Project Design Report

Lake Terrell Dam Channel Restoration and Fish Passage Project

Prepared for:
Washington Department of Fish and Wildlife

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Executive Summary

This design report documents the development of the engineering design for the *Lake Terrell Dam Channel Restoration and Fish Passage Project*. The design focuses on restoring fish passage from Terrell Creek past the Washington Department of Fish and Wildlife's (WDFW) dam at the outlet of Lake Terrell in Whatcom County, Washington. The purpose of the project is to restore passage for anadromous and resident fish from Terrell Creek into Lake Terrell and upstream tributaries. The eventual implementation of the project is anticipated to contribute to restoring historic populations of coho salmon, chum salmon and cutthroat trout, among other fisheries resources, in Terrell Creek.

Whatcom Conservation District (WCD) and WDFW staff identified specific ecological, engineering and land use objectives to guide the development of the design. They then identified a range of potential engineering design alternatives for meeting the project's objectives. These alternatives included constructing a fishway, reconstructing the channel below the dam to provide fish passage over the dam, removing the dam, and constructing a high flow overflow system. Each alternative was then evaluated at a general screening level for its ability to meet each of the specific objectives.

Based on the evaluation of the pros and cons of each design alternative the project team identified a preferred project alternative that combines slightly lowering the dam, reconstructing the channel to simulate morphological and habitat conditions at local "reference sites," and installing a high flow bypass pipe around the dam. The report then presents a discussion of the detailed engineering considerations for hydrology, hydraulic performance, sediment design, beaver management, dam safety considerations, and construction costs estimates. Finally, an evaluation of the integrity of the existing dam structure, and its suitability for incorporation into the project design, is included as an attachment to the report.

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1 Introduction

This design report documents the development of the engineering design for the *Lake Terrell Dam Channel Restoration and Fish Passage Project*. The design focuses on restoring fish passage from Terrell Creek past the Washington Department of Fish and Wildlife's (WDFW) dam at the outlet of Lake Terrell in Whatcom County, Washington. The design was developed through cooperative efforts by staff of WDFW, the Whatcom Conservation District (WCD) and the Nooksack Salmon Enhancement Association (NSEA).

1.1 Purpose of the Project

The purpose of the project is to restore passage for anadromous and resident fish from Terrell Creek into Lake Terrell and upstream tributaries. The eventual implementation of the project is anticipated to contribute to restoring historic populations of coho salmon, chum salmon and cutthroat trout, among other fisheries resources, in Terrell Creek.

1.2 Description of the Problem

Prior to 1950, the area covered by the present Lake Terrell was a natural lake and wetland system. Historical records document extensive beaver dam-impounded wetlands and tributaries that supported a natural coho salmon run (Vasak, 2010). In 1950, the Washington Department of Game built a concrete spillway and timber flashboard dam across Terrell Creek. The dam impounded the present lake of about 550 acres, which reportedly covers about twice the area of the natural lake (ibid.). The height of the dam and the fact that it blocks essentially all surface stream flow from the lake into the downstream channel during the summer dry season present a complete barrier to upstream fish passage. Consequently, the historic salmon runs have been extirpated.

WDFW currently manages Lake Terrell for recreational fishing and waterfowl hunting as part of its Whatcom Wildlife Area. Due to the shallow depth of the lake and the flat topography of the surrounding land, WDFW's management practices include regulating the lake's water surface elevation to control for nuisance aquatic weeds in summer and to reduce localized flooding in winter. The primary tool for regulating the lake's water level is manipulating timber flashboards at the dam. This task can be dangerous and difficult, as WDFW staff must remove and replace the flashboards manually from a narrow catwalk placed across the dam spillway (Kessler, 2011).

1.3 Specific Objectives

The project team identified the following specific objectives to guide the development of the project design.

<u>Ecological Objectives</u>

- Provide adult salmonid access from Terrell Creek to the tributaries of Lake Terrell during at least 90% of anticipated stream flow conditions during the typical migration period of November through January
- Provide juvenile salmonid access from the tributaries upstream of Lake Terrell dam into Terrell Creek during at least 90% of anticipated stream flow conditions during the typical outmigration period of March through June

- Ensure consistent stream flow of at least 1 cubic feet per second (cfs) for as much as the low flow summer season as practicable in order to improve summer water quality conditions for resident fish in Terrell Creek between the dam and the confluence of Fingalson Creek.
- Preserve and enhance existing riparian forest conditions along the banks of the project reach of Terrell Creek
- Preserve the existing ecological function and value of the extensive wetlands adjacent to the project reach of Terrell Creek

Engineering and Operational Objectives

- Maintain and improve WDFW staff's ability to safely regulate the water surface elevation in Lake Terrell to respond to localized flooding and management of nuisance aquatic plants.
- Minimize maintenance requirements for the project reach and the adjacent infrastructure on WDFW's Lake Terrell Wildlife Management Area
- To the extent practicable, minimize construction costs and construction related impacts on the surrounding land.

Land Use Objectives

- Preserve existing recreational boating and fishing opportunities at Lake Terrell
- Preserve the existing level of drainage capacity for the county road culvert under Aldergrove Road and for the two culverts under the access road to WDFW's dam.

2 Previous Studies and Supporting Work

Over the past decade, NSEA, WDFW, the Chums of Terrell Creek and other community members have carried out several research studies and implemented projects for improving salmonid habitat conditions in Terrell Creek. Ryan Vasak documented stream flow and water quality monitoring efforts in the project area and other reaches of Terrell Creek between 2004 and 2010. The data show that stream flow in the project reach is insufficient in summer months to maintain water quality standards that can support salmonids. (Vasak, 2010). Based on these observations, NSEA and WDFW initiated a pilot program to pipe water over Lake Terrell Dam through two small siphons to augment summer creek flow. This effort supplemented NSEA's operation of a remote site incubator (RSI), located immediately downstream of the dam, for incubating chum salmon eggs in an attempt to revive the creek's historical chum salmon run. More generally, NSEA, British Petroleum's Cherry Point Refinery and many individual community members have planted acres of native trees and shrubs along the creek in order to improve riparian habitat conditions for salmon.

Over the past decade, Whatcom County and Washington State Department of Transportation (WSDOT) have also replaced road culverts that presented barriers to anadromous fish passage at road crossings downstream of the Lake Terrell Dam. WSDOT replaced the culvert at Grandview Road, which was the last major fish passage barrier on the main stem of Terrell Creek below the dam, in August 2011.

3 Study Methodology

The project team's design study consisted of the following tasks. The evaluation of the study's resulting data is presented in Section 4.

3.1 Field Survey

WCD staff completed a topographic survey of the channel profile and several channel cross sections of Terrell Creek and the adjacent side channel and tributary channels in the project area. The survey identified the ordinary high water (OHW) line at each cross section based on observation of field conditions. The topographic data were used to generate channel and profile drawings in the project plan set.

3.2 Stream Flow and Water Level Monitoring

WCD staff and NSEA volunteers measured water surface elevations (wse) and stream flows at key locations in the project area on a regular basis for a twelve-month period from January through December 2011. Measurements were taken manually on a weekly basis as well as during high stream flow events in order to bracket the range of flows and wse during a fairly typical/slightly above average precipitation year. Direct water surface elevations were measured at four locations: the staff gage at the Lake Terrell public fishing dock, the fore bay of the Lake Terrell dam, Terrell Creek at the inlet of the Aldergrove Road culvert and Terrell Creek at the outlet of the Aldergrove Road culvert.

WCD usually measured stream flows indirectly by measuring the depth of flow over the dam crest and in the Aldergrove Road culvert and estimating flow rates from standard weir equations (for the dam) and culvert open channel flow equations (for the culvert). WCD then calibrated and verified the estimated flows by spot checking a subset of the data with a propeller type electronic flow meter.

3.3 Sediment Characterization

WCD staff sampled sediment size distribution at representative channel cross sections to characterize the existing sediment conditions in the project area. Grab samples were collected to a depth of about four inches from the channel thalweg, at the OHW line and from the creek bank above the OHW line, and then tested using standard sieve testing methods (ASTM C136). WCD supplemented the sieve test data with additional pebble count samples are various points of interest, including at one of the few well-defined riffles in the creek and in the small tributary channel east of the access road.

WCD used the baseline sediment data, as well as pebble count data from two local creek reference sites (see Item 4.5, below) to field check various sediment design modeling analyses. The analytical methods included the Unit Discharge Bed Design method (Bathhurst, 1978), US Army Corps of Engineers EM 1110-2-1601 and the Critical Shear Stress/Shields Diagram method (Leopold et al, 1964).

3.4 Structural Evaluation of the Dam

WCD contracted with Wilson Engineering, LLC to complete a structural evaluation of the integrity of existing dam. Wilson Engineering's evaluation included visual observation and physical testing of the integrity of the concrete and verification that the as-built structure is consistent with the original 1949 Department of Game design drawings (WDOG, 1949).

3.5 Hydrologic and Hydraulic Modeling

WCD used the baseline flow monitoring data to field check and calibrate the results of a basic hydrologic and hydraulic modeling analysis. WCD modeled a typical range of stream flow rates in the project area using standard USGS regression equations for 2, 25, 100 and 500-year flow events (USGS, 2011). These estimates were supplemented with modeling of 90 percent exceedence flows for anadromous fish passage using WDFW's published regression equations (WDFW, 2003). WCD then developed a simple, one dimensional HEC-RAS model of the baseline and design creek channel morphologies to estimate the expected range of water surface elevations and velocities under the baseline and design conditions.

In both the hydrologic and hydraulic models, WCD did not attempt to include the flow attenuation effect of the hundreds of acre-feet of water storage capacity in Lake Terrell. Comparison of our actual high flow measurements at the dam spillway with the modeling results indicated that our simplified "flow through" modeling approach overestimated the actual stream flow characteristics in the project area. Because of the considerable level of effort that would have been required to model the lake storage accurately, WCD believed that its simplified modeling approach was warranted for developing conservative design parameters.

4 Description of the Site

4.1 Existing Conditions

The Lake Terrell Dam is located on Terrell Creek, approximately 500 feet downstream from the lake's outlet. The dam, which was constructed in about 1950, consists of a 20-foot long by 18-foot wide reinforced concrete spillway and a roughly 18-foot wide by 7-foot high timber flashboard dam. The top of the spillway structure is at or below the grade of the surrounding land, and the crest of the flashboard dam is approximately 1.1 feet below the top of the spillway. Consequently, all of the water impounded by the dam lies below the existing ground surface level. Sheet No. 5 of the drawing set depicts the layout of the spillway and dam.

