Revised Draft

Gravel Transport Study Report for Energy Northwest's Packwood Lake Hydroelectric Project FERC No. 2244 Lewis County, Washington

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1.0 INTRODUCTION

Energy Northwest operates the Packwood Lake Hydroelectric Project (Project) near the town of Packwood in Lewis County, Washington. On November 12, 2004 Energy Northwest filed a Notice of Intent (NOI) to file an application for a new license to operate the hydroelectric project. Energy Northwest also concurrently filed with the Federal Energy Regulatory Commission (FERC) and the resource agencies, a Pre-Application Document (PAD), containing existing, relevant, and reasonably available information describing the existing environment and the potential effects of Project facilities and operations. Additional studies of the potential effects of project operations on gravel transport in Lake Creek were requested to supplement information contained in the PAD (USFS 2005).

Energy Northwest, in consultation with tribes and agencies, developed and has implemented a study to evaluate the potential effects of Project operations on gravel transport in lower Lake Creek (Watershed GeoDynamics 2005). This report provides results of the gravel transport study.

1.1 Project Area and Study Area

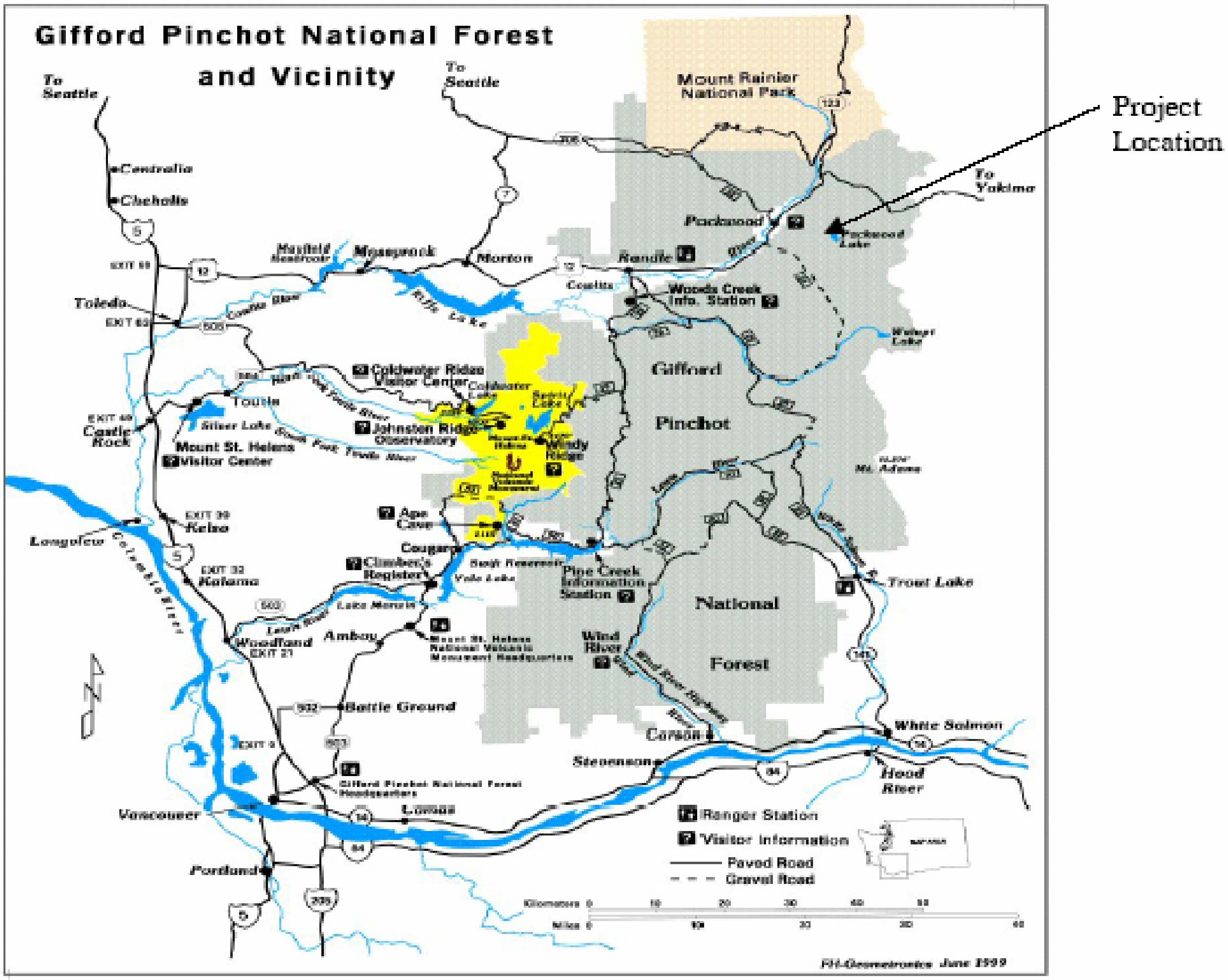
1.1.1 Project Area

Energy Northwest's Packwood Lake Hydroelectric Project, FERC No. 2244, received its initial license in 1960. The majority of the Project is located in the Gifford Pinchot National Forest, east of the town of Packwood (Figure 1.1). The Project consists of an intake canal, a concrete drop structure (dam) and intake building on Lake Creek located about 424 feet downstream from the outlet of Packwood Lake, a 21,691-foot system of concrete pipe and tunnels, a 5,621-foot penstock, a surge tank, and powerhouse with a 26,125 kW turbine generator.

The source of water for the Project, Packwood Lake, is a lake that pre-existed the Project, situated at an elevation of approximately 2,857 feet above mean sea level (MSL), about 1,800 feet above the powerhouse. Water discharged from the Project is released to the Cowlitz River via a tailrace channel. Power from the Project is delivered over an 8,009-foot 69 kV transmission line to the Packwood substation.

1.1.2 Study Area

The study area includes Lake Creek from the drop structure to the confluence with the Cowlitz River.



<u>Figure 1.1</u> – Project location.

2.0 STUDY GOALS AND OBJECTIVES

The goal of this study is to assess how operation of the Packwood Lake Hydroelectric Project affects the transport of gravel in the size range suitable for use by spawning fish in Lake Creek downstream of the drop structure. Project operation does not affect the gravel supply to the creek.

Study objectives included:

- Document the relative amount of spawning gravel and its longitudinal distribution in Lake Creek downstream of the drop structure.
- Determine the flows that are necessary to transport spawning-sized gravel down Lake Creek from the drop structure to the mouth of Lake Creek at its confluence with the Cowlitz River.
- Determine if flows that transport spawning-sized gravel from the upstream reaches of Lake Creek will maintain spawning gravel pockets in the lowest 1-2 miles of Lake Creek (the anadromous reach).

- Evaluate the project-induced change in magnitude and frequency of peak flows that are capable of transporting gravel in lower Lake Creek.

3.0 METHODS

3.1 Spawning-sized Gravel Survey in Lake Creek

A survey of existing spawning-sized gravel in Lake Creek downstream of the drop structure was made on September 2, 3, 5, 6, and 7, 2005. The survey was made during the low flow period, the normal fish release from the dam (3.5 cfs) was augmented by base level inflows through the reach. Flows were not measured through the reach, but average inflow between the drop structure and the gage location near the mouth (RM 0.3) is 8.6 cfs in September (EES 2005). Gravel was considered suitably sized for spawning if it was 0.5-4 inches median diameter based on the size range used by anadromous fish that have access to Reach 1. In each 100-foot long section of stream, the area of each gravel patch larger than 25 square feet was recorded. Gravel patches were recorded if more than 50% of the surface area was composed of spawning-sized gravel based on a visual assessment. Gravel within the wetted channel was recorded separately from gravel stored above the wetted, but within the bankfull channel. Since the objective of this study was to determine the quantity of spawning-sized gravel rather than if the gravel was situated in a location with suitable water depth/velocity characteristics for spawning, water depth and velocity were not recorded or used to classify sites.

3.2 Gravel Movement Study Sites

At seven gravel study sites (shown on Figure 3.1 and listed in Table 3.1), a more intensive study of gravel size and hydraulic conditions was made.

Table 3.1 – Location and characteristics of gravel study sites in lower Lake Creek

Study Site	Location (ft. from mouth)	Drainage Area* (sq mi)	Total gravel at site (sq. ft.)		Pieces of LWD at site
			Wetted channel	Bankfull channel	
Gravel 1	2,200	6.85	175	50	1 (in bankfull)
Gravel 2	4,200	5.97	200	25	0
Gravel 3-1	19,000	2.53	225	100	5 (2 wetted, 3 bankfull)
Gravel 3-2	12,700	3.89	100	150	6 (2 wetted, 5 bankfull)
Gravel 4-3	21,600	0.89	200	200	3 (1 wetted, 2 bankfull)
Gravel 4-2	23,200	0.56	500	0	4(2 wetted, 2 bankfull)
Gravel 4-1	24,800	0.37	625	0	3 (1 wetted, 2 bankfull)

* Drainage area includes area downstream of the drop structure only. Drainage area upstream of the drop structure is 19.2 sq mi.

The seven sites were located close to the anticipated seven locations listed in the study plan. The specific locations of sites in the field were selected to be representative of conditions within each study reach based on a visual assessment of stream characteristics made by surveyors walking each reach as they conducted the gravel/large wood inventory. Sites were chosen that had the following characteristics: contained at least several patches of spawning-sized gravel; hydraulic conditions were such that the site could be modeled fairly well using the one-dimensional hydraulic calculations identified in the study plan; visually appeared to be representative of the channel conditions (width, large wood, roughness) in the reach. No attempt was made to quantify the range of channel conditions in the stream for this study since that was not part of the study plan.

