FINAL

Hydraulic and Sediment Transport Analysis of Dam Removal at Tokul Creek Fish Hatchery

US Army Corps
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Seattle District

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Purpose

The purpose of this project is to determine the impact on Tokul Creek from the removal of a low head dam (River Mile (RM) 0.41). Removing the dam will increase the likelihood of adult fish passage to approximately 0.6 mile of spawning areas upstream. This Hydraulics & Hydrology (H&H) study used hydraulic parameters to analyze the changes in the river's sediment transport capacity when the dam is removed. Using this analysis, impacts to primary areas of concern were determined.

Study Area

Tokul Creek is a tributary of the Snoqualmie River. The study limits are from the confluence with the Snoqualmie River, past the dam, to a natural fish passage barrier (waterfall) 6000 ft upstream (from RM 0.0 to RM 1.14). The creek bed is confined to a narrow valley that has a greater than 1% slope with large boulders scattered throughout the active channel. The channel is braided in areas of deposition (upper landslide area (RM 0.52) and is narrow and deep where confined (SR 202 Bridge (RM 0.56)). The river abuts the valley wall in many locations resulting in bank erosion and in some cases landslides. When the hatchery as it is today was built, a portion of the flood plain was armored with riprap and backfilled (Topo 1951, Washington Department of Fish and Wildlife (WDFW)). The study reach shows evidence of actively eroding, depositing, sorting, and transporting sediments ranging in size from fines to boulders.

The dam was constructed by WDFW in the 1950s to supply water to a fish hatchery just downstream of the dam on the right bank. The fish hatchery and water intake are still operational. The reservoir behind the dam has completely filled with sediment. From a 1951 WDFW drawing, it appears that a retaining wall approximately 20 feet in length forms the left-most section across the channel. It was backfilled and a large vegetated bar with large woody debris formed upstream of the wall. Visual observations and as-builts indicate that the base of the dam is grounded in the stream bed with H pilings and extensive concrete poured over large boulders.

There is a large scour hole downstream of the dam apron. Water cascades from the scour hole through what looks like large placed rock until reaching the flatter alluvial channel downstream. The WDFW 1951 as-builts for the dam show that riprap was placed from the apron downstream to form a sill for transition to the river bed. The large rock in the river downstream of the dam may be from displacement of this original rock as well as dislocated riprap from the bank stabilization. Fish can migrate only as far as the dam apron because the fish ladder constructed at the dam is inoperable.

Primary areas of concern are:

- SR 202 Bridge (RM 0.56)

The channel becomes narrow and deep at the bridge, indicating that it may be a hydraulic control. The banks are already eroding. There are two sets of piers; the old piers in the channel, and the new piers set back in the banks. A Washington Department of Transportation (WSDOT) bridge inspection report indicates the need for repair of sloughing at the new piers on the right bank (WSDOT, June 2003).

- Riprap above dam along SR 202 (RM 0.41 - 0.53)

Riprap exists on both left and right banks upstream and downstream of the dam. Large riprap extensively armors the right bank for approximately 1000 feet downstream of the dam and approximately 650 feet upstream of the dam almost to the SR 202 Bridge protecting the hatchery and SR 202. From WDFW drawings it appears that the riprap downstream was placed in approximately 1951. A 1968 WDFW drawing indicates that additional riprap was added upstream and downstream of the hatchery during this repair, but it does not account for the extensive riprap on the right bank upstream of the dam. Time of placement for upstream riprap is unknown.

- Upstream slide between dam and SR 202 Bridge (RM 0.52)

This slide is actively eroding. It consists of mostly sand with some cobbles and appears to be overloading the channel, causing some aggradation.

- Spawning area upstream of WSDOT slide (RM 0.25)

This area is adjacent to the recently repaired WSDOT slide. A gravel point bar exists on the right bank across from this area. This was an active slide and the spawning area may likely have been created in response to periodic sediment input. Due to the slide repair and the riprap on the hatchery bank, the creek is channelized and restricted through the slide area, which indicates an area of deposition may exist upstream of the slide.

Methods

To determine the impact of dam removal, it was necessary to look at sediment transport rates at existing conditions and with project conditions (dam removed). To generate the hydraulic parameters necessary for sediment transport calculations, the hydraulic model HEC-RAS 3.1 was chosen. Survey data provided the streambed profile and the cross sections for the model. Pebble counts provided the sediment distribution. A 2-yr storm event was used to compare the transport rates between scenarios. These methods were used to address questions about the specific area of concern:

- How will the removal affect the banks at the SR 202 Bridge?
- How will the riprap be affected?
- Will the removal result in additional erosion of upstream slide?
- Will the spawning area be filled in with larger gravel and cobble?

Field data Collection

- **Surveys**

USACE Seattle district contracted with APS Inc. to acquire channel and floodplain cross-sections in the study area. In all more than 45 cross-sections were surveyed from valley wall to valley wall. 1000 feet upstream and downstream of the dam was surveyed every 100 feet. Beyond this, cross sections were surveyed at approximately 250-foot intervals down stream to the confluence and upstream to the natural rock barriers. Total length of the survey was 1.14 miles. The cross section data was used to create a digital terrain model (DTM) of the site.

- **Pebble Counts**

Four surface pebble counts were taken by USACE at key study areas: a spawning area near the WSDOT landslide (RM 0.25), just upstream of the dam (RM 0.42), at the 1st bend upstream of the dam (RM 0.46), and at the toe of the landslide upstream of the dam (RM 0.52). Two to three samples were taken in strips ranging from 50 ft to 100 ft long at each site. The samples were averaged to get a representative grain size distribution for the area. The sediment distribution is presented in Table 1.