At some time in the past, Terrell Creek downstream of the original lake outlet was dredged and straightened to form relatively featureless, deep trapezoidal channel morphology. The channel drops about 2.2 feet over 912 lineal feet from the base of the spillway to the inlet of the county's culvert under Aldergrove Road at a uniform slope of 0.0024 ft/ft. Except for some concrete debris bank armoring in the first 30 feet of the channel below the dam, the stream banks consist of steep cuts into hardpan soil. A gravel access road runs from Aldergrove Road to the dam along the right (east) bank of the creek and a continuous berm of dredge spoils is piled along the left bank. In the years since the channel was dredged, mature alders, cedars and firs have grown up along the narrow banks and currently provide abundant shade for the creek in summertime.

Immediately west of and parallel to the main channel there is a smaller side channel. It appears likely that this side channel was excavated for the purpose of bypassing lake flow around the dam site during construction of the dam, but no records have been identified to verify this. The inlet to the side channel is located upstream of the dam, so that the water surface elevation in the channel is the same as that in Lake Terrell. Since the side channel has no surface outlet below the large wetland impounded by

Aldergrove Road [1], stream flow rates in it are negligible and over the years a thick layer of muck has accumulated in the bottom of the channel.

Three culverts affect stream flow in Terrell Creek in the project reach between the dam and Aldergrove Road. At the downstream end of the reach (designated as Station 0+00) is the inlet to the 5-foot diameter by 80-foot long corrugated metal pipe (CMP) culvert under Aldergrove Road. The culvert has adequate hydraulic capacity to pass flows of a 2-year flow event, but backwaters the creek flow at higher flow rates (see Section 4.4 below). At reach Sta. 2+12 an 18-inch diameter by 25-foot long CMP culvert carries runoff from a wetland area east of the access road into Terrell Creek. The outlet of the culvert is perched about 5 feet above the channel thalweg and has formed a small scour pool. Finally, at reach Sta. 8+15 a 36-inch diameter by 36-foot long CMP culvert carries runoff from a network of small, ephemeral stream channels that drain the area northeast of Lake Terrell, under the gravel access road, and into Terrell Creek. It appears that the downstream end of this channel network was dredged and widened at some time in the past, probably at the time that the culvert was installed. The outlet of this culvert, the invert of which has rusted out, is perched about 3.0 feet above the Terrell Creek thalweg.

4.2 Wetlands

Large wetlands flank the project reach on both sides of the historic Terrell Creek floodplain. East of the creek are extensive, discontinuous patches of forested wetland dominated by mature alder, cedar and spruce trees.[2] These wetland areas tend to hold standing surface water during much of the wet season. West of the creek is a large, continuous emergent wetland bounded by Aldergrove Road to the north, the linear dredge spoil berm to the east, and rising forested slopes to the west[3]. The wetland holds standing water throughout the year, with its water surface elevation maintained by lake overflow via the side channel (see section 4.1, above) as well as by beaver dams. Because of the large size of both of these wetland areas, WCD has made no attempt to formally delineate them or rate their "functions and values" from a regulatory perspective.

4.3 WDFW's Lake Level Management Practices

WDFW regulates the water surface elevation (wse) of Lake Terrell for three purposes. First, during normal conditions, WDFW maintains the lake wse at between roughly 97.5 feet and 99.0 feet, relative to an assumed 100.0' benchmark on the top of the dam spillway wall, for the purpose of providing recreational fishing, water fowl hunting and boating for the public.[4]

Secondly, during the wet season, when the lake wse begins to rise, the area manager generally removes one or more of the flashboards to spill more flow in an attempt to reduce localized flooding around the shores of the lake. The lowest point of the paved road to the headquarters area lies at an elevation of about 99.3' relative to the benchmark at the dam, so that when the lake wse rises to elevation 99.3' the road begins to flood (WCD, 2011). The area manager reports that it is only safe and practical to manipulate the flashboards when the water surface elevation is lower than the flashboard crest, the elevation of which is 98.9'.

[1] During high flow events when the lake wse rises about a foot above the dam crest, water in the side channel overflows through low points in the spoils berm into the main channel of Terrell Creek downstream of the dam.
[2] WCD has informally designated this wetland area as a "PFO" Cowardin classification on Sheet 3 of the Plan Set.
[3] WCD has informally designated this wetland area as a "PEM1" Cowardin classification on Sheet 3 of the Plan Set.
[4] The elevation of "0.0" on WDFW's staff gage at the public fishing dock corresponds to an elevation of 96.5' relative to the assumed 100.0' elevation of the top of the dam spillway wall. For example, a wse measurement of 1.0' on the staff gage corresponds to a wse measurement of 97.5' at the dam.

Removal of flashboards allows the lake water to maintain stream flow in Terrell Creek longer than it would otherwise if the flashboards were left in place. During typical years, the lake wse begins to drop below the flashboard crest elevation of 98.9' by mid spring, but because of the gap in the dam crest caused by the removal of one or more flashboards, water typically flows over the dam into the creek in diminishing flow rates through June. Between early July and November, there typically is negligible surface flow from the lake into Terrell Creek. A small amount of water seeps through the joints in the flashboards and roughly 0.2 cubic feet per second (cfs) runs through the pilot siphon pipes, but even this dwindles to nothing by late August.

The third purpose for regulating the lake level is for controlling nuisance aquatic weeds along the shallow margins of the lake. On approximately a five-year cycle, WDFW removes several flashboards from the dam in early summer and allows the lake to drain out to a final wse of roughly 95.8', relative to the assumed benchmark of 100.0' (Kessler, 2011). This wse, which is about 18" to 20" below the typical late summer wse in the lake, exposes the beds of nuisance aquatic weeds to the air and causes much of them to die back. At the end of summer, WDFW replaces the flashboards and allows the lake to gradually refill to normal winter levels.

4.4 Hydrology and Hydraulics

WCD and NSEA measured outflow from the dam into Terrell Creek for a 12-month period from January to December 2011. WCD used these data to corroborate the results of a basic hydrologic and hydraulic modeling effort for the watershed and creek in the project reach. Applying the USGS' "StreamStats" internet-based modeling application, WCD estimated the following stream flow rates from the 5.32 square mile watershed upstream of the project site:

Statistic	Flow (cfs)	Standard Error
Peak 2 yr flow	66.3	56%
Peak 50 yr flow	140	53%
Peak 100 year flow	181	54%
Peak 500 year flow	234	

For the purpose of evaluating fish passage conditions for the existing creek and various design scenarios, WCD estimated 90 percent exceedance flow levels for anadromous fish passage using WDFW's fish passage flow regression equations. The following flow rates were calculated:

Statistic	Flow (cfs)	Standard Error
January Q_{FP}	29.5	48.6%
May Q_{FP}	7.0	75%

WCD developed a simplified one-dimensional HEC-RAS model to evaluate water surface elevations and velocities in the existing creek and under various design scenarios for the project reach. As described in Section 3.5, for conservative purposes, the model did not account for storage in Lake Terrell, but assumed a direct flow-through condition. Likewise, the model also didn't apportion the total flow from the watershed between runoff from upstream of the dam and runoff draining from the much smaller catchment of the network of stream channels that enter Terrell Creek through the culvert at project reach Sta. 8+15.

Selected HEC-RAS water surface elevation estimates are shown in the channel profile drawings in Sheets 3, 4 and 5 of the drawing set. WCD's field observations of the OHW mark along the creek roughly concur with HEC-RAS elevations predicted for the peak two-year flow event, suggesting that the model results do approximate the actual situation. Flow velocities for the existing "baseline" condition stay within the 1.5 to 3.0 feet per second (fps) range, except at the 100-year peak flow level, where a velocity of over 4.0 fps is estimated at the inlet of the Aldergrove Road culvert. The model predicts that the culvert inlet submerges and begins to backwater the creek at roughly 10-year stream flow events. At the predicted 100-year flow level, the model predicts that the culvert is submerged by about 4 feet of water, which backwaters the entire project reach.

For the purpose of achieving the project's objectives, it is just as important to bracket the summer low flow wse in the lake and creek as it is to predict peak flow rates. In 2011, our flow monitoring data show that the lake wse fell below the flashboard crest elevation of 98.9' by the end of April. At this time, the top layer or stop logs had been removed from one third of the length of the flashboard crest, so that lake water continued to spill into the downstream channel until the lake elevation had dropped to about 98.0' at the beginning of July. After flow over the dam ended in July, the lake wse continued to drop to a low wse of 97.3 in late September. This observation implies that the lake wse dropped by 0.7', which represents approximately 385 acre-feet of water[5], due to seepage and evaporation over a fairly typical summer. During 2011, despite typical autumn rainfall, the lake wse did not rise again to the flashboard crest elevation of 98.9' until early December. In the intervening months, there was essentially no flow in the reach of Terrell Creek below the dam (WCD, 2011).

4.5 Sediment

The Terrell Creek channel in the project reach was dredged to the hardpan till subsoil decades ago. The channel bottom currently lies 6 feet to 8 feet below its surrounding floodplain. Over the years, beaver damming and tree fall have trapped silts and small amounts of gravel here and there, but in general the bottom material is still primarily hardpan. WCD sampled sediments in representative locations and measured the following size distribution.

Location	Morphology	Particle size D_{16}	Particle size D_{50}	Particle size D_{84}	Particle size D_{100}
Sta. 4+80	Thalweg – riffle	0.8 mm coarse sand	6 mm fine gravel	12 mm medium gravel	19 mm coarse gravel
Sta. 7+10	OHWM – run	0.2 mm fine sand	0.6 mm coarse sand	2.9 mm very fine gravel	19 mm coarse gravel

Sediments in the side channel to the west of the main channel consist of silt muck, which has accumulated to varying depths over the underlying (dredged) hardpan. Sediment in the small tributaries that enter the main channel at Sta. 8+15 ranges from fine sand to fine gravel. An exception is the downstream-most 15 feet of the channel, above the culvert inlet, which has gravel and small cobble. WCD suspects that these larger particles were placed in the creek at the time that the culvert was constructed.