The Forest Service indicated that they were primarily interested in transport of gravel through Reaches 3 and 4, and retention of gravel in the lower mile of the stream where it would be most available for use by anadromous fish. The sites in Reach 1 and 2 were located in areas that were identified as containing anadromous fish redds by the spawning survey crew. They were located in the lower mile of the stream, in reaches with moderate amounts of gravel and conditions typical of the reach. Sites were not placed in the four locations with larger amounts of gravel (over 500 sq. ft.) because these sites were not typical of the conditions in the reach. The sites with large amounts of gravel had large wood jams or other channel characteristics that favored retention of gravel, however, the majority of reaches with gravel in the lower mile of stream (39 out of 43 sites) had 300 sq. ft. or less gravel and did not contain large wood jams.

At each of the study sites, the following information was collected:

1. Grain Size Characteristics. The grain size distribution of existing patches of spawning-sized gravel (0.5-4 inches median diameter) was sampled at three locations at each study site. Pebble counts were made to document surface (armor layer) sediment size distribution by measuring the size of 100 grains using a gravelometer. The armor layer was then scraped away and a shovel was used to collect sub-surface sediment. Shovel samples have been found to be comparable to other sample methods (such as McNeil corers) in shallow/slow moving water conditions similar to those found in Lake Creek during the sampling period (Grost et. al 1991). The sub-surface sediment samples were air dried and sieved using a standard shaker (each sieve stack was shaken for 10 minutes). The sediment collected on each sieve was weighed and entered into a spreadsheet for calculation of size distribution.

2. Hydraulic Characteristics. At each grain size sample location, channel cross section and slope were measured using a tape, rod and hand level to provide information for hydraulic calculations. Wetted and bankfull channel edges were noted. High water markers were also noted following the flow releases to help calibrate hydraulic calculations.

3. Painted Gravel Markers. Painted rocks were deployed at each gravel study site transect to document substrate mobility thresholds. Painted rocks in the following size classes representing spawning-sized gravel were used: 0.5-1 inch; 1-2 inches; 2-3 inches; 3-4 inches. A group of these four gravel sizes was placed at approximately 2-foot intervals across the entire wetted transect and on any gravel deposits on the banks up to the assumed edge of the bankfull channel. The 3-4 inch rock was placed on the cross section, the 2-3 inch rock one foot upstream of the 3-4 inch rock, the 1-2 inch rock was placed one foot upstream of the 2-3 inch rock, etc. This placement scheme prevented artificial shielding of the smaller marked rocks by the larger ones. Each marked rock was placed on the bed surface so that its exposure mimicked that of the surrounding rocks as much as possible.

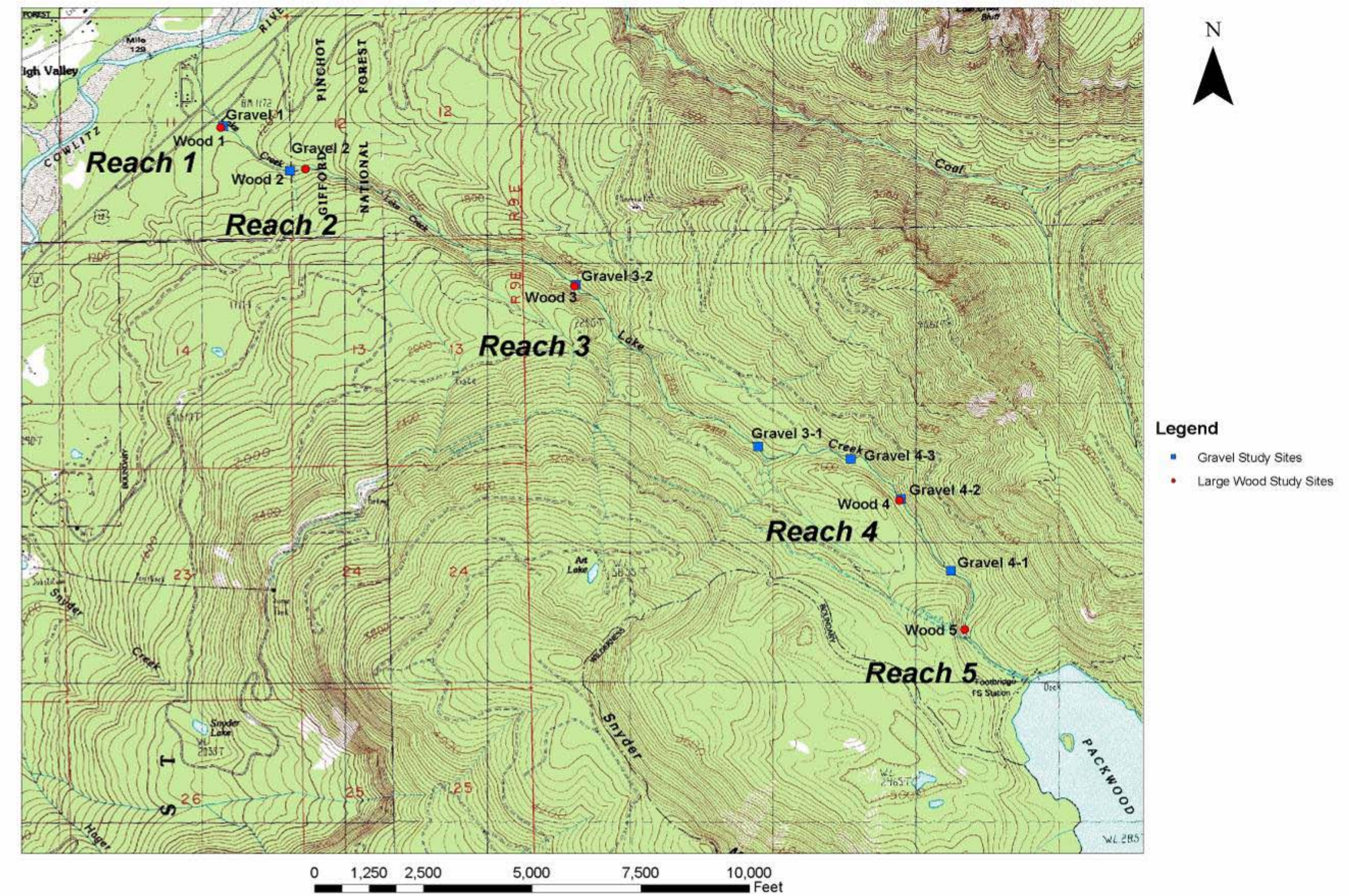


Figure 3.1 – Gravel and large wood study sites.

The marked rock sites were revisited to document mobility following the controlled release of 15-17 cfs, 30-35 cfs, and 299 cfs. Movement was considered to have occurred if a rock moved more than 2 feet downstream from its set position.

4. Photos. Photos were taken at each site during each field visit to document channel conditions and gravel locations.

3.3 Gravel Transport Calculations

The Andrews Formula (Andrews 1983, Andrews 1984) was used to estimate initiation of substrate movement. The equation has the form:

$$\tau^*_{ci} = 0.0834(d_i/d_{50})^{-0.872}$$

where τ^*_{ci} = critical Shields stress for mobility of particle size d_i
d_i = particle size at threshold of mobility
d_{50} = median particle size of *subsurface*

From this value of τ^*_{ci}, the depth D for mobility was computed using the relationship:

$$\tau^*_{ci} = DS/((\gamma_s/\gamma_w - 1)d_i)$$

where D = depth
S = slope
γ_s and γ_w are the specific weights of sediment and water, respectively.

Discharge versus stage at each of the measured cross sections was computed using the WinXSPRO software (Hardy et al. 2005). Channel elevation and position (xy) coordinates were entered for each cross section, along with measured water slope at low flow and estimated reach-average high flow water gradient. The Jarrett equation for Manning's roughness coefficient option was chosen to estimate the stage:discharge relationship, and was checked against the stage and discharge estimated during low flow and high flow (high flow stage was estimated based on indicators of high water at each transect). The Jarrett equation for Manning's roughness coefficient is internal to WinXSPRO and does not require any input on roughness elements; roughness is calculated based on water surface slope and hydraulic radius. Other hydraulic equations in WinXSPRO were also tested for comparison (user-supplied Manning's n, Thorne and Zevenbergen). The reader is referred to the WinXSPRO manual for more detailed information on calculations.

4.0 RESULTS

4.1 Gravel in Lower Lake Creek

Spawning-sized gravel was inventoried in Lake Creek downstream of the drop structure. Gravel was inventoried separately in the wetted channel and stored on the banks within the bankfull channel. Gravel patches over 25 square feet in area were included in the inventory. Please note that the gravel areas reported in this report are areas of spawning-sized gravel (per the study plan), regardless of water depth/velocities that may or may not make them suitable for spawning by different fish species. Data from the gravel inventory is tallied in Appendix C. A total of 42,660 sq. ft. of gravel was inventoried in the wetted channel, and 20,550 sq. ft in the bankfull channel (Table 4.1). The most gravel was located in Reaches 2, 3, and 4; there was less gravel in Reach 1 and very little gravel in Reach 5.

Table 4.1 – Area of spawning-sized gravel inventoried in Lake Creek

Reach	River Mile	Average Gradient	Gravel in wetted channel		Gravel in bankfull channel	
			Area (sq ft)	Sq ft/mile	Area (sq ft)	Sq ft/mile
1	0-0.7	2.9%	2,775	4,070	2,700	3,960
2	0.7-1.3	7.3%	6,175	11,644	2,375	4,479
3	1.3-3.5	8.0%	22,025	8,946	7,550	3,066
4	3.5-4.9	4.3%	11,635	9,599	7,925	6,538
5	4.9-5.3	8.4%	50	132	0	0
Total	0-5.3	6.3%	42,660	8,102	20,550	3,903

Gravel in the anadromous reach (up to RM 1.95) was further broken out into different reaches for comparison. Reach 1 was further sub-divided into the area downstream of Highway 12 (Reach 1A; Station 0-1500) and the area upstream of Highway 12 (Reach 1B, Station 1600-3600) at the request of the USFS. The portion of Reach 2 up to 1.03 mile from the mouth (Reach 2A, Station 3700-5300) was also separated out. Gravel in these reaches are shown in Table 4-2.

