Washington State Department of Transportation
Douglas B. MacDonald
Secretary of Transportation

Transportation Building
310 Maple Park Avenue S.E.
P.O. Box 47300
Olympia, WA 98504-7300

360-705-7000
TTY: 1-800-833-6388
www.wsdot.wa.gov

November 9, 2005

Mr. Steven Wright, P.E.
Business Services – Engineering Division
Washington Department of Fish and Wildlife
Olympia, WA 98504

Dear Mr. Wright:

Please find attached the final version of the *Tokul Creek Dam Removal: Review of USACE Analysis / Impacts to WSDOT Infrastructure and Available Countermeasures* report. Based on this review and observations of the area of interest, we have concluded that the WDFW diversion dam has had a pronounced effect on the lowermost portion of Tokul Creek for decades, and it is reasonable to assume that considerable reach-based changes would result from its removal. There is sufficient concern that these changes will adversely impact WSDOT infrastructure to recommend expansion of WDFW's current scope of work to incorporate countermeasures that will protect at-risk portions of SR 202 and its crossing at Tokul Creek. Countermeasures described in our report are meant to address the potential impacts to WSDOT infrastructure of an uncontrolled channel regrade, which may occur in response to total or partial dam removal.

We are concerned that no alternatives analysis was performed to consider methods of providing fish passage above the dam that doesn't involve dam removal. In our report, we identify an alternative approach to site-specific countermeasures: controlling channel regrade by installation of grade control structures or construction of a stable channel above and/or below the dam site. If properly designed and constructed, this approach would likely reduce or eliminate the need for most of the countermeasures described above, while allowing for fish passage.

Given the consequences and cost associated with potential impacts to WSDOT infrastructure identified in this report, we encourage consideration of alternatives that achieve the goal of providing fish passage without destabilizing the channel.

Sincerely,

Kevin Lautz, P.E
Hydrologist
Environmental Services Office

Jim Park
Hydrologist
Environmental Services Office

Tokul Creek Dam Removal:

Review of USACE Analysis

Impacts to WSDOT Infrastructure and Available Countermeasures

Kevin Lautz, P.E.
Hydrologist

Watershed Management Program

November 8, 2005

Washington State Department of Transportation
Environmental and Engineering Service Center
Environmental Services Office

TABLE OF CONTENTS

Executive summary..... 1

Introduction..... 3

Geologic and geomorphic setting.....3

Field observations 5

Review of USACE hydraulic and sediment stability analysis 6

Potential impacts to WSDOT infrastructure and available countermeasures..... 9

References..... 12

LIST OF FIGURES

Figure 1. Area of interest for this report.....4

Figure 2. Generalized stratigraphy for previously glaciated area around Puget Sound ...5

Executive Summary

The WDFW diversion dam has had a pronounced effect on the lowermost portion of Tokul Creek for decades, and it is reasonable to assume that considerable reach-based changes would result from its removal. There is sufficient concern that these changes will adversely impact WSDOT infrastructure to warrant expansion of WDFW's current scope of work in order to incorporate countermeasures to protect at-risk portions of SR 202 and its crossing at Tokul Creek.

Geologic and geomorphic setting

Owing to the influence of past glaciation and position on the landscape, Tokul Creek within the area of interest is tightly confined by valley walls, and naturally erodes and transports large quantities of sediment to its confluence with the Snoqualmie River.

Field observations

My field observations generally concur with those reported in the USACE study.

An actively eroding hillslope occurs on the left bank upstream of the dam; its steepness and stratigraphy suggest a significant risk of failure that may be exacerbated as a result of channel regrade and subsequent toe erosion.

Review of USACE hydraulic and sediment stability analysis

Hydraulic analysis was performed using a generally accepted computer model (HEC-RAS) and methods; specific concerns regarding the application of the model are relatively minor. Results of hydraulic modeling appear reasonable.