4.6 Reference Conditions

WCD compared sediment size distribution and channel morphology characteristics at two local reference sites in order to gain insights for design alternatives at the project site. The sites are located

[5] That is, 0.7' depth multiplied by the lake area of about 550 acres

in Whatcom County lowland areas that have had few impacts of development. The first site is a reach of Tenmile Creek immediately upstream of Noon Road. The reach has several similarities to the Terrell Creek project reach, with an upstream drainage area of 3.2 mi^2 and extensive forested wetlands on its floodplain. Characteristic features of this site include:

Channel feature	2-year flow	Bankfull width	Bankfull depth	Channel slope	Particle size D_{16}	Particle size D_{50}	Particle size D_{84}	Particle size D_{100}
Run	67.1 cfs	19 ft	1.7 ft	0.2 %	fine sand	coarse sand	fine gravel	medium gravel
Riffles	67.1 cfs	17.5 ft	1.7 ft	0.7 % to 1.3%	0.3 mm (medium sand)	1.6 mm (coarse sand)	22 mm (coarse gravel)	75 mm (small cobble)

The second site is Chuckanut Creek downstream of Arroyo Park. The watershed and channel characteristics are not as similar as Tenmile Creek, having a larger upstream drainage area (6.8 mi^2) of steep, forested hillsides. Even so, WCD believes that the site serves as a useful “upper limit” comparison of expected morphological conditions for potential design alternatives at the Terrell Creek projects site, such as reconstruction of the channel to a steeper slope than the current condition. Relevant characteristics of the Chuckanut Creek site include:

Channel feature	2-year flow	Bankfull width	Bankfull depth	Channel slope	Particle size D_{16}	Particle size D_{50}	Particle size D_{84}	Particle size D_{100}
Run	144 cfs	41.5 ft	2.7 ft	2.4 %	5 mm (fine gravel)	26 mm (coarse gravel)	80 mm (small cobble)	300 mm (small boulder)

4.7 Existing Dam Structure

Wilson Engineering, LLC evaluated the structural integrity of the existing dam. The evaluation showed that the concrete spillway structure is structurally sound and continues to be serviceable. The timber flashboard dam is deteriorating and should be replaced on a regular basis to ensure its structural integrity (Wilson Engineering, 2011). Wilson Engineering’s evaluation report is included as **Attachment 2** of this design report.

5 Identification and Evaluation of Design Alternatives

WCD and WDFW staff identified the following potential engineering design alternatives for meeting the project's objectives. Each alternative was then evaluated at a general screening level for its ability to meet each of the specific objectives.

5.1 Fishway

A concrete fishway could be constructed at the downstream side of the dam to improve fish passage conditions past the dam. An appropriate design would be a "pool and chute" fishway, in which weirs set at sequentially higher elevations are separated by deep pools. The pools would be sized to allow for dissipation of turbulence, per WDFW's design guidance (WDFW, 2000). The design of the upstream weir notch elevation should take into consideration optimizing the range of flows for supporting both anadromous and resident fish over the course of the annual wet and dry seasons.

5.2 Channel Reconstruction

The dredged channel downstream of the dam could be reconstructed to a morphology that is closer to a "natural" condition (as defined by local reference site conditions). The upstream end of the new channel would be at a high enough elevation to allow fish to pass into Lake Terrell. The channel should be designed to improve hydraulic conditions such as flow velocity for fish passage and summer low flow water depth for resident fish, compared to the existing condition. The design could also include elements for improving in-stream fish habitat, such as large wood debris, pools, riffles, and other features to increase channel complexity.

Two potential channel reconstruction design options include a relatively short, steep "roughened channel" and a longer, less steep channel that more closely matches the grade of natural creek channels at local reference sites.

5.3 Dam Removal or Modification

The existing dam could be removed or lowered to improve upstream fish passage. Full removal of the dam and concrete spillway structure would require significant re-grading and armoring of the creek channel immediately upstream and downstream of the dam site to prevent large-scale erosion of the banks during high flow events. Because the existing concrete spillway structure is still structurally sound, it would be more cost-effective to avoid large scale re-grading and armoring of the channel by leaving the concrete spillway in place and removing or lowering only the timber flashboard dam.

5.4 High Flow Overflow

An overflow structure for passing high flows and for draining the lake to control invasive weeds could be included as a design element in all of the alternatives. Some potential design options include 1) constructing a surface outlet from the side channel to the main channel so that the side channel could route high flows from the lake to the creek; 2) including some form of removable flashboards or slide gate in a modified dam; or 3) constructing an overflow pipe to pass flow from upstream of the dam to the main creek channel. Options for locating the overflow pipe could include running it directly through the dam into the main channel, or bypassing the dam and reconnecting with the main channel at some point downstream.

5.5 Evaluation of Alternatives

The following matrix compares how each of the alternatives addresses the project's specific objectives.

Ecological Objectives

Design Alternative	Project Objective				
	Provide adult anadromous fish passage	**Provide juvenile anadromous fish passage**	**Improve habitat quality for resident fish**	**Protect riparian forest cover**	**Protect adjacent wetlands**
Fishway	A fishway meeting WDFW's design criteria could be built in the existing channel.	A fishway meeting WDFW's design criteria could be built in the existing channel.	May not allow for resident fish passage, but would increase summer stream flow and improve stream water quality. Would allow more non-native "sport" fish to swim from Lake Terrell into the creek.	Could be constructed within the existing channel with minimal impact to trees on the creek banks.	Depending on the notch elevation, could have negligible impact on adjacent wetlands.
Roughened channel	A roughened channel meeting WDFW's design criteria could be built in the existing channel.	A roughened channel meeting WDFW's design criteria could be built in the existing channel.	There is little data on suitability of roughened channels for resident fish. Increased summer flows would improve water quality. Would increase downstream passage for sport fish.	Could be constructed within the existing channel with minor impact to trees on the creek banks.	Depending on the inlet elevation, could have negligible impact on adjacent wetlands.
"Reference site" channel	A channel mimicking reference sites would allow for fish passage.	A channel mimicking reference sites would allow for fish passage.	Could be designed to provide similar habitat characteristics as natural "reference" creeks. Would increase downstream passage for sport fish.	Longer length would involve greater construction impacts to riparian forest	Depending on the inlet elevation, could have negligible impact on adjacent wetlands.
Remove the dam	Would allow for unrestricted upstream passage	Would allow for unrestricted downstream passage	Would restore natural stream hydrology, water quality and sediment transport. Unrestricted access for sport fish.	Minor localized removal of trees at dam site	Would drain the large wetland west of the project site in summer
Lower the dam	No benefit unless combined with channel reconstruction	No benefit unless combined with channel reconstruction	Would improve stream hydrology, but would increase passage for sport fish.	Minor localized removal of trees at dam site	Depending on new crest elevation, could have small or large

					impact on the west wetland.
High flow overflow	Could be designed to have negligible impact, but wouldn't by itself improve conditions.	Could be designed to have negligible impact, but wouldn't by itself improve conditions.	Could be designed to have negligible impact, but wouldn't by itself improve conditions.	Flashboards or a pipe in the main channel would not impact the forest. A pipe bypassing the dam would require cutting trees.	Negligible impact on wetland hydrology. A bypass pipe would need minor dredging in the side channel.

Engineering, Operational and Land Use Objectives

Design Alternative	**Project Objective**				
	Maintain WDFW's ability to regulate the lake water level	**Minimize the project's maintenance requirements**	**Minimize construction costs and temporary construction impacts on surrounding environment**	**Maintain recreational fishing boating in Lake Terrell**	**Maintain drainage capacity of downstream culverts**
Fishway	Would require a high flow overflow to reduce flooding and to drain the lake.	Highest maintenance requirements to clear floating debris and beaver damming	Highest construction cost of all alternatives. Moderate temporary construction impacts	Would maintain existing level of boating and fishing	Would not effect downstream drainage capacity
Roughened channel	Could be designed to pass floods but would require a bypass to drain the lake	Occasional maintenance to clear debris and beaver dams	Moderate construction costs, low construction impacts	Would maintain existing level of boating and fishing	Would not effect downstream drainage capacity
"Reference site" channel	Could be designed to pass floods but would require a bypass to drain the lake	Occasional maintenance to clear debris and beaver dams	Moderate construction costs, highest construction impacts	Would maintain existing level of boating and fishing	Would require replacement of the culvert at Sta. 8+15
Remove the dam	Would not allow WDFW to regulate the lake level	No maintenance requirements	Moderate construction costs. Moderate impacts during construction	Would greatly reduce recreational boating and fishing	After the initial draining of the lake, would not effect downstream drainage capacity
Lower the dam	Could be designed to pass floods but	Occasional maintenance to clear debris and	Low construction costs, lowest temporary	Depending on final dam crest elevation,	Depending on elevation, might overwhelm the

	would require a bypass to drain the lake	beaver dams	construction impacts	would have low to moderate impact	Aldergrove Road culvert at high flows.
High flow overflow	Required in some form by most design alternatives	Moderate maintenance requirements to clear debris and to operate the inlet gate.	Moderate construction costs, low to moderate impacts during construction, depending on design	Could be operated to maintain existing level of boating and fishing	Flow capacity would need to be restricted to avoid overwhelming the Aldergrove Road culvert.

6 Preferred Design Alternative

Based on the evaluation of the pros and cons of each design alternative that is summarized in Section 5.5, the project team identified a preferred project alternative that combines slightly lowering the dam, constructing a “reference site” channel and installing a high flow bypass pipe around the dam. This alternative is described below.

6.1 Description of the Design

The project design plans depict the elements of the preferred alternative. The basic design elements are as follows.

Modification of the Dam

The concrete spillway structure will be left in place in its existing condition. The wood flashboards will be replaced with reinforced concrete planks and fitted into the existing slot in the spillway that secures the existing flashboards. The top tier of the new concrete flashboards will be configured with sloping shoulders and a central 90° notch measuring 26” wide and 13” deep. The elevation of the tops of the shoulders will be 99.0’.[6] The weir notch elevation will be 97.0’. Note that the new weir will not function as an overflow weir, but serve merely as a structural bulkhead between the dredged upstream channel and the reconstructed downstream channel, as described below. Detail A (Sheet 8) of the plan set shows the weir’s design.