Table 4.2 – Area of spawning-sized gravel inventoried in sub-reaches of Lake Creek

Reach	Station (ft)	River Mile	Gravel in wetted channel		Gravel in bankfull channel	
			Area (sq ft)	Sq ft/mile	Area (sq ft)	Sq ft/mile
1A	0-1500	0-0.28	575	2,024	225	792
1B	1600-3600	0.28-0.68	2,425	6,097	2,475	6,223
2A	3700-5400	0.68-1.03	4,825	14,153	2,050	6,013
2B/3A	5500-10300	1.03-1.95	5,000	5,388	2,700	2,909
Anadromous accessible	0-10300	0-1.95	12,825	6,577	7,450	3,821

The majority of Lake Creek downstream of Packwood Lake is a relatively high gradient (5-8%) stream flowing in a confined valley. The lower 0.7 mile, designated Reach 1, is lower gradient (3%) and less confined. The stream has a boulder step-pool configuration with cascades and pools the principal habitat type. Substrate is dominantly boulders and cobbles.

Due to the relatively steep, step-pool configuration and limited gravel sources observed in Lake Creek downstream of Packwood Lake, gravel was not abundant except in a few locations. Of the 278 100-foot long segments of stream between the mouth and the drop structure, a total of 201 (72%) had at least one patch of gravel over 25 sq. ft. and thus was counted in the inventory (Figure 4.1). The majority (57%) of the 201 stream segments with inventoried gravel had less than 250 sq. ft. of instream gravel (these include both the 25-100 sq. ft and 100-250 sq. ft categories on the graph). Five units (2% of total number of segments with gravel) had over 1,000 sq. ft of gravel.

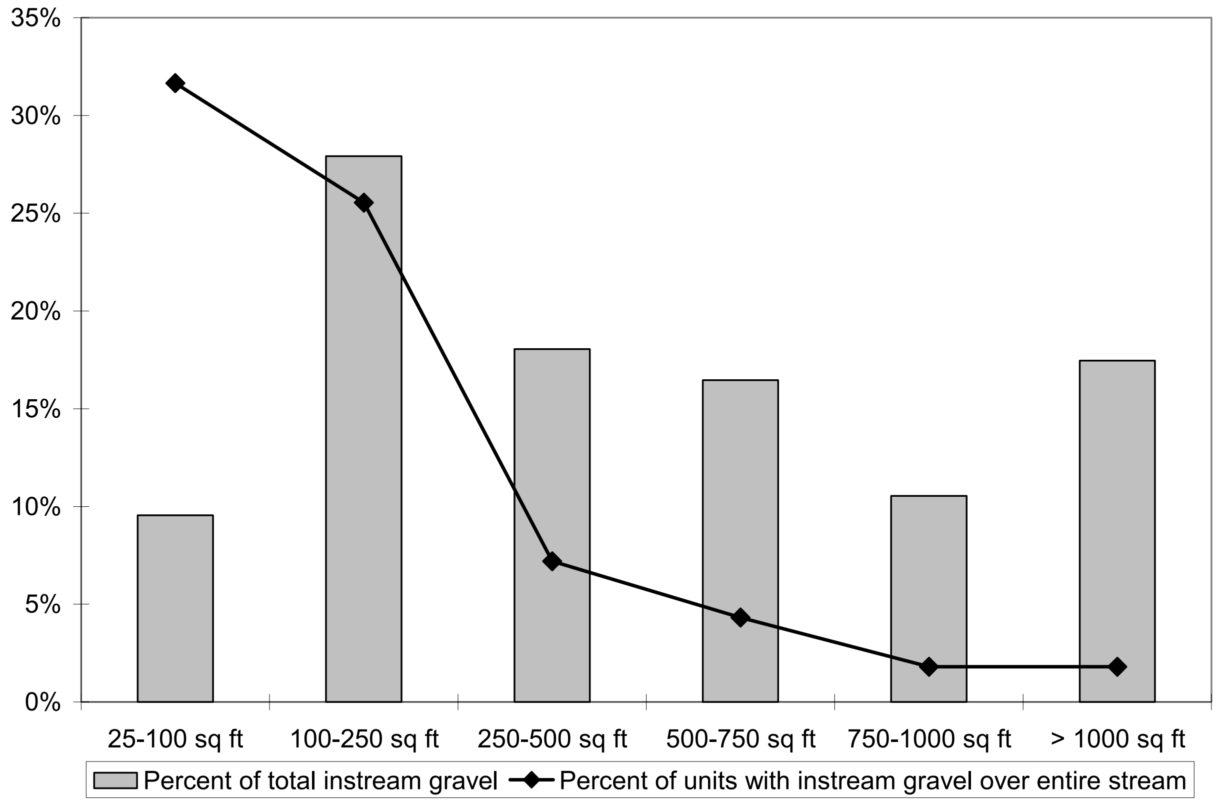


Figure 4.1 – Units with spawning-sized gravel in lower Lake Creek wetted channel.
Note: in addition to the 201 inventory units with gravel shown in this graph, another 77 units had no inventoried gravel.

Most of the gravel stored in the creek or on the banks was in patches downstream of large boulders, along the margins of the stream, or associated with large woody debris (see photos of each 100 foot section of stream in the separate 2005 Gravel/Large Wood Inventory Photographs PowerPoint file). The correlation of gravel deposits with large roughness elements (behind boulders, upstream of log jams) was not known before the field inventory. Therefore, quantitative information on exactly where gravel was stored in the stream was not collected, and this correlation is based on visual observations made during the inventory. Please view the photographs of the gravel/wood inventory to see conditions in the stream.

Four out of the five stream segments containing over 1,000 sq. ft. of gravel had the gravel stored upstream of log jams or in segments with large instream wood present. The other segment was located just downstream of a large tributary. Figure 4.2 shows cumulative gravel, starting at the mouth of Lake Creek, along with the longitudinal profile of the stream and log jams identified in the large wood inventory (Watershed GeoDynamics 2006).

Figure 4.3 is relatively complicated, but shows a great deal of information on one graph to illustrate the influence of different channel attributes on gravel in the stream:

- Stream gradient is shown as a dashed blue line (based on USGS topographic map contours)
- Tributaries are shown as blue squares

- Log jams are shown as green triangles
- The area (sq ft) of gravel in each 100-foot long reach is shown with the solid line
- Gravel study site locations are shown as black circles

There is relatively little gravel in Reach 5 despite the presence of numerous log jams. This is due to the fact that there are few gravel sources in Reach 5, and all gravel from upper Lake Creek is trapped in Packwood Lake.

There is a relatively high concentration of gravel between approximately RM 2 and RM 4.8, particularly when compared to gravel between RM 1.1 and RM 2 despite the similar, 5-10% or higher gradient of these areas. One reason for this could be the higher concentration of log jams (green triangles) upstream of approximately RM 2.1. Log jams and large wood were observed to trap gravel during the inventory.

There is a relatively high concentration of gravel in Reach 2 between RM 0.8 and 1.06. This gravel is likely there because: 1) it has been transported through the higher gradient, confined reach between RM 1 and RM 2, and has been deposited where the channel gradient drops and is less confined downstream of RM 1; and 2) there are two relatively large tributaries that are a source of gravel.

Resource agencies are particularly interested in gravel resources in the portion of Lake Creek accessible to anadromous fish. There is a barrier at approximately RM 1.03 for coho and Chinook, and another for coho, Chinook, and steelhead at approximately RM 1.95. These barriers were evaluated to determine passage potential (see Fish Passage Barriers study report). As shown on Figures 4.2 and 4.3 there is a relatively high concentration of gravel between RM 0.8 and RM 1.06. There is also gravel stored in lower gradient portions of the channel between RM 1 and RM 2, but little in the higher gradient portions.

Lake Creek between Packwood Lake and the Cowlitz River is a boulder/cobble step/pool stream and has relatively little gravel, a condition that is the result of the natural low sediment input rates from the confined bedrock valley, and high stream gradient. Since one of the objectives of this study is to determine if gravel in the channel can be transported downstream and be retained in the lower 1-2 miles, it is important to understand the channel characteristics and features that favor retention of gravel in the areas of Lake Creek that do contain spawning-sized gravel:

- Relatively low gradient in the habitat unit (less than 2%)
- Large-scale roughness elements such as large boulders, large woody debris, or log jams to provide hydraulic conditions that retain gravel (lower velocity zones)
- Low gradient unconfined reaches downstream of higher gradient confined reaches.

Most of the areas in the lower 0.8 miles of Lake Creek are low gradient, but do not contain the large-scale roughness elements to help retain gravel.

