hr = inches per hour
min = minutes

Field and laboratory falling head rates ranged from 70 to 423 inches per hour. All field and laboratory results were within the calculated ranges. This equates to an average loss of 0.0045 fps. Graphs of the falling rate for each station evaluated in the field are shown in Figures 19 through 23. Photographs of each station showing representative examples of the substrate are also shown in Photographs 1 through 10.

The STA 12+00 pump test included a measurement of a static water elevation at a pumping rate of 200 gpm in a flow area of 79.1 square feet (sf). An apparent velocity was calculated at 1.6 feet per minute (fpm).

6.3 Discussion

The tests were performed within the ranges of the new habitat channel and represent a good cross-section of the channel profile. Based on observations of the substrate, results of the falling head tests, and the one static pump test performed, it is apparent Reach 4 of the Chelan River has a very high potential to percolate water into the surrounding floodplain. Not only was groundwater not present (even at levels below the Chelan River tailrace WSEL), but the sediment size and poorly graded gravel with sand appear to extend deep down into the floodplain.

Applying the average flow rate of 0.0045 fps over the proposed channel length of 1,800 feet and 60 feet wide, potential water loss equals 484 cfs. Powers (1992) developed empirical relationships between groundwater seepage in floodplains relative to spawning channels and measured a reduction factor to account for uncertainties in applying a small test area result to a full channel length. Data showed total groundwater flows were actually 5 to 15 percent of the predicted values. Applying these empirical relationships to the Chelan Reach 4 site, one would expect a water loss in the range of 25 to 75 cfs. The loss would likely be less over time as the Reach 4 area receives continuous flow. Losses in the range of 25 cfs or less would not likely reduce the effective operation of the channel. Given the potential error in estimating the losses, additional monitoring is recommended to measure downstream flow reduction during an 80 cfs flow release.

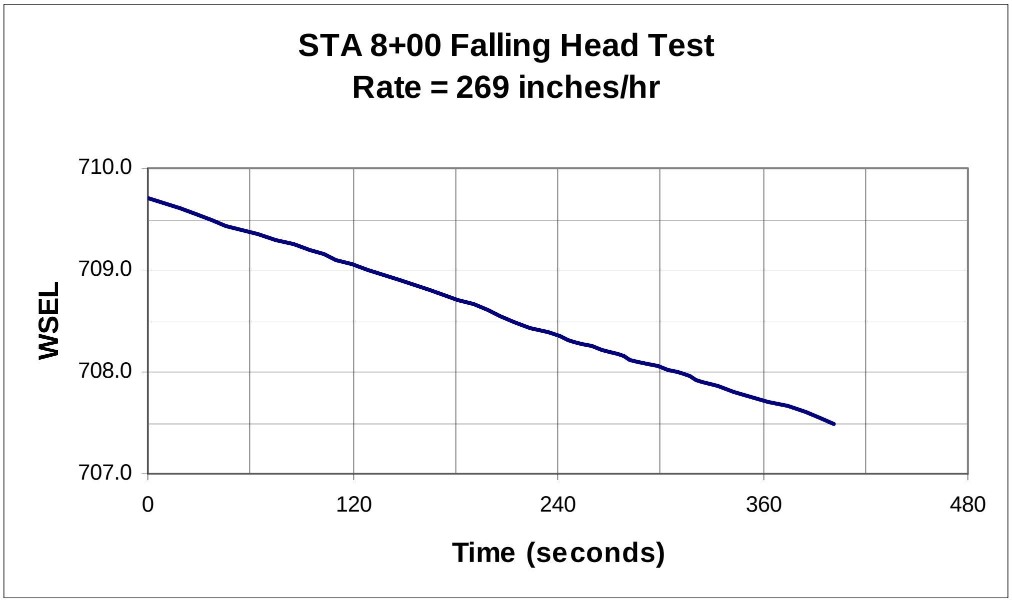


Figure 19
STA 8+00 Falling Head Test

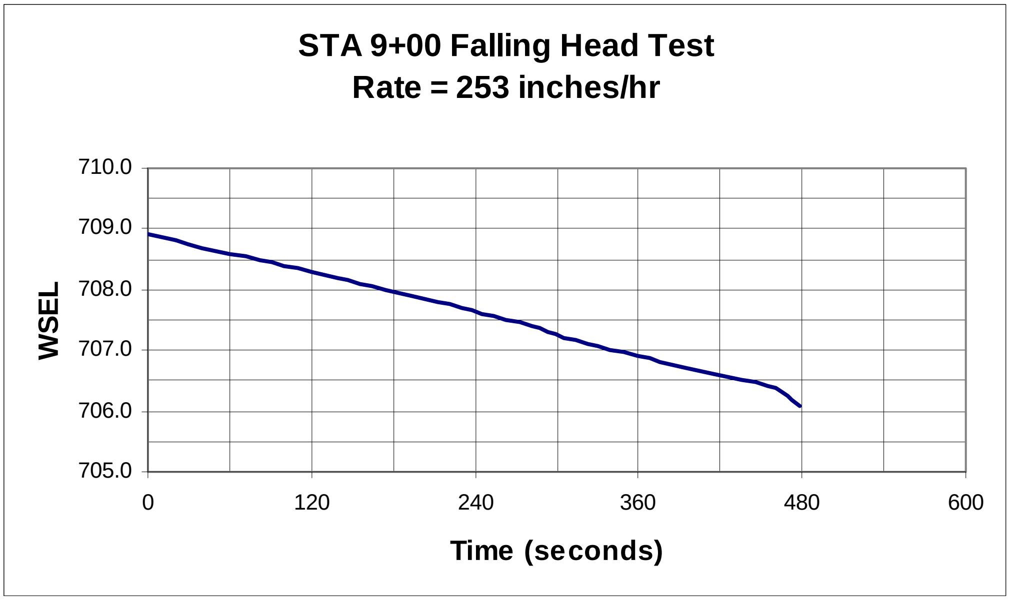


Figure 20
STA 9+00 Falling Head Test

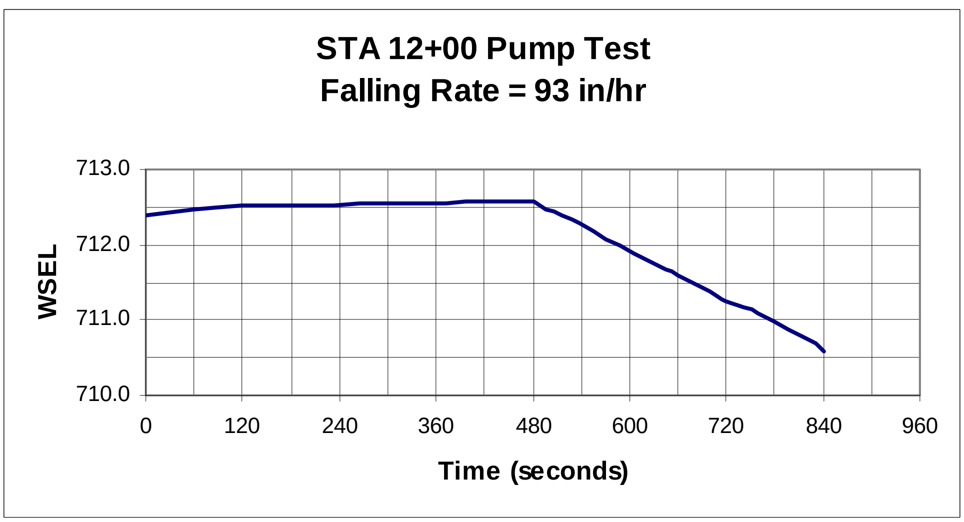


Figure 21
STA 12+00 Pump and Falling Head Test

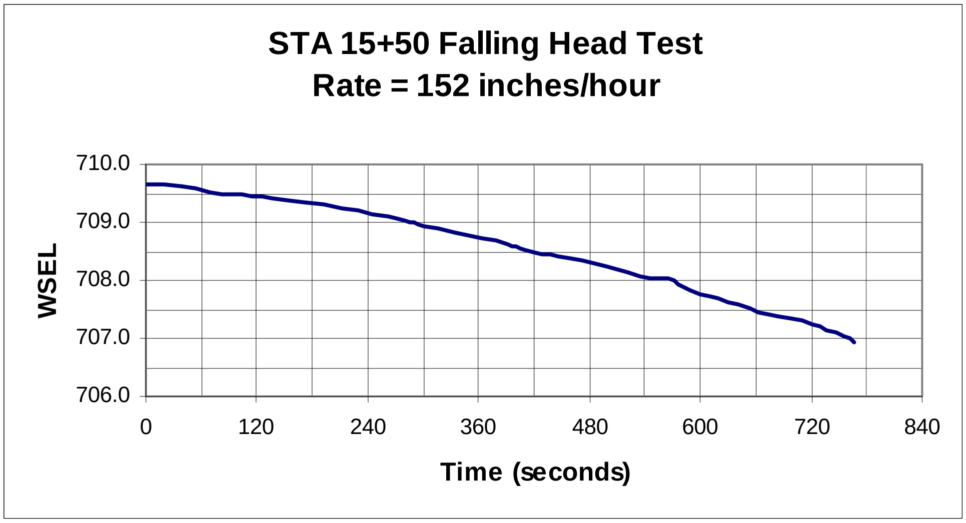


Figure 22
STA 15+50 Falling Head Test

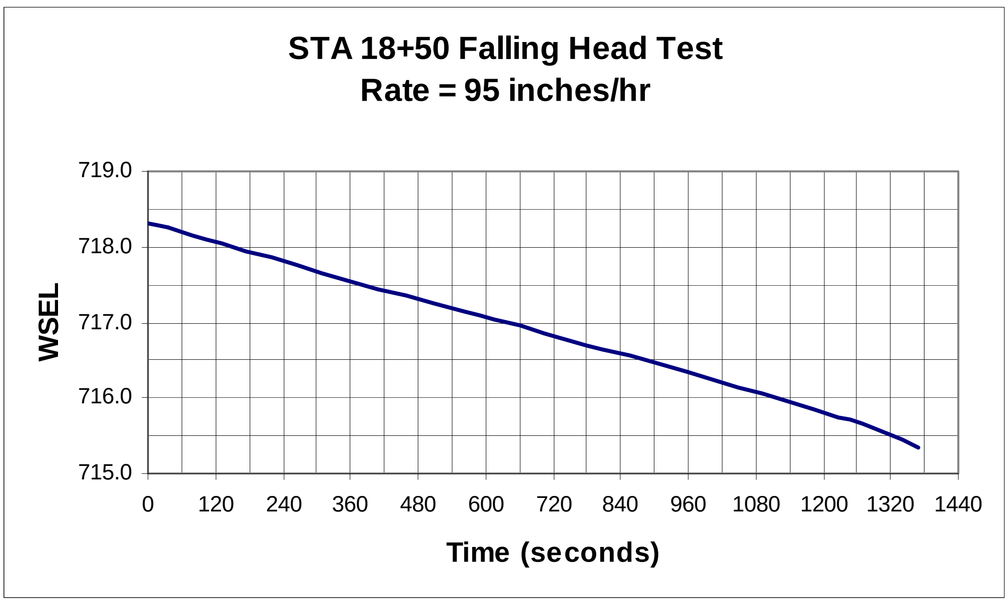


Figure 23
STA 18+50 Falling Head Test

Photograph 1 – STA 8+00 Falling Head Test

Photograph 2 – STA 8+00 Staff Gage

Photograph 3 – STA 9+00 Test Hole

Photograph 4 – STA 9+00 Substrate

Photograph 5 – STA 12+00 Test Hole

Photograph 7 – STA 15+50 Charging Test Hole

Photograph 8 – STA 15+50 Substrate

Photograph 9 – STA 18+50 Charging Test Hole

Photograph 10 – STA 18+50 Falling Head Test

7 GEOTECHNICAL ANALYSIS OF HCS

The following geotechnical evaluations were performed for the HCS:

- Seepage
- Piping analysis
- Uplift analysis

The HCS will consist of grouted rocks and boulders placed in a mass downstream of the pool that will be formed at the discharge point from the conveyance channel.

The proposed HCS is approximately 30 feet wide, 180 feet long, and will impound approximately 3 to 6 feet of water depending on flow conditions from the conveyance channel.

Seepage beneath the HCS was modeled using the groundwater code within the software package Slide 5.0. The following soil parameters and model assumptions were used, and several different conditions were evaluated to estimate the potential for flow to short-circuit beneath the HCS.

7.1 Soil Parameters

Soils along the alignment of the habitat channel generally consist of a granular matrix of poorly- to well-graded gravel with sand, with less than 1 percent fines (silt and clay). Anchor performed two permeability tests at two different test pit locations. The resulting permeability from these tests was approximately $5x10^{-2}$ centimeters per second (cm/s) and $3x10^{-1}$ cm/s.

Anchor evaluated two scenarios for the permeability of the ground beneath the channel using the results of the permeability tests. Anchor also reviewed published correlations of permeability versus soil type, which compared well to the results obtained from the field testing. For example, a permeability of approximately $1x10^{-2}$ cm/s can be expected for gravelly sand with a dry density of 110 pounds per cubic foot (Cedergren 1989)

The model assumed an impermeable base at elevation 664 feet (56-foot depth) to represent the bedrock that was encountered in the borings performed by CH2MHill (2007) at the tailrace pump station.

7.2 Groundwater Parameters

Soil borings and test pits advanced by CH2MHill indicate that regional groundwater is likely controlled by the water elevation at the tailrace (CH2MHill 2007). Thus, the range of potential groundwater elevations was modeled assuming that the minimum groundwater elevation downstream of the HCS would be elevation 706 feet, and the maximum groundwater elevation downstream would be 715 feet. These elevations were used to set downstream boundary conditions in the model for groundwater conditions.

