PRELIMINARY DRAFT
LAKE CREEK
ANADROMOUS BARRIER ANALYSIS

2004

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EES Consulting

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SECTION 1: INTRODUCTION

In accordance with the Cowlitz River Project settlement agreement of August 10, 2000, anadromous fish are being reintroduced into the upper Cowlitz River above Barrier, Mossyrock, and Cowlitz Falls dams via the trap-and-haul of adults. The target species under this agreement are Chinook and coho salmon and steelhead trout. There are also plans to release cutthroat trout above the dams (City of Tacoma 2000). With this reintroduction strategy, there is the potential for these species to utilize lower Lake Creek. Because there are no current data on species utilizing either lower Lake Creek or the tailrace slough, Energy Northwest requested that EES Consulting conduct electrofishing, snorkeling, and/or spawner surveys to verify the presence and relative abundance of anadromous salmonids as well as rainbow trout, cutthroat trout, lamprey, and sucker (EES Consulting, 2005).

An integral part of the Lake Creek instream flow study is a physical habitat survey of Lake Creek in its entirety. An anadromous barrier (a 25 ft falls) exists at RM 1.9 and has been noted by the USDA Forest Service (1995) and Wieman (2004). Lucas (WDFW 1992) also identified this as the probable end of anadromous fish distribution and cited three independent surveys to support his conclusions including WDFW foot survey (1992), Bryant (1949) and Kray (WDW 1949) (as cited in Wieman 2004).

EES Consulting noted a chute/falls complex that has the potential to be a barrier to upstream migration of anadromous fish at RM 1.03. Energy Northwest, in consultation with EES Consulting, the tribes and natural resource agencies, discussed the feasibility of analyzing this chute against established, published criteria and evaluating its potential as an anadromous barrier. This report summarizes the results of this evaluation.

Three anadromous fish species that would attempt to migrate upstream in Lake Creek are spring Chinook and coho salmon and steelhead trout. Chinook and coho salmon have been observed spawning below the chute/falls complex in 2004; steelhead trout have not been seen to date (latest survey March 10, 2005).

SECTION 2: METHODS

EES Consulting surveyed the falls/chute complex at RM 1.03 at three separate flows. Lake Creek flows are regulated by the Packwood Lake Hydroelectric Project plus additional accretion to tributaries downstream. Measurements were taken of the barrier at base, middle, and high calibration flows for the Lake Creek instream flow study.

We took cross sectional measurements at lip (crest) of the falls/chute, in the middle section of the chute, and near the top of the chute. The longitudinal profile of the falls/chute complex was surveyed using a Topcon auto level and stadia rod and extended from the plunge pool at the base of the falls approximately 50 ft upstream of the lower end of the barrier.

Detailed photographs and a video were taken of the falls/chute complex at flows of 46 cfs, 25 cfs and 11 cfs as measured at the downstream gage (releases of 33 cfs, 13 cfs and 3 cfs at the outlet structure, respectively). Velocities were taken at the falls crest, mid-channel in the chute, and near the top of the chute.

2.1 Survey of Potential Barriers

There are numerous boulder cascades, turbulent cascades, multiple falls and chutes present in Lake Creek below the intake structure. A total of 11 falls and 23 chutes were noted by the USDA Forest Service (1993) during its survey, and these were verified by EES Consulting in 2004. A chute/falls complex located at RM 1.03 has the potential to preclude upstream passage of anadromous salmonids. This chute was evaluated by EES Consulting for Energy Northwest.

Upstream passage potential was analyzed for steelhead trout, the species with the greatest leaping ability among the anadromous fish present in the upper Cowlitz River system, as well as Chinook and coho salmon, which are known to utilize Lake Creek for spawning. The barrier was analyzed according to its height, horizontal distance, plunge pool exit conditions, crest depth and velocities, landing zone conditions and chute velocities ranging from flows of 3 cfs to 34 cfs as released from the project drop structure (i.e., flows at the barrier from approximately 11 – 46 cfs). EES Consulting then used the criteria established in Powers and Orsborn (1985), including leaping ability, to assess passage.

Several factors are important to evaluate when determining passage success at barriers: 1) the plunge pool (fish entrance zone); 2) landing conditions (fish exit zone) and the barrier itself (fish passage zone) (Powers and Orsborn 1985). White water and turbulence are also important to evaluate when assessing barriers. Jackson (1950) noted turbulence deflects a swimming fish from its course, causing it to expend energy resisting upwellings, eddies, entrapped air and vortices, which in turn make it impossible for a fish to use its swimming power effectively (Powers and Orsborn 1985). Factors influencing the fish entrance, passage and exit zones are summarized below and are derived from Powers and Orsborn (1985). Additional information was obtained from R2 and IA (2000).