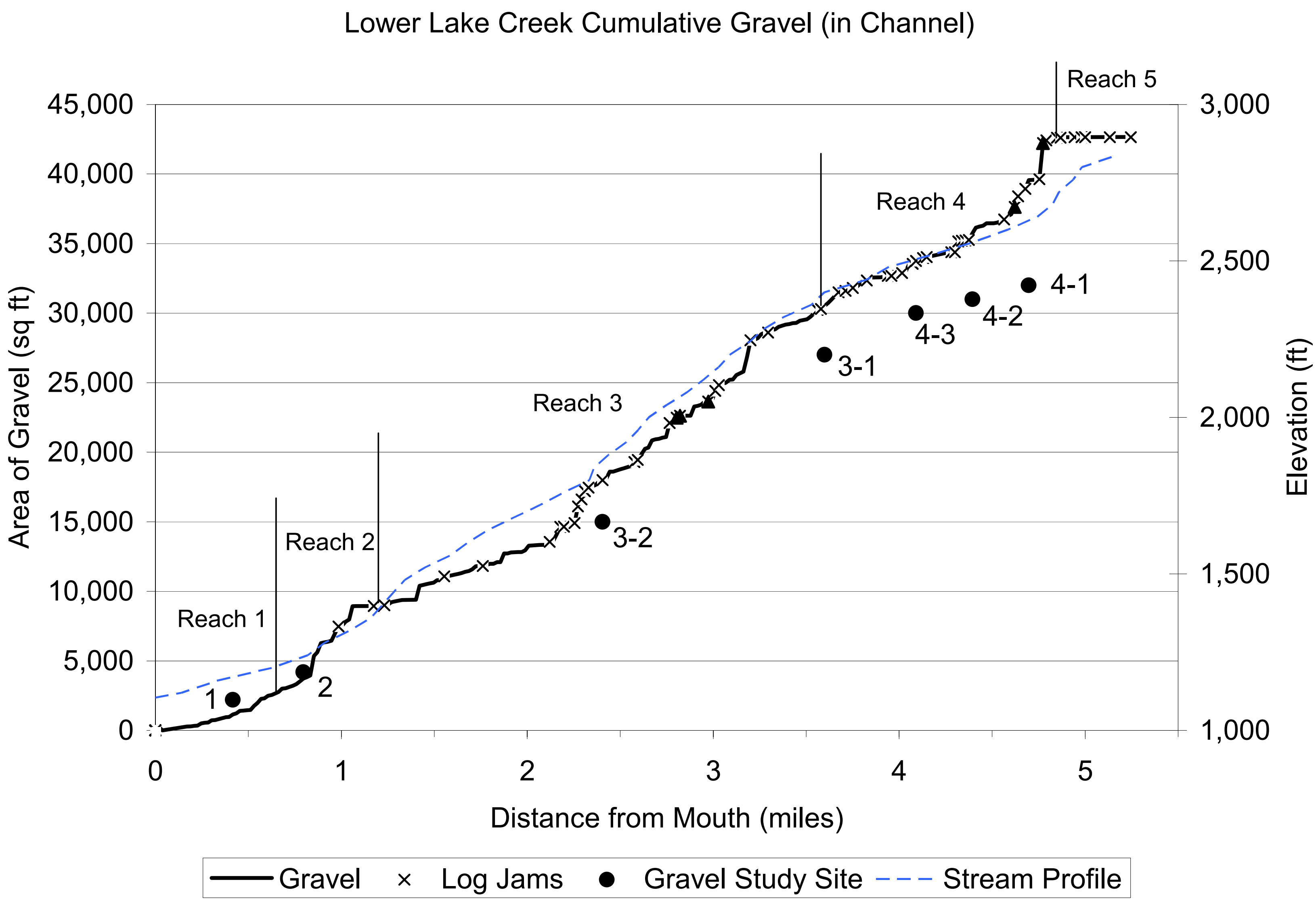


Figure 4.2 – Cumulative spawning-sized gravel in lower Lake Creek wetted channel.
Note: Gravel study site locations are marked with a solid circle and labeled with site number.

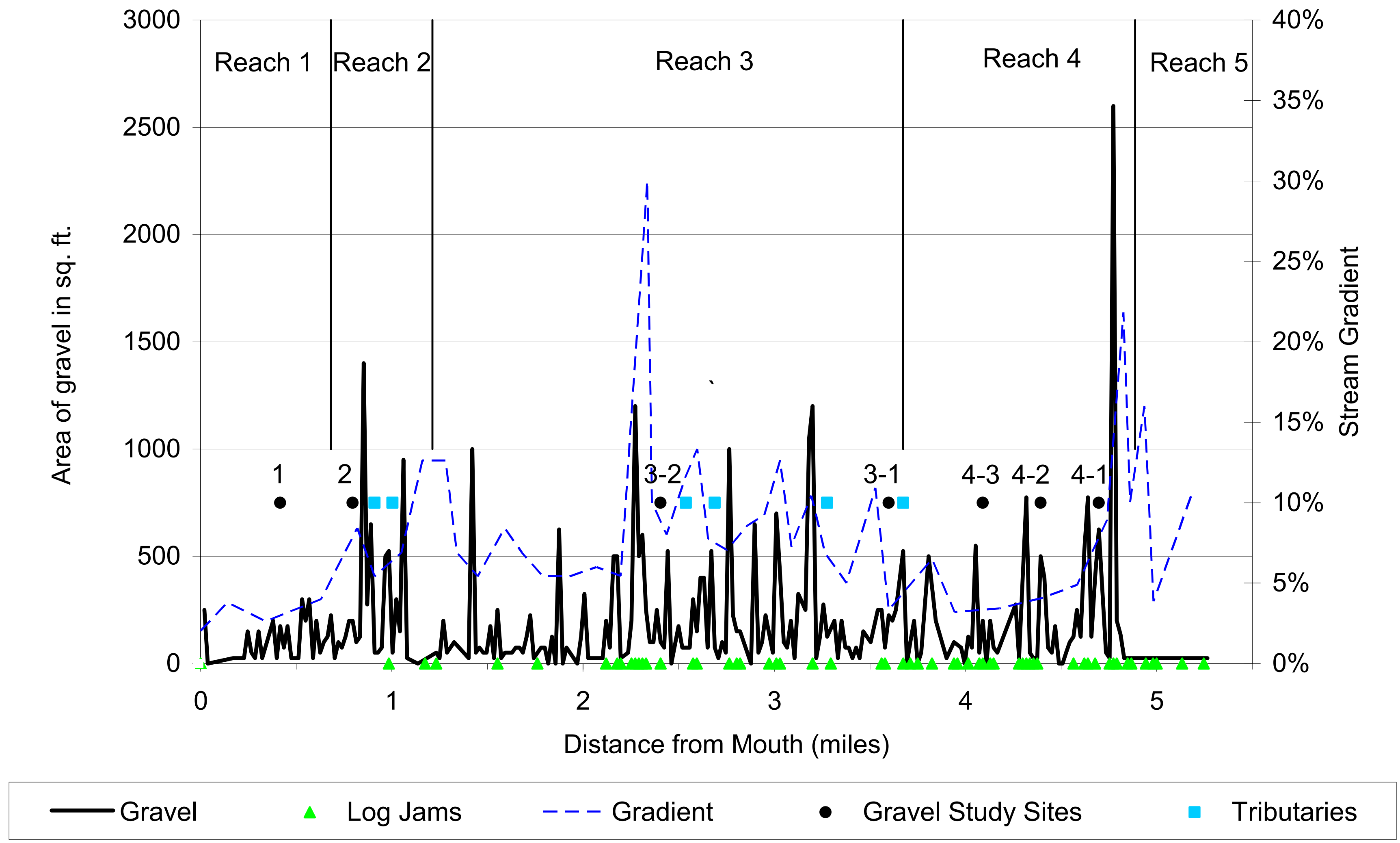


Figure 4.3 – Spawning-sized gravel in wetted channel and stream gradient in lower Lake Creek

4.2 Gravel Size Distribution

Three samples of spawning-sized gravel were taken at each gravel study site. A pebble count of the armor layer was made, and sub-armor samples were sieved to provide information on the size distribution. Figure 4.4 summarizes the size distribution of armor layer samples and Figure 4.5 summarizes the size distribution of armor layer samples. Detailed size distribution data from each sample is included in Appendix A. It should be noted that the gravel samples were taken to document the grain size of existing spawning-sized gravel patches, and are not representative of total substrate at each site; dominant substrate is boulder and cobble, and the gravel samples taken were generally located behind obstructions where hydraulic conditions allowed retention of gravel and smaller sized particles.

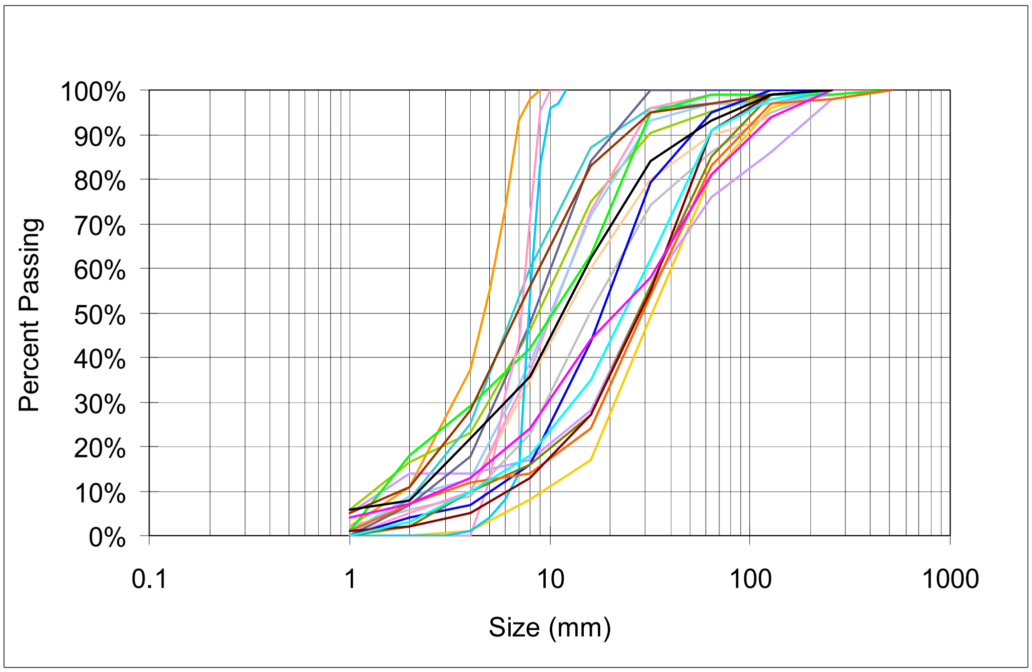


Figure 4.4 – Size distribution of armor layer samples
(Note: each line represents a separate gravel sample)