7.3 HCS Parameters

The HCS was modeled assuming a worst-case seepage condition where water behind the structure was present at elevation 721 feet, but water in front of the structure was not present (as in the case when the structure would be initially filling). Three different cutoff scenarios were modeled:

1. No cutoff present
2. Cutoff provided by grouted rock to a depth of 9 feet below grade
3. Cutoff provided by an impervious sheet pile wall to a depth of 16 feet below grade

The grouted rock was modeled assuming a post-grout hydraulic conductivity of approximately $1x10^{-6}$ cm/s. The sheet pile cutoff was modeled as impervious using a hydraulic conductivity of $3x10^{-14}$ cm/s for the model material representing sheet pile.

7.4 Seepage Evaluation Results

Figure 24 presents a cross-section through the model for the grouted rock case without a groundwater cutoff wall present (Scenario 2 presented in Table 10).

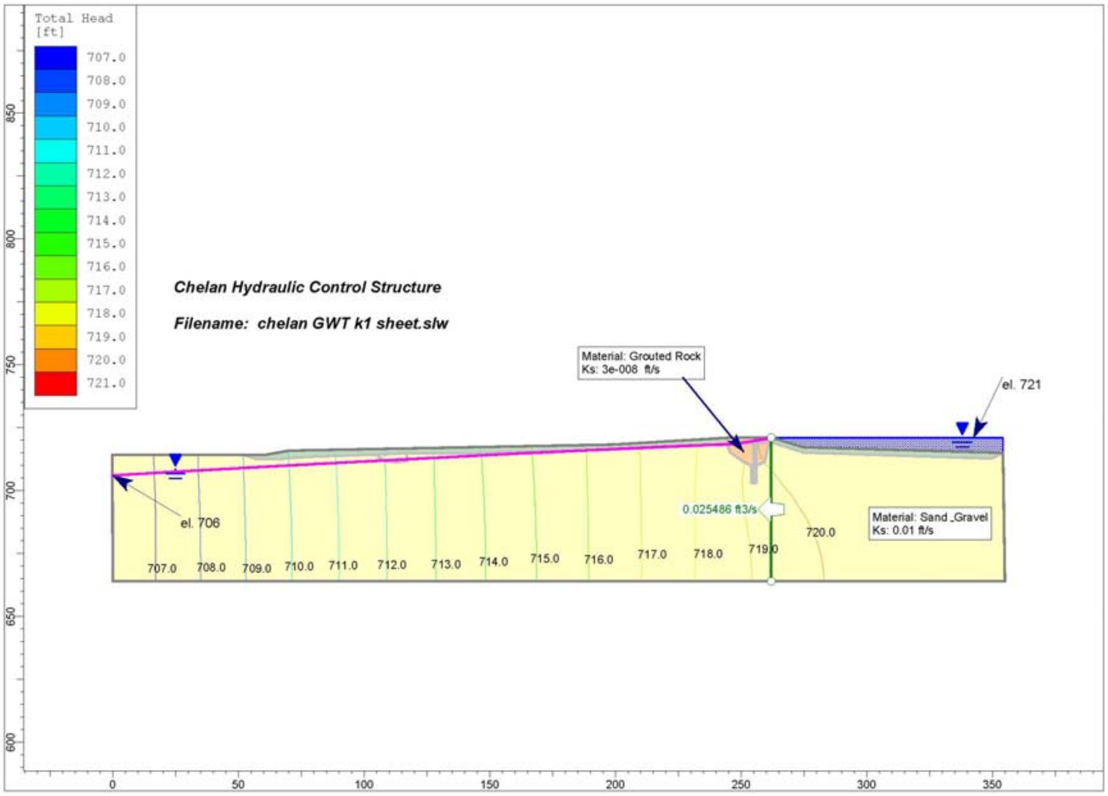


Figure 24
Slide 5.0 Groundwater Model

Table 10 presents the results for each of the analyses, assuming a 180-foot-long HCS.

Table 10
HCS Seepage Analysis

Scenario	Subgrade Soil Permeability (cm/s)	Downstream Groundwater Elevation (ft)	Cutoff Wall Assumption	Estimated Seepage (cfs)
1	$3x10^{-1}$	706	None	4.8
2			Grouted Rock	4.6
3			Sheet Pile	4.5
4		715	None	3.0
5			Grouted Rock	2.7
6			Sheet Pile	2.6
7	$5x10^{-2}$	706	None	0.8
8			Grouted Rock	0.7
9			Sheet Pile	0.7
10		715	None	0.6
11			Grouted Rock	0.5
12			Sheet Pile	0.5

Note:
ft = feet

7.5 Piping Potential

As described in Cedergren (1989), the upward force exerted by seeping water can be determined from the hydraulic gradient. When the upward force exceeds the buoyant unit weight, the soil is in a state of flotation, which leads to heave, boiling, and piping.

The factor of safety against piping can thus be computed as follows:

$$FOS_{PIPING} = \frac{\gamma_{soil}}{i \times \gamma_{water}}$$

where:

FOS = Factor of Safety

γ_{soil} = Buoyant unit weight of soil (pcf)

i = Hydraulic gradient

γ_{water} = Unit weight of water (62.4 pcf)

For the range of conditions analyzed, the total hydraulic gradient was 0.03 to 0.06 downstream of the HCS. Samples collected from the test pits had an average buoyant unit weight of 60.5 pcf. Thus, the factor of safety against boiling is substantially higher than 1.0, which indicates that heave or piping would not be expected to be caused by the construction of the HCS.

7.6 Uplift Potential

Anchor evaluated the potential for uplift pressure to move the grouted rock structure for two scenarios:

- Flow beneath the grouted rock
- Flow beneath a combination of grouted rock and sheet pile

For each flow scenario, a ponded water elevation of 721 feet behind the HCS and a downstream groundwater elevation of 706 feet (which was the condition with the greatest estimated seepage) were assumed. The Slide 5.0 software was used to generate a flow net, and the net uplift on the grouted structure was computed using this information. The resisting force was computed as the buoyant unit weight of the grouted rock mass. Figures 25 and 26 depict the flow net as well as the calculations of factor of safety against uplift. The factor of safety ranged from 2.0 to 2.4, which indicates that uplift is not expected under these flow conditions.

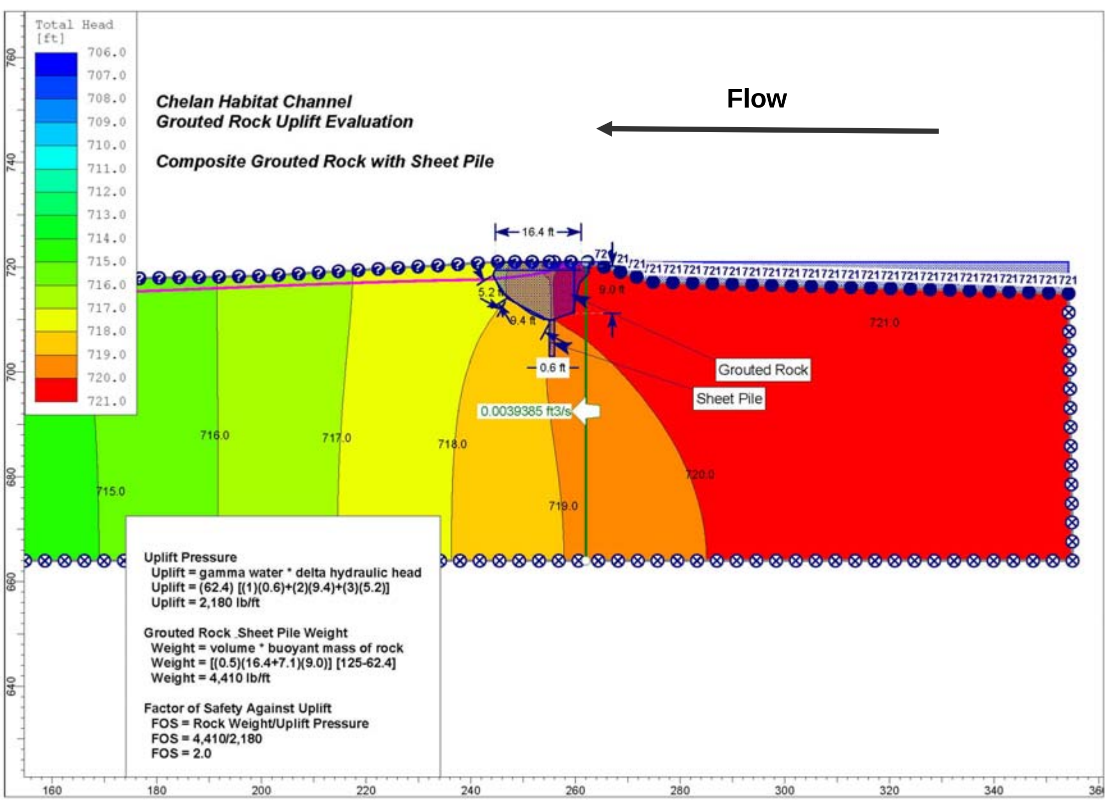


Figure 25
Uplift with Sheet Pile and Grouted Rock

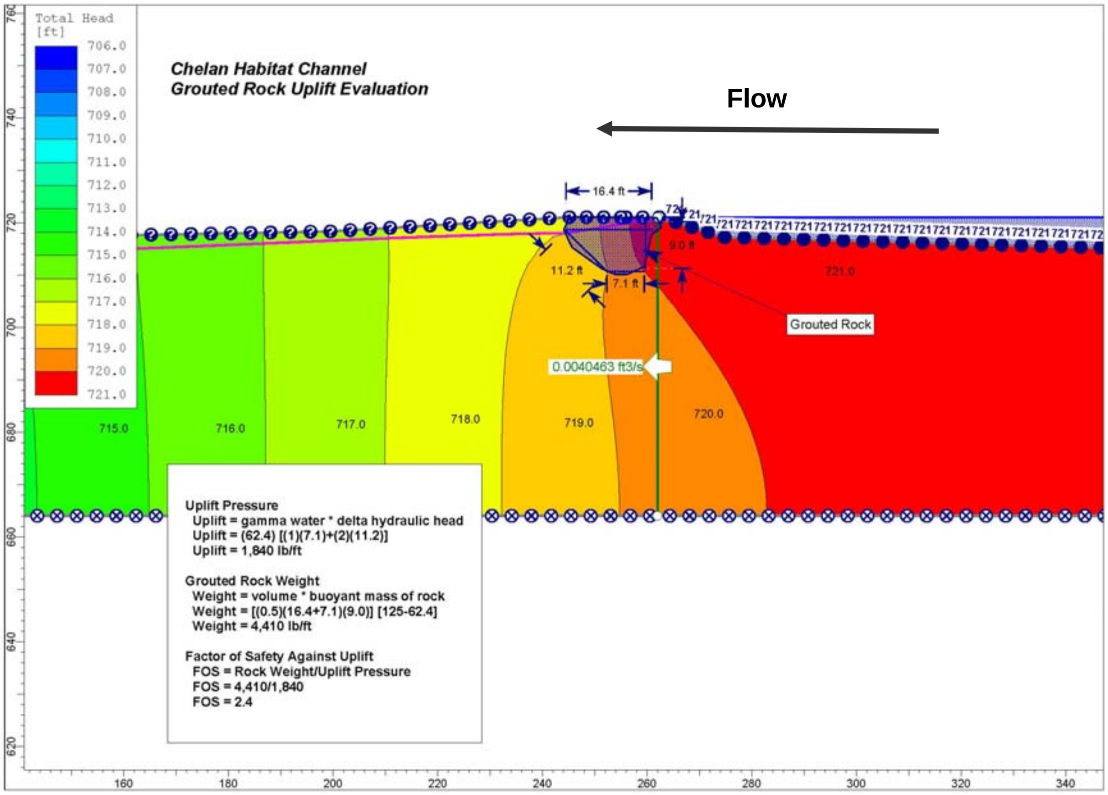


Figure 26
Uplift with Grouted Rock

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APPENDIX A

CHELAN_SPILL_HYDROLOGY.XLS

(Excel file with daily and peak flow values and analyses)

APPENDIX B

MONTHLY FLOW EXCEEDANCE VALUES

Monthly Flow Exceedance Values

Based on mean daily "Actual Spill" flows provided by the District for 1974 to 2003

Percent Exceedance (%)	Jan (cfs)	Feb (cfs)	Mar (cfs)	Apr (cfs)	May (cfs)	Jun (cfs)	Jul (cfs)	Aug (cfs)	Sept (cfs)	Oct (cfs)	Nov (cfs)	Dec (cfs)
0	0	2,000	33	2,400	6,754	12,763	9,896	6,821	1,200	3,750	14,633	10,700
2	0	1,364	0	900	3,500	8,118	6,117	2,544	200	0	0	0
4	0	100	0	0	2,799	6,992	5,000	1,545	25	0	0	0
6	0	0	0	0	2,400	6,076	4,482	1,100	0	0	0	0
8	0	0	0	0	1,954	5,642	3,999	799	0	0	0	0
10	0	0	0	0	1,402	4,902	3,642	400	0	0	0	0
12	0	0	0	0	686	4,026	3,455	240	0	0	0	0
14	0	0	0	0	0	3,751	3,097	200	0	0	0	0
16	0	0	0	0	0	3,303	2,879	141	0	0	0	0
18	0	0	0	0	0	3,034	2,584	100	0	0	0	0
20	0	0	0	0	0	2,805	2,309	46	0	0	0	0
22	0	0	0	0	0	2,482	2,094	0	0	0	0	0
24	0	0	0	0	0	2,149	2,000	0	0	0	0	0
25	0	0	0	0	0	2,035	1,998	0	0	0	0	0
26	0	0	0	0	0	2,000	1,863	0	0	0	0	0
28	0	0	0	0	0	1,789	1,683	0	0	0	0	0
30	0	0	0	0	0	1,566	1,526	0	0	0	0	0
32	0	0	0	0	0	1,303	1,400	0	0	0	0	0
34	0	0	0	0	0	1,100	1,250	0	0	0	0	0
36	0	0	0	0	0	1,000	1,100	0	0	0	0	0
38	0	0	0	0	0	900	1,071	0	0	0	0	0
40	0	0	0	0	0	653	1,000	0	0	0	0	0
42	0	0	0	0	0	400	898	0	0	0	0	0
44	0	0	0	0	0	378	800	0	0	0	0	0
46	0	0	0	0	0	300	786	0	0	0	0	0
48	0	0	0	0	0	200	683	0	0	0	0	0
50	0	0	0	0	0	200	544	0	0	0	0	0
52	0	0	0	0	0	30	400	0	0	0	0	0
54	0	0	0	0	0	0	400	0	0	0	0	0
56	0	0	0	0	0	0	333	0	0	0	0	0
58	0	0	0	0	0	0	210	0	0	0	0	0
60	0	0	0	0	0	0	200	0	0	0	0	0
62	0	0	0	0	0	0	200	0	0	0	0	0
64	0	0	0	0	0	0	124	0	0	0	0	0
66 to 100	0	0	0	0	0	0	0	0	0	0	0	0