Sediment transport and channel stability analysis was performed using software (SAMwin) developed by USACE for simple evaluations such as were performed here. Specific concerns regarding these analyses include:

- use of a "stepped" synthetic hydrograph, which may provide an excessively high estimate of flow energy available for transport;
- methods used to evaluate channel stability (Shield's approach) and sediment transport (Einstein and Meyer-Peter and Mueller equations) have been shown to provide inaccurate estimates for conditions found in the channel reach being analyzed;
- no channel stability and sediment transport analyses were conducted downstream of the dam site, so channel, habitat and infrastructure impacts in this reach could not be evaluated;
- impacts of bank erosion and contributions from hillslope failure were not included and may have a significant bearing on how channel regrade would progress.

Assumptions regarding subsurface bed conditions and potential extent of channel regrade ("daylight point") are, in the absence of additional information on these conditions, reasonable and conservative.

Selection of scenarios for hydraulic and sediment transport modeling represent an appropriate range of conditions; a more accurate assessment of risk would include larger flows likely to occur over the "life-cycle" of WSDOT infrastructure.

Quantitative results of channel stability and sediment transport analyses are suspect because of the questionable applicability of the models/equations used. Qualitative interpretations of results, and relative changes in stability and transport capacity between scenarios appear to be reasonable and consistent.

Despite the limitations of this analysis, the results do suggest that there is potential for significant impacts to the channel and infrastructure. Further analysis may be warranted.

Potential impacts to WSDOT infrastructure and available countermeasures

Three potential impacts to WSDOT infrastructure were identified:

(1) Undermining of existing riprap along the right bank upstream of the dam by a regrading channel may result in toe erosion and subsequent failure of the hillslope below the SR 202 roadway west of the Tokul Creek bridge;

(2) Extension of channel regrade to or beyond the SR 202 bridge at Tokul Creek may undermine the bridge piers nearest the channel, resulting in road closure or structural damage;

(3) Undermining of toe of large, actively eroding hillslope by a regrading may result in local to extensive (and potentially catastrophic) failure of the hillslope, with potential impact dependent upon the proximity of the SR 202 roadway to the upper extent of the slope scarp.

Appropriate countermeasures vary depending on the type and extent of the impact, and may include:

- emergency placement of riprap and/or bank stabilization in response to actual or impending damage to infrastructure;
- installation of Integrated Streambank Protection Guidelines (ISPG)-recommended bank protection and/or channel grade controls in advance of anticipated regrade;
- minor or major slope stabilization measures.

As an alternative approach to the use of site-specific countermeasures, channel regrade may be limited by installation of grade control structures or construction of a stable channel above and/or below the dam site; if properly designed and constructed, this would likely reduce or eliminate the need for most of the countermeasures described above, while allowing for fish passage.

Introduction

The purpose of this report is to:

- conduct a technical review of a hydraulic and sediment transport analysis conducted by the US Army Corps of Engineers (USACE, 2004);
- identify potential impacts to WSDOT infrastructure (SR 202 Bridge 202/58 and adjacent roadway) which may occur as a result of the partial or total removal of a low-head dam located immediately upstream from the Washington Department of Fish and Wildlife (WDFW) Tokul Creek Fish Hatchery;
- list some of the available countermeasures to protect WSDOT infrastructure against identified impacts.

The "area of interest" for this report includes the lowermost section of Tokul Creek, from the confluence with the Snoqualmie River (RM 0.0) to a natural fish passage barrier at RM 1.14 (Figure 1). This includes all features of interest, including the WSDOT slide repair site (MP 0.25), the WDFW diversion dam (RM 0.41), an actively eroding slope (MP 0.52), and the WSDOT SR 202 bridge (RM 0.56).

A detailed description of the area of interest and the hydraulic and sediment transport analysis may be found in USACE (2004), and is not included here.

Geologic and geomorphic setting

Topography, landforms and channel dynamics in and around the area of interest are derived primarily from the most recent glacial event (~13,000 – 15,000 years before present), and subsequent erosion and transport of glacial deposits. Most of the upper Tokul Creek watershed is a glacial plateau consisting of deep (hundreds of feet) advance outwash deposits capped with a shallow (less than 20 feet) layer of dense, relatively impermeable glacial till. Recessional outwash deposits are found along channel margins and in shallow depressions in the plateau. This generalized stratigraphic sequence, which is found over a large portion of the previously glaciated areas around Puget Sound, is depicted in Figure 2.