Cross Section	D30	D50	D65	D90
WSDOT slide (spawning area) RM 0.25	0.25″	0.5″	1.5″	10″
Dam RM 0.41	3″	5″	6″	12″
1st Bend u/s of dam RM 0.42	3″	6″	8″	15″
Upstream Slide RM 0.52	4″	6″	8″	18″

Table 1. Sediment Distribution.

In the "spawning area" (a large pool of slack water at low flow) the measured average grain size was much smaller (D65 = 1.5″) than that of the other three pebble counts (D65 = 6″ - 8″)). The sample was taken at very low flows (November 2003 93 cfs) and was probably not a good representation of the complete cross section. Visual inspection indicated that the bottom of the pool for the ~30 feet in the middle of the 100 ft sampling strip -is sandy like the rest, just too deep to sample. The gravel bar on the right bank contains pebbles similar in size to the area above the dam (D65 = 6″)(visual observation, L. Melder).

- **Discharge Measurements**

H&H staff made two site visits to conduct velocity profiles. In June 2003, upstream of the Fish Hatchery Bridge (RM 0.094), the discharge was approximately 40 cfs and the average velocity was approximately 1.21 fps. In November 2003, at the Fish Hatchery Bridge (RM 0.09) the discharge was approximately 93 cfs and the velocity was approximately 3.04 fps.

Hydrology

- **Flood Frequency**

To evaluate the sediment transport capacity of Tokul Creek both before and after dam removal, it was necessary to estimate the magnitude and frequency of peak discharges and to estimate the channel forming flows. Tokul Creek is now an un-gaged creek, but historical data exists from a USGS gage in place from 1914 through 1945 (USGS). Also presented are a flood frequency curve developed by the United States Army Corps of Engineers (USACE) and the as-builts for the SR 202 Bridge (USACE 1979, WSDOT 1983). In December 2001, GeoEngineering conducted a hydrologic and hydraulic analysis and compared Tokul Creek to the Raging River, a river of similar drainage area (GeoEngineering, 2001). They evaluated the hydrology with two widely recognized procedures: the USGS Regression Equations and the Log Pearson III distribution. Dr. Catherine Petroff presented an analysis using depth-duration-frequency curves to estimate peak stream flows (Petroff, 2003).

A comparison of analyses is presented in the Table 2. The 2 to 5 year flows are considered to be the channel-forming flows and could have the most effect on sediment movement downstream. Based on the comparison, an average of 1000 cfs was chosen as the flow to use in the hydraulic modeling.

Recurrence Flows (yrs)	Tokul Creek USGS Regression Equation (GeoEng, 2001)	Tokul Creek Log Pearson III (using Raging River, GeoEng, 2001)	Tokul Creek USACE Flood Frequency Basin 32.2 sq mi (1973)	Tokul Creek Dr. Petroff 2003	WSDOT Hwy 202 As-Builts 100 year flood (1983)	Taylor Creek USACE Flood Frequency Basin 17.2 sq mi (1987)	Raging River USACE Flood Frequency Basin 30.6 sq mi (1990)	North Fork Snoqualmie River USACE Flood Frequency Basin 64 sq mi	North Fork Tolt River USACE Flood Frequency Basin 39.9 sq mi (2000)
1			590			230	740	2600	2000
2	**727**	1900	**960**	**1297**		**860**	1900	7000	4800
5			1175			1400	2700	11000	6500
10	1279	3534	1300	1765		1800	3250	13000	7600
25	1565	4523	1450			2400	4000	16000	9000
50	1829	5334	1550	2300		2800	4600	18000	10000
100	2049	6211	1600		2100	3400	5250	21000	11000

Table 2. Comparison of Hydrologic Data.

- **2-yr Hydrograph**

For sediment transport calculations, a storm duration was needed. From the recorded USGS flows, several storm events were compared and a typical hydrograph shape was chosen. It was scaled to represent the peak flow of 1000 cfs. The duration of this typical hydrograph was 4 days: Day 1 and 4 at 500 cfs, Day 2 at 1000 cfs and Day 3 at 700 cfs. This represents a typical 2-year storm event and was used in the calculations for sediment transport capacity.

Hydraulics

- **HEC-RAS, GeoRAS**

To aid in the prediction of how the creek will respond following dam removal, a 1-dimensional backwater model was constructed from the surveyed cross sections using HEC-RAS 3.1. HEC-GeoRAS was used to spatially reference the cross section data and topography, and to generate the input geometry for HEC-RAS. The existing condition model includes cross sections of the dam (RM 0.41) and of the two bridges: Fish Hatchery Road (RM 0.09) and SR 202 (RM 0.56). The Fish Hatchery Road Bridge has an impact on floodplain flow and was modeled explicitly with the HEC-RAS bridge modeling routines. SR 202 spans the channel but old freestanding bridge piers constrict the channel. The constriction is represented in the cross section geometry. Although the bridge is not modeled formally, cross sections are included at the same location where cross sections for formal modeling of the bridge would be needed, energy loss coefficients are increased, and ineffective flow areas are added to simulate the velocity shadow of the piers on flow. Representative average Manning's n-values were initially estimated at 0.04 and 0.065 for the channel and floodplain respectively. The 0.04 channel n-value resulted in frequent model instabilities and was increased to 0.065 to restrict computation of critical depth to locations where it was observed or expected. This is at the high end for channel n-values for streams of this type (steep, bouldery) but not unreasonable. Floodplain n-values were not adjusted.