Fish Entrance Zone

A good takeoff pool is essential if fish are to leap effectively to any height. If the turbulent pool conditions, created from the falling water impacting the shallow pool, prevent a good takeoff, a relatively low fall my act as a total barrier (Powers and Orsborn 1985). In addition, air bubbles are created by the mixture of air and water as the falling water impacts the surface and entrain large quantities of air. When this occurs, the leaping height attained by fish attempting to leap the barrier is much less than the recorded maximum at other passable falls because of the reduced attraction flow (Stuart 1964). As stated in R2 Consultants (2000), "A pool which is deep enough to absorb the falling water will result in the formation of a well-defined standing wave relatively close to the falls from which a fish can leap. A shallow plunge pool will result in highly turbulent conditions which produce difficult leaping conditions for fish. A shallow plunge pool will also result in the formation of the standing wave further downstream of the falls. This results in a greater leaping distance, since fish usually leap from the standing wave towards the barrier crest. In addition, the air bubbles created by the falls under these conditions greatly reduce the propulsive power of a fish's tail, resulting in smaller leaps (Stuart 1964). Aaserude (1984) concluded that two conditions should be satisfied to provide optimum leaping conditions in the plunge pools:

1. Depth of penetration of the falling water should be less than the depth of the plunge pool (turbulent pool conditions disorient fish and the standing wave is reduced and moved downstream).

2. Depth of the plunge pool must be >= the length of the fish attempting to pass (if the depth < length of fish, propulsive power of fish's tail may be reduced for leaping).

Stuart (1964) also states that the depth of the plunge pool should be at least 1.25 times the falls height in order to create optimal leaping conditions for fish. Any waterfall that is steep enough to accelerate flow to violent white water should be considered a total barrier to upstream fish passage (Powers and Orsborn 1985).

Fish Passage Zone

Analysis of Falls

One type of passage barrier is a falls. When the change in water surface elevation between pools exceeds the leaping height of the species in question, the falls is considered a barrier. For Pacific salmon and steelhead, the highest calculated leap from a level pool is 10.9 ft for steelhead. Falls where a change in water surface elevation is in excess of 11 ft can be considered a barrier (Powers and Orsborn 1985). Evans and Johnstone (1980) state that for natural bedrock falls, if the vertical drop is > 6 ft, it should be considered to be a barrier for salmon and steelhead without further study.

In many cases, the actual distance the fish must leap is greater than the vertical drop between pools. Unless the water is falling vertically, some horizontal component of the leap will be required for successful passage. Assuming that the plunge pool and landing conditions are satisfied, the following conditions assess passage at waterfalls (from Table 8, Powers and Orsborn 1985):

1. If the change in water surface elevation > the height the fish can leap, it is an elevational barrier.
2. If the change in water surface elevation < the height the fish can leap, two analyses can be conducted:
   a. If the horizontal distance from the crest to the standing wave > horizontal leap at the highest point of the leap, it can either be passable or a horizontal distance barrier. b. If the horizontal distance from the crest to the standing wave < horizontal leap at the highest point of the leap, it is passable.

Analysis of Chutes

Another type of barrier is a chute. Powers and Orsborn (1985) states that by definition, the flow must be supercritical down the chute (Froude number is greater than unity). At the start of the chute the flow will pass through critical depth and then into a transition zone of varied flow for some distance before uniform flow is established. If the chute length is shorter than the transition length required to reach normal depth, uniform flow cannot be attained.

The mean velocity of turbulent uniform flow in chutes can be expressed by the following equation:

$$V = (1.49/n)(R)^{0.67}(Sp)^{0.5}$$

where V = mean velocity (ft/sec), n = empirical roughness coefficient, R = hydraulic radius in ft and Sp = passage slope.

The n value for smooth bedrock is 0.025 – 0.030; the hydraulic radius was calculated by using the HYDSIM submodule of RHABSIM (by Thomas R. Payne and Associates), and the slope was calculated from the change in bed elevation and horizontal distance from the top to the bottom of the chute.

The conditions for analyzing a chute are listed below and come directly from Powers and Orsborn (1985), assuming that plunge pool requirements, landing conditions and depth of flow are sufficient.

Table 1. Chute conditions, given that plunge pool requirements, landing conditions, and depth of flow are sufficient (Powers and Orsborn 1985).

Condition		Result
1	If the Velocity of the water > Fish speed	Velocity Barrier
2	The velocity of the water < fish speed	
	Length of the slope > distance the fish can swim	Distance/velocity barrier
	Length of the slope < distance the fish can swim	Passable

Classification of Barriers

Powers and Orsborn (1985) assign a degree of passage difficulty rating (from 1 to 10, with 10 being the most difficult) that is independent of barrier height and velocity. The rating is based on the following assumptions:

1. The differential elevation and water velocities are within the swimming and leaping capabilities of the species in question.
2. At higher swimming speeds (> 9 ft/s) leaping is more energetically efficient than swimming (Blake 1983 as cited in Powers and Orsborn 1985).
3. Fish will be attracted to the area of highest momentum (flow *x* velocity) when migrating upstream; therefore, if multiple paths are present the fish may try to ascend the one with the highest attraction which will be created by the highest combination of drop, velocity, and discharge.
4. Turbulent flow (for white water) with surges, boils, and eddies make it difficult for fish to orientate themselves and make full use of their swimming power.