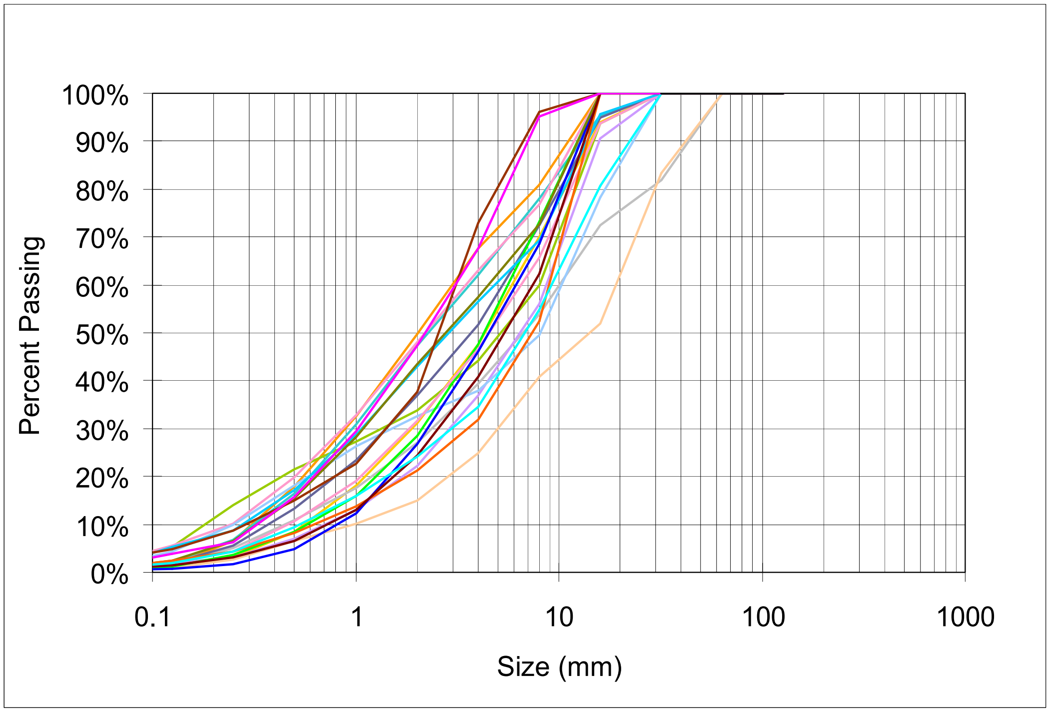


Figure 4.5 – Size distribution of sub-armor layer samples
(Note: each line represents a separate gravel sample)

4.3 Painted Rock Movement

Brightly colored rocks in four size classes (0.5-1 inch, 1-2 inches, 2-3 inches, and 3-4 inches) were placed across the stream at each of the seven gravel study sites (Figure 4.6). The rocks were checked for movement, defined as displacement of more than two feet, following flow releases of approximately 16 cfs, 35 cfs, and 299 cfs.

Figure 4.6 – Example of painted rock study site

Discharge at the drop structure during the time the painted rocks were in place is shown in Figure 4.7 and listed at the end of Appendix B. A flow of approximately 15 cfs (mean daily flow of 14 cfs; 16 cfs release for 19.5 hours) was released on September 11, 2005. Painted rocks were checked for movement on September 12. A flow of approximately 35 cfs (mean daily flow of 22 cfs; 33.5 cfs released for 24 hours) was released on September 13, 2005. Rocks were again checked for movement following this flow. Flows of 22-65 cfs were spilled in January 2006 due to high inflows. Flows of 11-294 cfs (mean daily flow) were released on 28 days in May and June for the high flow release (peak approximately 299 cfs). The length of the release and variable flows shows the difficulty in controlling spill flows at the drop structure since once the lake level reaches the top of the structure, the only control available is by varying the flow through the powerhouse (up to 260 cfs can be withdrawn).

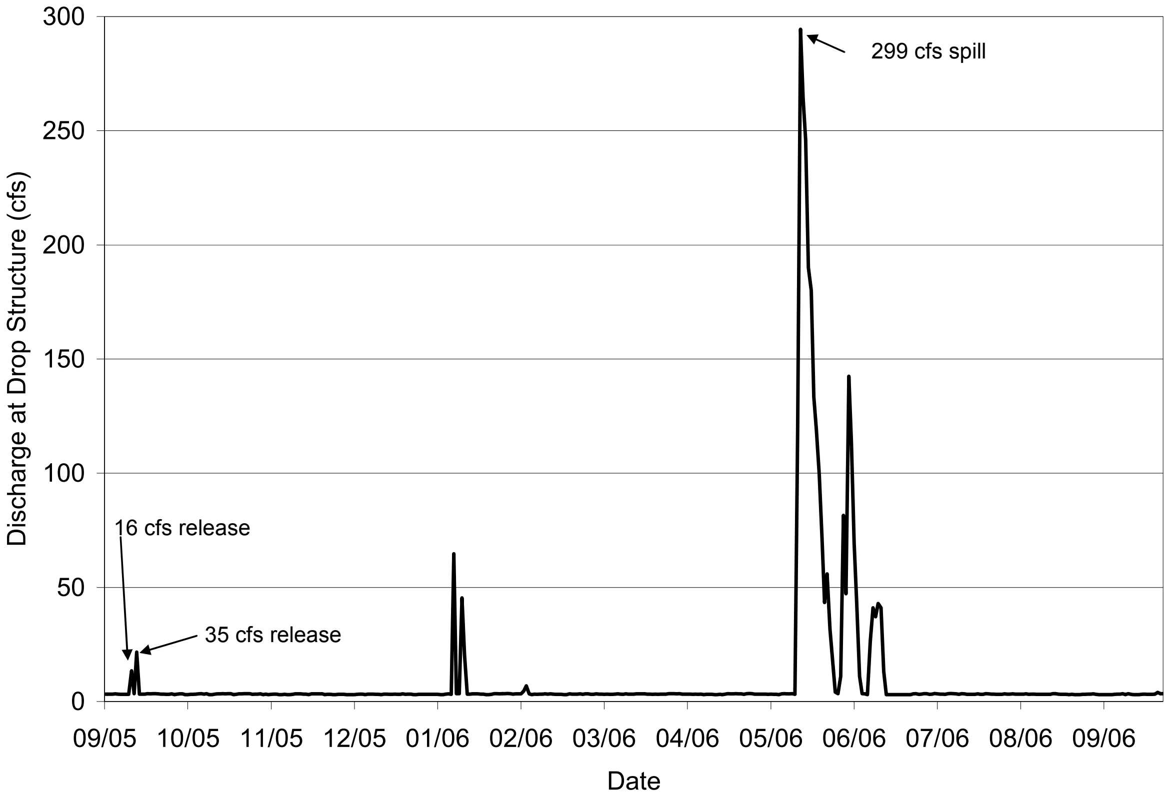


Figure 4.7 – Flow releases during painted rock study

Accretion and inflows during the releases resulted in higher flows at downstream study sites. It was not raining during or immediately prior to any of the releases. An analysis of average monthly accretion rates between the upper (near drop structure) and lower (bridge near mouth) USGS gages is included in Section 4.5.2. Average monthly accretion during September is 8.6 cfs, so flows at study transects would have been up to approximately 9 cfs higher than released at the drop structure. Average monthly accretion during May is 27.9 cfs, so flows at downstream transects would likely have been up to 30 cfs higher during the 299 cfs release. Additional analysis of accretion (inflow/unit area by month) is being performed as part of the instream flow study. This information will be included in the updated gravel transport study to provide estimates of monthly and peak flow accretion expected at the different gravel study site locations.

There was very little movement of the painted rocks following the 16 cfs release; a few of the smallest rocks (0.5-1 inch) had moved but 88-100% of the rocks were in place. Rock movement is summarized in Table 4.3, which shows the measured gradient (at low water), bankfull width, and percent of painted rocks remaining at each of the transects following each release. Additional detail on the painted rock study is provided in Appendix B. A few of the remaining small rocks (0.5-1 inch) shifted positions or moved slightly following the 35 cfs release; 87-100% of the rocks remained at all sites except Site 3-2. At site 3-2 only 22% of the 0.1-1 inch rocks and just over half of the 1-2 inch remained following the 35 cfs release.

Many of the rocks (45-95%), particularly the smaller sized rocks and those in the middle of the transects, had moved after the 299 cfs release. Figure 4.8 shows the painted rocks remaining following the high flow release at each transect. Painted rocks of various sizes still on the transect are displayed as orange squares, diamonds, triangles, or circles on the figure. The top row of orange squares shows the 3-4 inch rocks that remained; the next row of orange diamonds shows the 2-3 inch rocks, the next row of orange triangles shows the 1-2 inch rocks, and the bottom row of orange circles shows the 0.5-1 inch rocks.

The painted rock movement data helps to calibrate the gravel transport calculations, and suggests that spawning-sized gravel would be mobile at many of the transects under approximately bankfull flows (250-300 cfs). However, it also suggests that spawning-sized gravel may not move through some of the reaches (e.g., two of the wider transects in Reach 4 had little movement), and gravel may not be mobilized from the locations it is currently being stored; along channel margins and behind boulders and logs under bankfull flow conditions.