In the lowest part of the watershed (including the area of interest for this memorandum), the creek has eroded through the till cap and rapidly downcut through outwash as it seeks the local base level formed by the Snoqualmie River. As a natural consequence of this downcutting, the channel in this area recruits large quantities of sediment as it erodes into the unconsolidated outwash deposits that form the steep valley walls, and transports this sediment rapidly to the confluence with the Snoqualmie River. More detailed information on local geology and geomorphic processes can be found in Tabor et al. (1993) and Peacock (1995).

Figure 1. Area of interest for this report.

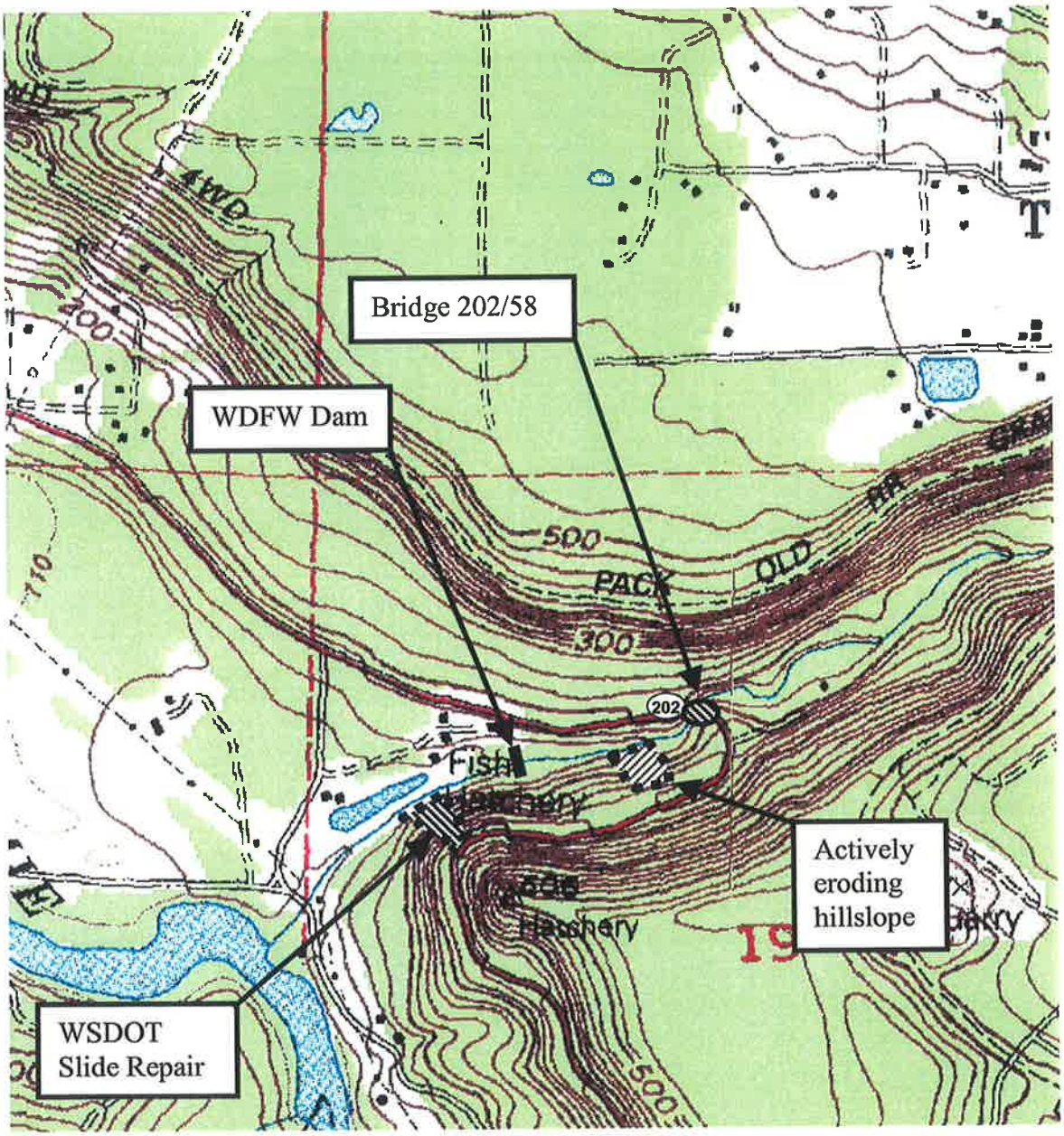
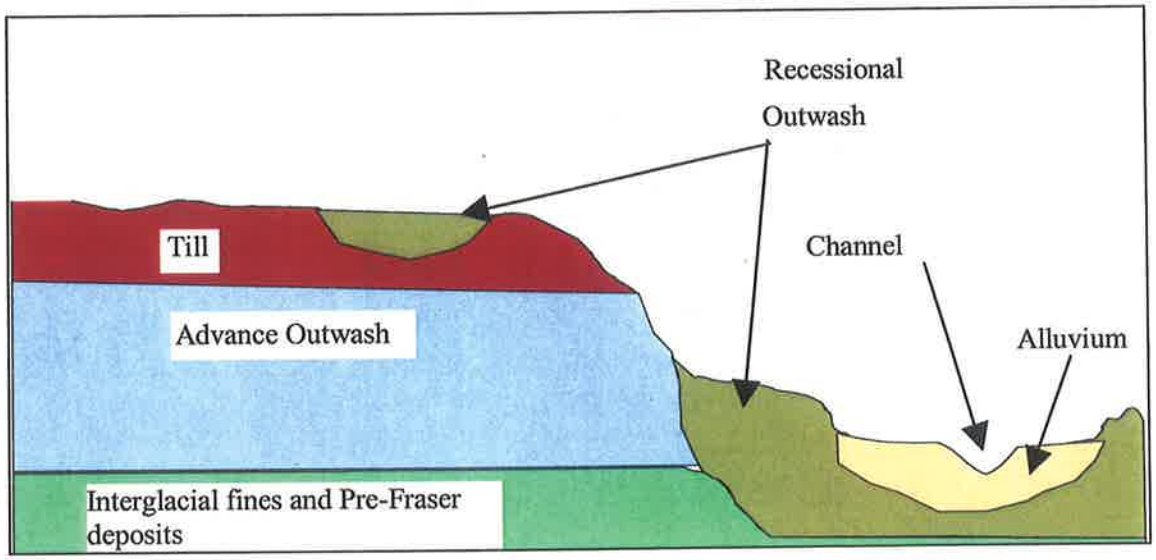