- **Scenario Profiles**

Three dam removal scenarios were investigated. The basis for the scenario development is as follows:

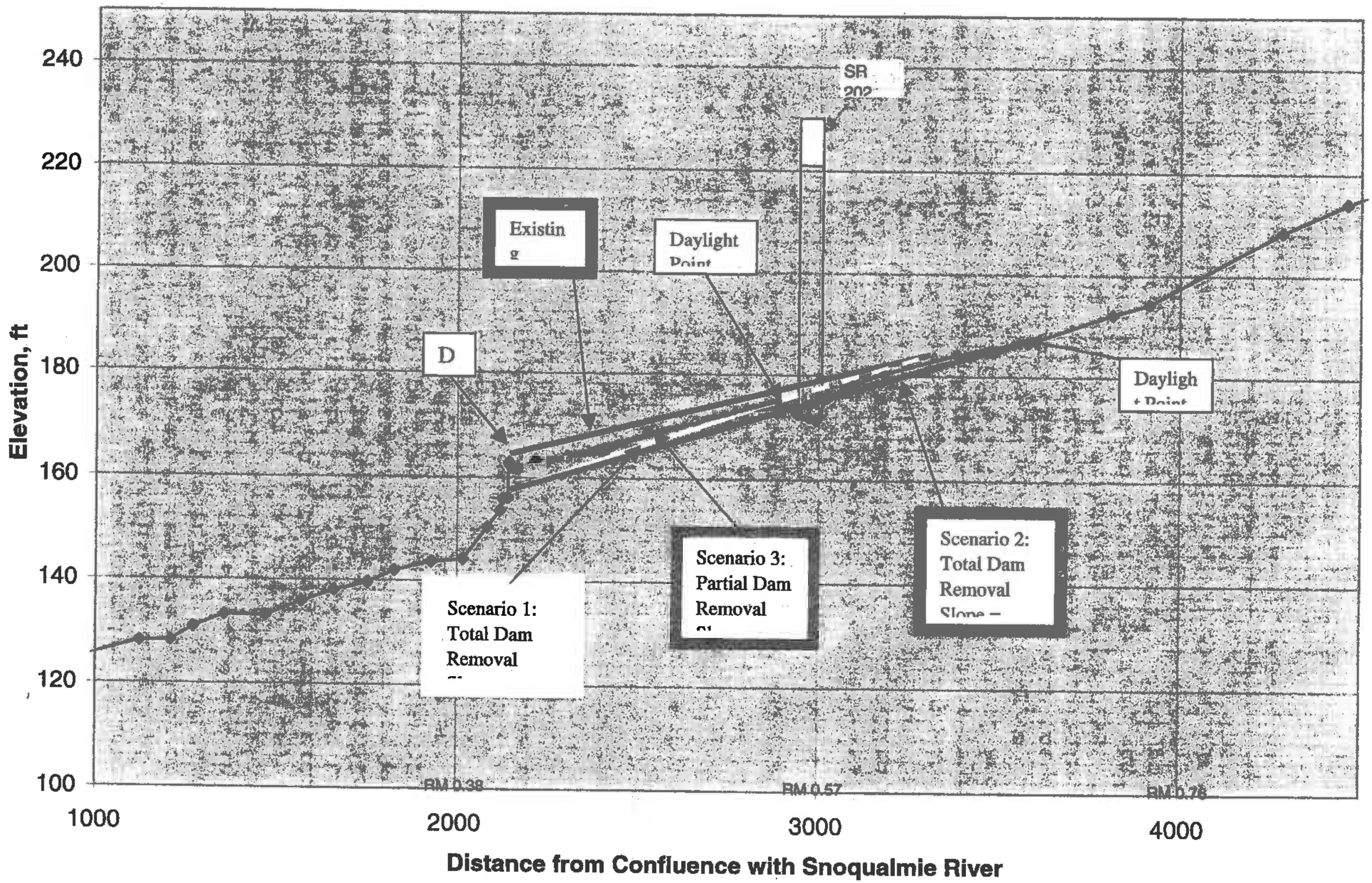
De-constructing the dam eliminates a structural control that has caused decades of deposition behind the dam to the point that the reservoir is now completely filled and the channel slope has become less steep upstream of the dam. De-construction of the dam (removal) will rapidly increase the slope of the water surface in the vicinity of the dam. The local acceleration of water will increase its kinetic energy, resulting in increased forces imparted on the streambed deposits. Stored sediments above the former dam site will adjust to the changed hydraulic conditions. This adjustment will likely be erosion of material incapable of maintaining a stable configuration following dam removal. In areas with course alluvium, the length of the headcut propagation is shortened by the availability of larger stable streambed materials that resist movement and "armor" the streambed. The channel should have two armor layers in the reservoir aggradation zone. The top armor layer is what presently exists on the surface. The bottom armor layer is the historic channel bottom. Erosion into the historic armor layer is possible but not anticipated. It is expected that the channel may regrade back to its historic elevation following dam removal by scouring away deposited materials. Unless subsurface explorations can be taken upstream of the dam it is not possible to know exactly where the historic channel is located, and thus the ultimate extent of erosion.

The with- project scenarios are **assumptions** about how the channel regrades and the resulting shape of the channel cross-section. The scenarios are based on:

- the scour hole at the SR 202 Bridge
- the existing stream slope
- breaks in the existing stream slope
- graphical estimates of pre-dam stream slope
- the vertical extent of dam removal
- an assumption of trapezoidal channels and stable side slopes

Choosing a daylight point for the extent of erosion was based on existing conditions and the streambed profile. Looking at the creek profile from the dam (RM 0.41) upstream through the SR 202 Bridge (RM 0.56), a pre-dam slope would have been greater than the existing slope (1.45%)(Figure 1). One possible daylight point was chosen at the riffle below the tail-out of scour pool just downstream of the SR 202 Bridge. Graphically, a line from the base of the dam through this point aligns with the slope of the creek just upstream of the bridge (Figure 1). This point is approximately 750 feet upstream of the dam at RM 0.55. Another possible daylight point was chosen further upstream where the channel gets significantly steeper (Figure 1). This point is approximately 1500 feet upstream of the dam and 650 feet upstream of the bridge at RM 0.68.