APPENDIX C

REACH 1 PAINTED ROCK STUDY DATA SHEETS

Chelan River Reach 1 Spill Test - Erosion Form
Site: Bank 3

Description: raveling outwash. 200 feet of orange dots; start at bush on upstream end

After Flow (cfs)	Date	Surveyor	Photo #s	Description of Change (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		#2 & 3 dots washed away; #19 & 20 covered by dirt from hill
3,250	4/26/07	Gordon B		First 60 feet soil eroded, rocks moved. End 20-30 ft covered by dirt from hill above. Does not appear to be flow related
4,780	4/27/07	Gordon B		More significant erosion throughout entire length. Loose dirt eroded away, some block fall and some paint left behind on the rocks
6,710	5/1/07	Gordon B, Kathy D.	74-75	4-5 scattered rocks remain; rest are eroded (soil/bank erosion)
8,000	5/30/07	Gordon B		Definate erosion but most rocks are ~~th~~ where I Painted them. I painted rocks above erosion point also this time
10,000	6-6-07	G. Boon		over half the painted rocks are still in the area. Dirt from hill has been washed down River leaving the rock

Chelan River Reach 1 Spill Test - Erosion Form
Site: Bank 4

Description: raveling outwash. 200 feet of orange dots; start at boulder on upstream end

After Flow (cfs)	Date	Surveyor	Photo #s	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		Dots 14-19 (counting from upstream) are missing. Dots 7, 9 are sliging toward river. Dot 11 is 90% covered by dirt sliding form above. 21 dots counted total
4,780	4/27/07	Gordon B		First 50-60 feet – slight erosion. Paint marks still visible. Last 150 ft more significant erosion, dirt form bank eroded and river rocks left behind, no visible paint marks
6,710	5/1/07	Gordon B, Kathy D.	70-73	Rocks #1, 2 remain; rest gone. Bank erosion
8,000	5-30-07	G Boon		Definate erosion 15 of 25 Rocks still Visable.
10,000	6-6-07	G Boon		5 painted Rocks left. The dirt from the NW side has been washed away + Rocks are left.

Chelan River Reach 1 Spill Test - Erosion Form
Site: Bank 5

Description: raveling outwash LONG bend with orange dots; start at boulder on upstream end

(Photos below)

After Flow (cfs)	**Date**	**Surveyor**	**Photo #s**	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		Area downstream of "V" 60 feet of dots missing near end of rip rap
4,780	4/27/07	Gordon B		Same as above with more erosion of dirt and rock from uphill
6,710	5/1/07	Gordon B, Kathy D.	51-69	Soil areas – 1-2 rocks missing in dirt areas upstream of "V" 3-4 rocks missing in 2 places upstream of "V" Plus 100 feet of erosion downstream of "V" See red areas on photos on next page.
8,000	5-30-07	G Boon		up river of V 85% of painted rocks are still visiable ~~[illegible]~~. Down Stream of V 75% of painted rocks are visiable
10,000	6-6-07	G Boon		upstream from V there are 20 rocks painted + down Stream there are 14. Dirt from the hill side ~~has~~ has been washed away and rocks are left in its place Some erosion but bank is sluffing down to the river also

Bank 5 photos

Chelan River Reach 1 Spill Test - Erosion Form
Site: Bank 6

Description: high bank of raveling outwash orange dots; rip rap on downstream end

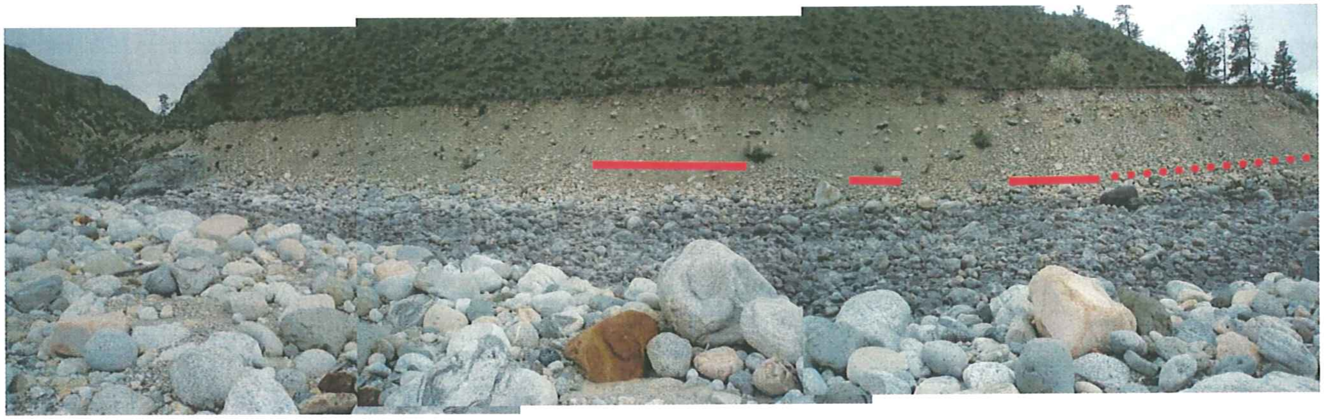
(more below)

After Flow (cfs)	Date	Surveyor	Photo #s	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		About 100 feet downstream from rip rap – block fall for 1 dot.
4,780	4/27/07	Gordon B		Same as above. Some block fall from above throughout length.
6,710	5/1/07	Gordon B, Kathy D.		Ravel; block fall occurred recently from top at location noted. Erosion as noted in photo above (6 rocks from downstream end of rip rap still there, then gone for 100-200 feet, then all present).
8,000	5-30-07	G Boon		The painted rocks are gone. There is visible erosion.
10,000	6-6-07	G Boon		The dirt from [illegible] has been washed away + rocks are visible now

Bank 6 additional photo (upstream end)

Chelan River Reach 1 Spill Test - Erosion Form
Site: Bank 7

Description: raveling outwash orange dots along terraces (high/low)



(more photos below)

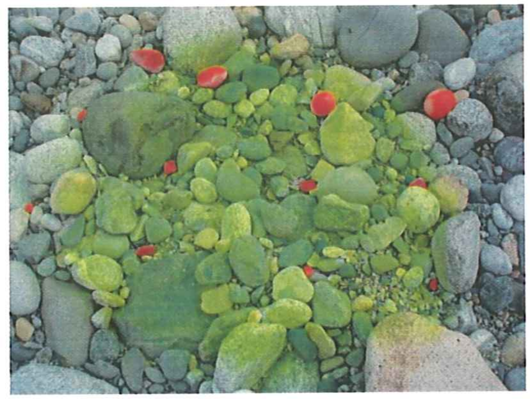
After Flow (cfs)	Date	Surveyor	Photo #s	Description of Change (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No substantial change. Possibly 1-2 rocks missing in the vicinity of where the bank changes form high to low.
4,780	4/27/07	Gordon B		Same as above
6,710	5/1/07	Gordon B, Kathy D.		Starting at downstream end, rocks # 1-13 still there; then many missing (from dirt areas) on high bank. Most still present on lower bank (see next page; solid lines indicate all eroded, dashed lines indicate some missing)
8,000	5-30-07	G Boon		I found 2 painted rocks here. Visible erosion Painted new rocks
10,000	6-6-07	G Boon		There are 14 painted Rocks left, The dirt has been washed down River leaving only the rock at high water cut.

Reach 1, Bank 7 continued:

(photos going upstream – site goes to upstream end of low bank)

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 1

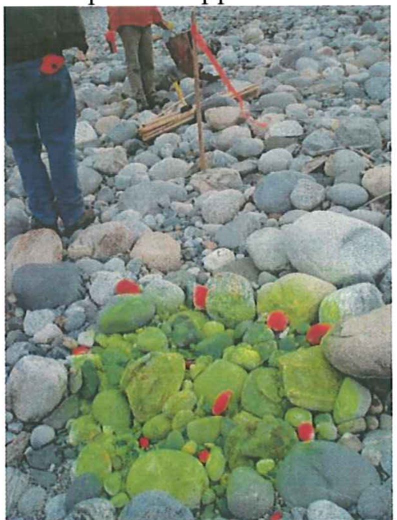
Description: Approx. Station 21+50

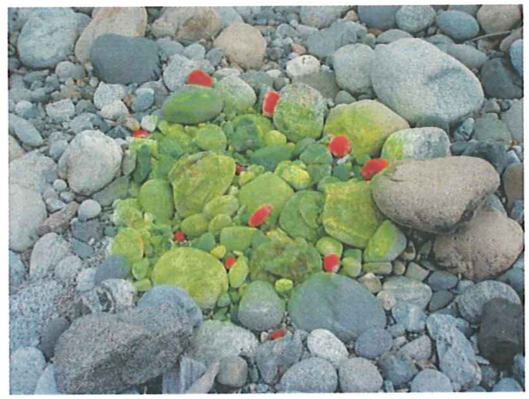


After Flow (cfs)	Date	Surveyor	Photo #s	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change. Was under water
3,250	4/26/07	Gordon B		No apparent change
4,780	4/27/07	Gordon B		Significant change. (Gordon has photo)
6,710	5/1/07	Gordon B, Kathy D.		All of orange rocks gone, most of yellow rocks gone (see photo below). Rocks over 12" still on site; marked rocks smaller than approx. 6" have moved 5-50 feet downstream. Peak water depth est. 5 feet.
8,000	5-30-07	G. Boon		Was unable to locate
10,000	6-6-07	G Boon		Washed away

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 2

Description: Approx. Station 19+00

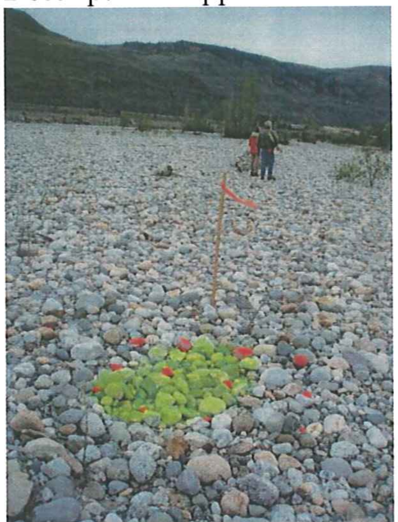




After Flow (cfs)	Date	Surveyor	Photo #s	Description of Change (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No change
4,780	4/27/07	Gordon B		Slight change (Gordon has photo)
6,710	5/1/07	Gordon B, Kathy D.		12" boulder moved on top of the one large orange rock that remains (rest gone). 8-10" yellow rocks stable. 4-6" yellow rocks found 5-40 feet downstream. Smaller rocks gone (see photo below)
8,000	5-30-07	G Boon		found yellow Rocks Scattered over a large area no orange rocks
10,000	6-6-07	G Boon		Looked but couldn't find any painted Rocks

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 3

Description: Approx. Station 15+50 – near standpipe



After Flow (cfs)	**Date**	**Surveyor**	**Photo #s**	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No change
4,780	4/27/07	Gordon B		No change
6,710	5/1/07	Gordon B, Kathy D.		One medium rock moved approx. 1 foot downstream. Est. high water depth 1 foot. Photo below.
8,000	5-30-07	G Boon		Stake still in place yellow square visible 3 little rocks, 4 medium in area 3 large rocks where they were placed
10,000	6-6-07	G Boon		Scattered yellow about 30' down stream 2 large rocks 2 med + 1 small in area

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 4

Description: Lines up with downstream end of powerhouse

After Flow (cfs)	Date	Surveyor	Photo #s	Description of Change (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No change
4,780	4/27/07	Gordon B		No change
6,710	5/1/07	Gordon B, Kathy D.		Small (0.5-1") one moved 1 ft Med (1-2") 2 moved 2-5 ft Large (3-4") all stable Many yellow rocks up to 1" moved downstream. High water depth est. 0.5-1 ft. See photo.
8,000	5-30-07	G Boon		Stake in place, yellow area spread out 4 large rocks in original location 1 small + 2 medium outside yellow area
10,000	6-6-07	G, Boon		Stake in place yellow scattered over large area 2 large close to original area 1 med 20' down stream 1 med 30' down stream