Figure 2. Generalized stratigraphy for previously glaciated areas around Puget Sound.



Field observations

Observations are based primarily on a site visit conducted on October 27, 2005. I walked the creek from the confluence with the Snoqualmie River to the county road bridge (RM 0.1), and from just upstream of the diversion dam (~ RM 0.42) to a point approximately 600 ft above the SR 202 bridge (~ RM 0.67). Because of the presence of hazardous conditions and fresh redds, the section between the county road bridge and the diversion dam was observed from the right bank. My field observations do not differ significantly from those reported in the USACE (2004) report. Based on my visual observation, sediment distributions appeared consistent with reported values in the locations where sampling was performed. I did observe areas where the channel bed was substantially coarser immediately below the SR 202 bridge, and between the dam and the downstream slide repair site.

Of particular interest during the field assessment was the actively eroding hillslope located along the left bank at RM 0.52. This hillslope is very similar in size (about 200 feet in length and 80 to 100 feet high) and stratigraphy to the repaired slope located downstream. Slopes exceeding 100 percent (1:1) occur over most of the exposed face, and in some places approached vertical. Slope strength (i.e. resistance to failure) appears to be provided by the moderately cohesive silt/silty sand layer that occupies approximately the middle 50 feet vertically. The underlying layer is a medium sand about 25 feet high grading upwardly into a coarse strata of material ranging in size from gravel to small (up to 3 feet in diameter) boulders. Vegetation is sparse and consists of young alder, most of which is growing on a fan deposit at the toe of the slope derived from relatively recent small slides. Proximity of the SR 202 roadway to the upper extent

of the slide scarp was not determined at this time. Based on these qualitative observations, there is significant potential for a slope failure of similar magnitude to the slide repair site; further investigation to more accurately ascertain risk to the roadway and to people and infrastructure located downstream may be warranted.