In the case of the barrier in question at RM 1.03, Powers and Orsborn (1985) would consider it a compound barrier, consisting of both a falls and chute.

Vertical Distance. According to Powers and Orsborn (1985), the curved trajectory of a fish leaping a falls can be best described as a projectile motion (see Figure 1, from Powers and Orsborn 1985). The leap can be divided into two components: vertical (y axis) and horizontal (x axis). Vertical distance represents the height a fish must leap in order to reach the top of the falls, and was calculated by subtracting the water surface elevation (WSE) of the plunge pool at each flow from the crest elevation of the barrier. The crest elevation is not always the highest elevation along the longitudinal profile, but the point which provided a resting area for the fish (R2 and IA 2000).

Horizontal Distance. The leap of a fish must be of sufficient length as to allow it to clear the horizontal distance between the plunge pool and the crest elevation. As stated by R2 and IA (2000), “This distance may be relatively short, such as at falls where water free-falls down to the plunge pool below. However, many bedrock waterfalls and most boulder cascades possess a steeply inclined face over which water flows at high velocities before striking the water. If the horizontal distance of a barrier is too long, then a falls which has a height which a fish can normally leap will still be a total barrier."

EES Consulting determined the horizontal distance the fish was required to travel by subtracting the position of the base of the falls from the horizontal position of the crest with the resting area.

Fish Landing Zone

When fish leap at waterfalls, often the landing conditions near the crest are such that the fish may be swept back by high velocities or unable to propel themselves in water depths less than their body depths, where they are not totally submerged. The following factors should be evaluated when assessing landing conditions:

1. The depth of flow where the fish lands must be equal to or greater than the depth of the fish (generally considered to be 1.0 ft for steelhead).
2. The velocity where the fish lands should be within the range of the sustained swimming speed for the species in question.
3. The velocity and depth should be analyzed under a range of fish migration flows (Powers and Orsborn 1985).

2.1 Fish Condition

The ability of a fish to leap and swim is dependent upon its condition. Powers and Orsborn (1985) distinguish three different coefficient of fish condition (C_{fc}) based on the following definitions (Table 2):

Table 2. Fish Condition (C_{fc}) (from Powers and Orsborn (1985).

C_{fc}	Fish Condition
1.00	Bright: fresh out of salt water or still a long distance from spawning grounds; spawning colors not yet developed.
0.75	Good: in the river for a short time; spawning colors apparent but not fully developed; still migrating upstream.
0.50	Poor: in the river for a long time; full spawning colors developed and fully mature; very close to spawning grounds

Figures 1 and 2 show the leaping ability of steelhead trout and Chinook and coho salmon with C_{fc} 1.00 and 0.75, respectively (Figures 7 and 8 in Powers and Orsborn 1985)). Table 3 shows the leaping and swimming capabilities of steelhead trout in excellent, good (from R2 and IA 2000) and poor conditions. Table 4 gives the leaping and swimming capabilities of Chinook and coho salmon (from Powers and Orsborn 1985). [*Note: per agency consultation with P. Powers, WDFW, fish condition should no longer be considered a factor influencing the ability of a salmon or trout to negotiate a barrier. As a result, the tables and figures are retained with C_{fc} values < 1.0 but are not used in the subsequent analysis*].

Table 3. Leaping and swimming capabilities for steelhead trout in excellent (bright) condition. Leaping and performance values assume that no air is entrained in the water (sources: Powers and Orsborn 1985; Bell 1990). Table from R2 and IA (2000).

Description	Excellent Condition $C_{fs} = 1.00$
Maximum Height, 80^{o} Trajectory	10.8 ft
Maximum Horizontal Distance, 80^{o} Trajectory	` 8 ft
Maximum Height, 60^{o} Trajectory	8.0 ft
Maximum Horizontal Distance, 60^{o} Trajectory	`19 ft
Maximum Height, 40^{o} Trajectory	4.5 ft
Maximum Horizontal Distance, 40^{o} Trajectory	`22 ft
Maximum burst swimming speed	26.5 ft/s
Maximum prolonged swimming speed	13.7 ft/s
Maximum sustained swimming speed	4.6 ft/s
Maximum swimming distance, water velocity = 10 ft/sec	83 ft

Table 4. Leaping and swimming capabilities for Chinook and coho salmon in excellent (bright), Leaping and performance values assume that no air is entrained in the water (sources: Powers and Orsborn 1985; Bell 1990).