Reconstruction of the Channel

Approximately 753 lineal feet of the dredged Terrell Creek channel downstream of the dam will be reconstructed to be similar to natural conditions found in other lowland Whatcom County streams. The channel will start at the new weir at project reach Sta. 9+13 and descend at an average slope of 1 percent (0.01 ft/LF) to meet the existing creek thalweg at Sta. 1+60. The final channel grade will include morphologic and habitat features that are typical of local “reference” sites, including a sloping channel cross section (as opposed to the current trapezoidal shape), a meandering low flow thalweg with small pool and riffle features, and clusters of large wood debris. Design specifications for the channel are shown in Detail B, Sheet 9.

The channel fill will consist of two distinct types of material. The majority of the fill will be a compacted silt/sand/fine gravel material that is designed to simulate the hardpan till of the natural underlying and

[6] All elevations are cited relative to the assumed 100.0’ foot elevation at the top of the existing spillway wall.

surrounding subsoil. The purpose of this compacted layer is to restrict subsurface seepage of stream flow, so that the creek will retain surface flow during summer low flow conditions.

A six-inch thick layer of gravel and cobble will be placed on top of the compacted fill up to the final grade of the channel. This material is designed to be stable at peak flow rates, based on the engineering factors discussed in Section 6.3, below. The top course will include very large cobble of sizes up to 10" (median diameter) to provide channel roughness and complexity. Large cobble of this size is not present in the Tenmile Creek reference reach, but its selection is an attempt to balance conservative engineering models for channel bed stability with a desire to allow some degree of dynamic sediment sorting during high flows, as well as suitable habitat for benthic macroinvetebrates. The final grade of the gravel and cobble layer will be about 0.2 higher than the concrete weir notch at the head of the channel. This difference is intended to allow some flexibility for adaptive management in adjusting the effective thalweg elevation at the weir, should assumptions about the optimal summer low flow lake elevation prove to be a bit off. Specifications for the hardpan fill and the gravel/cobble top course are included in Detail B.

Construction of a High Flow Bypass

Because the flashboards will be replaced with a concrete weir, WDFW staff will no longer be able to directly raise and lower the dam crest elevation to respond to winter flooding and to drain the lake for aquatic weed control. To maintain WDFW's ability to regulate the lake surface level, the design will include a high flow bypass system. Detail C (Sheet 10) shows the design elements of the bypass. A prefabricated concrete catch basin will be installed on the edge of the side channel at project reach Sta. 7+55, which is about 180 feet downstream of the existing inlet to the side channel at project reach Sta. 9+35. Muck will be dredged from about 80 feet of the existing channel to reach the grade of the underlying hardpan.

Two 24-inch diameter drain pipes will be installed at the catch basin and run through the existing spoils berm to discharge into the reconstructed main creek channel at Sta. 7+30. A screw gate will be installed at the inlet to the catch basin so that WDFW staff can easily open and close the inlet to whatever level they desire. A lightweight pedestrian gangway will be constructed from the access road across the creek to the catch basin to allow for safe access to the overflow inlet. The project team believes that this arrangement will be considerably safer and more flexible to operate than the current flashboard arrangement. The hydraulic capacity of the overflow system is discussed in Section 6.2, below.

Replacement of the Culvert at Sta. 8+15

The proposed thalweg of the reconstructed channel will intersect the outlet of the existing drainage culvert at project reach Sta. 8+15 approximately 6 inches above its invert elevation. Because of the incompatible new thalweg profile and the fact that the culvert is both undersized for fish passage and is rusting out, the project design includes replacing this culvert with a new one that meets WDFW's "no slope" design guidelines for fish passage (WDFW, 2003). The new culvert will be a 60" nominal diameter pipe arch culvert with the outlet channel bed elevation intersecting the bed of the reconstructed Terrell Creek channel at grade. To achieve this new channel bed elevation will require filling about 45 lineal feet of the small tributary channel directly upstream of the culvert with a fill mix similar to the one specified for the main channel. Profile and section views of the new culvert and channel, as well as specifications for the fill mix, are shown in Figure D, Sheet 11.

Supplemental Planting to Improve Riparian Forest Conditions

Reconstruction of the channel and, particularly, the high flow overflow system, will necessitate the clearing of approximately ten trees from the right creek bank and the left bank spoils berm. To replace the shade lost by the clearing of these trees, the project will include replanting additional cedars, firs and native shrubs along the entire riparian zone between Aldergrove Road and the dam site. The planting plan is shown on Sheet 12 of the plan set.

6.2 Hydraulic Design

The hydraulic design of the preferred alternative attempts to balance several considerations:

- The desire to increase water flow from the lake into Terrell Creek during the summer and fall, when lack of flow contributes to elevated instream water temperatures and delays upstream passage of migrating adult salmonids,

- The desire to maintain more or less the same water level in the lake during summer as currently occurs, in order not to diminish recreational boating and fishing opportunities, and

- The desire to maintain or increase the existing flow capacity from the lake into the downstream channel during winter high flow events.

Relevant design considerations that were applied for achieving these interests are discussed below.

6.2.1 Typical Flows

The design thalweg elevation for the highest point in the profile of the low flow design channel (Sta. 9+13, at the existing dam flashboards) is 97.2'. This elevation is 0.1' below the lowest observed 2011 lake wse (late September). The following table shows typical wse and flow levels observed each month in 2011 and the corresponding flows that would be expected to pass through the new design channel.

Estimated Typical Range of Flows for Design Channel and Existing Dam

Date	Typical Lake wse	Design Channel			Existing Dam		
		Typ. Water Depth (ft)	Typ. Flow (cfs)*	Monthly Volume (ac-ft)	Typ. Water Depth (ft)**	Typ. Flow (cfs)	Monthly Volume (ac-ft)
Late January	99.2'	2.0	28.8	1714	1.1	36	2142
Late February	98.9	1.7	13.3	793	0.8	24	1428
Late March	98.7	1.5	7.3	436	0.6	14	833
Late April	99.0	1.8	17.3	1028	0.9	20	1190
Late May	98.6'	1.4	5.2	312	0.5	11	655
Late June	98.2'	1.0	1.6	97	0.1	2	119
Late July	98.0'	0.8	1.0	58	0.0	0.2	12
Late August	97.6'	0.4	0.2	9	0.0	0	0
Late September	97.4'	0.2	0.0	2	0.0	0	0
Late October	97.5	0.3	0.1	5	0.0	0	0
Late November	97.7'	0.5	0.3	17	0.0	0	0
Late December	TBD	TBD	TBD	TBD	TBD	TBD	TBD
Total				**4471**			**6379**

*Flows were estimated for the design channel configuration using Manning's Equation.

**Depth of water above lowest flash board. From January to June, WDFW had removed one flashboard from 1/3 of the width of the dam crest. The board was replaced in July and remained in place until December.

Based on the flow hydrology observations for 2011 as described in Section 4.4, we estimate that the design channel will pass about 70 percent of the total volume passed over the dam as it was managed in 2011, assuming the same lake wse for both scenarios. The simplified Manning's Equation model that was used for developing these estimates did not take into account the variation in lake wse between the "existing" and "design" scenarios that would accompany the smaller flow rate for the design scenario. Obviously, if the lake wse were higher than the figures used in the model, the flow rate through the design channel would increase accordingly. Nevertheless, WCD believes that the model's rough approximations accurately reflect the general trend that would be expected.

Various modifications can be made to the design and/or operational settings to adjust the design outflow to better match the existing lake outlet hydrology. Two examples include running the high flow overflow structure during winter months and changing the new weir elevation. The following table shows the estimated outflows under two such modifications: 1) keeping the final thalweg elevation at the weir at 97.2' while also running the overflow structure at a flow rate of 8 cfs from December through April, and 2) lowering the final thalweg elevation at the weir to 97.0'.

Estimated Typical Range of Flows for Selected Design and Operational Adjustments

Date	**Existing Dam**		**Thalweg at 97.2' plus 8 cfs flow through overflow pipes**		**Thalweg at 97.0'**	
	Flow (cfs)	Volume (ac-ft)	Flow (cfs)	Volume (ac-ft)	Flow (cfs)	Volume (ac-ft)
January	36	2142	36.8	2190	36.8	2192
February	24	1428	21.3	1269	17.9	1063
March	14	833	15.3	912	10.6	630
April	20	1190	25.3	1504	22.9	1364
May	11	655	5.2	312	7.9	470
June	2	119	1.6	97	2.3	139
July	0.2	12	1.0	58	1.7	98
August	0.0	0	0.2	9	0.4	25
September	0.0	0	0.0	2	0.1	9
October	0.0	0	0.1	5	0.3	15
November	0.0	0	0.3	17	0.6	38
December	TBD	TBD	TBD	TBD	TBD	TBD
Total		**6379**		**6375**		**6044**

For the preliminary design, the thalweg elevation at Sta. 9+13 is set at elev. 97.2' It is recognized that the modeling has several limitations. Not only is the methodology simplistic, but it is calibrated with only one year of field observations. For this reason, it seems prudent to begin with a conservative design (i.e. thalweg at 97.2'), which then can be adjusted in subsequent years. Depending on how the design actually performs in the first year, it will be relatively easy to either run the overflow pipes throughout the winter, or lower the thalweg elevation to 97.0' as an adaptive management adjustment in subsequent years.

The new lake outlet design has two main implications. First, the design channel will not be expected to lower the lake level significantly more than the existing situation and consequently is not expected to have a significant impact on recreational boating and fishing opportunities.

Second, the design channel downstream of the dam will contain water flow, even if only a small amount, for three months longer each year than the current situation. Most importantly from the perspective of trying to restore salmonid habitat, the new design is expected to have flow characteristics that meet minimal fish passage requirements during November and December, when the adult coho and chum salmon migration typically occurs. Currently, the existing dam prevents virtually all flow during October and November, which local fisheries biologists believe is a main factor for the failure to re-establish regular salmon runs in Terrell Creek.

6.2.2 Peak Flows

WCD used the HEC-RAS model to evaluate the anticipated hydraulic performance of the design channel. The particular focus was to estimate the water surface elevations and flow velocities in the design channel under the relevant stream flow conditions listed in Section 4.4. Selected water surface profiles are shown in the proposed channel design profile drawings on Sheets 4 and 5 of the plan set.

The modeling exercises show that while the 2-year, 10-year and 100-year water surface elevations are obviously higher in the reconstructed channel than in the existing channel, the channel, and particularly its inlet at Sta. 9+13, can accommodate these flows. The primary hydraulic control in the project reach is the Aldergrove Road culvert: the models predict the same wse at the culvert inlet (about 3.8’ over the crown) for both the existing and design 100-year flow event.