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 5

Description: Just downstream of red/white fencepost line

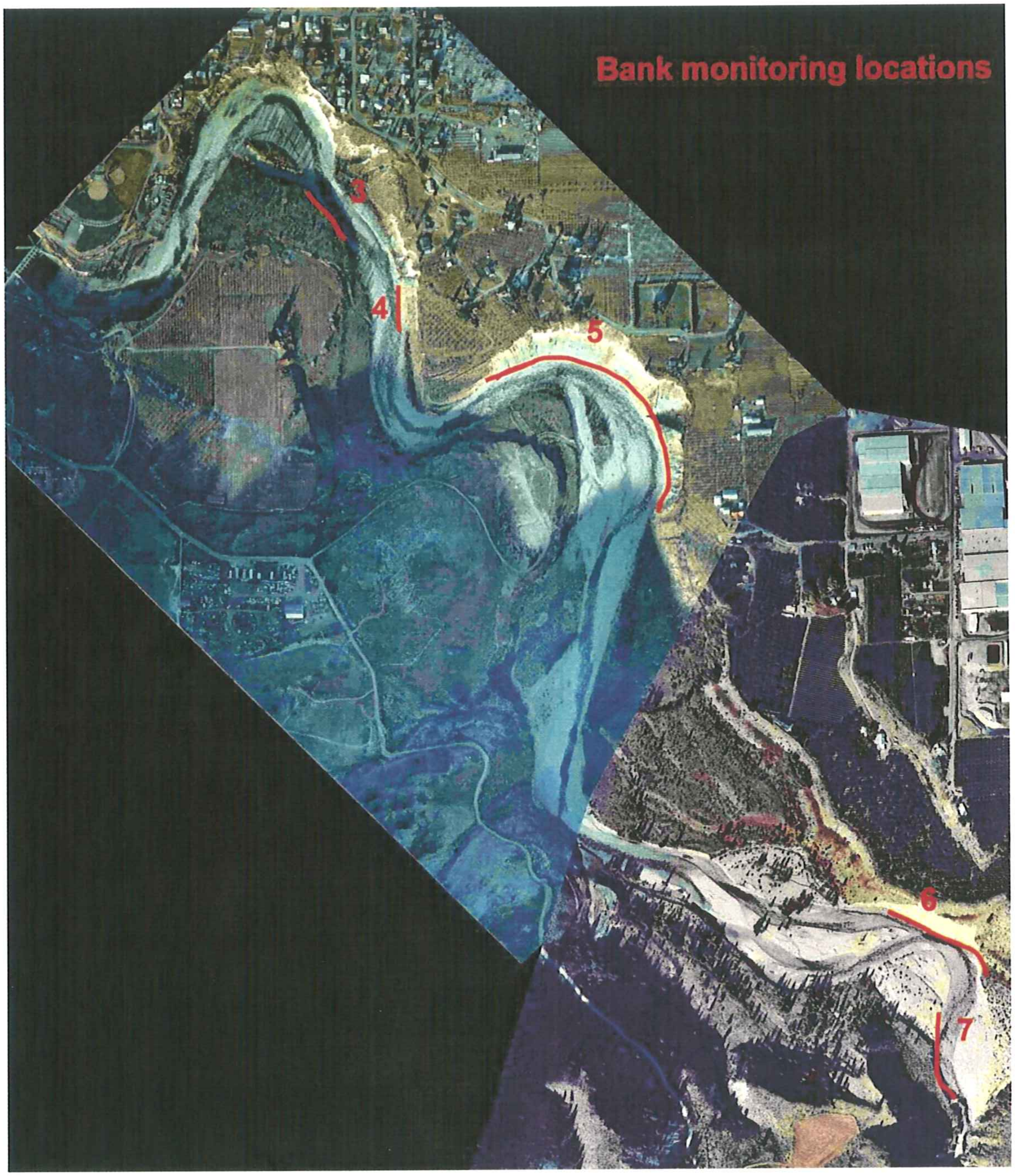
After Flow (cfs)	Date	Surveyor	Photo #s	Description of Change (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No change
4,780	4/27/07	Gordon B		No change
6,710	5/1/07	Gordon B, Kathy D.		2 small (0.5-1") rocks missing. One medium, one large moved. 0.5"-1" yellow rocks moved 15-25 feet. High water depth est. 1 ft. See photo below.
8,000	5-30-07	G Boon		I couldn't locate
10,000	6-6-07	G Boon		Found 5 yellow scattered over large area 1 large orange stone

Chelan River Reach 4 Spill Test - Erosion Form
Site: Gravel Site 6

Description: Approx. Station 4+00

After Flow (cfs)	Date	Surveyor	Photo #s	**Description of Change** (#, position of missing dots; type of erosion – ravel or block fall?)
1,850	4/25/07	Gordon B		No change
3,250	4/26/07	Gordon B		No change
4,780	4/27/07	Gordon B		No change
6,710	5/1/07	Gordon B, Kathy D.		3 small (0.5-1") rocks moved 1-3 ft 2 med (1-2") rocks moved 0.5-8 ft 1 large (3-4") moved 1 ft Yellow rocks - <1" moved 15 ft Est. high water depth 0.5-1 ft See photo below
8,000	5-30-07	G Boon		Stake in place. yellow area scattered out 4 large rocks in area 1 little rock in area 1 med about 30' down Stream
10,000	6-6-07	G Boon		yellow scattered out about 60' 3 large Stones about 20' apart going down Stream

Reach 1 Bank Monitoring Locations



APPENDIX D

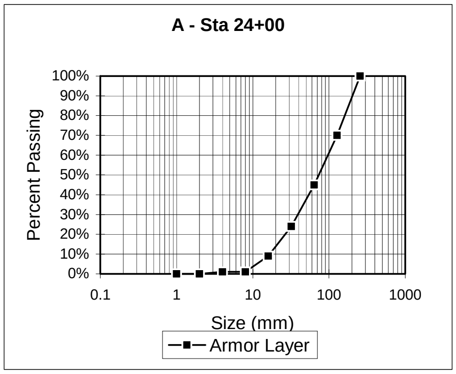
REACH 4 GRAIN SIZE DATA SHEETS

SURFACE SEDIMENT SIZE DATA FROM PEBBLE COUNTS

Station **A - Sta 24+00**

D65= 115.2 mm
D50= 76.8 mm

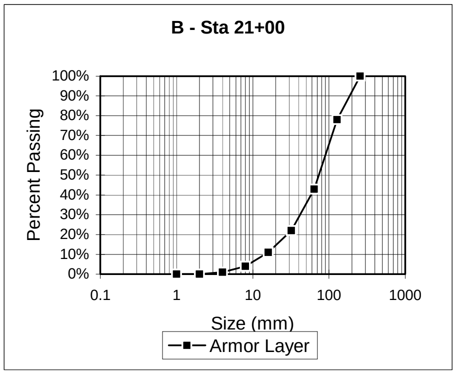
Armor Layer Size (mm)	**Armor Layer Size (in)**	**Percent**	**Cum %**	**Avg size**		**No.**
1	**0.04**	0%	0%	0.00		0
2	**0.08**	0%	0%	0.00		0
4	**0.16**	1%	1%	0.06		1
8	**0.31**	0%	1%	0.00		0
16	**0.63**	8%	9%	1.92		8
32	**1.26**	15%	24%	7.20		15
64	**2.52**	21%	45%	20.16		21
128	**5.04**	25%	70%	48.00		25
256	**10.08**	30%	100%	38.40		30
			Dg	115.74	mm	100
				0.3797	ft	



Station **B - Sta 21+00**

D65= 104.2 mm
D50= 76.8 mm

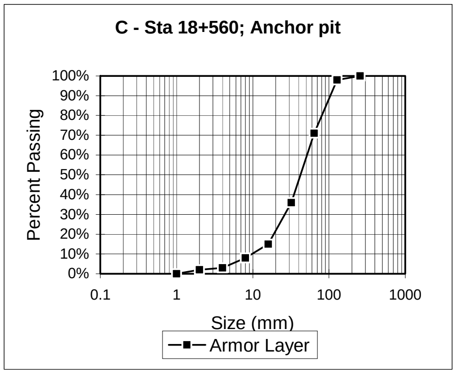
Armor Layer Size (mm)	**Armor Layer Size (in)**	**Percent**	**Cum %**	**Avg size**		**No.**
1	**0.04**	0%	0%	0.00		0
2	**0.08**	0%	0%	0.00		0
4	**0.16**	1%	1%	0.06		1
8	**0.31**	3%	4%	0.36		3
16	**0.63**	7%	11%	1.68		7
32	**1.26**	11%	22%	5.28		11
64	**2.52**	21%	43%	20.16		21
128	**5.04**	35%	78%	67.20		35
256	**10.08**	22%	100%	28.16		22
			Dg	122.90	mm	100
				0.4032	ft	



Station **C - Sta 18+560; Anchor pit**

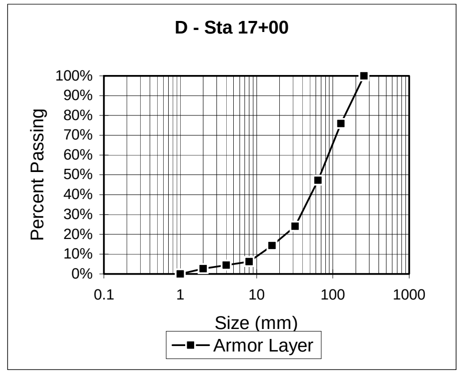
D65= 58.5 mm
D50= 44.8 mm

Armor Layer Size (mm)	**Armor Layer Size (in)**	**Percent**	**Cum %**	**Avg size**		**No.**
1	**0.04**	0%	0%	0.00		0
2	**0.08**	2%	2%	0.06		2
4	**0.16**	1%	3%	0.06		1
8	**0.31**	5%	8%	0.60		5
16	**0.63**	7%	15%	1.68		7
32	**1.26**	21%	36%	10.08		21
64	**2.52**	35%	71%	33.60		35
128	**5.04**	27%	98%	51.84		27
256	**10.08**	2%	100%	2.56		2
			Dg	100.48	mm	100
				0.3297	ft	



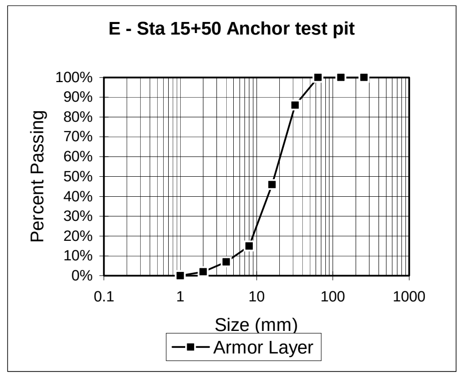
Station **D - Sta 17+00**

Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	103.6	mm	
			D50=	70.0	mm	
1	**0.04**	0%	0%	0.00		0
2	**0.08**	3%	3%	0.08		3
4	**0.16**	2%	4%	0.11		2
8	**0.31**	2%	6%	0.21		2
16	**0.63**	8%	14%	1.93		9
32	**1.26**	10%	24%	4.71		11
64	**2.52**	23%	47%	22.29		26
128	**5.04**	29%	76%	54.86		32
256	**10.08**	24%	100%	30.86		27
			Dg	115.04	mm	112
				0.3774	ft	



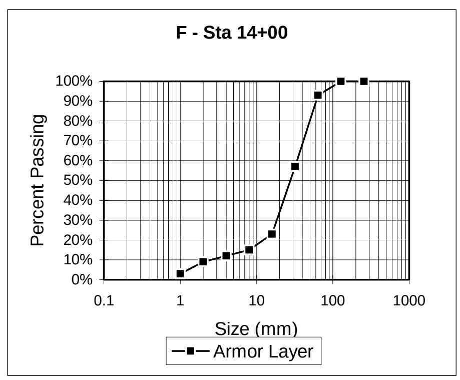
Station **E - Sta 15+50 Anchor test pit**

Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	23.6	mm	
			D50=	17.6	mm	
1	**0.04**	0%	0%	0.00		0
2	**0.08**	2%	2%	0.06		2
4	**0.16**	5%	7%	0.30		5
8	**0.31**	8%	15%	0.96		8
16	**0.63**	31%	46%	7.44		31
32	**1.26**	40%	86%	19.20		40
64	**2.52**	14%	100%	13.44		14
128	**5.04**	0%	100%	0.00		0
256	**10.08**	0%	100%	0.00		0
			Dg	41.40	mm	100
				0.1358	ft	



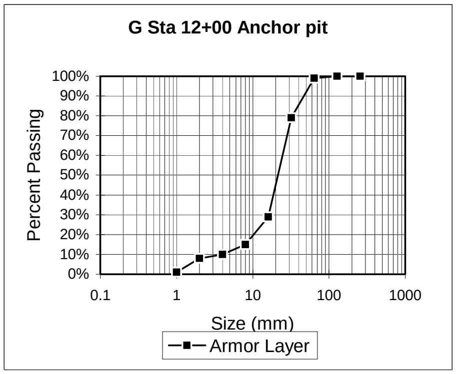
Station **F - Sta 14+00**

Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	39.1	mm	
			D50=	28.7	mm	
1	**0.04**	3%	3%	0.03		3
2	**0.08**	6%	9%	0.18		6
4	**0.16**	3%	12%	0.18		3
8	**0.31**	3%	15%	0.36		3
16	**0.63**	8%	23%	1.92		8
32	**1.26**	34%	57%	16.32		34
64	**2.52**	36%	93%	34.56		36
128	**5.04**	7%	100%	13.44		7
256	**10.08**	0%	100%	0.00		0
			Dg	66.99	mm	100
				0.2198	ft	



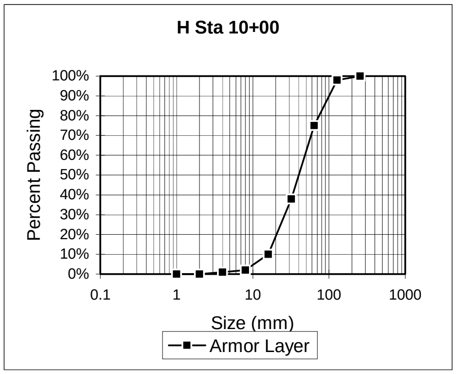
Station **G Sta 12+00 Anchor pit**

Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	27.5	mm	
			D50=	22.7	mm	
1	**0.04**	1%	1%	0.01		1
2	**0.08**	7%	8%	0.21		7
4	**0.16**	2%	10%	0.12		2
8	**0.31**	5%	15%	0.60		5
16	**0.63**	14%	29%	3.36		14
32	**1.26**	50%	79%	24.00		50
64	**2.52**	20%	99%	19.20		20
128	**5.04**	1%	100%	1.92		1
256	**10.08**	0%	100%	0.00		0
			Dg	49.42	mm	100
				0.1621	ft	