Description	Excellent Condition $C_{fs} = 1.00$
Maximum Height, 80^{o} Trajectory	7.6 ft
Maximum Horizontal Distance, 80^{o} Trajectory	` 5 ft
Maximum Height, 60^{o} Trajectory	5.8 ft
Maximum Horizontal Distance, 60^{o} Trajectory	`13 ft
Maximum Height, 40^{o} Trajectory	3.2 ft
Maximum Horizontal Distance, 40^{o} Trajectory	`15 ft
Maximum burst swimming speed	22.4 ft/s
Maximum prolonged swimming speed	10.8 ft/s
Maximum sustained swimming speed	3.4 ft/s
Maximum swimming distance, water velocity = 10 ft/sec	62 ft

The burst speed of steelhead trout is given above for fish in excellent condition. It is important to note that the values of fish speeds suggested by Bell (1990) are for fish swimming in water without entrained air. When swimming in white water, the density of the water/air mixture will be reduced and detract from the propulsive power of the fish's tail, reducing its speed (Powers and Orsborn 1985).

SECTION 3: RESULTS AND DISCUSSION

3.1 Fish Condition

EES Consulting has observed many anadromous salmonids in both Lake Creek and the tailrace slough during 2004 (Chinook and coho salmon; see Lake Creek Spawner Survey report (EES Consulting, 2005) for details . All fish observed would have been classified as C_{fc} 0.50 (poor) in that they already had been in the river a long time and trucked to the Skate Creek Bridge in Packwood; all were in spawning colors or had begun to fungus-up; with many of them physically deteriorating; and all were on or within a mile of the spawning grounds. Fish condition, per agency consultation with

P. Powers of WDFW, should be excluded from the analysis. As result, all species will be analyzed as if in excellent condition (C_{fc} 1.00).

3.2 Description of Potential Barrier

This potential barrier is classified as a compound falls and complex chute. The barrier is composed completely of bedrock. It has a total height (Water surface elevation [WSE] of the plunge pool to WSE of the crest) of 9.32 ft as measured at the low flow release with an average gradient in the chute of over 41%. The upper half of this barrier is a very steep, narrow, twisting chute with measured velocities at the middle flow release of over 14 ft/s. The water is very shallow in the chute (< 0.5 ft), is fully entrained with air, and changes direction at the base, and there is a curved alignment of the chute (Appendix Photo A3). There is no resting area in the chute, nor is there a place for fish to re-orient themselves before attempting to swim or leap the chute. There is only one possible route through this compound barrier, although the chute has two flow streams. Figure 3 shows the bed profile and various WSEs of this barrier.

3.2 Passage Analysis

Photos of the chute at low, middle and high flows are included in Appendices A, B and C respectively.

Plunge Pool

Exit conditions for steelhead trout and Chinook and coho salmon can be considered good at all flows (see photos 1 in Appendices 1, 2 and 3, respectively). Although the surface of the plunge pool is highly turbulent, the depth of the pool is over 5 ft at the low flow and the depths increase with additional discharge (Table 5). Several smaller fish (approximately 12” in length) were observed attempting to jump into this falls, but were not successful.

Table 5. Depth of plunge pool at measured flows

Flow	Depth (ft)
Low	5.54
Middle	5.81
High	3.02

Vertical Distance

Steelhead salmon with C_{fc} 1.00 would be able to leap 10.8 ft at an 80^{o} angle (the angle with the highest leap). Chinook and coho salmon leaping in excellent condition would be able to achieve a leap of 7.6 ft since the lip of the falls immediately above the plunge pool is only. All species would be able to leap these falls.

Although the lip of the falls immediately above the plunge pool is only 4.3 ft in elevation above the plunge pool WSE, there is no resting or landing zone available at top of this falls. The water is fully entrained with air, reducing the propulsion effectiveness of the fish’s tail, reducing the effective speed of the fish. As defined by Powers and Orsborn (1985), a good fish landing (i.e., exit) zone would have velocities where the fish lands within the sustained swimming speed of that species. Table 6 summarizes velocity measurements taken at the falls crest. The minimum velocity (at base flow) was 8.30 ft/s, which exceeds the sustained swimming speeds of steelhead trout and Chinook and coho salmon in excellent condition (4.6 ft/s and 3.4 ft/s, respectively).

Therefore, the total vertical distance to be leaped would need to be 9.32 feet to clear both the falls and the chute. This vertical distance exceeds the leaping capabilities of Chinook and coho salmon in excellent condition. Although steelhead trout in excellent condition have the ability to exceep the vertical component of the barrier, consideration must be given to the horizontal component.

Horizontal Distance

As mentioned above, the lip of the falls immediately above the plunge pool is only 4.3 ft above the plunge pool WSE; however, there is no resting or landing zone available at top of this falls. Measured velocities exceed the sustained swimming speeds for steelhead trout and Chinook and coho salmon in excellent condition (as shown in Tables 4 and 5). In addition, the water is fully entrained with air, reducing the propulsion effectiveness of the fish's tail and the effective capabilities of the fish. The only way for fish to make it past the falls and the chute would be to leap the horizontal distance from the plunge pool at the bottom of the barrier to the top of the barrier (explanation of chute characteristics are given below).