Review of USACE hydraulic and sediment stability analysis

Approach and methods

The USACE conducted a hydraulic and sediment transport analysis to evaluate four questions related to the total or partial removal of the WDFW diversion dam on Tokul Creek :

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

Hydraulic analysis consisted of a one-dimensional water surface profile analysis performed using HEC-RAS (Hydraulic Engineering Center River Analysis System) version 3.1 software, and sediment transport analysis (using results from the hydraulic analysis) was conducted using SAMwin software. Both products were developed by the USACE. HEC-RAS is approved for use by the Federal Highway Administration (FHWA) for hydraulic analyses of channels and stream crossings (bridges and culverts) associated with highway projects SAMwin was developed cooperatively with FHWA, and is used by the USACE for simple evaluations of channel stability and sediment transport capacity for a single channel cross-section.

Hydraulic analysis was conducted using surveyed cross sections; location and spacing of the cross sections appears to be generally adequate to provide an accurate portrayal of channel hydraulics in the study reach. Representation of the SR 202 bridge and the WDFW diversion dam are consistent with guidance provided in the HEC-RAS Users Manual (USACE 2002).

To evaluate channel hydraulics and sediment transport, the 2-year recurrence interval (RI) flow was selected to evaluate sediment transport, based on the assumption that flows in the 2- to 5-year RI range represent the "channel-forming flows", which "could have the most effect on sediment movement downstream" (quoted from USACE 2004). This concept is generally accepted by hydrologists and fluvial geomorphologists, with some disagreement over the most appropriate RI in certain circumstances. Because of a lack of recent stream gage information for this creek, the flow used for analysis was selected from several estimates of peak flows conducted by others. Estimation methods used are commonly applied and accepted by hydrologists and geomorphologists. Based on these estimates, the selected value of 1000 cubic feet per second (cfs) is very likely between the "true" values of the 2- and 5-year RI flows.

A storm hydrograph was also required for the sediment transport analysis. The selected hydrograph "shape" is apparently based on actual USGS gage data (presumably for Tokul Creek), scaled to provide a peak flow of 1000 cfs. While the storm duration appears reasonable, the "stepped" nature of the hydrograph seems unorthodox and may not be a reasonable representation of the "typical" storm hydrograph. It is likely that this "shape" represents a conservative (i.e. high) estimate of flow energy available to transport sediment for this flow, given that the storm "peak" extends over an entire day.

One of the most important parameters in the HEC-RAS hydraulic model is the estimate of channel roughness (Manning's "n"). Initial estimates of channel roughness of 0.040 appear to be low, based on available guidance and estimating methods (Barnes, 1967; Chow 1959; Arcement and Schneider, 1989). My estimate, based on this guidance, is in the range 0.050 – 0.060, a little less than the adjusted value of 0.065. The estimated floodplain roughness of 0.065 also appears to be low; a better average estimate, also based on the above guidance, is in the range 0.08 – 0.1. It should be understood that, without calibration using actual flows, estimation of Manning's "n" for mountain streams is often more art than science. The effect of these deviations from my estimates on the analysis results are likely to be minimal over the entire reach, but may be significant where cross sectional attributes deviate significantly from average reach conditions.

Sediment transport analysis was conducted using modeled hydraulics and channel sediment distributions (gradations) derived using pebble counts (Wolman, 1954), a standard, accepted method for sampling the bed surface. Two types of analysis were conducted: a channel stability analysis using the Shields (1936) approach, and analyses of sediment transport capacity using two commonly used equations: Einstein (1950) and Meyer-Peter and Mueller (1948). It has been demonstrated (Buffington and Montgomery, 1997; Wilcock, 2004) that the application of the Shields approach to evaluate channel stability is problematic in gravel-bed (and coarser) mountain streams, especially where an armor layer has developed. Also problematic is the application of the two sediment transport equations used; these equations, developed for large rivers having substantially lower slopes and finer bed material, may not provide reasonable results in the study reach. Alternative sediment transport analyses developed for gravel-bed channels with armor layers (e.g. Ackers and White, 1973; Parker, 1990) should be performed as a check, if more confidence in the actual sediment transport rate is required.