Table 4.3 – Percent of painted rocks remaining after flow releases.							
Rocks remaining after approx. 16 cfs release							
Sample Location	**Gradient (%)**	**Bankfull Width (ft)**	**Size class of painted rocks**				
			0.5-1 in.	**1-2 in.**	**2-3 in.**	**3-4 in.**	**Total (all sizes)**
4-1	4.5%	40.7	80%	100%	100%	100%	88%
4-2	3.0%	47.6	100%	100%	100%	100%	100%
4-3	4.8%	49.0	92%	100%	100%	100%	98%
3-1	3.9%	42.0	100%	100%	100%	100%	100%
3-2	3.4%	29.5	100%	100%	100%	100%	100%
2	1.4%	35.7	87%	93%	100%	100%	95%
1	2.0%	50.0	92%	100%	100%	100%	89%
Rocks remaining after approx. 33.5 cfs release							
Sample Location	**Gradient (%)**	**Bankfull Width (ft)**	**Size class of painted rocks**				
			0.5-1 in.	**1-2 in.**	**2-3 in.**	**3-4 in.**	**Total (all sizes)**
4-1	4.5%	40.7	60%	100%	100%	100%	87%
4-2	3.0%	47.6	100%	100%	93%	100%	98%
4-3	4.8%	49.0	92%	93%	100%	100%	96%
3-1	3.9%	42.0	100%	100%	100%	100%	100%
3-2	3.4%	29.5	22%	56%	100%	100%	69%
2	1.4%	35.7	73%	93%	100%	100%	92%
1	2.0%	50.0	92%	93%	100%	100%	88%
Rocks remaining after approx. 299 cfs release							
Sample Location	**Gradient (%)**	**Bankfull Width (ft)**	**Size class of painted rocks**				
			0.5-1 in.	**1-2 in.**	**2-3 in.**	**3-4 in.**	**Total (all sizes)**
4-1	4.5%	40.7	0%	8%	20%	13%	12%
4-2	3.0%	47.6	14%	43%	73%	87%	55%
4-3	4.8%	49.0	8%	0%	40%	80%	33%
3-1	3.9%	42.0	0%	0%	18%	27%	11%
3-2	3.4%	29.5	22%	22%	11%	11%	17%
2	1.4%	35.7	0%	0%	0%	20%	5%
1	2.0%	50.0	0%	0%	0%	33%	9%

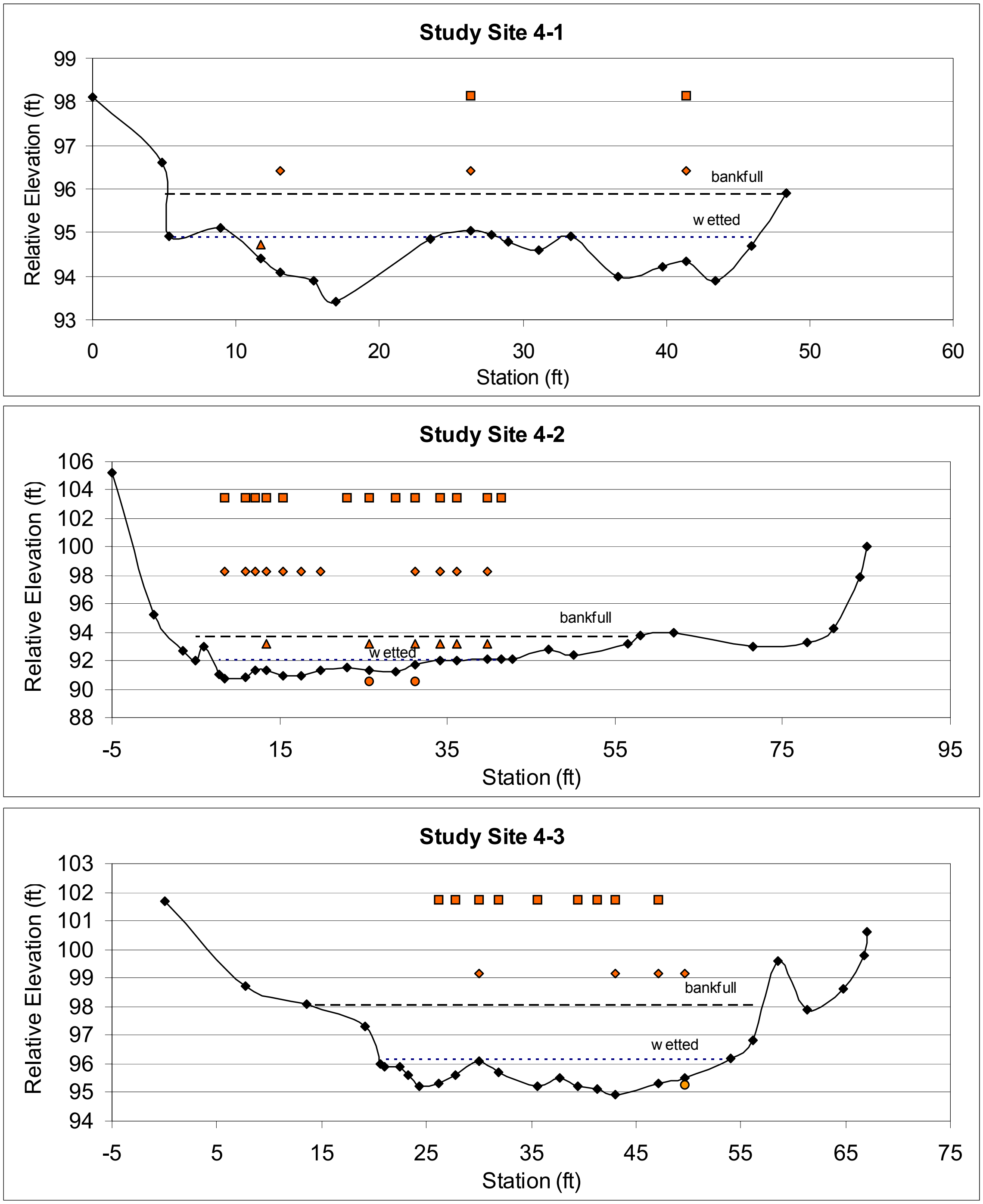


Figure 4.8 – Cross sections and painted rocks remaining after 299 cfs flow release.
(Note: Painted rocks were placed across wetted transect; those remaining are noted with lines of orange symbols. Top squares are 3-4" rocks, diamonds are 2-3" rocks, triangles are 1-2" rocks and bottom circles are 0.5-1" rocks.)

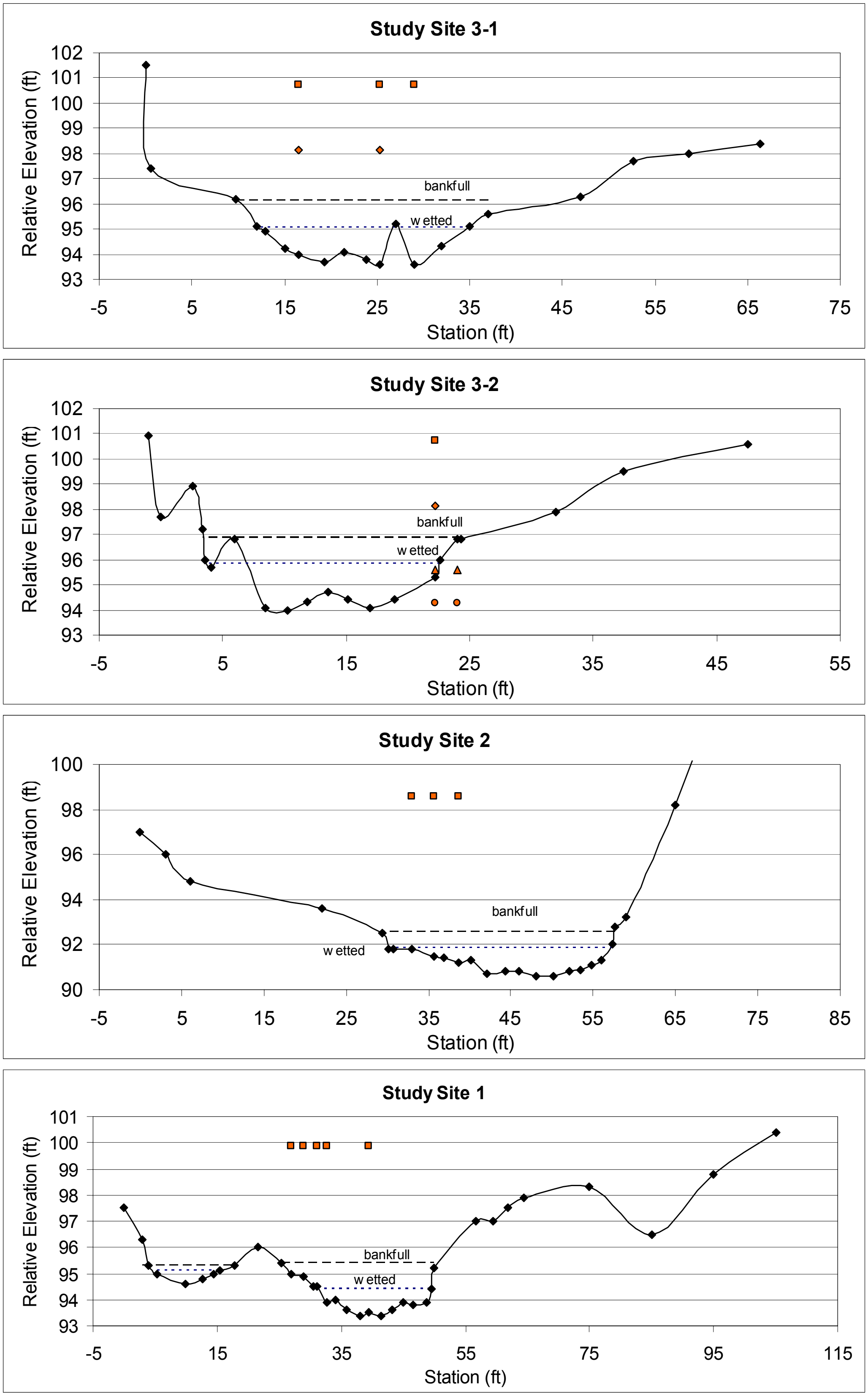


Figure 4.8 (cont'd.) – Cross sections and painted rocks remaining after 299 cfs flow release.
(Note: Painted rocks were placed across wetted transect; those remaining are noted with lines of orange symbols.)