This compound barrier consists of a falls, and complex chute. Although the total length of this barrier is approximately 55 ft in length, the portion of interest extends from the base of the falls to the crest elevation immediately above the chute. This portion of the barrier is 26 ft long. This value exceeds the maximum horizontal leaping distance (assuming a 40° leap) of 22 ft for steelhead trout in excellent condition and the maximum horizontal leaping distance for Chinook and coho salmon of 15 ft in excellent condition.

Table 6. Velocities (ft/s) at the lip of the falls at measured flows.

Flow	Velocity (ft/s)
Low	8.30
Mid	13.47
High	10.8 [1/]

[1/] Measurement not at same location do to safety concerns

The creek will stay within the bedrock channel at the falls over the range of flows expected in Lake Creek; therefore, there is not an alternative channel for fish migration (Figure 4).

Chute Conditions

Under all flow conditions, the upper half of this chute is steep and very narrow. Flow conditions in the chute ranged from measured velocities of 7.9 ft/sec at low flow to 14.08 ft/sec at middle flow. Velocities were so high at the high flow that they could not be effectively measured. However, using Equation 1 in Powers and Orsborn (1985), velocities would approach 25.3 ft/s using a Manning's n of 0.030 (Table 7).

As stated in Powers and Orsborn (1985), swimming speeds are predicated upon having depth of at least 1.0 feet for salmon and steelhead and there being no air entrained in the water. In this chute, water depth is approximately 0.4 – 0.5 feet in depth and the water is completely entrained with air (please see photos Appendix A 2 and 3; B 2; and C 2 and 3). The steepness of the chute as well as the high velocities can be observed in Appendix photos A- 4; B-3, and C-4. This portion of the chute is significantly entrenched (Figure 5).

Table 7. Velocities (ft/s) in the main portion of the chute at measured flows.

Flow	Velocity (ft/s)
Low	7.9
Mid	14.08
High	25.36[1/]

[1/] Not measurable; Velocity calculated from Equation 1.

None of the conditions required for fish to migrate this chute is present at this location. The depth of the water at the chute is less than 1.0 ft, so the fish's body is partially uncovered which reduces swimming effectiveness. The water is totally entrained with air (see photo C-2). Further, Powers and Orsborn (1985) state that any waterfall that is steep enough to accelerate flow to violent white water should be considered a total barrier to upstream fish passage. Because of these high chute velocities (> 9 ft/s), the fish would ascend this barrier by leaping (Powers and Orsborn 1985). However, there is no zone within the chute that would allow a fish to leap (depth of water inadequate; fully air-entrained water; turbulent white water associated with high velocities). The fish would need to leap from the plunge pool at the base of the falls to the crest elevation, a distance (26 ft) and height (9.3 ft) outside the leaping ability for all salmonids, including steelhead in excellent condition.

Crest Conditions

The crest of this barrier is approximately 7.2 ft in width. Average crest velocities were somewhat lower than those velocities noted in the chute and ranged from 4.8 ft/s to 7.0 ft/s (Table 8); however, even these exceed the sustained swimming speeds of steelhead trout and Chinook and coho salmon in excellent condition. Depths were sufficient for passage at all flows noted (i.e., they exceeded the minimum depth of 1.0 ft required for upstream passage). Figure 7 shows the cross-sectional profile of the crest, which can also be viewed in Appendix Photos A-4, B-3, and C-4.

Table 8. Velocities (ft/s) at the crest at measured flows.

Flow	Velocity (ft/s)
Low	4.84
Mid	7.59
High	7.01[1/]

[1/] Measurement not at same location do to safety concerns

SECTION 4: CONCLUSIONS

Based upon the results of this analysis, the compound falls/chute barrier at RM 1.03 on Lake Creek should be considered an impassible barrier to upstream migration to anadromous fish. This conclusion is based upon passage criteria for steelhead and Chinook and coho salmon in excellent condition. All the fish observed by EES Consulting during spawning surveys in Lake Creek and the tailrace slough indicate poor condition, so these estimates are conservative. The following conclusions can be made regarding upstream passage for steelhead trout and Chinook and coho salmon in excellent condition at the compound fall/chute barrier at RM 1.03:

The falls at the base of this compound barrier could be leapt by a steelhead and Chinook and coho salmon in excellent condition. There is no adequate landing zone at the crest of this falls, however, so that any fish landing here would be swept back downstream (velocities measured at base flow exceed the sustained swimming speed of steelhead, Chinook, and coho in excellent condition). The chute which flows into the falls presents a number of factors that when combined (i.e., inadequate depth, very steep, completely whitewater, highly turbulent, with velocities exceeding 14 ft/s at a release of 16 cfs at Lake Creek) would prevent all anadromous fish from successfully navigating the chute. At low flows, the water in the chute is still shallow and air-entrained, which would effectively negate the swimming speed of salmonids attempting to migrate up this barrier. At higher flows, the chute remains steep, highly air-entrained, shallow, and velocities exceed the burst swimming speeds of all species in good – fair condition.