Assumptions

The existence of two armor layers, the existing armor, and a historic (i.e. pre-dam) armor, is a reasonable (and conservative) assumption, and represents a likely situation if the area behind the dam filled relatively quickly with finer material from the upper watershed after the dam was installed. Other situations (e.g. multiple armor layers associate with periodic fill episodes, rapid filling with mixed coarse and fine sediment from a local slope failure) may occur in which the subsurface sediments may act to arrest the assumed headcut; without subsurface exploration, this is all speculation, and so the conservative assumption is in this case rightfully applied.

Selection of modeling scenarios includes both full (Scenarios 1 and 2) and partial (Scenario 3) dam removals. Selection of the "daylight point" for the channel regrade is somewhat speculative, but appears to represent a reasonable first approximation of the likely minimum (Scenarios 1 and 3) and maximum (Scenario 2) extents of regrade. Bed coarsening (large cobbles, small boulders) which I observed below the SR 202 bridge suggests that the existing bed in this location may be able to resist additional regrade, indicating that the extent of regrade described for Scenarios 1 and 3 may be more likely than Scenario 2. Again, in the absence of more detailed information, a conservative estimate of "daylight point" is probably prudent. More detailed field investigation and analysis of potential channel response may be warranted to more firmly establish regrade potential.

Model results

Existing condition – Comparison of field measurements with channel stability (Shields) analysis results seem to indicate that the analysis is providing reasonable results. This may reflect judicious selection of the dimensionless shear stress parameter, and may or may not extend to Scenarios 1-3, where the existing armor layer is presumably breached.

Scenarios 1 – 3 – Relative changes in velocity, channel stability, and sediment transport between the existing condition and three scenarios appear consistent with assumed corresponding changes in slope and base level. Modeled hydraulics appear to be reasonable. Predicted values of stable bed material size and sediment transport capacity are suspect because of concerns with the applicability of the stability and transport equations mentioned previously.

Are the conclusions supported by the analysis?

In a qualitative sense, yes. Dam removal will result in increased bed slopes, some degree of channel regrade, some degree of bank instability and erosion (which may propogate upwards to cause hillslope instability), some risk to existing bank protection (riprap), and delivery of large amounts of sediment downstream over a short period of time. Predictions of channel and infrastructure impacts associated with a 2-year RI flood event are proportionate to quantitative estimates of stable bed material size and sediment transport capacity. However, the estimates themselves may be questionable based upon the validity of equations used.

Potentially important flaws in the analysis include:

- the use of sediment transport equations that may be inappropriate for the conditions encountered;
- no evaluation of transport capacity downstream, both to evaluate likely channel and habitat response, and potential effects to infrastructure downstream (the hatchery, the slide repair site, and the county road bridge);

- bank erosion (and contributions from failing hillslopes) was not explicitly considered in the analysis. This may be an important factor in how a channel regrade would progress, in that substantial quantities of material transported downstream may contribute to aggradation below the dam, thereby acting to limit regrade by raising the local base level;
- analysis was limited to a nominal estimate of the 2-year RI flow; a more accurate assessment of risk should include analysis of a broader range of flows (larger, higher recurrence interval) that are likely to occur over the "life-cycle" of WSDOT infrastructure.

Despite the limitations of this analysis, the results do suggest that there is potential for significant impacts as a result of dam removal, both to the channel and human infrastructure. Further analysis may be warranted, including:

- more detailed assessment of channel bed characteristics (including subsurface characteristics) upstream of the dam, especially in the vicinity of the SR 202 bridge, in order to better evaluate the likely extent and rate of channel regrade;
- application of more appropriate sediment transport models, e.g. Acker and White (1973) and Parker (1990), to provide more confidence in the evaluation of sediment dynamics in the study area;
- modeling of larger, less frequent flows to better evaluate risk over the life-cycle of WSDOT infrastructure;
- extension of sediment transport analysis downstream, to better evaluate impacts to channel, habitat, and infrastructure in this reach;
- geotechnical investigation of the left bank hillslope at RM 0.52, to evaluate risk of failure, especially in the context of potential undercutting of the toe by a channel regrade;
- incorporation of possible countermeasures (see below) into the model geometry to evaluate effectiveness.