The HEC-RAS model was used to evaluate flow velocities and depths during the 90 percent exceedence flows for fish passage. The model predictions were as follows:

Predicted Fish Passage Flow Hydraulics

90% Exceedence Flow	Channel depth Range (ft)	Velocity range (ft/sec)	WDFW velocity criteria For salmonids (ft/sec)
January	1.6 to 2.5	1.9 to 3.5	4.0 to 6.0 (adults)
May	0.9 to 2.5	1.5 to 2.8	2.4 (juveniles)

6.2.3 High Flow Overflow System

The design for the high flow overflow system consists of a catch basin fitted with a screw gate and two 24”-diameter by 40 foot long pipes that route overflow from the side channel into the main channel at Sta. 7+30. The smooth-walled HDPE pipes have a slope of 0.75%, with their inlet inverts at elevation 95.6’, which is 1.6 feet below the thalweg of the new channel at the dam site. A standard open channel pipe flow nomograph (n = 0.012) predicts a flow capacity for each pipe of 21 cfs, for a total capacity of 42 cfs. By comparison, this flow rate is equivalent to the highest flow rate that WCD measured at the existing dam during 2011, following a 0.66-inch 24-hour rain event on January 21, 2011. The flow rate into the pipes can be adjusted between 0 and 42 cfs by means of the manually operated screw gate.

During the five-year lake drawdown to manage aquatic weeds, WCD estimates that roughly 1200 acre-feet of water must be drained, in addition to the normal flow through the outlet. This estimate is based on dropping the lake wse from a typical late June level of 98.2’ to the final draw down elevation of 95.8’, multiplied by an average surface area of 500 acres. Assuming an average flow through the overflow pipes of 21 cfs (i.e. half of the total system capacity, since the flow rate will decrease as the lake level drops), it would take about 29 days to draw down the lake.

6.3 Sediment Design

The design for the fill for constructing the new channel includes two distinct sediment classes: the underlying "hardpan fill" and the "gravel and cobble fill" top course. Specifications for each class are listed on Detail B, Sheet 9 of the drawing set. The hardpan fill is designed to simulate the underlying native hardpan till. Because it is designed to be covered at all times by the overlying top course, the design is based on simulating the existing conditions, rather than on engineering stability.

The top course of "gravel and cobble fill" is designed to be relatively stable at peak design flows, while allowing some degree of dynamic sediment sorting during high flows, as well as suitable habitat for benthic macroinvetebrates. WCD developed the design for this top course by evaluating and comparing the results of three different engineering models against what we have observed in the Tenmile Creek and Chuckanut Creek reference sites. Applying the Critical Shear Stress/Shields Diagram method for expected 100-year flows in the upstream 300 feet of the design channel,[7] a D_{84} particle size of 30 mm was estimated. That is, a 100-year flow event would be expected to generate sufficient sheer stress to move a 30 mm particle size. Applying the ratios published in WDFW's channel design guidance (WDFW, 2003) for typical particle size distribution in natural streams, the following distribution was estimated:

Particle Size Distribution by Critical Shear Stress method

D_{16}	D_{50}	D_{84}	D_{100}
3.8 mm	12 mm	30 mm	75 mm

For comparison, the US Army Corps of Engineers EM 1110-2-1601 unit discharge method was used to measure a stable D_{30} particle size of 67 mm. Applying the method's scaling factor of $D_{84} = 1.5D_{30}$, a D_{84} of 100 mm was calculated. Using WDFW's distribution ratios, the following distribution was estimated:

Particle Size Distribution by EM 1110-2-1601 method

D_{16}	D_{50}	D_{84}	D_{100}
12.5 mm	40 mm	100 mm	250 mm

Finally, the results were compared with a distribution estimated using the Unit Discharge Bed Design Method (Bathurst, 1978), again based on the estimated 100-year flow channel cross section and hydraulic slope. Assuming a unit discharge at the Sta. 8+87 cross-section of 10.8 cfs/ft, the Bathurst method estimates a D_{84} of 45 mm. Using WDFW's distribution ratios, the following distribution was estimated:

Particle Size Distribution by Unit Discharge Bed Design method

D_{16}	D_{50}	D_{84}	D_{100}
5.6 mm	18 mm	45 mm	113 mm

Note that these methods are primarily intended for estimating sediment transport rates in creeks and rivers, and only secondarily for designing stable beds in constructed channels. They imply that all

[7] As determined by the HEC-RAS one-dimensional model. Note that backwatering caused by the Aldergrove Road culvert reduces the hydraulic gradient of the project reach at the 100-year flow level, which also reduces the expected sheer stress on the channel bed.

particle sizes less than D_{84} are potentially mobile under the 100-year design flow. Consequently, for designing a channel in which the majority of particles are intended to be stable, the majority of the particles need to be at larger than the D_{50} predicted in the models. Several factors tend to counter the predicted transport rates, including interaction between smaller and larger particles in the creek bed and, in this case, the attenuation of the predicted 100-year flow rate caused by the large amount of water storage in Lake Terrell.

In order to calibrate the modeled particle size distributions against actual distributions in lowland Whatcom County creeks, the estimates were compared with actual particle size distribution measured at the two local reference sites:

Measured Particle Size Distribution at Local Reference Sites

Site	D_{16}	D_{50}	D_{84}	D_{100}
Tenmile Creek (riffle)	0.3 mm	1.6 mm	22 mm	75 mm
Chuckanut Creek (run)	5 mm	26 mm	80 mm	300 mm

Taking into account the results of the three engineering methods, bracketed by the two reference sites on the low (Tenmile Creek) and high (Chuckanut Creek) sides, the design identified the following particle size distribution as a reasonable balance between the need to maintain a fairly robust top coarse to protect the underlying hardpan, the desire to provide channel complexity to improve fish passage conditions at high flows, and the desire to allow some degree of dynamic sorting of the sediment under high flow events.

Design Particle Size Distribution for the "Gravel and Cobble Fill" Top Course

D_{16}	D_{50}	D_{84}	D_{100}
11 mm (Medium gravel)	36 mm (Very coarse gravel)	90 mm (Small cobble)	225 mm (Large cobble)

6.4 Beaver Damming

Currently there is active beaver dam-building activity at the project site. In the summer of 2011 alone, beaver built a small dam across Terrell Creek at approximately reach Sta. 3+00 as well as a large dam across the outlet of the lake, about 500 feet upstream of the dam. Two elements of the proposed design are susceptible to being dammed by beavers: the new channel at Sta. 9+13 at the location of the existing dam, and the inlet to the overflow structure on the side channel at Sta. 7+55.

The project design takes a different approach at each location to respond to the potential for damming by beavers. At Sta. 9+13, the head of the new channel, the design approach is simply to let beavers dam it. The thalweg elevation is 2.8' below the top of the existing spillway structure walls, which are only slightly below the grade of the surrounding floodplain. The top of the channel side slopes/weir shoulder is only 1 foot below grade. If beavers block this with a dam, the height difference between the top of the dam and the channel bed is probably not sufficient to block fish passage, either in the upstream (adult) or downstream (juvenile) directions. If WDFW staff choose to remove dams at this location, they will be able to do so safely, but it doesn't seem necessary from a fish passage perspective.

A beaver dam blocking the high flow overflow structure would be more of a problem if WDFW staff need to open the gate in a hurry to respond to upstream flooding. Two design features are included to make the structure not attractive for beaver damming activity. First, the overflow structure will be shut by a screw gate when it is not in use, so for most of the year, there will not be any flowing water at this location to attract beavers. Second, the pipes are set at an elevation such that in normal winter conditions, they will be completely submerged, which also will minimize attraction for beavers.

6.5 Dam Safety Considerations

During the conceptual design phase of the project, WCD corresponded with the Washington Department of Ecology's (WDOE) Dam Safety Office regarding WDOE's expectations for modification of the dam. WDOE identified the dam as having a low (Level 3) downstream hazard setting. Because the filling the channel below the existing flashboard dam will reduce the dam height to less than 6 feet (actually to zero feet), WDOE staff indicated that project could qualify the dam for removal from WDOE's jurisdiction, per WAC 173-155-020 (WDOE, 2011).

In this case, WDOE's only requirement would be that the channel at the buried concrete weir be designed to pass a 500-year flood event. WCD's HEC-RAS model predicted that the design channel can pass the 233 cfs 500-year design flow that is predicted by USGS' StreamStats static flow-through hydrologic model.[8] The modeled water surface elevation at the head of the new channel (Sta. 9+13) is 100.32', which is 0.3' above the top of the walls of the existing spillway. This flood elevation is results from the backwatering of the creek flow by county's culvert under Aldergrove Road, and not by the size of the constructed channel. In this case, water that rises above the existing spillway walls would backwater into the side channel and wetland system west of the creek, rather than cause scour or other damage to the constructed channel.

6.6 Construction Cost Estimate, Maintenance and Operation

WCD estimates a preliminary construction cost estimate for the project of approximately $160,000. The primary cost elements are shown in **Attachment 1**.

The project is designed to be self-sustaining, with minimal maintenance requirements. WDFW's Whatcom Wildlife Area manager will be responsible for maintain and operating the system. The main operational requirements will be 1) opening and closing the overflow gate and 2) adjusting the channel elevation at the new weir. The overflow gate can be manually opened and closed to meter flow out of the lake for reducing flooding of the road at the headquarters area and for maintaining the desired summer wse in the lake. The channel elevation at the weir can be adjusted by placing or removing cobble and boulder as needed. It is anticipated that an optimal level will be determined by an adaptive management approach over the first few years of operation.

Maintenance requirements will likely be limited to clearing branches and debris from the channels at the weir and overflow structures and to managing beaver activity. The design approach to managing beaver activity is described in Section 6.4.

[8] As discussed in Section 4.4, this figure is conservative because it does not take into consideration the flow attenuation effect of the water storage capacity of Lake Terrell.

7 References

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WCD, 2011. Field measurements and observations by Whatcom Conservation District staff, 2011. Data for the Tenmile Creek reference site was presented by Tom Slocum, PE at NSEA’s 2003 annual “Salmon Summit” conference.

Wilson Engineering, 2011. Report of Structural Evaluation of the Lake Terrell Dam, 2011 (in prepration).