The only way to clear this barrier would be to leap it, and the height (9.3 ft) and distance (26 ft) required exceeds the leaping ability of even steelhead trout in excellent condition. This barrier can therefore be regarded as a total barrier to upstream migration.

Although anadromous spawner surveys conducted in 2004 and 2005 are not conclusive, the results presented here are consistent with the surveys on Lake Creek conducted to date. Both Chinook and coho salmon have been observed migrating and spawning in Lake Creek. All spawning activity has been documented below this barrier at RM 1.03, although several of the surveys have extended upstream to nearly the previously-acknowledged barrier at RM 2.0 (Energy Northwest 2005). The area above this barrier also lacks spawning substrates of proper size, with the first substantial suitable substrates noted approximately 100 yards below this compound barrier. A Chinook redd was found at the site of this gravel bar, and no spawning activity has been observed upstream of this site.

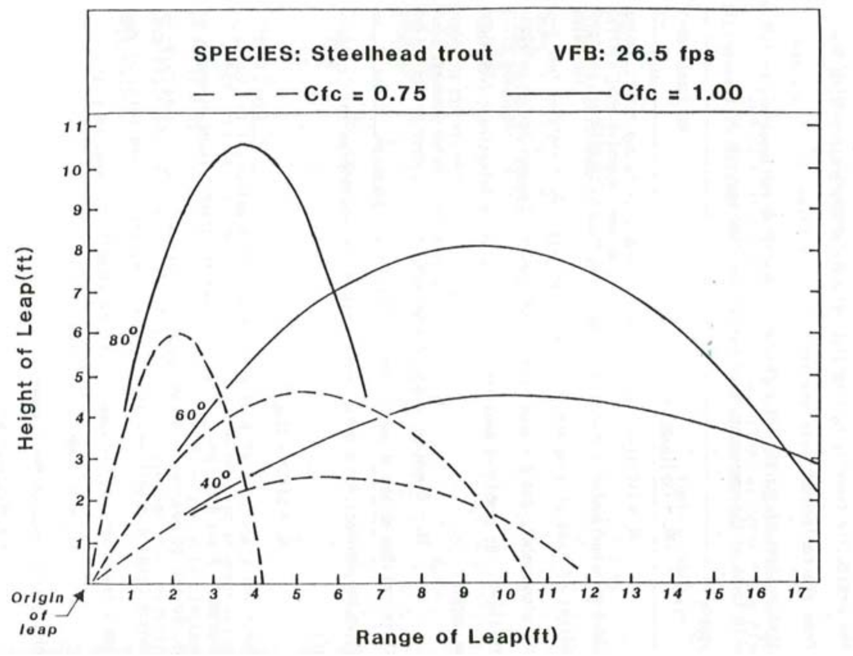


Figure 1. Leaping curves for steelhead trout (From Powers and Orsborn 1985; Figure 7)

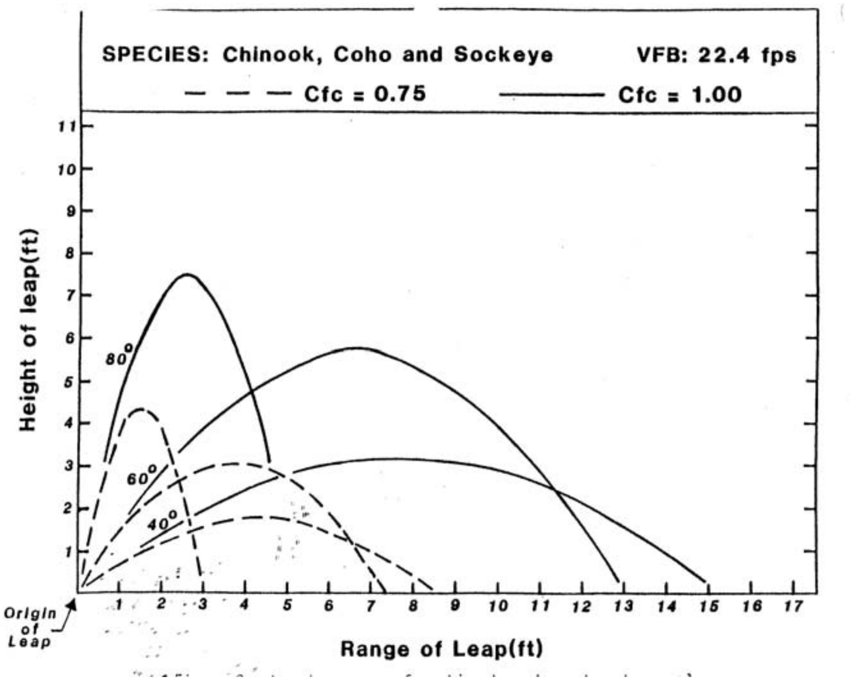


Figure 2. Leaping curves for Chinook and coho salmon (From Powers and Orsborn 1985; Figure 8)