4.4 Gravel Transport Calculations

A number of different gravel transport formulas have been developed to compute initiation of substrate movement and bedload transport rates in gravel-bedded rivers. Much of this work was done in alluvial rivers with pool/riffle profiles and gravel beds because these rivers have relatively uniform flow characteristics across the channel. Steep, boulder-bedded channels with cascades such as Lake Creek are very difficult to model because the large roughness elements result in non-uniform flow and turbulent eddies (Wohl 2000). Most transport and hydraulic formulas perform poorly in these conditions.

The Andrews equation was used to predict the depth of water necessary to initiate movement of gravel in the 0.5 in. to 4 in. size range, and the WinXSPRO software was used to estimate discharge at those stages (Table 4.4 and Appendix D). The equations were calibrated based on the depth at which movement occurred during the painted gravel study. However, it should be noted that little movement took place until the high flow event (299 cfs), when many of the rocks moved, so exact calibration was not possible. In addition, the depth of water at each of the painted gravel locations varied across the transect, so rocks in the deepest parts of the channel would be expected to move at discharges closer to those listed in Table 4.4, and rocks in shallower water or protected locations along the margins would be expected to move at higher flows.

Table 4.4 – Estimated water depth (ft) and discharge (cfs) to initiate gravel movement

Study Site	0.5-1 in. gravel		1-2 in. gravel		2-3 in. gravel		3-4 in. gravel	
4-1	1.1 ft	8 cfs	1.5 ft	33 cfs	2.0 ft	96 cfs	2.5 ft	204 cfs
4-2	1.0 ft	18 cfs	1.2 ft	35 cfs	1.5 ft	51 cfs	2.0 ft	118 cfs
4-3	1.9 ft	150 cfs	2.2 ft	240 cfs	2.4 ft	260 cfs	2.8 ft	350 cfs
3-1	1.5 ft	48 cfs	1.6 ft	60 cfs	1.8 ft	80 cfs	2.0 ft	100 cfs
3-2	2.0 ft	74 cfs	2.2 ft	85 cfs	2.5 ft	118 cfs	2.8 ft	150 cfs
2	2.3 ft	175 cfs	2.5 ft	205 cfs	2.8 ft	280 cfs	3.0 ft	311 cfs
1	1.5 ft	47 cfs	1.8 ft	90 cfs	2.2 ft	140 cfs	2.5 ft	184 cfs

The results presented in Table 4.4 vary considerably, and show the challenges of modeling sediment movement in step-pool streams with large roughness elements. In addition, since most of the gravel stored in the channel was not located in the center of the channel, but along the margins or behind large boulders or logs where hydraulic conditions were much different, the modeling results may not be the best tool to use to characterize sediment movement in Lake Creek and should be used with care.

4.5 Hydrologic Conditions

4.5.1 High Flows

Gravel transport occurs during high flows. Operation of the Packwood Lake Hydroelectric Project could affect transport of gravel through lower Lake Creek by controlling peak flow magnitude and frequency. Bankfull flow is approximated as 285 cfs based from the USGS statistic of the annual peak flow exceedance probability of 0.8 (USGS 1984); this is also approximately the flow that transports spawning-sized gravel in the center of many of the study transects in Lake Creek.

Instantaneous peak flows were reported by the USGS only until 1980. Therefore, in the following analysis of peak flows, the annual highest mean daily flow has been used. This allows analysis of the complete record of with-project hydrology through 2006. Please note that the annual highest mean daily flow is lower than the instantaneous peak flow; the absolute magnitude of the difference is dependent upon the shape and timing of the high flow hydrograph for each high flow event. The analysis that follows is based on flows just below the Project drop structure (USGS 14225500).

The highest peak flows in Lake Creek occur in the November-February time period (Figure 4.9). These correspond to high rainfall and/or rain on snow events. Moderate peak flow events occur in response to snowmelt, and occur in June and July.

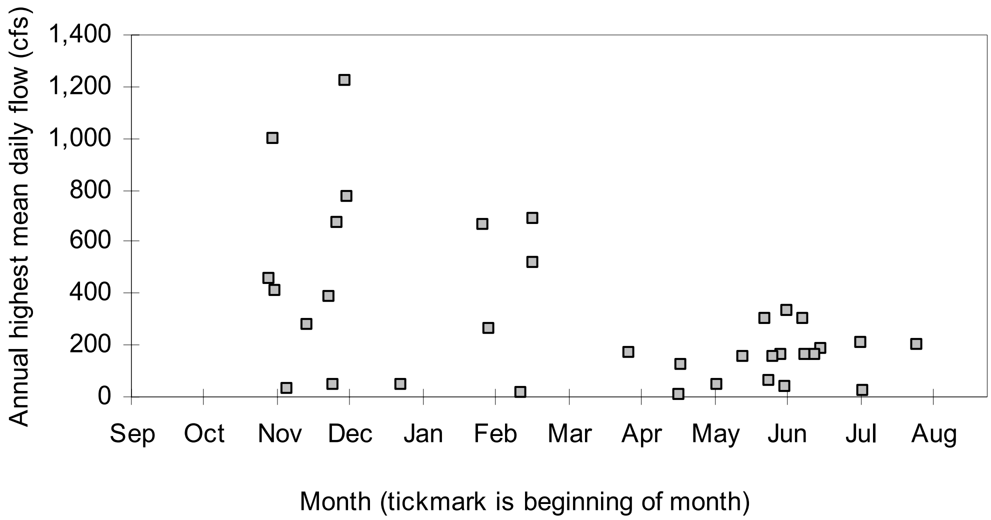


Figure 4.9 – Highest mean daily flow timing at Lake Creek near Packwood Gage (with project; 1965-2006).

An analysis of the effects of the Project on high flows (Figure 4.10) was made by comparing the magnitude of the annual highest mean daily flow for the period of record prior to the project (1912-1917, 1919-1924, 1931-1942, 1950-1954, 1960-1963) with the period of record with the project in place (1965-2006). While the best analysis of the effects of the Project would be to compare inflows to outflows at Packwood Lake, inflow data is not readily available for the entire period of project operation. A flood frequency analysis was not performed because of the relatively short period of record available for each period.

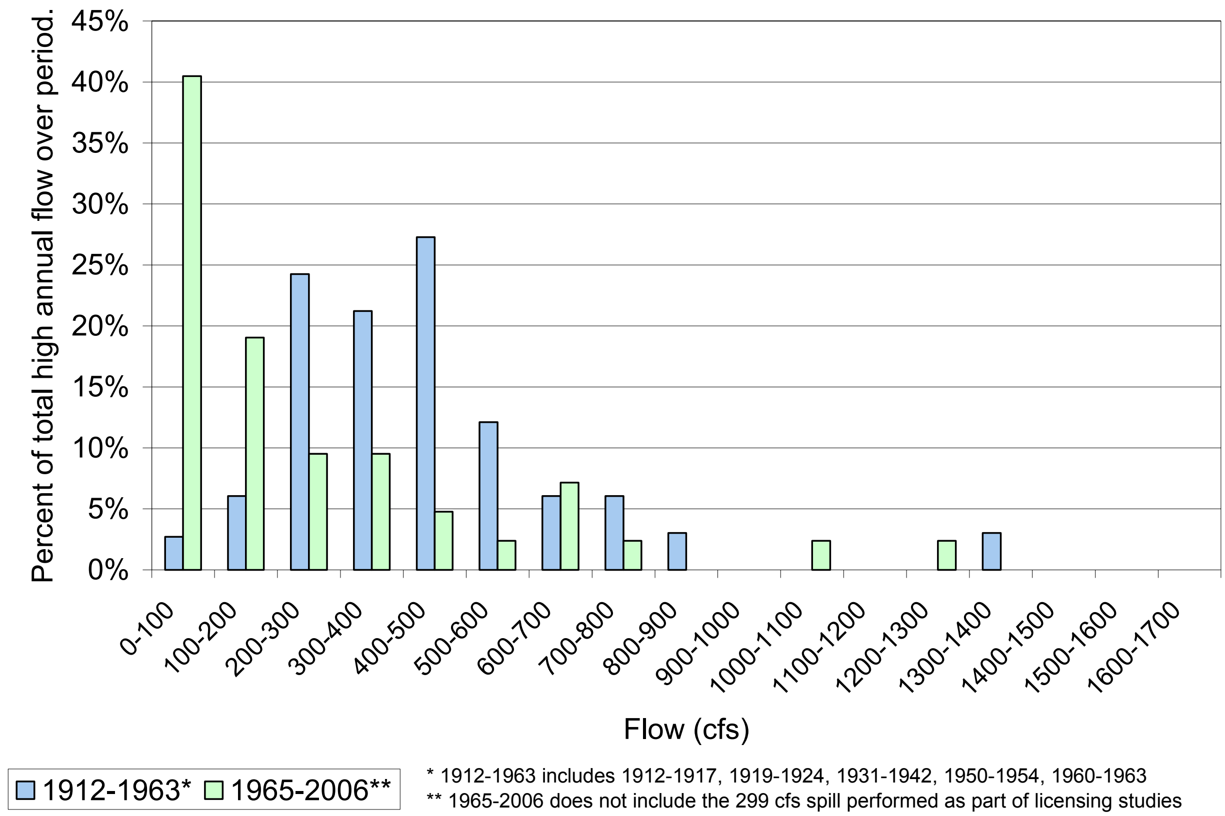


Figure 4.10 – Comparison of before and with Project annual highest mean daily flow, Lake Creek near Packwood Gage.

The majority (65%) of highest annual flows before the Project were between 200-500 cfs. During the with-Project period, 24% of the high flows were between 200-500 cfs. Sixty percent of high flows during the with Project period were between 0-200 cfs. Flows over about 600 cfs appear to have a similar frequency during the before and with Project periods, but these flows occur less frequently so a longer period of record is required to get results that are statistically valid.