Attachment 1: Conceptual Construction Cost Estimate

Construction Item and Description	Units	Unit Cost	Quantity	Cost
Construction dewatering				
Isolate spillway from upstream creek	ft	$100	20	$2,000
Pumping	l.s.	$2,000	1	$2,000
Water quality protection BMPs	l.s.	$3,000	1	$3,000
Modify Dam				
Demolish stop log dam	l.s.	$1,000	1	$1,000
Precast concrete planks, furnished and installed	l.s.	$5,000	1	$5,000
High flow overflow system				
Channel dredging	cy	$25	40	$1,000
Catchbasin, furnished and installed	l.s	$4,000	1	$4,000
gate valve system, furnished and installed	l.s	$5,000	1	$5,000
24" HDPE pipe, furnished and installed	ft	$50	80	$4,000
concrete footings for crossing structure	ea.	$500	2	$1,000
Prefab gangway structure, furnished and installed	l.s	$10,000	1	$10,000
Replace culvert on tributary creek				
excavate and remove existing culvert	cy	$20	150	$3,000
furnish new 60" culvert	lf	$120	36	$4,320
Channel Reconstruction				
Hardpan fill	cy	$20	1430	$28,600
Gravel/cobble/boulder fill	cy	$45	200	$9,000
LWD pieces	ea.	$550	8	$4,400
pilings	ea.	$100	12	$1,200
Labor				
Excavator time	hr	$160	60	$9,600
Hand labor	ft	$45	100	$4,500
Riparian revegetation	stem	$5.50	750	$4,125
subtotal				$106,745
Mobilization and demobilization (20%)				$21,349
Tax (9%)				$11,528
Contingency (15%)				$20,943
Total				**$160,566**

Attachment 2: Dam Structural Evaluation Report

The attached report was completed by Wilson Engineering, LLC in December 2011. It should be noted that the report describes the installation of a pre-cast concrete weir to replace the existing timber flashboards. After subsequent review of the draft design by WDFW representatives on January 10, 2012, the design was simplified to replacing the flashboards with prefabricated concrete planks. The structural evaluation report was not updated to account for this design change, but its original conclusions support the new design.

Wilson
SURVEY/ENGINEERING

December 5, 2011

Mr. Frank Corey
Whatcom Conservation District
6975 Hannegan Road
Lynden, WA 98264-9019

Re: Structural Testing and Engineering Design Support
Terrell Creek Dam Fish Passage Project

Wilson Project 2011-103

Dear Mr. Corey:

Wilson Engineering is pleased to present this report on proposed modifications to the Lake Terrell Dam. Per the scope of our agreement, it includes the following elements:

- Description of on-site testing
- An analysis of a practical method for carrying out the work
- An opinion of probable construction cost

ON SITE TESTING AND MEASUREMENTS

We were on site to check the spillway on September 19 and followed up to check details on September 30, 2011.

We performed testing with a rebound hardness ("Schmidt") hammer. The rebound of a calibrated steel weight from the surface of concrete is a direct measure of its hardness, and correlates well to the strength of the concrete. While there was variation, the concrete hardness generally correlated with a strength of approximately 4000 psi, which is equivalent to good quality contemporary concrete material.

In general, the concrete appeared to be in good condition. No significant cracks or spalls have been noted. There has been some surface erosion, so that the surface appears almost to be an exposed aggregate finish. However, this is excellent for bonding new concrete provided that it is cleaned.

Our spot checks were made with a magnetic rebar detector (4" depth limitation) did not find any indications of bars on the abutment, which is consistent with the drawings, as the bars are shown to be on the soil side of the wall. No interference with the setting of rebar dowels is anticipated, therefore.

We probed the soil on the upstream side of the dam, and found it to be soft muck to the base of the slab below – no hammering was required for any of four locations. Shots with a level indicate that the slab is indeed at 8' below the top of the concrete pillars, as shown on the drawings.

The pillars are of a slightly different shape than shown on the drawings. The 18" wide (downstream) face of each of the two wood stop pillars are 8" thick, rather than 10" as shown on the drawings.

ANALYSIS OF PRACTICAL METHOD FOR CARRYING OUT THE WORK

The proposed method is best understood by making reference to the attached Figures 1, 2, and 3. The soil profiles are based on information provided by the Whatcom Conservation District, and per instructions of the WCD, we did not check them with our survey crew.

In Figure 1, the dark object at reference 20' horizontal is the wood stop. The base line at 90' is the top of an 8" slab (thickness not verified) at the base of the concrete spillway.

In Figure 2, the finished concrete weir is shown at reference 20.' Note that the proposed soil profile on the upstream side of the weir is nearly identical to that shown (current profile) in Figure 1. The soil downstream of the dam, however, is just below to the weir, reflecting the re-profiled stream bed.

Figure 3 shows the minimum requirements for construction of the new weir. The base of the spillway should be clear a minimum of 3'-0" from either side of the new weir. The re-profiled streambed may or may not be nearly complete by this time. However, soil which is presently on the upstream side of the wood stop dam should be excavated at a slope no steeper than 1:2.

The following are steps needed to pursue all other work:

- Excavate soil to required profile
- Lower water level through bypass channel
- Plastic sheeting and sandbags to impound lake water from demolition and construction activities

Note that the three above listed activities take place nearly in unison. Immediately after initial excavation and lowering of the lake level, a system of sandbags and plastic sheeting should be installed to keep wind driven water from rapidly entering the excavation and eroding the soil. A clean working surface at the base of the new concrete weir will be required. Then the following activities will be required:

- Remove metal parts from surface of concrete spillway, not including the cast-in-channels which may remain
- Other misc. demolition, including the removal of the wood stops. Do not demolish, and if required, use temporary means to support steel grating walkway, until after pillars are shortened.
- Concrete saw to shorten spillway pillars to 6' rather than 8' (specialty subcontractor work)
- Complete demolition of platform (used for access to tops of pillars for demolition)
- Bush-hammer to roughen surface of concrete where it may be smooth
- Water blast other concrete surfaces to clean them
- Drill for dowels (4" typical)
- Set adhesive rebar dowels
- Place rebar for new wall that provides structure for weir
- Place waterstop grout material
- Form for new weir
- Place concrete – assume access for both concrete mix truck and pumper
- Allow 4 days or tested to 2500 psi before stripping forms
- Sack form ties
- Remove sandbags and plastic sheathing for impoundment of work area
- Backfill excavated material – use existing or new, as required by biological needs

When demolishing the concrete pillars, it will be necessary to use a water slurry to cool the concrete saw for cutting. I have assumed that the bottom of the area below the wall will be lined with plastic, and this slurry will be pumped out for offsite disposal. This area would then be rinsed thoroughly, again with all the material being disposed of offsite. In addition, since the portions of the pillars which are to be removed will weigh approximately 600 pounds each, they might be removed by use of epoxied closed loop anchors, lifted away by a short crane on a wheeled vehicle.

Vehicles to access the site are assumed to be of significant size. It is possible to perform the work, of course, with manual labor and small tools, but at a much higher cost.

ANALYSIS OF SEISMIC SAFETY: SLIDING

A sliding analysis was performed including the combination of seismic forces along with static forces from passive soil loads on an unyielding surface of the weir. This is a very conservative analysis, since even a slight movement of the weir surface will reduce soil forces considerably. Seismic forces were computed with an updated version of the 1929 Matsuo & Okabe method, published in 2010 by Maleki and Mahjoubi. Sliding was assumed to be resisted by the base slab and the keyways. Friction on sidewalls of the spillway was neglected, which is conservative. The factor of safety for sliding was found to be 3.67, which is acceptable.

Due to the aspect ratio of the structure (9' of new soil, 18' wide, more than 20' long) it is clear by inspection that the structure is stable for overturning.

OPINION OF PROBABLE CONSTRUCTION COST

The opinion of probable construction cost is based on the preliminary drawings. This opinion of costs includes the work necessary to install the concrete weir in place of the wood stop system. Excavation and the installation of the HDPE line, the valve, the access to the valve, and the restoration of the stream bed to a suitable profile for fish passage are not included.

This opinion of probable construction cost makes use of our estimating spreadsheet, calls to local suppliers, and standard estimating guides. It is not a bid, but can be used to set a budget for the work.

The probable construction cost for the work is summarized below:

Task	$Estimate
Concrete demolition with diamond saw	$2,500
Other demolition	$2,000
Bush hammer / waterblast / dowel reinforcing	$1,600
Expansive type waterstop grout for new to existing concrete	$500
Reinforcing placed	$1,000
Forming	$5,200
Concrete Placement	$500
Remove impoundment materials	$200
Subtotal	$13,500
Contingency for budget	$2,700
TOTAL Budget level Opinion of Probable Construction Cost	$16,200

CONCLUSION

The project is feasible, and structural drawings are nearly ready to be sealed and made final. In the meantime, we are ready to assist with review of specifications and concrete mix designs.

Very Truly Yours,
WILSON ENGINEERING, LLC

Charles Waugh

Charles Waugh, P.E., S.E.