Figure 3. Falls/Chute Complex at RM 1.03

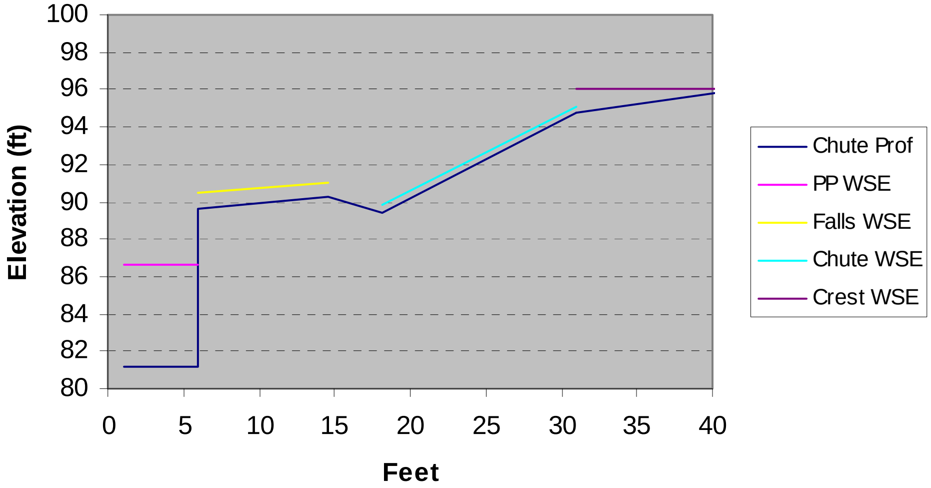
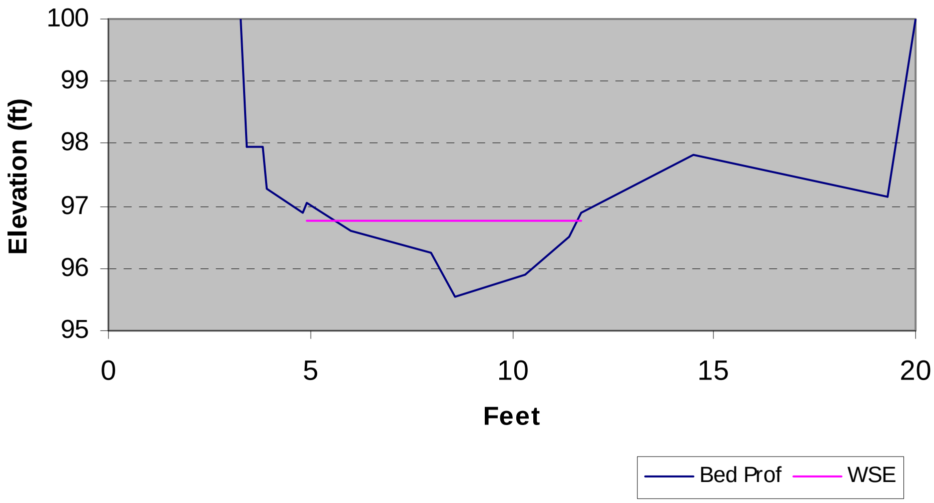