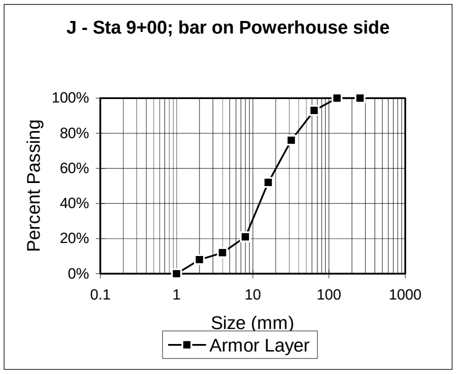
Station **H Sta 10+00**

Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	55.4	mm	
			D50=	42.4	mm	
1	**0.04**	0%	0%	0.00		0
2	**0.08**	0%	0%	0.00		0
4	**0.16**	1%	1%	0.06		1
8	**0.31**	1%	2%	0.12		1
16	**0.63**	8%	10%	1.92		8
32	**1.26**	28%	38%	13.44		28
64	**2.52**	37%	75%	35.52		37
128	**5.04**	23%	98%	44.16		23
256	**10.08**	2%	100%	2.56		2
			Dg	97.78	mm	100
				0.3208	ft	

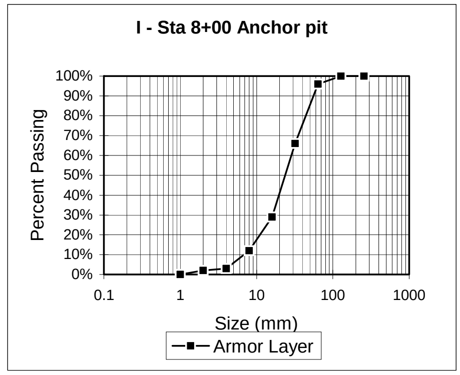


Station **J - Sta 9+00; bar on Powerhouse side**

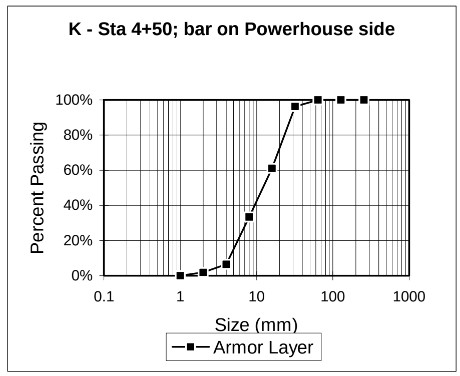
Armor Layer Size (mm)	Armor Layer Size (in)	Percent	Cum %	Avg size		No.
			D65=	24.7	mm	
			D50=	15.5	mm	
1	**0.04**	0%	0%	0.00		0
2	**0.08**	8%	8%	0.24		8
4	**0.16**	4%	12%	0.24		4
8	**0.31**	9%	21%	1.08		9
16	**0.63**	31%	52%	7.44		31
32	**1.26**	24%	76%	11.52		24
64	**2.52**	17%	93%	16.32		17
128	**5.04**	7%	100%	13.44		7
256	**10.08**	0%	100%	0.00		0
			Dg	50.28	mm	100
				0.1650	ft	



Station		I - Sta 8+00 Anchor pit				
			D65=	31.6	mm	
Armor Layer	Armor Layer		D50=	25.1	mm	
Size (mm)	Size (in)	Percent	Cum %	Avg size		No.
1	**0.04**	0%	0%	0.00		0
2	**0.08**	2%	2%	0.06		2
4	**0.16**	1%	3%	0.06		1
8	**0.31**	9%	12%	1.08		9
16	**0.63**	17%	29%	4.08		17
32	**1.26**	37%	66%	17.76		37
64	**2.52**	30%	96%	28.80		30
128	**5.04**	4%	100%	7.68		4
256	**10.08**	0%	100%	0.00		0
			Dg	59.52	mm	100
				0.1953	ft	



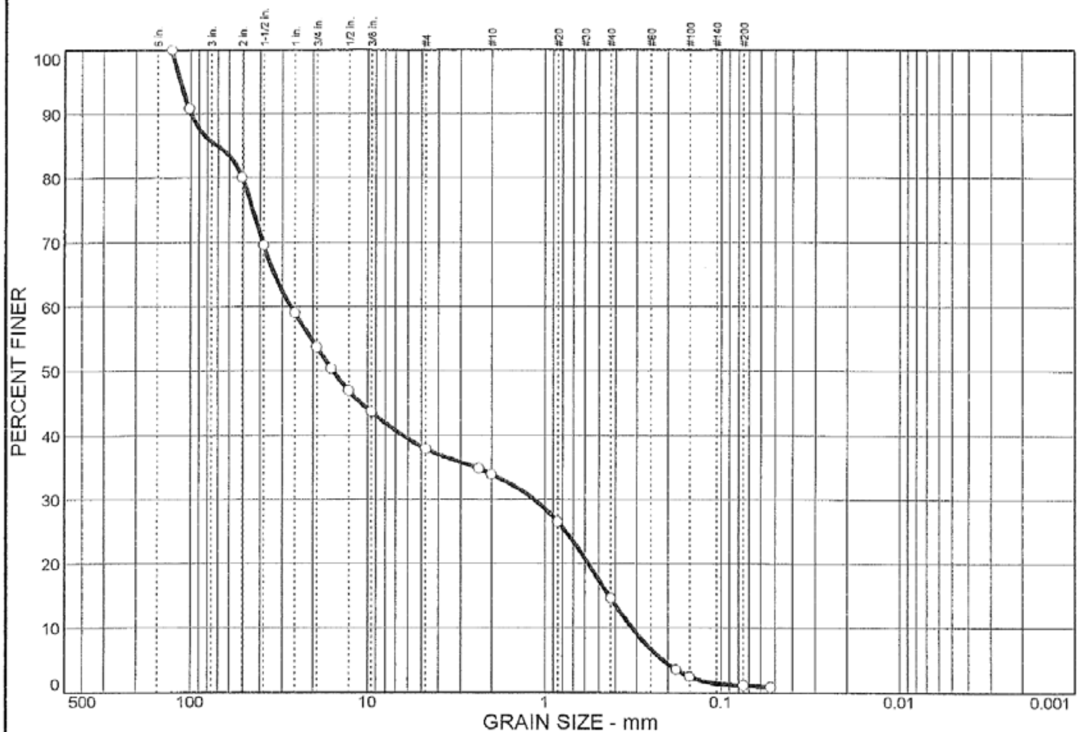
Station		K - Sta 4+50; bar on Powerhouse side				
			D65=	17.8	mm	
Armor Layer	Armor Layer		D50=	12.8	mm	
Size (mm)	Size (in)	Percent	Cum %	Avg size		No.
1	**0.04**	0%	0%	0.00		0
2	**0.08**	2%	2%	0.06		2
4	**0.16**	5%	6%	0.28		5
8	**0.31**	27%	33%	3.22		29
16	**0.63**	28%	61%	6.67		30
32	**1.26**	35%	96%	16.89		38
64	**2.52**	4%	100%	3.56		4
128	**5.04**	0%	100%	0.00		0
256	**10.08**	0%	100%	0.00		0
			Dg	30.67	mm	108
				0.1006	ft	



SUB-SURFACE SEDIMENT SIZE DATA FROM DRY SIEVE ANALYSIS

0702- 07

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
14.3	47.8	36.8	1.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	90.8		
2 in.	80.1		
1.5 in.	69.5		
1 in.	59.0		
.75 in.	53.7		
.625 in.	50.4		
.5 in.	46.9		
.375 in.	43.7		
#4	37.9		
#8	34.8		
#10	33.9		
#20	26.5		
#40	14.6		
#80	3.6		
#100	2.5		
#200	1.1		
#270	0.9		

* (no specification provided)

Soil Description

Poorly graded gravel with sand
4+00 60' Left
Dated 2-02-2007

Atterberg Limits

PL= LL= PI= NP

Coefficients

D_{85}= 70.2 D_{60}= 26.7 D_{50}= 15.5
D_{30}= 1.15 D_{15}= 0.435 D_{10}= 0.319
C_u= 83.74 C_c= 0.16

Classification

USCS= GP AASHTO= A-1-a

Remarks

Permeability: 70.05 inches per hour
Wet Density(water settled): 120.64 lbs.cu.ft
Moisture Content: 15.3%

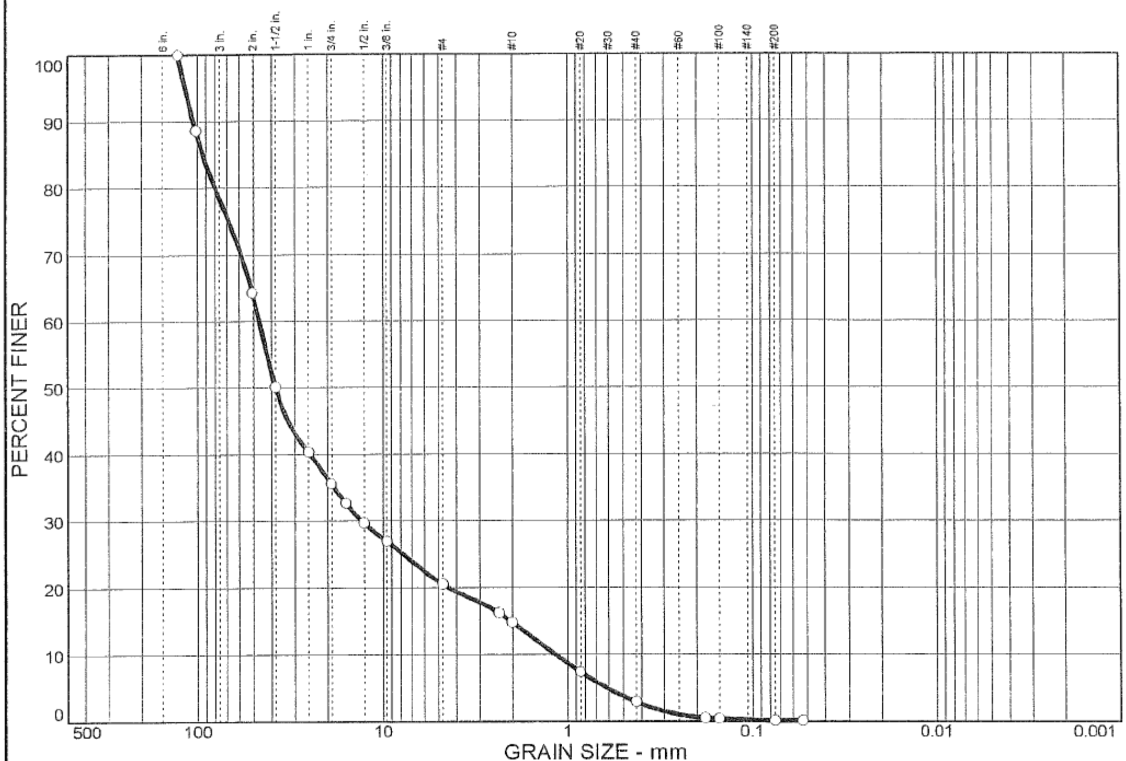
Sample No.: 6784 **Date:** 2-12-2007
Location: **Elev./Depth:**

CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E. 126TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-6800

Client: Anchor Envirmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:**

AE, CH, 2/22

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
21.6	57.9	20.4	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	88.6		
2 in.	64.3		
1.5 in.	50.1		
1 in.	40.3		
.75 in.	35.5		
.625 in.	32.6		
.5 in.	29.6		
.375 in.	26.9		
#4	20.5		
#8	16.2		
#10	14.8		
#20	7.4		
#40	2.9		
#80	0.5		
#100	0.4		
#200	0.1		
#270	0.1		

* (no specification provided)

Soil Description

Poorly graded gravel with sand
8+00 60' Right
Dated 2-02-2007

Atterberg Limits

PL= LL= PI= NP

Coefficients

D_{85}= 93.1 D_{60}= 46.6 D_{50}= 38.0
D_{30}= 13.1 D_{15}= 2.05 D_{10}= 1.16
C_u= 40.04 C_c= 3.19