Figure 1: Profile of Tokul Creek Thalweg



The scenarios involved total and partial removal of the dam. The dam crest (elevation 162.2 ft) is approximately 6 feet above the apron. Total removal was modeled with cross sections reflecting the removal of the three sections of the dam, the retaining wall, and all apron thrust blocks to the apron elevation of 156.2 ft. Vertical wall abutments at the intake structure remain. As a first phase of a total removal, partial removal implies just the top 3 feet of the dam were removed with cross sections reflecting an elevation of 159.2 across the crest. Although partial dam removal may not allow fish passage upstream, this two-phased approach with total removal at a later time will increase the likelihood of fish passage. This alternative could control erosion and provide a lower impact from sediment loading to the downstream reach. Partial removal may also allow an interim look at the upstream effect on the creek in areas such as the reach with the riprap above the intake structure and the slide upstream of the first bend. The cross sections upstream of the dam were modified to reflect the type of dam removal and the daylight point for extent of erosion. The hydraulic conditions presented are as dependent on the ultimate shape of the cross section as they are on the slope of the streambed following dam removal. For purposes of this study it is assumed that the condition of greatest change from the existing condition would resemble a narrow trapezoidal channel with steep side slopes (Figure 2). The width of the channel is controlled by the stability of the existing side slopes. In areas with riprap this side slope is assumed to have a maximum side slope ratio of 1.75 to 1 (horizontal distance to vertical distance). This limits the maximum bottom width of the eroded channel to approximately 30-35 ft. Near the bridge the channel was narrowed to a bottom width of approximately 20 ft. Side slopes were assumed to be no steeper than 1.5 to 1 (riprap at toe). Bank erosion is not considered. As the channel erodes back, the initially steep stream slope will begin to flatten and match the upstream reach slope as it encounters areas with a greater supply of course alluvium (cobbles and boulders). In reality, this configuration would result in unstable banks that would erode and deposit sediment on the bed. The more erosion and deposition the wider the channel would become. It is possible that the channel configuration could ultimately resemble the existing configuration given time to adjust to the changed conditions.

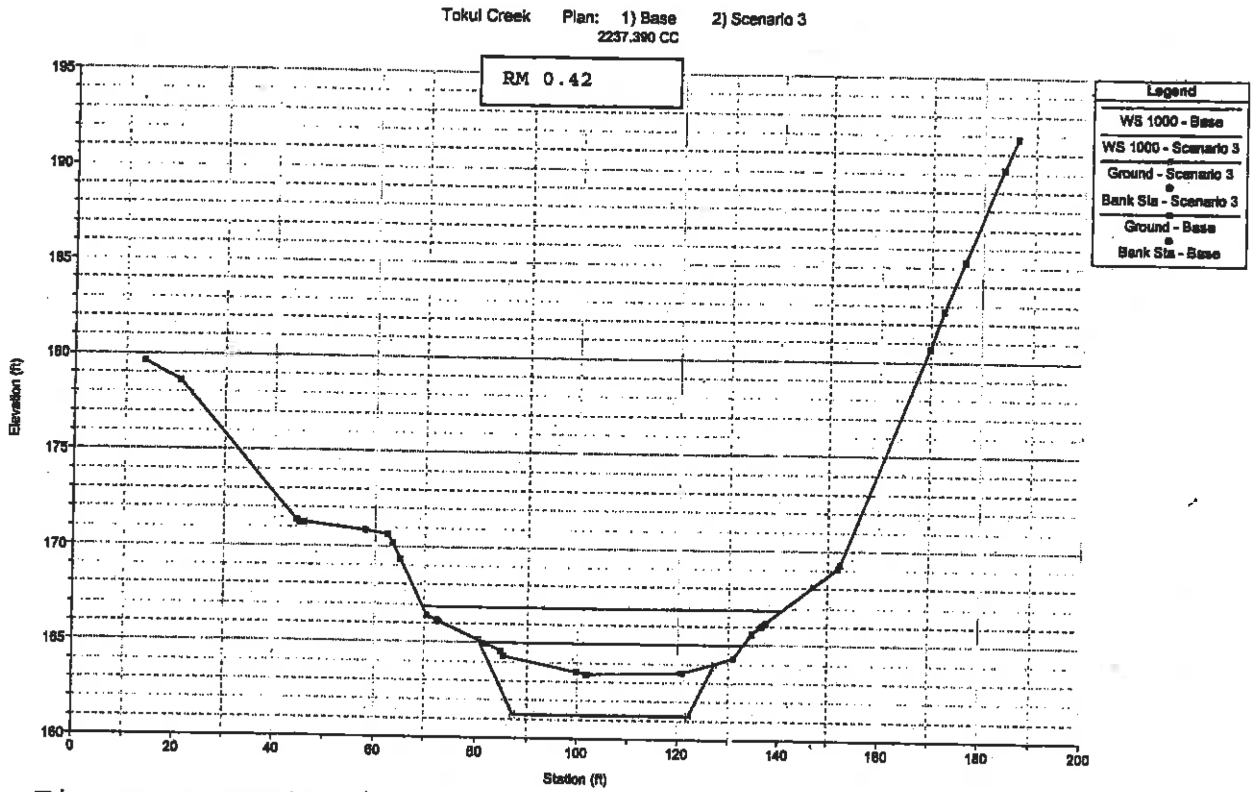


Figure 2: Typical cross section changes for removal scenarios (RM 0.42 approximately 100 feet upstream of the dam).