Figure 4. Mouth of Chute Profile



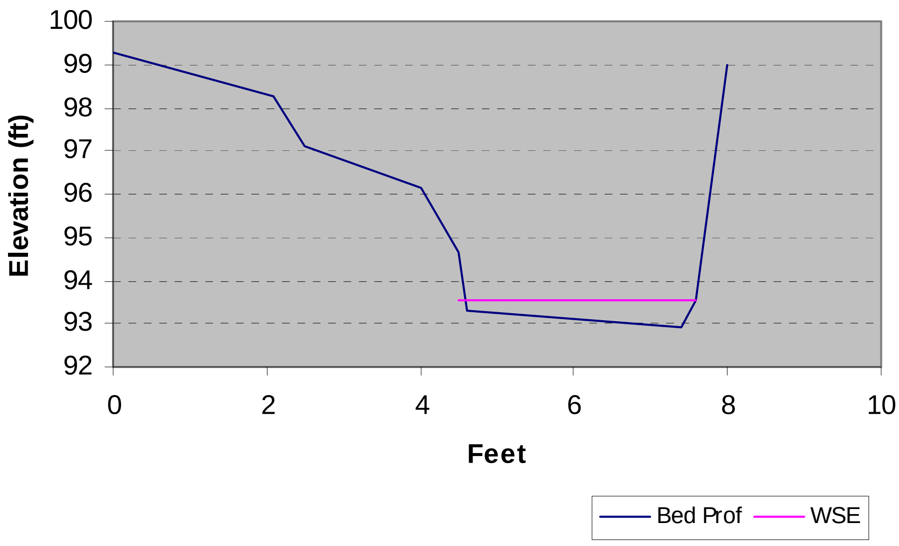


Figure 5. Chute Cross Sectional Profile - Middle Section

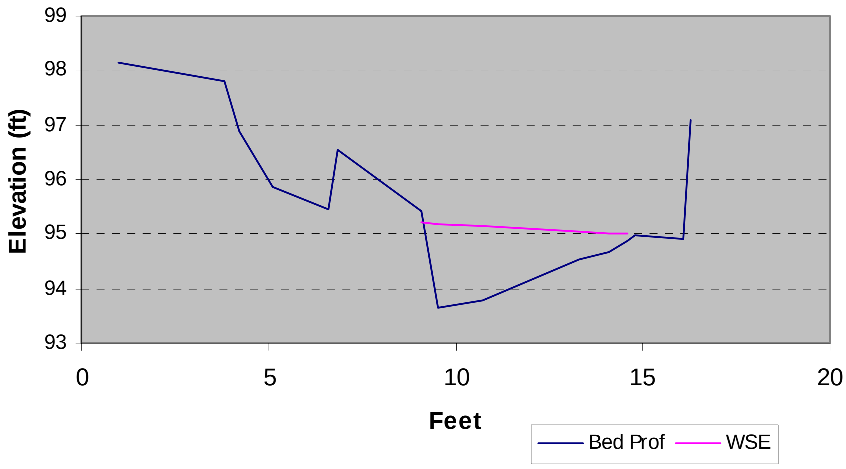


Figure 6. Chute - Top Profile

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APPENDIX A

COMPOUND FALLS/CHUTE BARRIER

LOW FLOW PHOTOS

Photo 1. Plunge pool and lip of falls at middle flow

Photo 2. Chute at low flow.

Photo 3. Mid chute complex, low flow.

Photo 4 Top of chute, low flow.

APPENDIX B

COMPOUND FALLS/CHUTE BARRIER

MIDDLE FLOW PHOTOS

Photo 1. Plunge pool and lip of falls at middle flow

Photo 2 Mid chute at middle flow

Photo 3. Top of chute at middle flow

APPENDIX C

COMPOUND FALLS/CHUTE BARRIER

HIGH FLOW PHOTOS

Photo 1. Plunge pool and lip of falls at high flow

Photo 2. Lower part of chute, high flow

Photo 3. Chute at high flow

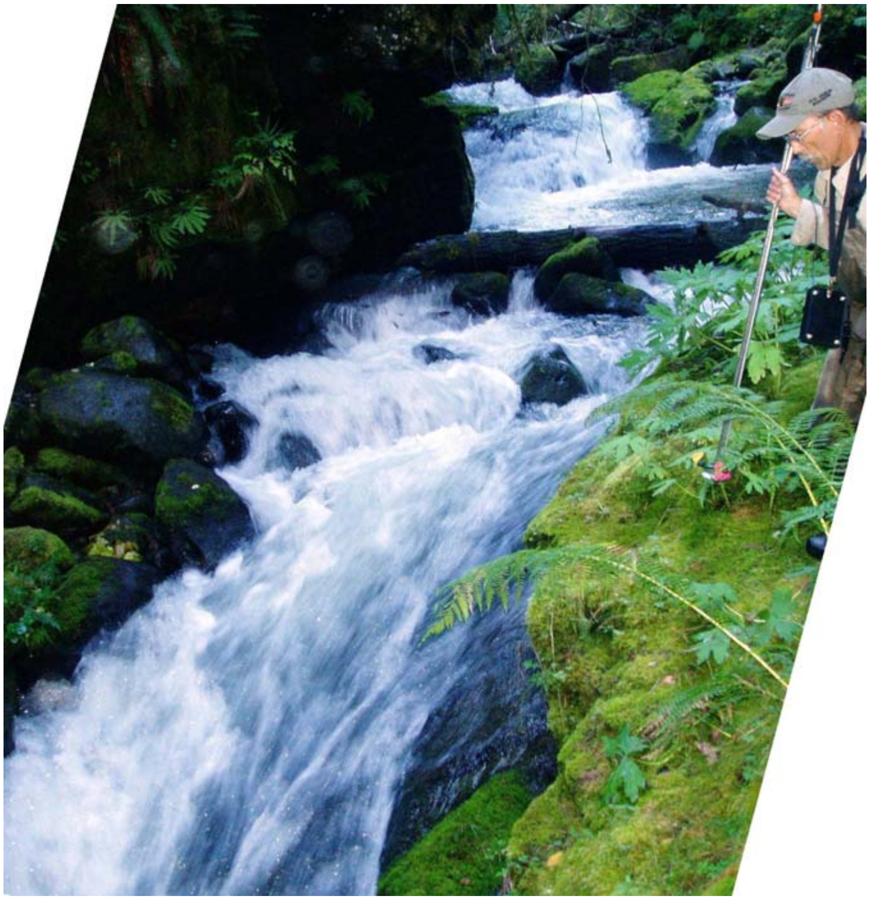

Photo 4. Top of chute at high flow