Classification

USCS= GP AASHTO= A-1-a

Remarks

F.M.=4.50

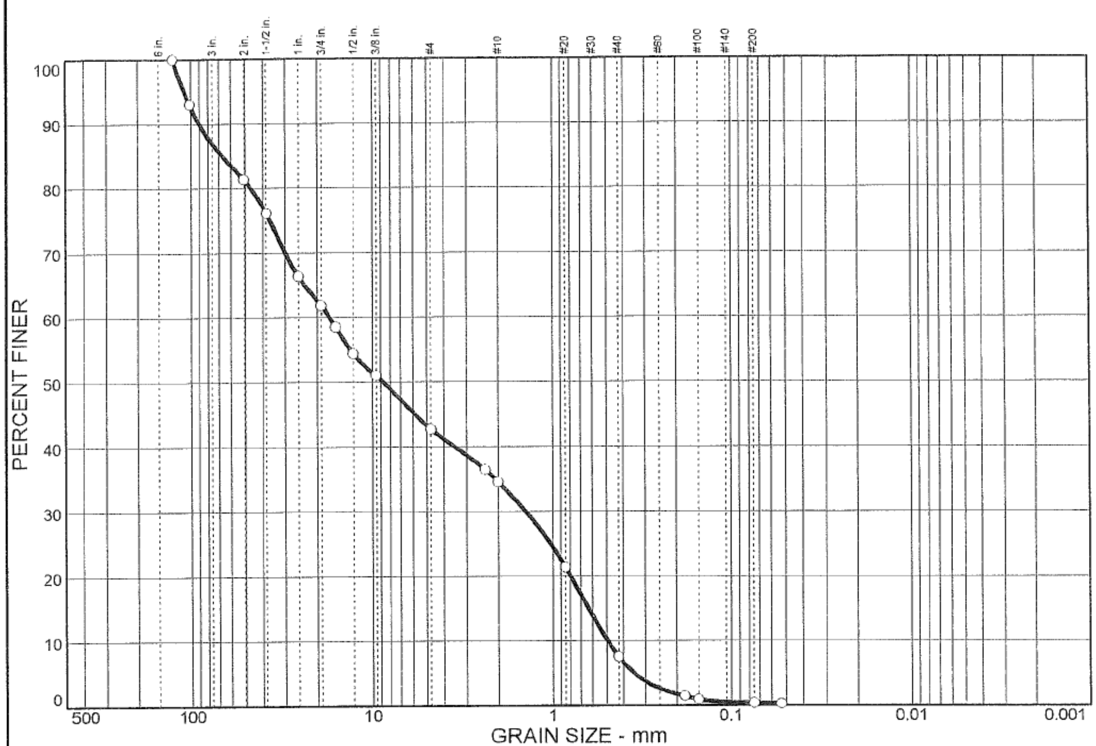
Sample No.: 6785 **Date:** 2-12-2007
Location: **Elev./Depth:**

CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E. 126TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-9800

Client: Anchor Envirnmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:**

AE, CH 2/20

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
13.0	44.3	42.3	0.4	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	93.0		
2 in.	81.3		
1.5 in.	76.1		
1 in.	66.3		
.75 in.	61.8		
.625 in.	58.5		
.5 in.	54.4		
.375 in.	51.0		
#4	42.7		
#8	36.4		
#10	34.5		
#20	21.4		
#40	7.6		
#80	1.5		
#100	1.0		
#200	0.4		
#270	0.3		

* (no specification provided)

Soil Description

Poorly graded gravel with sand
9+00 60' Left
Dated 2-12-2007

Atterberg Limits

PL= LL= PI= NP

Coefficients

D_{85}= 66.8 D_{60}= 17.2 D_{50}= 8.71
D_{30}= 1.42 D_{15}= 0.627 D_{10}= 0.490
C_u= 35.06 C_c= 0.24

Classification

USCS= GP AASHTO= A-1-a

Remarks

F.M.=3.31

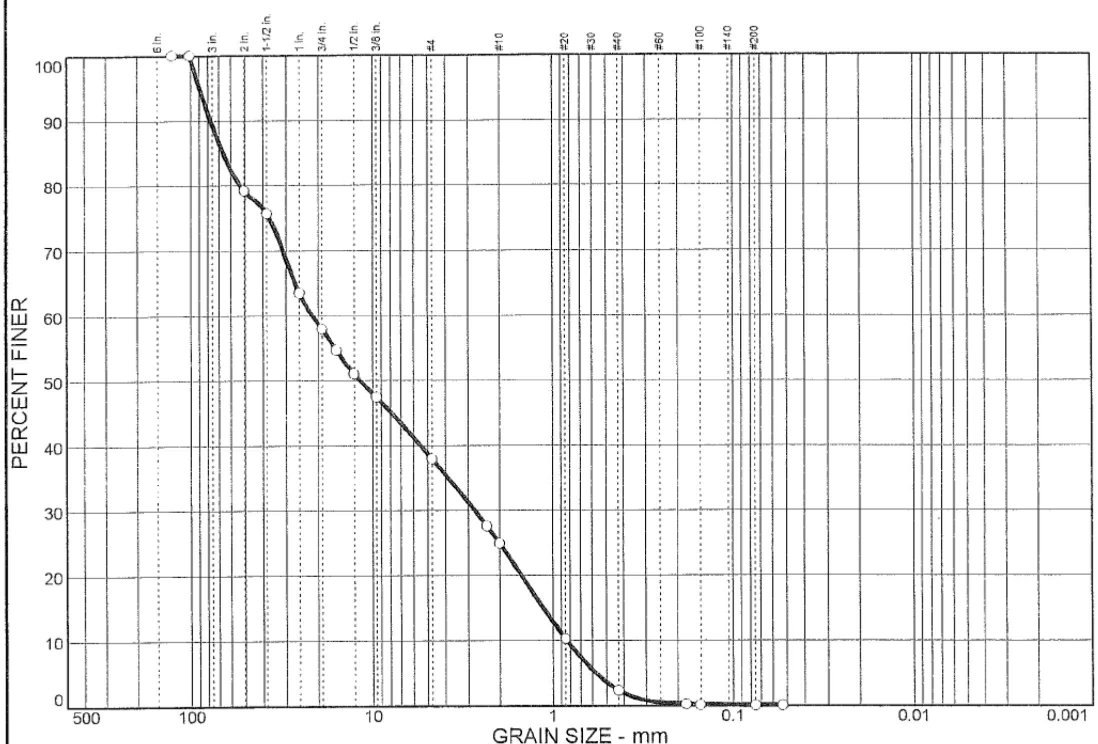
Sample No.: 6786 **Date:** 2-12-2007
Location: **Elev./Depth:**

CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E 126TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-5800

Client: Anchor Envirmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:**

AE, CH 2/21

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
10.6	51.4	37.9	0.1	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	100.0		
2 in.	79.2		
1.5 in.	75.7		
1 in.	63.5		
.75 in.	58.0		
.625 in.	54.7		
.5 in.	51.1		
.375 in.	47.5		
#4	38.0		
#8	27.6		
#10	24.9		
#20	10.3		
#40	2.4		
#80	0.3		
#100	0.2		
#200	0.1		
#270	0.1		

* (no specification provided)

Soil Description

Poorly graded gravel with sand

12+00 60' Left
Dated 2-02-2007

Atterberg Limits

PL= LL= PI= NP

Coefficients

D_{85}= 66.3 D_{60}= 21.5 D_{50}= 11.7
D_{30}= 2.75 D_{15}= 1.13 D_{10}= 0.833
C_u= 25.77 C_c= 0.42

Classification

USCS= GP AASHTO= A-1-a

Remarks

F.M.=3.53

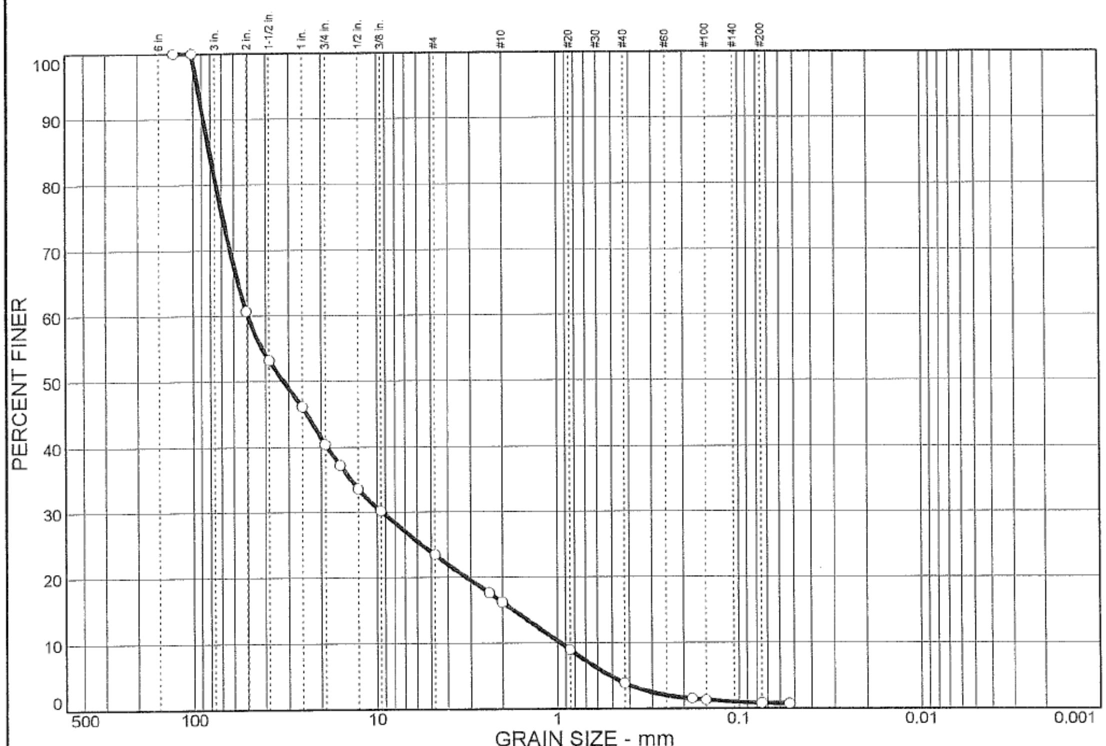
Sample No.: 6787 **Date:** 2-12-2007
Location: **Elev./Depth:**

CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E 125TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-9800

Client: Anchor Envirmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:** [signature]

AE, CH 7/20

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
18.8	57.8	22.6	0.8	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	100.0		
2 in.	60.7		
1.5 in.	53.2		
1 in.	46.1		
.75 in.	40.4		
.625 in.	37.2		
.5 in.	33.6		
.375 in.	30.2		
#4	23.4		
#8	17.6		
#10	16.2		
#20	9.0		
#40	3.9		
#80	1.5		
#100	1.3		
#200	0.8		
#270	0.7		

* (no specification provided)

Soil Description

Well-graded gravel with sand
15+50 60' Right
Dated 2-02-2007

Atterberg Limits

PL= LL= PI=

Coefficients

D_{85}= 80.9 D_{60}= 49.8 D_{50}= 31.8
D_{30}= 9.34 D_{15}= 1.74 D_{10}= 0.958
C_u= 51.98 C_c= 1.83

Classification

USCS= GW AASHTO=

Remarks

F.M.=4.34

Sample No.: 6788 **Date:** 2-12-2007
Location: **Elev./Depth:**

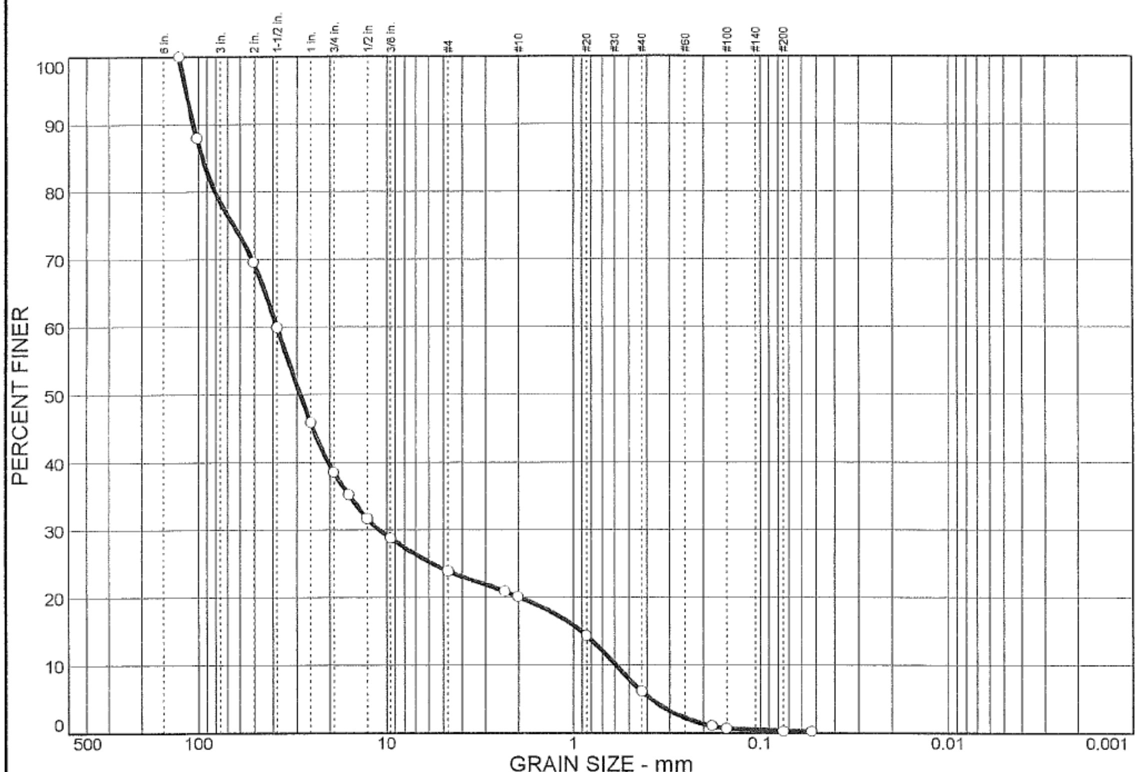
CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E. 125TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-9800

Client: Anchor Envirmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:** [signature]

AE, CH 2/20

0702-01

Particle Size Distribution Report



% COBBLES	% GRAVEL	% SAND	% SILT	% CLAY
21.6	54.5	23.6	0.3	

SIEVE SIZE	PERCENT FINER	SPEC.* PERCENT	PASS? (X=NO)
5 in.	100.0		
4 in.	87.9		
2 in.	69.5		
1.5 in.	59.9		
1 in.	45.9		
.75 in.	38.5		
.625 in.	35.2		
.5 in.	31.7		
.375 in.	28.8		
#4	23.9		
#8	20.9		
#10	20.1		
#20	14.4		
#40	6.2		
#80	1.1		
#100	0.7		
#200	0.3		
#270	0.3		

* (no specification provided)

Soil Description

15+50 60' Left
Dated 2-02-2007

Atterberg Limits

PL= LL= PI= NP

Coefficients

D_{85}= 94.8 D_{60}= 38.2 D_{50}= 28.8
D_{30}= 10.9 D_{15}= 0.903 D_{10}= 0.587
C_u= 65.12 C_c= 5.32

Classification

USCS= AASHTO=

Remarks

Permeability: 423.3 inches per hour.
Wet Density (water settled) ·125.08 lbs.cu.ft.
Moisture Content:12.3%

Sample No.: 6789 **Date:** 2-12-2007
Location: **Elev./Depth:**

CASCADE TESTING LABORATORY, INC.
TESTING & INSPECTION / ENGINEERS
12919 N.E 125TH PLACE
KIRKLAND, WASHINGTON 98034 (206) 823-5800

Client: Anchor Envirmental
Project: Chelan River Project
Project No: 0702-07
Technician: Nick Averill **Inspector:** [signature]

AE, CH 2/22

APPENDIX E

HAMMOND COLLIER WADE LIVINGSTONE GRAIN SIZE ANALYSIS AT DOWNSTREAM END OF REACH 4

104 EAST 9TH STREET
WENATCHEE, WA 98801
www.hcwl.com

HAMMOND COLLIER
WADE LIVINGSTONE

TEL: 509.662.1762
FAX: 509.663.8534

MEMORANDUM

TO: Vern Chamberlain, Chelan County PUD #1

FROM: Keith Anderson, Engineering Geologist

DATE: September 17, 2007

SUBJECT: Chelan Falls Reach 4

Vern:

As requested, we are submitting a separate memo to you for the estimated volume of material present in the gravel bar we evaluated in the Reach 4 area at Chelan Falls.