CHARLES B. WAUGH
STATE OF WASHINGTON
18826
STRUCTURAL ENGINEER
PROFESSIONAL ENGINEER

5 Dec 2011

Attached: Figures 1, 2, and 3 (Weir/Soil Profiles)
Preliminary Drawings
Sealed Calculations

Charles Waugh

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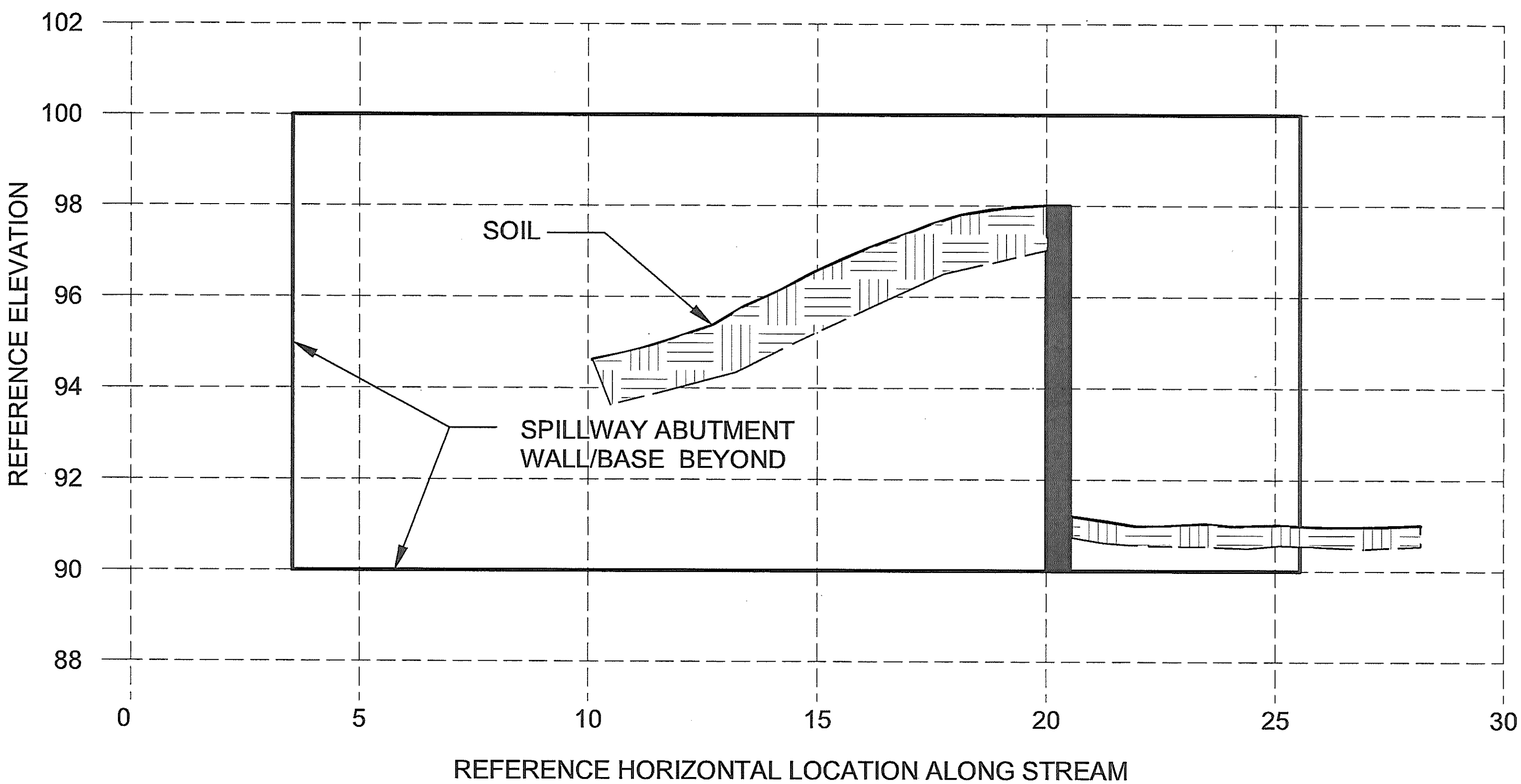
Date: 2011.12.05 17:19:41 -08'00'



TERRELL CREEK DAM FISH PASSAGE IMPROVEMENT - STRUCTURAL FEASIBILITY

FIGURE 1:

PRESENT PROFILE BASED ON INFORMATION FROM WCD

Wilson
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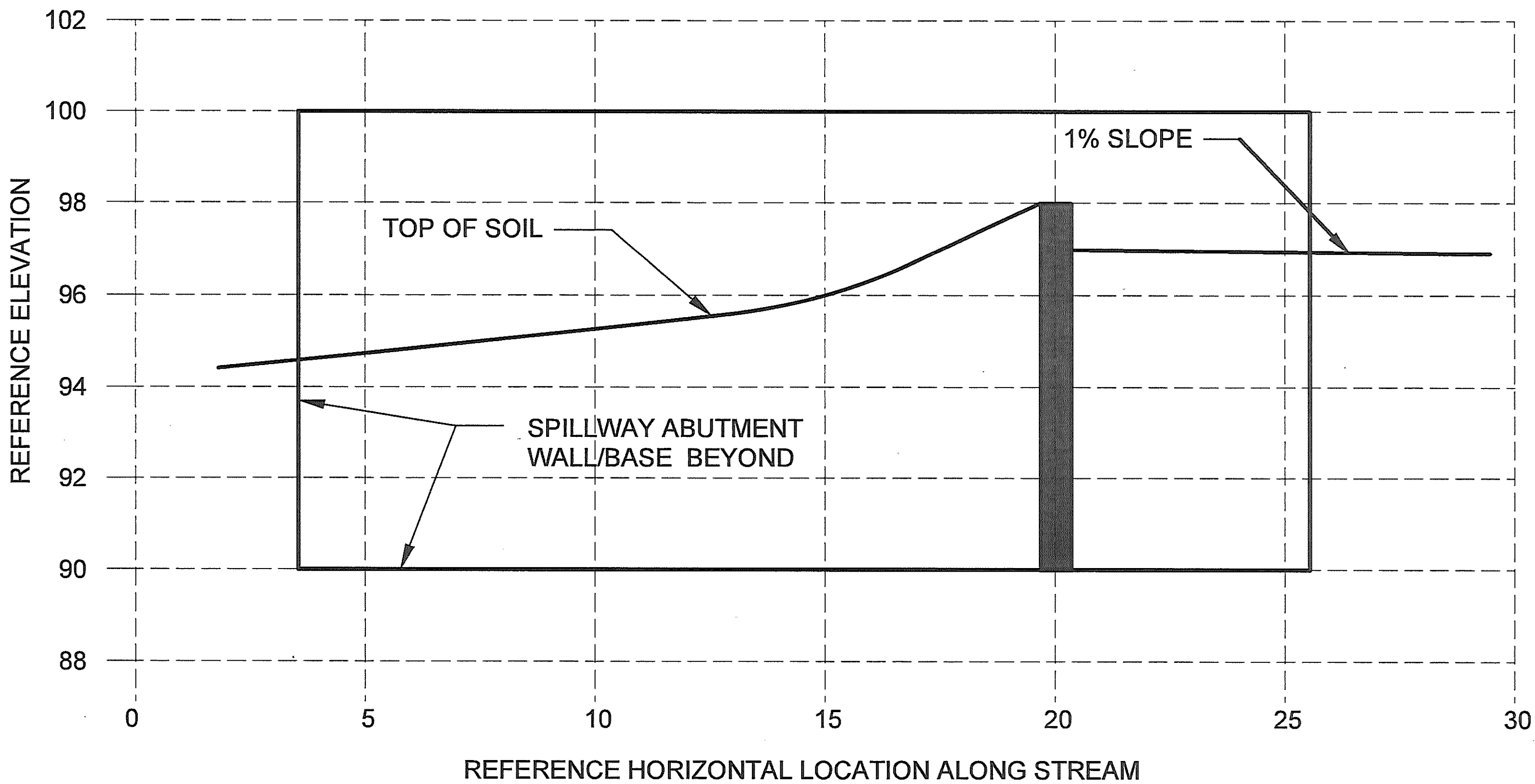

TERRELL CREEK DAM FISH PASSAGE IMPROVEMENT - STRUCTURAL FEASIBILITY

FIGURE 2:

PROPOSED PROFILE BASED ON INFORMATION FROM WCD

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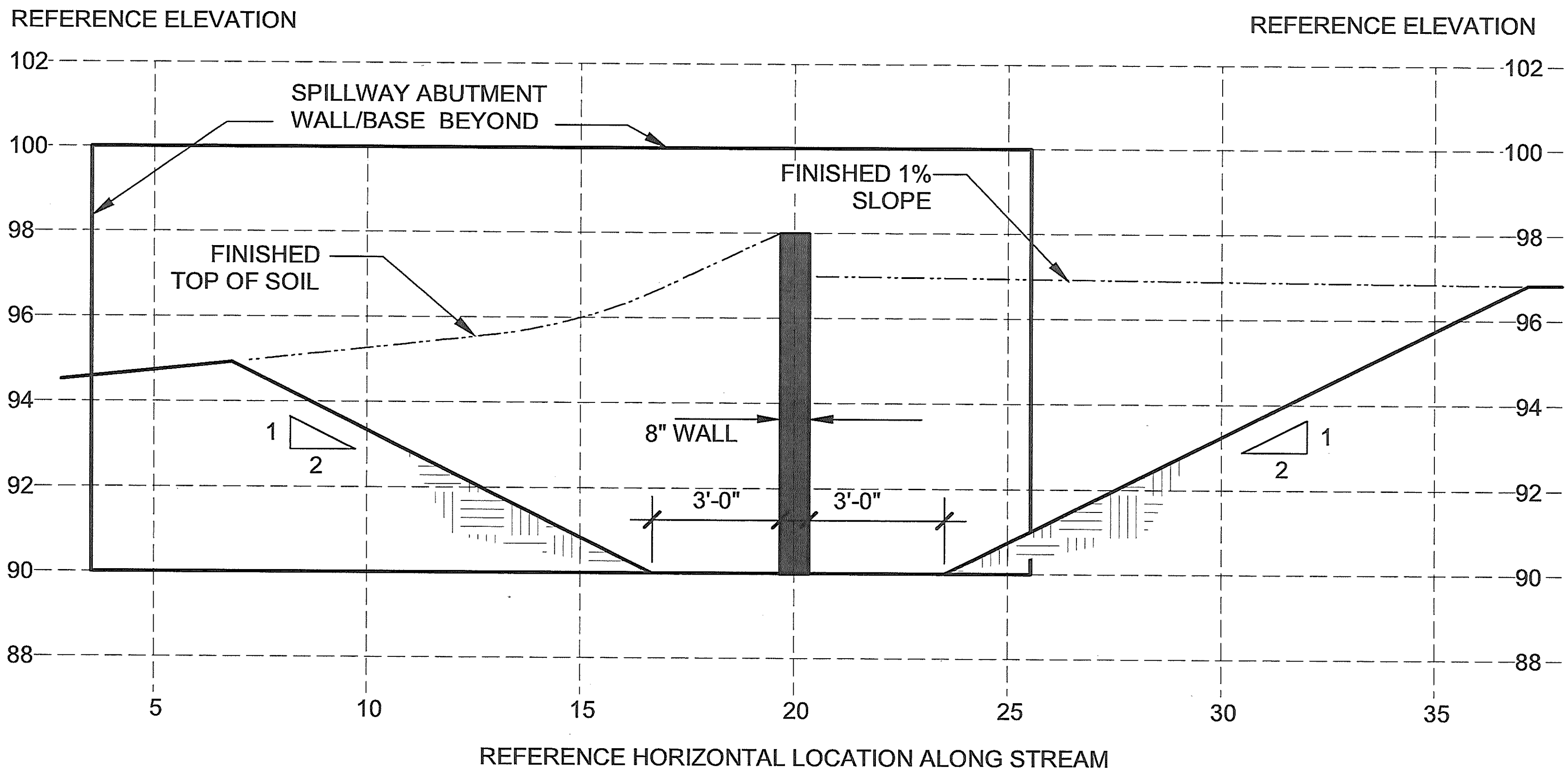