Scenarios 1 and 2 involve total removal of the dam to the apron elevation. The difference is in the extent of the erosion. Scenario 1 reflects erosion through the dam deposits for 750 feet upstream at a slope of 2.35% (Figure 1). Scenario 2 reflects erosion through the dam deposits, past the bridge for 1500 ft upstream at a slope of 2.1% (Figure 1).

Scenario 3 reflects the partial removal of the dam, with erosion through the dam deposits for 750 feet upstream of the dam (Figure 1).

For ease of comparison between the existing and scenarios, the 2-year channel-forming discharge, 1000 cfs, was used in the hydraulic modeling.

Scenario 1:

See Figure 3. It was assumed that the channel would regrade at a slope slightly steeper than existing, and daylight at a point 750 ft upstream. This coincides with the assumed daylight point of the historic channel. To form this channel, 9,100 tons of material would have to erode and be transported downstream (Table 3).

	Slope	Extent	Tons of material cut
Existing	1.45%		
Scenario 1	2.35%	750 ft	9100
Scenario 2	2.1%	1500 ft	15750
Scenario 3	1.85%	750 ft	5175

Table 3. Comparison of Scenarios to Existing Condition

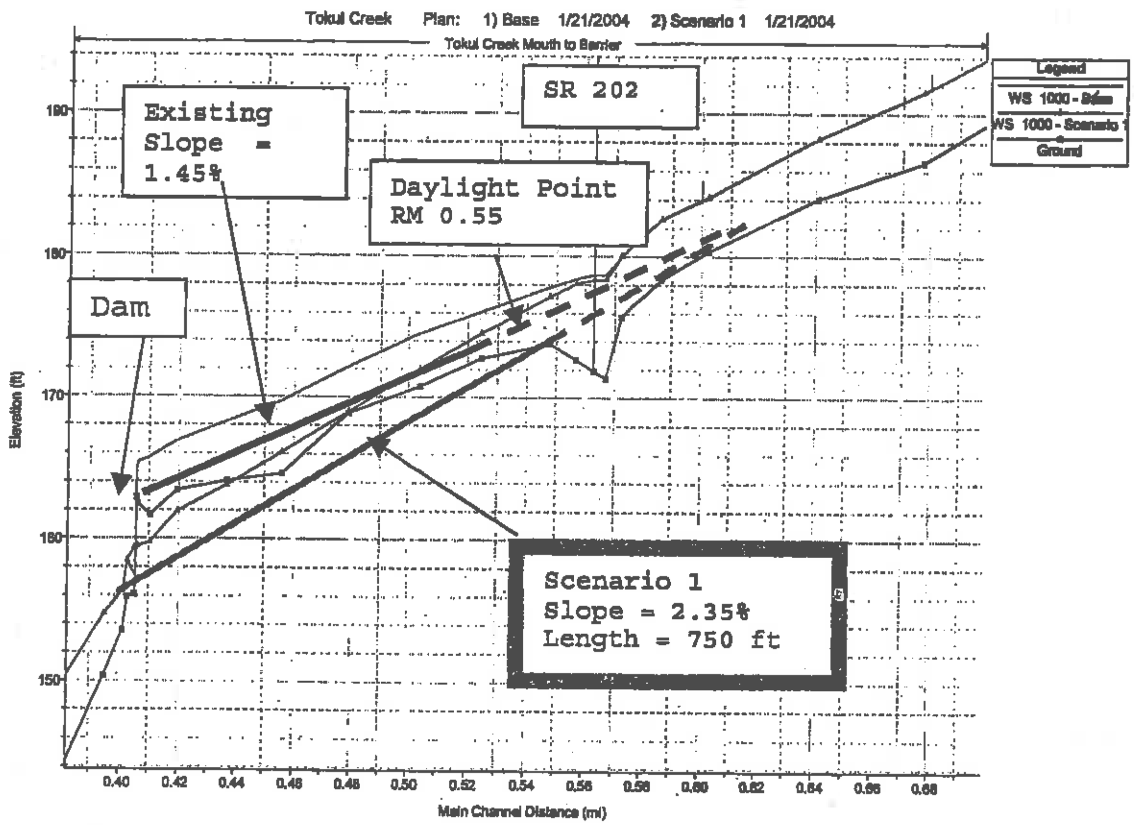


Figure 3: Scenario 1 Channel re-grade profile

Scenario 2:

See Figure 4. The erosion was assumed to propagate past SR 202 and the scour pool until it daylights near a point where the channel slope gets significantly steeper (about 1500 ft upstream of the dam). To form this channel, 15,750 tons of material would have to erode and be transported downstream (Table 3).