We calculated the total cubic yards of material using the area encompassed in the red polyline shown in Figure 1 of our report and attached here for reference. The area in the polyline is approximately 160,000 sq. ft. (159,644 actual per AutoCAD calc). Using a depth of 4 feet as a guideline for excavation depth, there is approximately 23,653 cubic yards of sand and gravel in the gravel bar.

Taking the average percentage of grain size distribution shown in Table 1 of our report, we calculated the following cubic yards of material per category as shown.

Cobbles = 3,950 CY
Gravel = 13,435 CY
Sand = 6,150 CY
Silt = 1,42 CY
= 23,676 CY (Variable volume due to rounding)

This volume is an estimate to be used in discussions with the contractor. It is the contractors responsibility to confirm the type and volume of material present in this gravel bar. We would be willing to assist in further defining the volume and type of material at your or the contractor's request.

Best regards,

Keith A. Anderson
Engineering Geologist

0 50 100 200

SCALE IN FEET

APPROXIMATE

NOTES:

1. THE LOCATIONS OF ALL FEATURES SHOWN ARE APPROXIMATE.
2. THIS DRAWING IS FOR INFORMATION PURPOSES IT IS INTENDED TO ASSIST IN SHOWING FEATURES DISCUSSED IN AN ATTACHED DOCUMENT. HAMMOND COLLIER CAN NOT GUARANTEE THE ACCURACY AND CONTENT OF ELECTRONIC FILES. THE MASTER FILE IS STORED BY HAMMOND COLLIER AND WILL SERVE AS THE OFFICIAL RECORD OF THIS COMMUNICATION.

LEGEND

TP-1 TEST PIT NUMBER AND APPROXIMATE LOCATION

GRAIN SIZE ANALYSIS AREA

DESIGNED BY	KA
DRAWN BY	GM
DATE	9-13-2007
SCALE	AS SHOWN
JOB NO.	07-90-041.01

HAMMOND COLLIER
WADE LIVINGSTONE
SEATTLE (206) 632-2664 WENATCHEE (509) 662-1762
LAKEWOOD (206) 732-2009 OMAK (509) 826-5861

CHELAN COUNTY PUD
CHELAN FALLS REACH 4
SITE PLAN

FIGURE 2

104 EAST 9TH STREET
WENATCHEE, WA 98801
www.hcwl.com

HAMMOND COLLIER
WADE LIVINGSTONE

TEL: 509.662.1762
FAX: 509.663.8534

COPY

September 17, 2007

Vern Chamberlain
Chelan County PUD #1
P.O. Box 1231
Wenatchee, WA 98807-1231

RE: Chelan Falls Reach 4
PSA No. 05-056

Dear Vern:

As requested, Hammond Collier has completed a grain size analysis evaluation on the gravel bar area in the Chelan Falls Reach 4 area. The purpose of the grain size analysis is to evaluate the volume and type of native soil material available for the proposed fish habitat improvements planned for construction in the Reach 4 area.

Site Exploration

On August 22, 2007, we directed Rayfield Brothers Excavation to excavate the five test pits in areas around the gravel bar using their trackhoe excavator. We excavated five test pits at the approximate locations shown on the attached Figure 2 –Site Plan. The test pits were dug to depths of or just past groundwater level which varied from 1 foot to 5 feet depth depending upon the location on the gravel bar. The groundwater elevation and depth of the test pits were also affected by the river water level fluctuation which was constantly rising during our site visit. The soil encountered was logged per the USCS classification and two soil samples were taken out of the five test pits for later grain size analysis in our material testing laboratory in Wenatchee. The soil test pit logs and the grain size analysis reports are attached to this draft report for your review.

Grain Size Results

The larger portion of the native soil material present on the gravel bar is best represented by the logs of test pits TP-1, TP-3 and TP-5. The gravel bar is comprised primarily of poorly to well graded gravel with cobbles and trace sand. We estimate that approximately 50 to 70 percent of the material is gravel ranging in grain size from 3 inches to 3/16 inches in diameter and that 15 - 20 percent of the material consists of well to sub-rounded cobbles on the gravel bar that are less than 1.5 feet and more than 4 inches in diameter. The finer grained native soil as defined as the percentage of material passing the #4 sieve (0.187 inches) more prevalent in test pits TP-2 and TP-4, represent approximately 20 - 25 percent by volume of material present in the gravel bar. The test pit TP-2 sample was skewed to obtain the finer grain material more representative of the sand bar areas and therefore is only representative of the smaller sand bar area east of the railroad tracks and of the fine grain sand area of the point bar in the test pit TP-4 area.

We also reviewed the grain size analysis data presented in the Anchor Environmental 60 percent design report "Habitat Restoration of the Chelan River Reach 4 and Tailrace" dated July 2007. The six particle size distribution reports in their document show that the river bar area on either side of the proposed reach improvement site is also comprised of poorly to well sorted gravel with sand. Tables 1 below shows the simplified results of the Hammond Collier sieve analysis and the Anchor sieve analysis.

TABLE 1

Sample ID	%Cobbles 3" or greater	% Gravel 3" > x < 0.187" 3" >x< #4	% Sand 0.187">x<0.0029" #4 >x< #200	% Silt & Clay 0.0029">x #200 > X
HC TP-1	34	52.2	13.4	0.4
HC TP-2	0	87.9	10.8	1.3
Anchor #6784	14.3	47.8	36.8	1.1
Anchor #6785	21.6	57.9	20.4	0.1
Anchor #6786	13.0	44.3	42.3	0.4
Anchor #6787	10.6	51.4	37.9	0.1
Anchor #6788	18.8	57.8	22.6	0.8
Anchor #6789	21.6	54.8	23.6	0.3
AVERAGE %	**16.7**	**56.8**	**26.0**	**0.6**

Conclusion

Visually, the gravel bar appears to have a higher percentage of cobbles than the grain size analysis data reveals. However, the coarse surface layer on the gravel bar is a normal deposition process known as armoring. "Extensive study of rivers worldwide in the last several decades has shown that most gravel-bed channels have larger cobbles or pebbles at the surface of the bed than in the layer immediately below the surface".[1] The armoring factor was evident in our test pits. After we excavated below the first one or two feet in depth from the surface, the larger cobbles were less abundant than seen on the gravel bar surface.

It is our opinion that by using the combined grain size analyses conducted by Hammond Collier and Anchor Environmental on the gravel bars in the Reach 4 area that the average shown in Table 1 is representative of the size and percentage of material present in this reach.

Please contact the undersigned if we can be of further assistance.

Sincerely,

HAMMOND COLLIER
WADE LIVINGSTONE

State of Washington
Engineering Geologist
1261
Licensed Geologist
Keith A. Anderson

Keith Anderson
Engineering Geologist
(509) 664-4828
kanderson@hcwl.com

Enclosure: Figures 1 and 2
USCS Soil Classification
Test Pit Logs
Grain Size Analysis

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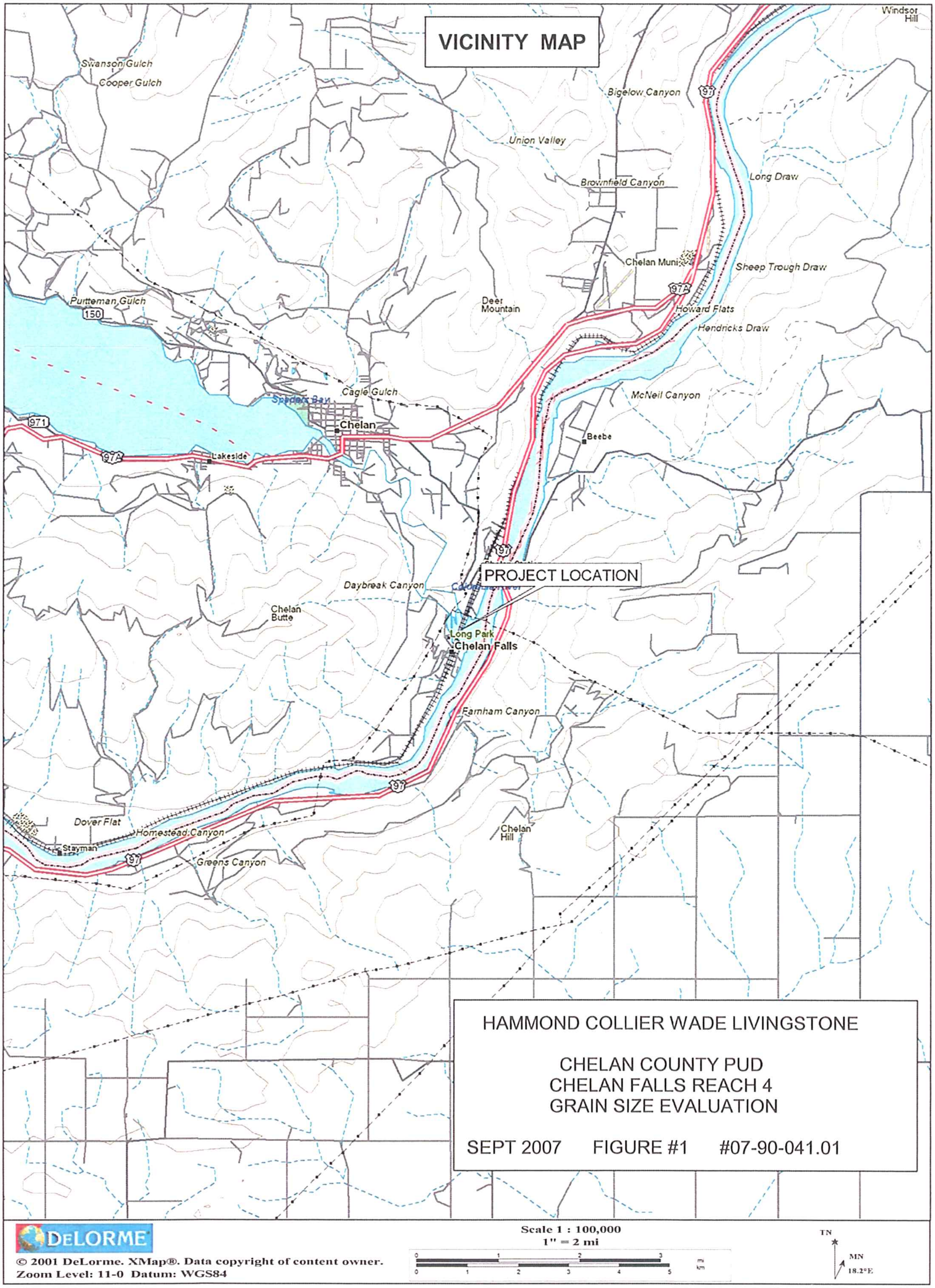
[1] "A View of the River" Luna B. Leopold, 1994, Harvard College


VICINITY MAP
Windsor Hill
Swanson Gulch
Cooper Gulch
Bigelow Canyon
Union Valley
Brownfield Canyon
Long Draw
Chelan Muni
Sheep Trough Draw
Puttteman Gulch
150
Deer Mountain
97A
Howard Flats
Hendricks Draw
Cagle Gulch
McNeil Canyon
971
Chelan
Beebe
97A
Lakeside
97
PROJECT LOCATION
Daybreak Canyon
Chelan Butte
Long Park
Chelan Falls
Farnham Canyon
97
Dover Flat
Homestead Canyon
Chelan Hill
Stayman
97
Greens Canyon
HAMMOND COLLIER WADE LIVINGSTONE
CHELAN COUNTY PUD
CHELAN FALLS REACH 4
GRAIN SIZE EVALUATION
SEPT 2007 FIGURE #1 #07-90-041.01
DELORME
© 2001 DeLorme. XMap®. Data copyright of content owner.
Zoom Level: 11-0 Datum: WGS84
Scale 1 : 100,000
1" = 2 mi
TN
MN
18.2°E

0 50 100 200
SCALE IN FEET

APPROXIMATE

NOTES:

1. THE LOCATIONS OF ALL FEATURES SHOWN ARE APPROXIMATE.
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LEGEND

TP-1 TEST PIT NUMBER AND APPROXIMATE LOCATION

GRAIN SIZE ANALYSIS AREA

DESIGNED BY	KA
DRAWN BY	GM
DATE	9-13-2007
SCALE	AS SHOWN
JOB NO.	07-90-041.01

HAMMOND COLLIER
WADE LIVINGSTONE
SEATTLE (206) 632-2664
WENATCHEE (509) 662-1762
LAKEWOOD (206) 732-2009
OMAK (509) 826-5861