Potential impacts to WSDOT infrastructure and available countermeasures

The WDFW diversion dam has had a pronounced effect on the lowermost portion of Tokul Creek for decades, and it is reasonable to assume that considerable reach-based changes would result from its removal. There is sufficient concern that partial or complete dam removal will destabilize the upstream channel in a manner that will adversely impact WSDOT infrastructure to warrant expansion of WDFW's current scope of work in order to incorporate countermeasures to protect at-risk portions of SR 202 and its crossing at Tokul Creek.

Identification of potential impacts to WSDOT infrastructure which may be caused or exacerbated by total or partial removal of the WDFW diversion dam is accomplished by linking potential post-removal channel impacts (like channel regrade) to changes in upslope processes or conditions (like bank and hillslope stability) and, subsequently, to direct infrastructure impacts.

The identification process (including identification of countermeasures which may be used to protect WSDOT infrastructure) is based on an evaluation of existing information (including the USACE analysis described above), observations made during site visits on October 14 and October 27, 2005, and consultation with WSDOT hydraulics and geotechnical specialists. The list of countermeasures provided below is not intended to be exhaustive; other countermeasures not listed may be applied if site conditions and situation dictate.

Identified potential impacts and countermeasures are as follows:

(1) *Undermining of existing bank protection (riprap):* Upstream of the dam, this riprap protects the toe of the slope below the west approach to the SR 202 bridge. Channel regrade may undermine and remove (or otherwise render ineffective) this material. Toe slope failure as a result of the loss of this protection may result in local or extensive failure of the hillslope, with potential for damage to the SR 202 roadway.

Countermeasures include:

- Emergency replacement of riprap at toe of bank and stabilization of the hillslope in response to failure or potential failure of bank, hillslope, and/or roadway.
- Installation of Integrated Streambank Protection Guidelines (ISPG)-recommended bank protection in advance of anticipated regrade. Examples include roughened rock toes, log toes, and buried groins.
- Installation of structural bank protection measures, including traditional riprap placement, cribwalls, slope reinforcement (e.g. soil nailing, sheet piles), or manufactured retention systems may be required because of the confined nature of the channel and the possible extent of regrade.

(2) *Propagation of channel regrade to the SR 202 bridge:* Extension of channel regrade to or beyond this structure may undermine the bridge piers nearest the channel, resulting in closure or structural damage. The USACE analysis indicates a worst-case scenario (associated with total removal) of up to five feet of downcutting in the vicinity of the bridge. The more likely total removal scenario and the partial removal scenario indicate the regrade stopping just below the crossing. Footing elevations for the bridge piers closest to the stream are higher in elevation than the existing channel bed, which increase the risk of undermining due to lateral bank erosion by the creek. Risk to the bridge is reduced somewhat due to the setback of the piers from the creek,

and the low erodibility of the bank material. The pier on the left bank appears to be at the greatest risk due to its relative closeness (<15 feet) to the channel and construction (pedestal footing without piles); inspection of the bank also indicates some erosion due to redirection of flow by a remnant support from the previous bridge.

Countermeasures include:

- Emergency placement of riprap at toe of bank in response to channel downcutting at or near the bridge;
- Installation of Integrated Streambank Protection Guidelines (ISPG)-recommended bank protection and/or channel grade controls in advance of anticipated regrade. Examples of bank stabilization include roughened rock toes, log toes, riprap blanket with launchable toe, and soil lifts; examples of grade stabilization include log controls, rock controls, and roughened channels.
- Removal of one or both remnant supports from the previous bridge.

(3) *Undermining of the toe of the large, actively eroding hillslope at left bank RM 0.52*: The USACE analysis indicates a worst-case scenario (associated with total removal) of nearly six feet of downcutting in the vicinity of this feThe more likely scenario for total removal of the dam indicates four to five feet of downcutting, and the partial removal scenario indicates two to three feet of downcutting. This, combined with continued erosion (toe is on the outside of a fairly large-radius channel bend) of cohesionless medium sand that forms the lower 20-25 feet of this slope, may result in local to extensive (and potentially catastrophic) failure of the hillslope. Potential for damage to WSDOT infrastructure (SR 202) depends on the proximity of the roadway to the upper extent of the failed portion of the slope. The worst-case here is a failure (and subsequent repair) similar in magnitude to the failure and repair site immediately downstream. In addition, large deposits of slide material may force the channel against the opposite bank, exacerbating the risk of Impact #1.