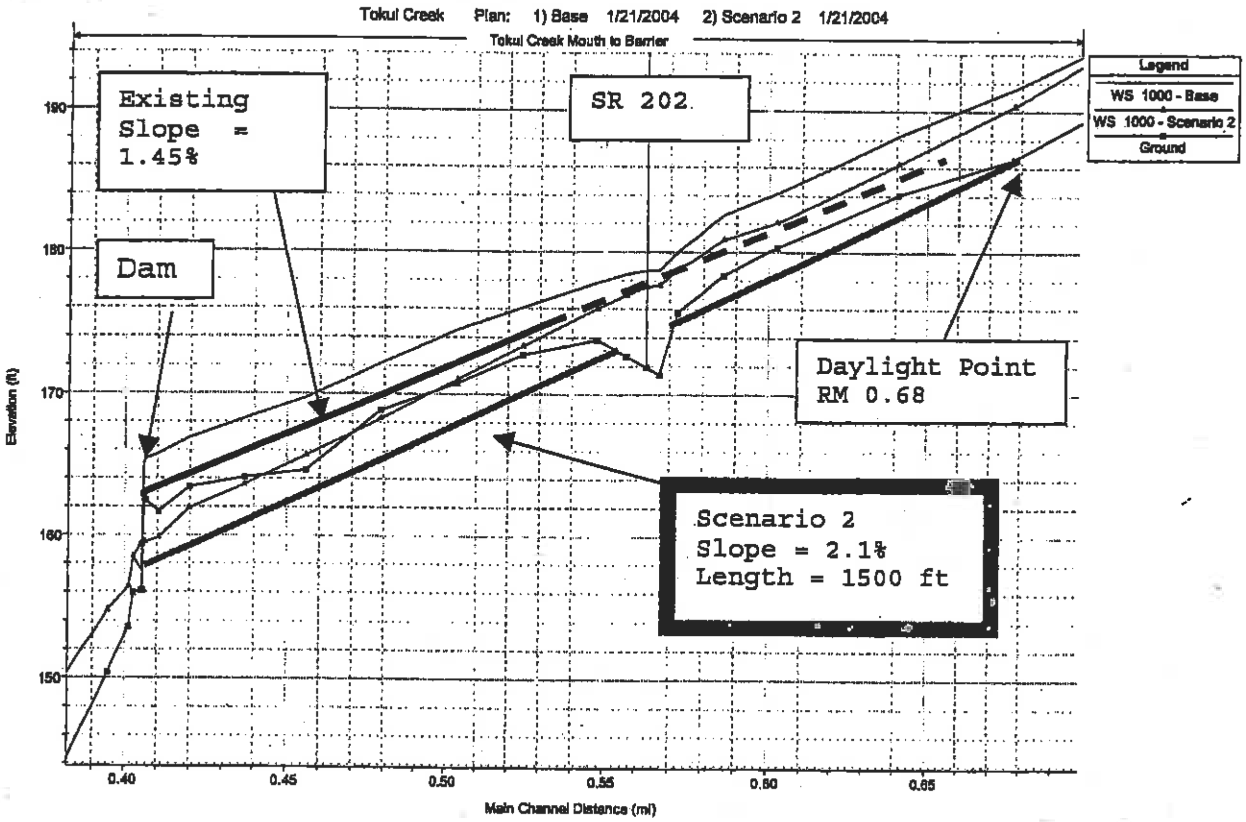


Figure 4: Scenario 2 Channel re-grade profile

Scenario 3:

See Figure 5. The channel was assumed to regrade at a slope slightly steeper than the existing, and daylight at a point 750 ft upstream. To form this channel, 5,175 tons of material would have to erode and be transported downstream (Table 3). Scenario 3 is assumed to erode back to the same location as Scenario 1; however, it may daylight at the 1st bend (RM 0.46), 250 ft upstream of the dam (Figure 5). It is possible that this could be the maximum extent of upstream erosion. This scenario may not allow fish passage upstream of the dam, but it may represent the first phase of a 2-phase complete dam removal project.

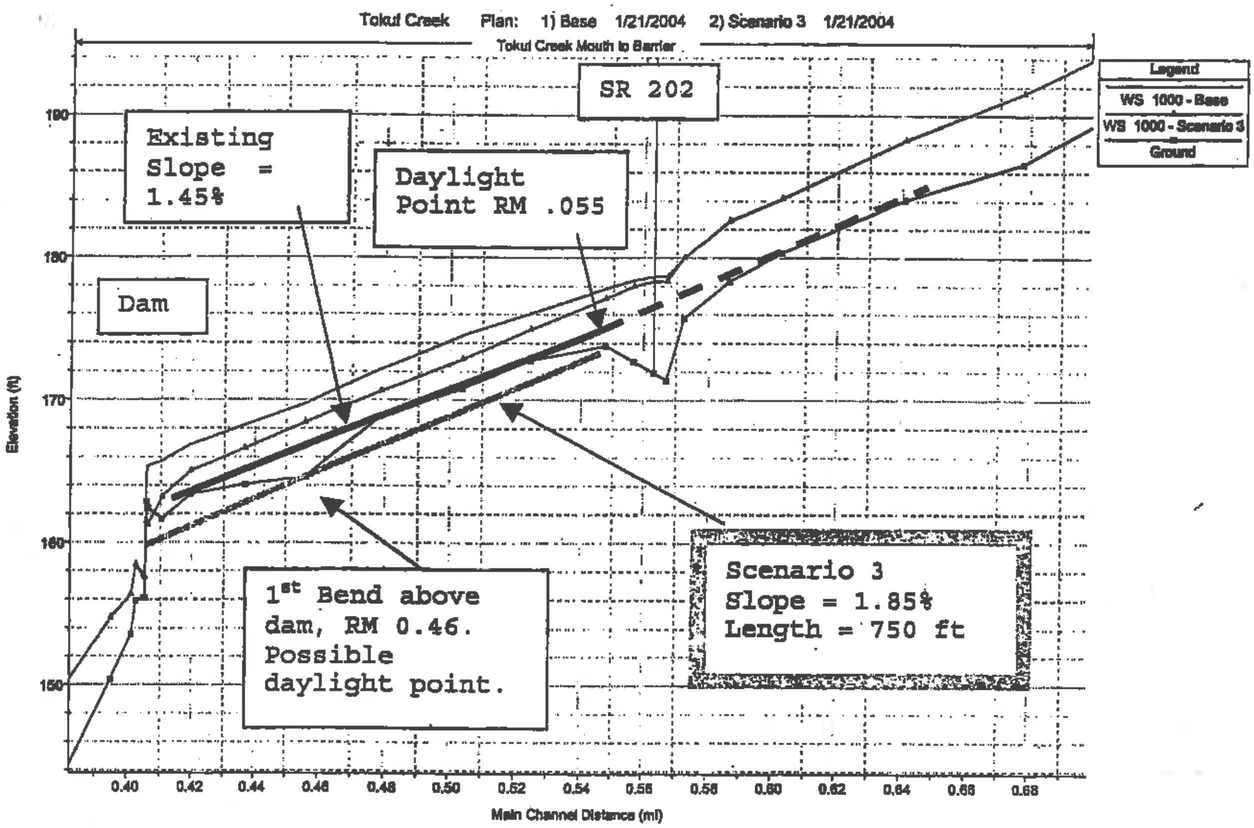


Figure 5: Scenario 3 Channel re-grade profile

Sedimentation

Since mathematical methods are good indicators of trends, three methods were used for comparison: Shield analysis, and the Meyer-Peter Mueller (MPM) and the Einstein Bed-Load transport equations. These three predictors serve similar but different purposes. Shields relationship was used to compare channel stability though the reach upstream of the dam for with and without dam removal. Einstein and MPM were used to compare transport potential at a given cross section.