CHELAN COUNTY PUD
CHELAN FALLS REACH 4
SITE PLAN

FIGURE 2

USCS SOIL CLASSIFICATION CHART

MAJOR DIVISIONS			SYMBOLS	GROUP NAME
COARSE GRAINED SOILS MORE THAN 50% OF MATERIAL IS LARGER THAN NO. 200 SIEVE SIZE	GRAVEL AND GRAVELLY SOILS MORE THAN 50% OF COARSE FRACTION RETAINED ON NO. 4 SIEVE	CLEAN GRAVELS (LITTLE OR NO FINES)	GW	WELL GRADED GRAVEL
			GP	POORLY GRADED GRAVEL
		GRAVELS WITH FINES (APPRECIABLE AMOUNT OF FINES)	GM	SILTY GRAVEL
			GC	CLAYEY GRAVEL
	SAND AND SANDY SOILS MORE THAN 50% OF COARSE FRACTION PASSING ON NO. 4 SIEVE	CLEAN SANDS (LITTLE OR NO FINES)	SW	WELL GRADED SAND
			SP	POORLY GRADED SAND
		SANDS WITH FINES (APPRECIABLE AMOUNT OF FINES)	SM	SILTY SAND
			SC	CLAYEY SAND
FINE GRAINED SOILS MORE THAN 50% OF MATERIAL IS SMALLER THAN NO. 200 SIEVE SIZE	SILTS AND CLAYS	LIQUID LIMIT LESS THAN 50	ML	INORGANIC SILTS
			CL	INORGANIC CLAYS OF LOW TO MEDIUM PLASTICITY
			OL	ORGANIC SILTS AND ORGANIC SILTY CLAYS OF LOW PLASTICITY
	SILTS AND CLAYS	LIQUID LIMIT GREATER THAN 50	MH	INORGANIC SILT
			CH	INORGANIC CLAYS OF HIGH PLASTICITY
			OH	ORGANIC CLAYS OF MEDIUM TO HIGH PLASTICITY, ORGANIC SILTS
HIGHLY ORGANIC SOILS			PT	PEAT, HUMUS, SWAMP SOILS WITH HIGH ORGANIC CONTENTS

LOG OF TEST PIT -1

DATE EXCAVATED	8-22-07	LOGGED BY	K ANDERSON
EQUIPMENT	TRACKHOE	SURFACE ELEVATION (FT)	UNKNOWN

DEPTH IN FEET	SAMPLE NO.	USCS GROUP SYMBOL	SOIL DESCRIPTION	PROBE T-BAR INCH DEPTH
0				
		GW	WELL SORTED GRAVEL WITH SAND AND COBBLES AVERAGE COBBLE 3-6" LARGER 10% <1.5FT SUBROUNDED	
	1			
5			END OF HOLE @ 5.0 FT	
10				
15				

REMARKS:

LOCATION: GRAVEL BAR

SURFACE CONDITIONS: RIVER BAR GRAVELS

GROUNDWATER: RAPID @ 5 FEET

CAVING MODERATE-SEVERE @ 4 FEET

PREPARED BY	KA
TYPED BY	GM
DATE	9-06-07
JOB NO.	07-90-041.01

HAMMOND COLLIER
WADE LIVINGSTONE
SEATTLE (206) 632-2664 WENATCHEE (509) 662-1762
LAKEWOOD (206) 732-2009 OMAK (509) 826-5861

CHELAN COUNTY PUD
CHELAN FALLS REACH 4
CHELAN, WA

FIGURE B-2

LOG OF TEST PIT –2

DATE EXCAVATED	8–22–07	LOGGED BY	K ANDERSON
EQUIPMENT	TRACKHOE	SURFACE ELEVATION (FT)	UNKNOWN

DEPTH IN FEET	SAMPLE NO.	USCS GROUP SYMBOL	SOIL DESCRIPTION	PROBE T–BAR INCH DEPTH
0				
	1	GW	WELL SORTED GRAVEL WITH SAND AND TRACE COBBLES <5%	
			END OF HOLE @ 2.5 FT	
5				
10				
15				

REMARKS:

LOCATION: **EAST OF RAILROAD TRACKS – GRAVEL BAR**

SURFACE CONDITIONS: **RIVER BAR GRAVELS**

GROUNDWATER: **RAPID** @ **1** FOOT

CAVING **MODERATE–SEVERE** @ **2** FEET

PREPARED BY	KA	HAMMOND COLLIER WADE LIVINGSTONE	CHELAN COUNTY PUD CHELAN FALLS REACH 4 CHELAN, WA	FIGURE B-3
TYPED BY	GM	SEATTLE (206) 632-2664 · WENATCHEE (509) 662-1762		
DATE	9–06–07	LAKEWOOD (206) 732-2009 · OMAK (509) 826-5861		
JOB NO.	07–90–041.01			

LOG OF TEST PIT -3

DATE EXCAVATED	8-22-07	LOGGED BY	K ANDERSON
EQUIPMENT	TRACKHOE	SURFACE ELEVATION (FT)	UNKNOWN

DEPTH IN FEET	SAMPLE NO.	USCS GROUP SYMBOL	SOIL DESCRIPTION	PROBE T-BAR INCH DEPTH
0		GP	COBBLES <1FT MEAN WITH GRAVEL AND TRACE SAND	
		GW	GRAVEL WITH SAND AND COBBLES – SIMILAR TO TP-1, SAMPLE 1	
5			END OF HOLE @ 5.0 FT	
10				
15				

REMARKS:

LOCATION: UNDER HIGHWAY BRIDGE – GRAVEL BAR

SURFACE CONDITIONS: RIVER BAR GRAVELS

GROUNDWATER: RAPID @ 5 FEET

CAVING MODERATE-SEVERE @ 2 FEET

PREPARED BY	KA	HAMMOND COLLIER WADE LIVINGSTONE SEATTLE (206) 632-2664 WENATCHEE (509) 662-1762 LAKEWOOD (206) 732-2009 OMAK (509) 826-5861	CHELAN COUNTY PUD CHELAN FALLS REACH 4 CHELAN, WA	FIGURE B-4
TYPED BY	GM			
DATE	9-06-07			
JOB NO.	07-90-041.01			

LOG OF TEST PIT -4

DATE EXCAVATED	8-22-07	LOGGED BY	K ANDERSON
EQUIPMENT	TRACKHOE	SURFACE ELEVATION (FT)	UNKNOWN

DEPTH IN FEET	SAMPLE NO.	USCS GROUP SYMBOL	SOIL DESCRIPTION	PROBE T-BAR INCH DEPTH
0				
		GW	GRAVEL WITH SAND AND TRACE COBBLES <3" AVERAGE	
			END OF HOLE @ 2.0 FT	
5				
10				
15				

REMARKS:

LOCATION: GRAVEL POINT BAR WEST OF ROAD

SURFACE CONDITIONS: RIVER BAR GRAVELS

GROUNDWATER: RAPID @ 1 FOOT

CAVING SEVERE @ 1 FOOT

PREPARED BY: KA TYPED BY: GM DATE: 9-06-07 JOB NO. 07-90-041.01	HAMMOND COLLIER WADE LIVINGSTONE SEATTLE (206) 632-2664 WENATCHEE (509) 662-1762 LAKEWOOD (206) 732-2009 OMAK (509) 826-5861	CHELAN COUNTY PUD CHELAN FALLS REACH 4 CHELAN, WA	FIGURE B-5

LOG OF TEST PIT -5

DATE EXCAVATED	8-22-07	LOGGED BY	K ANDERSON
EQUIPMENT	TRACKHOE	SURFACE ELEVATION (FT)	UNKNOWN

DEPTH IN FEET	SAMPLE NO.	USCS GROUP SYMBOL	SOIL DESCRIPTION	PROBE T-BAR INCH DEPTH
0		GW	GRAVEL WITH SAND AND COBBLES COBBLES <1FT	
5			END OF HOLE @ 5.0 FT	
10				
15				

REMARKS:

LOCATION: GRAVEL BAR WEST OF ROAD – WEST OF TEST PIT TP-1

SURFACE CONDITIONS: RIVER BAR GRAVELS

GROUNDWATER: MOD-RAPID@ 5 FEET

CAVING MODERATE-SEVERE @ 1 FOOT

PREPARED BY KA TYPED BY GM DATE 9-06-07 JOB NO. 07-900-41.01	HAMMOND COLLIER WADE LIVINGSTONE SEATTLE (206) 632-2664 WENATCHEE (509) 662-1762 LAKEWOOD (206) 732-2009 OMAK (509) 826-5861	CHELAN COUNTY PUD CHELAN FALLS REACH 4 CHELAN, WA	FIGURE B-6

HAMMOND COLLIER WADE LIVINGSTONE
ENGINEERING - SURVEYING - TESTING - INSPECTION

104 East Ninth Street
Wenatchee, WA 98801
(509) 662-1762

83 Copple Road
Omak, WA 98841
(509) 826 5861

4010 Stone Way N. #300
Seattle, WA 98103
(800) 562-7707

CLASSIFICATION SIEVE ANALYSIS ASTM C-136 OR D-422

CLIENT:	Chelan Co. PUD	LAB NO:	7O-0349
PROJ. NO:	07-90-041	DATE REC'D:	8/22/2007
PROJECT:	Chelan Falls Reach 4	DATE TESTED:	8/28/2007
CONTRACTOR:	Rayfield Bros.	SUBMITTED BY:	K. Anderson
LOCATION:	TP - 1	DEPTH:	4 Ft.

PERCENT MOISTURE OF FINES: 2.2%

SAMPLE DESCRIPTION: Well Graded GRAVEL with Cobbles

SCREEN SIZE	ACC. WT. RETAINED	PERCENT RETAINED	PERCENT PASSING	FRACTURE COUNT		TOTAL PERCENT	
7"	0.00	0%	100%			100%	
6"	11.14	6%	94%			94%	
4"	30.76	15%	85%			85%	
3"	69.00	34%	66%			66%	
2 1/2"	86.00	43%	57%			57%	
1"	137.35	68%	32%			32%	
5/8"	153.87	76%	24%			24%	
1/2"	160.33	79%	21%			21%	
3/8"	166.00	82%	18%			18%	
#4	174.39	86.2%	13.8%			13.8%	
TOTAL	202.23						
SIEVE	**ACC. WT. RETAINED**	**PERCENT RETAINED**	**PERCENT PASSING**	**X-FACTOR**			
#8	226.7	21%	79%	0.138		11%	
#16	410.6	39%	61%	0.138		8%	
#30	591.6	56%	44%	0.138		6%	
#40	734.6	69%	31%	0.138		4%	
#80	968.0	91%	9%	0.138		1%	
#100	990.0	93%	7%	0.138		1%	
#200	1032.0	97.4%	2.6%	0.138		0.4%	
TOTAL	1059.8						

WGT. OF PAN SAMPLE:	28.46	PAN I.D & WGT..:	13 377.5
WGT. OF PAN SAMPLE - MOISTURE:	27.84	WGT. PAN & WET SOIL	1460.9
		WGT. PAN & DRY SOIL:	1437.3

REMARKS:

TECHNICIAN: C. Dean

PROJ. MGR: T. HAGEMAN

Note: All sample material will be discarded after 30 days of receipt unless otherwise notified.

HAMMOND COLLIER WADE LIVINGSTONE
ENGINEERING - SURVEYING - TESTING - INSPECTION

104 East Ninth Street
Wenatchee, WA 98801
(509) 662-1762

83 Copple Road
Omak, WA 98841
(509) 826 5861

4010 Stone Way N. #300
Seattle, WA 98103
(800) 562-7707

CLASSIFICATION SIEVE ANALYSIS ASTM C-136 OR D-422

CLIENT:	Chelan County PUD	LAB NO:	7O-0348
PROJ. NO:	07-90-041	DATE REC'D:	8/22/2007
PROJECT:	Chelan Falls Reach 4	DATE TESTED:	8/27/2007
CONTRACTOR:	Rayfield Brothers	SUBMITTED BY:	K. Anderson
LOCATION:	Test Pit - TP-2	DEPTH:	2 Ft.

PERCENT MOISTURE OF FINES: 11.9%

SAMPLE DESCRIPTION: Well Graded GRAVEL

SCREEN SIZE	ACC. WT. RETAINED	PERCENT RETAINED	PERCENT PASSING	FRACTURE COUNT	TOTAL PERCENT	
3"	0.00	0%	100%		**100%**	
2"	0.56	1%	99%		**99%**	
1"	28.75	36%	64%		**64%**	
3/4"	41.65	52%	48%		**48%**	
1/2"	57.09	71%	29%		**29%**	
3/8"	63.42	79%	21%		**21%**	
#4	70.89	87.9%	12.1%		**12.1%**	
TOTAL	80.62					

SIEVE	ACC. WT. RETAINED	PERCENT RETAINED	PERCENT PASSING	X-FACTOR			
#8	56.7	10%	90%	0.121		**11%**	
#16	63.3	11%	89%	0.121		**11%**	
#30	72.2	12%	88%	0.121		**11%**	
#40	101.4	17%	83%	0.121		**10%**	
#80	359.7	62%	38%	0.121		**5%**	
#100	413.9	71%	29%	0.121		**4%**	
#200	522.0	89.3%	10.7%	0.121		**1.3%**	
TOTAL	584.8						

		PAN I.D & WGT..:	17 302.7
WGT. OF PAN SAMPLE:	10.86	WGT. PAN & WET SOIL	957.4
WGT. OF PAN SAMPLE - MOISTURE:	9.73	WGT. PAN & DRY SOIL:	887.5

REMARKS:

TECHNICIAN: C. Dean

PROJ. MGR: T. HAGEMAN

Note: All sample material will be discarded after 30 days of receipt unless otherwise notified.