Countermeasures include:

- Emergency placement of riprap at toe of slope in response to channel downcutting and toe erosion at or near the base of the slope
- Installation of Integrated Streambank Protection Guidelines (ISPG)-recommended bank protection in advance of anticipated regrade. Examples include roughened rock toes, log toes, and bank reshaping and revegetation.
- If significant failure of the slope were to occur, and it was determined that the roadway was at risk, then upslope stabilization measures (e.g. slope drainage, rock buttress, shear key) may be required.

Countermeasures described above are meant to address the site-specific impacts of an uncontrolled channel regrade in response to total or partial dam removal. An alternative approach to the use of these countermeasures would be to control channel regrade by installing grade control structures or constructing a stable channel above and/or below the dam site. If properly designed and constructed, this approach would likely reduce or eliminate the need for most of the countermeasures described above, while allowing for fish passage.

References

Ackers, P., and W. R. White. 1973. Sediment transport: New approach and analysis, J. Hydraul. Div. Am. Soc. Civ. Eng., 99, 2041–2060, 1973.

Arcement, G. J., Jr. and V.R. Schneider. 1989. Guide for selecting Manning's roughness coefficients for natural channels and flood plains. Department of the Interior, US Geological Survey. Water-Supply Paper 2339.

Barnes, H. H., Jr. 1967. Roughness characteristics of natural channels. Department of the Interior, US Geological Survey. Water-Supply Paper 1849.

Buffington, J. M., and D. R. Montgomery. 1997. A systematic analysis of eight decades of incipient motion studies, with special reference to gravel-bedded rivers. Water Resour. Res., 33(8), 1993–2029.

Chow, Ven Te. 1959. Open-channel hydraulics. McGraw Hill, New York. 680 pp.

Einstein, H. A. 1950. The bed-load function for sediment transportation in open channel flows. USDA Soil Conservation Service. Tech. Bull. 1026. Washington, D.C.

Meyer-Peter, E., and R. Mueller. 1948. Formulas for bed-load transport. In: Proceedings of the 2nd Meeting of the International Association for Hydraulic Structures Research, pp. 39–64, Inter. Assoc. for Hydraul. Res., Delft, Netherlands.

Parker, G. 1990. Surface-based bedload transport relation for gravel rivers. Journal of Hydraulic Research 28:417-436.

Peacock, Kathi. 1995. Griffin-Tokul watershed analysis. Appendix E: Stream channel assessment. Washington Department of Natural Resources, Forest Practices Division. 37 pp. + appendices.

Shields, A. 1936. Anwendung der Aehnlichkeitsmechanik und der Turbulenzforschung auf die Geschiebebewegung. In: Mitteilungen der Preussischen Versuchsanstalt fur Wasserbau und Schiffbau 26:26.

Tabor, R.W., V.A. Frizzell, Jr., D. B. Booth, R.B. Waitt, J.T. Whetten, and R.E. Zartman. 1993. Geologic map of the Skykomish River 30- by 60-minute quadrangle, Washington. Depatment of the Interior, US Geological Survey. Miscellaneous Investigations Series Map I-1963.

USACE. 2002. HEC-RAS River Analysis System users manual, version 3.1. US Army Corps of Engineers – Hydraulic Engineering Center. Report Number CPD-68.

USACE. 2004. Hydraulic and sediment transport analysis of dam removal at Tokul Creek Fish Hatchery – Final. US Army Corps of Engineers – Seattle District. 22pp. + appendices.

Wilcock, P.W. 2004. Sediment transport in the restoration of gravel-bed rivers. In: Proceedings Of The 2004 World Water and Environmental Resources Congress. pp. 1-11. Environmental and Water Resources Institute, American Society of Civil Engineers.

Wolman, M.G. 1954. A method of sampling coarse bed material. Transactions of the American Geophysical Union, 35, 951-956.