TERRELL CREEK DAM FISH PASSAGE IMPROVEMENT - STRUCTURAL FEASIBILITY

FIGURE 3:

Wilson SURVEY/ENGINEERING

INTERMEDIATE CONSTRUCTION PROFILE FOR SOIL STABILITY

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PROJECT Lake Terrell Dam
PROJECT # 2011 - 103 PAGE 1 OF 4
BY CW DATE 12·5·2011
SUBJECT

CALCULATIONS FOR REINF & SLIDING

STATIC FORCES PAGE 1
SEISMIC FORCES P 2
COMBINED / REBAR P 3
SLIDING CHECK P 4

Charles Waugh Digitally signed by Charles Waugh DN: ou=ARX CoSign, cn=Charles Waugh, email=cwaugh@wilsonengineering.com Date: 2011.12.05 16:58:30 -08'00'

CHARLES B. WAUGH STATE OF WASHINGTON 18826 STRUCTURAL ENGINEER PROFESSIONAL ENGINEER

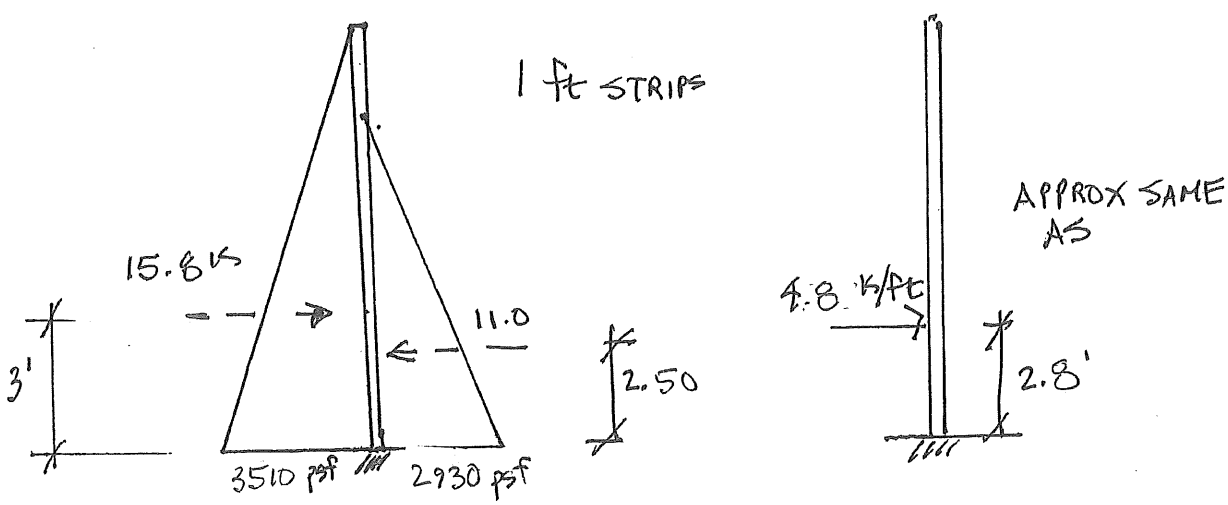
5 DEC 2011

STATIC:
PASSIVE SOIL (NO DISPLACEMENT, RIGID WALL)

$$K_p = \frac{1+\sin\phi}{1-\sin\phi} = \frac{1+\sin 32^\circ}{1-\sin 32^\circ} = 3.26$$

ASSUME DRY – AS AT DRAWN – DOWN LAKE, WITH ONLY 7.5' OF SOIL ON BACK SIDE VS 9' ON LAKE SIDE —

$\gamma = 120\ \#/ft^3$ SO EFD = $390\ \#/ft^3$



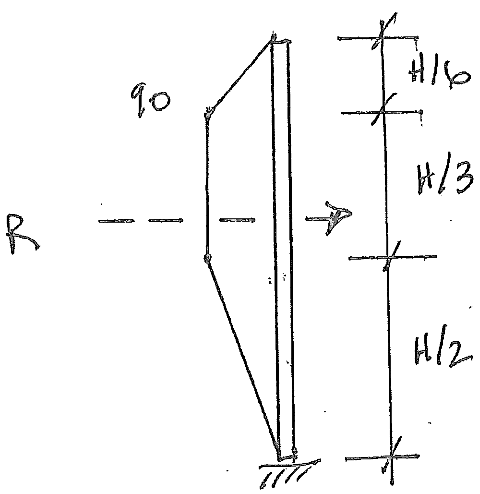
NOTE – THIS SEEMS VERY CONSERVATIVE GIVEN LONG'S SUCCESSFUL HISTORY OF WOOD STOP INSTALLATION

SEISMIC

SEE A NEW APPROACH FOR ESTIMATING THE SEISMIC SOIL PRESSURE ON RETAINING WALLS, BY S. MALEKI & S. MAHJOUBI, AUGUST 2010 (AVAILABLE ON INTERNET)

AS THIS IS A VERY SHORT (9') IMPOUNDMENT AND SQUAT AND WIDE (18' = 2X HEIGHT) USE RETAINING WALL ANALYSES

THE MALEKI/MAHJOUBI METHOD IS AN IMPROVEMENT ON THAT OF MATSUO & OKABE, IN USE SINCE THE 1920s AND STILL USED BY MANY ENGINEERS.



PGA FROM ASCE 7-10

$q_0 = \alpha K_h \gamma H = 0.32(0.60)(120\ LB/ft^3)(9\ ft)$

$q_0 = 0.192\ \gamma H = 207\ LB/ft^2$

$R = (216)(3) + \frac{1}{2}(216)(6) = 1.25\ k/ft$

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PROJECT: LAKE TERRELL DAM
PROJECT #: 2011-103 PAGE 3 OF 4
BY: WJ DATE: 12.5.2011
SUBJECT:

COMBINED RESULTANT (1' STRIP)

$4.8 + 1.25 = 6.05\ K/ft$

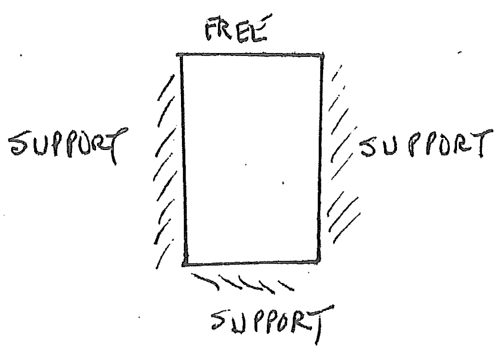
$$\frac{4.8(2.8) + 1.25(5.1)}{6.05}$$

$= 3.01' \cong 1/3$ OF WAY (3')

FOR ANALYSIS OF REBAR, USE EQUIVALENT FLUID DENSITY
$= 1.34\ K/ft^2$

REBAR - USE STRAIGHT LOAD COMBINATION (CONSERVATIVE)
AND LOAD FACTOR = 1.6

USE CHARTED SOLUTION FROM Raymond Roark, FORMULAS FOR STRESS AND STRAIN, 4TH EDITION, CASE 49, P 228



$6' \times 9'$ SO $\frac{a}{b} = 1.5$

$\beta = 0.28$

M PER UNIT LENGTH

$$M = \frac{\beta w b^2}{6}$$

$$M_u = 1.6 \frac{(1.34\ K/ft^2)(0.28)(6\ ft)^2}{6} = 3.60 \frac{K\text{-}ft}{ft}$$

$$\frac{M_u}{4d} = \frac{3.60}{4(4)} = 0.225\ in^2/ft$$ CONSERVATIVELY ✓ OK

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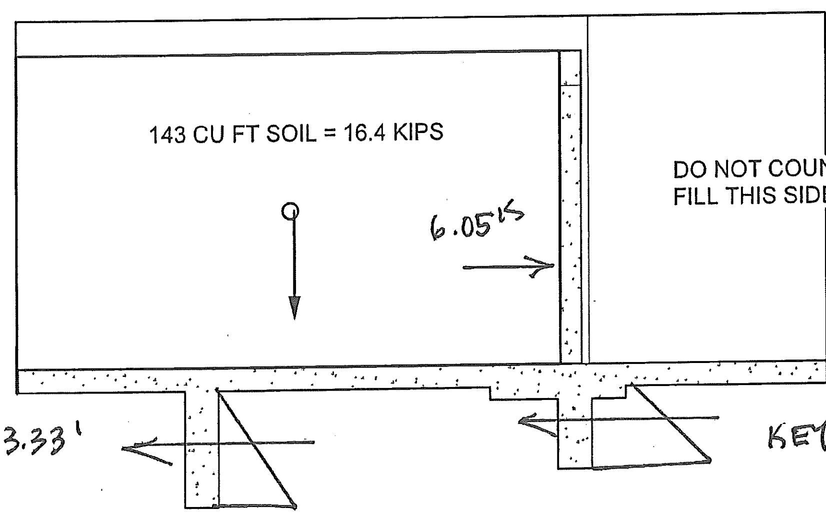
PROJECT: LAKE TERRELL DAM
PROJECT #: 2011-103

BY: WD
DATE: 12-5-2011
SUBJECT: SLIDING CHECK

SLIDING CHECK 1' STRIP

$\mu = 0.50$, EFD FOR PASSIVE PRESSURE = 300 LB/ft³



KEY = 3.33'

KEY = 2.33'

RESISTANCE

16.4
3.3
19.7

$19.7 \times 0.50 = 9.9^{k}$ FRICTION

SLAB AND KEYS 22.2 FT

$WT = 22.2 \times 0.15 = 3.33^{K}$

$\frac{(3.33)^2(0.30)}{2} + \frac{(2.33)^2(0.30)}{2} = 2.47$ PASSIVE

$19.7 + 2.47 = 22.2$

$\frac{22.2}{6.05} = 3.67$ FS ✓ OK