To evaluate transport potential, a single cross section was used. Cross section 2659 (RM 0.50) was selected because it had hydraulic properties that were typical of the reach between the dam and the SR 202 Bridge (Table 1 Appendix A). It is also upstream from the influence of the dam, just downstream of the upstream slide (RM 0.52), and near an existing pebble count location (RM 0.52). A comparison of transport capacity was done for several cross sections and the cross section 2659 exhibited a typical capacity (Table 1 Appendix B).

The hydraulic parameters generated by the HEC-RAS model were used to estimate the sediment transport characteristics for Tokul Creek. The pebble counts supplied the sediment data. A typical 2-year storm event of 4 days: Day 1 and 4 at 500 cfs, Day 2 at 1000 cfs and Day 3 at 700 cfs was used in the calculations for sediment transport capacity. This was done for the existing condition as well as the three scenarios.

- **Sediment Stability - Shields**

The Shields analysis determines a critical sediment grain size that is just at the point of being moved by the flowing water (threshold of movement) at a given discharge. Determining the critical size distribution at each cross section in a reach results in a picture of the streams character and ability to move a certain size of sediment from one cross section to the next. In addition, by comparing the analytical results to field measured grain size distributions we can tell if the model is predicting transport of measured grain sizes. For purposes of brevity the Existing and With Project stable grain sizes and measured grain sizes were plotted together in Appendix B, Figure 1.

- **Bedload Transport - SAM win, Einstein and MPM**

The sediment transport capacity was determined by using two methods: the Meyer-Peter Mueller and the Einstein Bed-Load Methods. The MPM and Einstein bedload functions were used to estimate the capacity of the stream to pick up and transport existing bed material at given flow rates. Like the Shields analysis they tell us about relative changes in the study reach relating to the streams ability to entrain and transport sediment. By relating the frequency and duration of a flow event to the transport potential we estimated the volume of sediment transported at a given point in a 2-yr storm event. This allows us to estimate the streams ability to erode a given volume of a given grain size at a given location. Combining the transport potential with the hydrology provided the sediment transport capacity for a 2-year event.

Results

- **Existing Conditions**

The existing condition hydraulic parameters (depths, velocities, area, etc.) are shown in Appendix A, Table 1. The existing condition water surface and creek bed profiles are shown in Appendix A, Figure 1.

Trends observed from reviewing the data are: Tokul creek is steep with gradients greater than 1%, and near critical depth for most of its length. Velocities average about 7 ft/s during the 1000 cfs event. Where the stream crosses the dam crest, velocities are approximately 20 ft/s.

- **Sediment Transport**

The Shield analysis in Appendix B, Figure 1 shows that the largest stable grain sizes for the existing condition at 1000 cfs occur primarily at the dam apron and scour hole (RM 0.41), and at the SR 202 Bridge (RM 0.56). Areas with the smallest stable grain sizes occur upstream of the Fish Hatchery Road Bridge (RM 0.094), upstream of the WSDOT landslide (RM 0.25), at the upstream slide (RM 0.52), and upstream of the SR 202 Bridge (RM 0.56). In general these areas can be thought of as deposition zones relative to the rest of the channel.

Measured bed sediments consist primarily of gravels, cobbles, and boulders. Appendix B, Figure 1 shows that the sediment grain sizes measured in two locations (RM 0.46 and 0.52) upstream of the dam indicate that a D65 grain size of approximately 8" matches somewhat closely the predicted critical grain size (6"-8") for that area, indicating that the Shields Analysis is doing a good job of predicting stable grain sizes upstream of the dam.

- **Sediment transport at RM 0.50 (cross section #2659)**

The following is the pebble distribution at the upstream landslide (RM 0.52):

D30 = 4"
D40 = 5"
D50 = 6"
D65 = 8"
D75 = 10"
D90 = 18"

Based on the Shields analysis and the pebble count distribution, the average stable grain size is the D50 of approximately 6″ (Table 4).

XS 2659 RM 0.50 2-year event	Shields Stable Grain Size inches	MPM Transport Capacity tons MPM	MPM Sediment less than XX size transported	Einstein Transport Capacity tons MPM	Einstein Sediment less than XX size transported
EXISTING	5.9″	3200	2.5″	1500	5″
Scenario 1	9.4″	15000	5″	18600	10″
Scenario 2	10.7″	10900	5″	13600	10″
Scenario 3	7.7″	7380	5″	6680	10″

Table 4. Sediment Transport Comparisons at RM 0.50.

- **Scenario 1**

As seen in Figure 3 above, dam removal could result in a 6 ft water surface drop at the dam, an increase in slope from the existing condition, and a resulting steepening of the water surface slope upstream. Figures 2-7 and Table 1 of Appendix A indicate a significant decrease of velocities at the former dam site, an increase in average channel velocities upstream of the dam of approximately 25%, a decrease in the top-width and flow area as the channel incises into the reservoir sediments, and a resulting increase in shear stress.