4.5.2 Accretion between Packwood Lake and Mouth of Lake Creek

There is inflow from tributaries and groundwater in the 7.3 square mile drainage area between the drop structure and the anadromous reach in the lower mile of Lake Creek. The Hydrology Report provides a comparison of flows between the two USGS Gages (just below drop structure and near the mouth). Average annual inflow is 26.7 cfs; inflow varies by month from 8.6 cfs in September to 55.6 cfs in January (Table 4.5).

Table 4.5 – Average inflow between USGS Gages (cfs)

Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Ann
9.2	20.9	40.6	55.6	40.9	35.5	31.8	27.9	24.4	15.6	9.8	8.6	26.7

During large rainfall or rain-on-snow events that cause peak flows, accretion is presumably larger than during non-storm periods. Comparisons of instantaneous peak flow events for the few years when the USGS gage near the drop structure (drainage area 19.2 sq mile) and the gage near the mouth (drainage area 26.5 sq mi) were operating showed inflows of 32-500 cfs, with the lower inflows at lower flows (200-400 cfs) and higher inflows at higher flows (850-1,000 cfs). Inflows during peak flow events will result in higher flows and higher sediment movement potential at the transects in the lower, anadromous reach. Inflow is not measurably affected by Project operations.

4.6 Alterations to Lower Lake Creek Channel

Resource agencies, landowners, and long-time residents of Packwood were contacted to attempt to obtain information about any channel alterations that took place in lower Lake Creek. Contacts included: Energy Northwest staff, Washington Department of Fish and Wildlife, Menasha Timber Company, and Lonnie Goebel (Packwood Fire Chief and long-time resident). The majority of people contacted had no recollection or records of channel alterations in lower Lake Creek.

The only definitive information on channel changes found was provided by Energy Northwest. As part of the original license, five stream channel improvement structures were installed in the lower 100 feet of Lake Creek. These instream channel control structures were rock weirs constructed across the streambed to help control the creek grade and provide upstream passage for anadromous fish (letter dated 6/15/69 from MM Nelson, US Forest Service to Gordon M. Grant, FERC). Evidently the lower three weirs were buried or disturbed during WDFW debris removal projects following a peak flow event, but the remaining two weirs are still in place. No issues with upstream passage were noted.

Additional information on changes in lower Lake Creek include a reference to a channelized stream: "...noted that the lower sections of the creek (which flow through private lands) lack large woody debris and riparian vegetation. They also noted that this section of the creek had been channeled." (USFS 1997). No specifics on channelization were found.

Menasha Timber Company said that they had no information on channel changes, but noted that timber harvest was evident in the lower Lake Creek area downstream from the USFS boundary on the 1958 aerial photographs (personal communication, Menasha Timber Company 2006). The following information was observed on the 1958 photos:

- Harvest down to the creek in the Goat Rocks development area that appeared to be 15-20 years old
- Harvest with a 30-50 foot buffer between Goat Rocks and the USFS boundary that appeared to be 4-5 years old
- No skid trails were seen crossing Lake Creek

No evidence of recent channel alterations other than rip rap at the two bridge locations were noted during the gravel/large wood inventory. Alders that appeared to be 40-50 years old were growing down to the stream throughout the reach suggesting that any alterations pre-dated the trees (see photos in Attachment 1).

5.0 DISCUSSION AND RECOMMENDATIONS

Gravel is an important component of aquatic habitats because it provides spawning substrate for fish, and habitat for other aquatic organisms. The Forest Service has identified spawning-sized gravel, particularly in the lower mile of Lake Creek that anadromous fish use for spawning, as an important resource. The size of gravel used by fish varies by species, but the majority of anadromous fish (Chinook, coho, chum, steelhead) prefer gravel in the range of 0.5-4 inches; sea-run cutthroat trout prefer gravel between 0.2 and 2 inches in diameter.

Packwood Lake was formed by a large landslide that blocked Lake Creek approximately 1100 years ago (Swanson 1996). Packwood Lake is large and deep enough (452 acres and over 100 feet deep) that it traps all sand, gravel, and larger material that is transported into it from upstream sources. The only source of sand, gravel, cobble, and boulder to Lake Creek downstream of Packwood Lake is from tributaries, landslides, and erosion in the lower stream watershed. Operation of the Project does not change the trap efficiency of sand and larger particles in the lake.

Critical Question No. 1: What is the relative amount of spawning gravel and its longitudinal distribution in Lake Creek downstream of the drop structure?

Lake Creek downstream from Packwood Lake is a cobble/boulder bedded stream with a dominantly step-pool structure. An inventory of spawning-sized gravel between the drop structure and the confluence with the Cowlitz River found a total of 42,660 sq ft of gravel, with the highest concentrations in Reaches 2, 3, and 4 between RM 0.8-RM 4.9 (Table 4.1, Figures 4.2 and 4.3, and Appendix C). Based on visual observations during the inventory, the majority of gravel in Lake Creek was stored along the margins of the channel, behind large scale roughness elements such as boulders or logs, or upstream of log jams.

The highest concentration of gravel in the potential anadromous reach (downstream of RM 1.95) was between RM 0.8 and RM 1.06 where the channel changed from a confined, high gradient reach to a less confined, lower gradient reach and several tributaries provided gravel to the channel. There was less gravel in the lower 0.8 mile of Lake Creek or in the high gradient areas between RM 1 and 2.

Critical Question No. 2: What flows are necessary to transport spawning-sized gravel down Lake Creek from the drop structure to the mouth of Lake Creek at its confluence with the Cowlitz River?

Movement of the painted rocks placed at gravel study sites throughout the stream suggest that high flows (on the order of 250-300+ cfs) are needed to mobilize the largest-sized spawning gravels (3-4 in. diameter) across the entire channel width. Lower flows would likely mobilize smaller gravels if they occurred in the middle of the channel, but the majority of gravel is stored on the channel margins or behind boulders/logs, requiring the higher flows to be mobilized. The painted rock study suggested that flows of 250-300 cfs mobilized spawning-sized gravel in Reaches 1, 2, and 3. Higher flows appear to be needed to move the painted rocks in Reach 4, possibly because several of the study transects in this reach were wider and closely associated with log jams.

Critical Question No. 3: Do flows that transport spawning-sized gravel from the upstream reaches of Lake Creek maintain spawning gravel pockets in the lowest 1-2 miles of Lake Creek (the anadromous reach)?

During the approximately 16 cfs test release, a small percentage (0-12%) of painted rocks, all less than 2 inches in diameter, moved at the study transects. Five to 11 percent of the rocks moved at the transects in Reaches 1 and 2. After the approximately 35 cfs release, 0-31% of the painted rocks were gone from the test transects, with 8-12% of the rocks moved from the transects in Reaches 1 and 2. Following the 299 cfs spill, 91-95% of the painted rocks were gone at the transects in Reaches 1 and 2 and 89-45% of the rocks were gone at transects in Reaches 3 and 4. These test results suggest that flows less than approximately 35 cfs would mobilize smaller (less than 2 inch) gravel in the middle of at all the study transects (note that most smaller sized gravel was not stored in the middle of the channel but behind obstructions or along channel margins). At flows of 299 cfs, gravel of all test sizes (0-4 inches) was moved at all study transects. However, the study transects in Reaches 1 and 2 had the highest percentage of painted rocks missing.

The study results show relatively little instream spawning-sized gravel downstream of approximately RM 0.8. The painted rock study showed that at the low test flows (approximately 35 cfs and lower) painted rocks less than 2 inches in diameter moved from the middle of all study transects. At higher flows (299 cfs peak), rocks of all test sizes moved. However, fewer rocks (5-9%) were retained at the transects in Reaches 1 and 2 than at the transect in Reaches 3 and 4. These test results are consistent with the gravel inventory results; there is less gravel downstream of RM 0.8 than in Reaches 3 and 4. One hypothesis for the lower amounts of gravel downstream of RM 0.8 is that the Project has reduced the frequency of flows capable of transporting gravel, so gravel is being retained in upstream reaches (Figure 4.10). Another hypothesis is that channel conditions that favor gravel retention (log jams, large woody debris, large boulders) are not as frequent downstream of RM 0.8 (Figure 4.3) so that much of the gravel transported from upstream reaches during high flows is not retained downstream of RM 0.8. The latter hypothesis is consistent with the results of the painted rock study.

Critical Question No. 4 What are the project-induced change in magnitude and frequency of peak flows that are capable of transporting gravel in lower Lake Creek?

Operation of the Project affects the magnitude and frequency of peak flows that transport bedload material in lower Lake Creek. Under current conditions, flows over 200 cfs at the drop structure have occurred in 40% of the years since the Project has been operational and flows over 300 cfs have occurred in 30% of the years. Based on the hydrologic record prior to construction of the Project, flows over 200 cfs occurred in 92% of the years and flows over 300 cfs occurred in 70% of the years. If it is assumed that flows between 200-300 cfs are necessary to move the full range of spawning-sized gravel, gravel transport would likely occur in 70-92% of the years if the Project were not in place, and has occurred in 30-40% of the years since the Project has been operational.

Inflow in the 7.2 square mile watershed between the drop structure and the lower two miles of Lake Creek result in more frequent flows above 200-300 cfs in the anadromous reach, primarily during large storm events. It is possible that the more frequent high flows in the anadromous reach result in more movement of gravel than in upstream reaches. Operation of the Project has not changed the inflow characteristics in the drainage basin downstream of the drop structure.

6.0 SCHEDULE OF ADDITIONAL STUDIES

A re-inventory of gravel and large wood in Reaches 1 and 2 is scheduled to take place in the Spring of 2007. This will provide information on the effects of a large –magnitude (estimated 1,000 cfs at the drop structure) high flow on gravel re-distribution and retention in Reaches 1 and 2. The gravel transport report will be updated to include the results of that inventory in early Summer 2007.

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