Shields analysis indicated that with a discharge of 1000 cfs, the stable grain size at RM 0.50 is approximately 9.4″, indicating that anything smaller than 9″-10″ inches could move.

Table 4 shows that for a 2 yr event, the MPM transport capacity is 15000 tons of sediment 5″ or less. Pebble count distribution indicates that approximately 40% of the existing bedload is 5″ or less. The Einstein transport capacity is 18600 tons of sediment 10″ or less. Approximately 75% of the existing bedload is 10′ or less. These capacities are 4.8 to 12.9 times the existing transport capacity.

- **Scenario 2**

As seen in Figure 4 above, dam removal could result in a 6 ft water surface drop at the dam, an increase in slope from the existing condition, and a resulting steepening of the water surface slope upstream. Figures 2-7 and Table 1 of Appendix A indicate a significant decrease of velocities at the former dam site, an increase in average channel velocities upstream of the dam of approximately 25%, a decrease in the top-width and flow area as the channel incises into the reservoir sediments, and a resulting increase in shear stress.

Compared to Scenario 1, Scenario 2 has marginally deeper and slower flows due to the flatter slope. The significant difference is that the impacts extend nearly twice the distance upstream. In the vicinity of SR 202, the water surface slope is smoothed out some due to the erosion of a portion of the creek bed upstream of the bridge.

Shields analysis indicated that with a discharge of 1000 cfs, the stable grain size at RM 0.50 is approximately 10.7", indicating that anything smaller than 10"-11" inches could move.

Table 4 shows that for a 2 yr event, the MPM transport capacity is 10900 tons of sediment 5" or less. Pebble count distribution indicates that approximately 40% of the existing bedload is 5" or less. The Einstein transport capacity is 13600 tons of sediment 10" or less. Approximately 75% of the existing bedload is 10" or less. These capacities are 3.4 to 9.5 times the existing transport capacity.

Trend is for transport potential to increase, but less than Scenario 1 due to flatter slope and lower velocities.

- **Scenario 3**

It is seen from Figure 5 the partial dam removal could result in a 3 ft water surface change at the dam, a slight increase in the slope from the existing condition, and a resulting steepening of the water surface slope upstream. Figures 2-7 and Table 1 of Appendix A indicate a slight decrease of velocities at the former dam site, an increase in average channel velocities upstream of the dam of less than 10%, a decrease in the top-width and flow area as the channel incises into the reservoir sediments, and a resulting increase in shear stress. Compared to Scenarios 1 and 2, Scenario 3 has hydraulic conditions most similar to the existing channel (slower, wider, shallower, less hydraulic stress).

Shields analysis indicated that with a discharge of 1000 cfs, the stable grain size at RM 0.50 is approximately 7.7", indicating that anything smaller than 7"-8" inches could move.

Table 4 shows that for a 2 yr event, the MPM transport capacity is 7380 tons of sediment 5" or less. Pebble count distribution indicates that approximately 40% of the existing bedload is 5" or less. The Einstein transport capacity is 6680 tons of sediment 10" or less. Approximately 75% of the existing bedload is 10" or less. These capacities are 2.3 to 4.6 times the existing transport capacity.

Trend is for potential capacity to increase due to the increase in slope and velocity. This scenario affects the creek the least, but it may not serve the purpose of providing fish passage.

Conclusion

Based on a 2-yr storm, removal of the Tokul Creek Dam could produce increased channel slopes upstream of the dam. The steeper slope could result in higher velocities and increased sediment transport potential. The stable grain size is likely to increase from 6" to 10". In Tokul Creek, 35% of the sediment above the dam is between 5"-10". The transport capacity depends on this bedload material distribution. In all three scenarios, much of the bedload could be transported with the first 2-yr storm event.

With total dam removal (Scenarios 1 and 2) results indicate a transport capacity of 4-12 times the existing conditions. The capacity is less with partial dam removaland fish passage may not be possible (Scenario 3). For Scenarios 1 and 2, the consequences of such bedload movement in a short period of time can result in unstable side slopes. As the creek bed is scoured, there is potential for undermining of the riprap lining the right bank for the creek upstream of the dam. The areas without existing bank stabilization measures in place (SR 202 Bridge and upstream slide) could experience increased sloughing until the channel stabilizes.

After dam removal, the cross sections downstream of the dam were not modified, so the hydraulic parameters did not change. Therefore, the sediment transport rates were not analyzed. Release of the sediments from dam removal may result in a "wave" of sediments moving downstream. As the sediment moves downstream, local changes in hydraulic parameters may cause aggradation in localized areas. As the creek stabilizes upstream of the dam, the sediment could continue to move through the downstream area. This sediment movement has the potential to impact the spawning areas near the WSDOT slide.

Flooding at the hatchery was not looked at specifically in this project. The WSDOT slide repair Biological Assessment indicated that when the hatchery was built and the bank armored, the flood storage was decreased to almost nothing. The report indicated some loss of flood storage in the area of the slide could be expected due to the repair. Looking at the volume of sediment behind the dam for Scenario #1 (4100 CY) and dispersing it over the creek bed (average width of 40 feet) from the dam downstream to the Fish Hatchery Bridge (approximately 1700 feet) results in average bed increase of approximately 1.6 feet. Due to the slope and confinement of the creek, it is most likely that the sediment would move through the system over time.

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Washington Department of Transportation As-Builts for SR 202 Bridge. 1983.

Appendices

A: Hydraulics

Figure 1. Tokul Creek Existing Condition Profile and Water Surface at 1000 cfs.

Figures 2-7. HEC-RAS Velocity Profiles.

Table 1. HEC-RAS Hydraulic Parameters - 16 pages.

B: Sediment Transport

Figure 1. Shields Analysis.

Table 1. Sediment Transport Comparisons