

ELOIKA LAKE OUTLET HYDRAULIC ANALYSIS



June 25, 2011

Prepared for:

Spokane County Conservation District

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APPENDICES

- A: Project Site Drawings

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1. INTRODUCTION

As outlined in the Spokane Conservation District LSR Eloika Lake RFQ, this engineering evaluation is intended to provide a better understanding of the current hydraulic conditions from the Eloika Lake outlet through two box culverts at Eloika Lake Road. This evaluation also includes an analysis of several scenarios to control / maintain the lake at a higher stage between June and October. Finally, several concerns that were identified in a previous study, *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility*, are addressed. These concerns include identifying the location and elevation of a natural lake level control in the outlet channel and assessing whether the NRCS proposed lake control structure would cause flooding along the Eloika Lake outlet during base flow conditions.

A project vicinity map (Sheet M1) is provided in Appendix A, as are a plan and profile view of the project site (Sheets M2 and M3).

2. SURVEY CONTROL

The June 2009 *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility* report provides a comprehensive history of activities at and near the Eloika Lake outlet. According to the report, lake levels fluctuate seasonally through elevations ranging from approximately 1904 feet to 1910 feet (mean sea level -MSL). However, the June 2009 report states, "None of the references and data sources reviewed for this study indicate whether the vertical datum is the 1929 datum (NGVD29) or the 1988 datum (NAVD88)." Our survey suggests that these early data sources were in fact reporting elevations relative to 1929 datum. To remain consistent with historically reported lake elevations, this 2011 report presents elevation data using the NGVD29 datum.

3. STUDY OBJECTIVES AND MODELING CRITERIA

In order to identify potential measures / treatments to maintain a higher lake stage through the summer season, an understanding of normal seasonal lake level changes occurring at the lake outlet is necessary. Lake level data is somewhat limited, but, in general, the lake level fluctuates between a low stage ranging from 1904.3 feet to 1904.8 feet to a normal high stage of over 1909.6 feet. Historically, various attempts have been made or proposed to control the lake level. Proposed control efforts have generally had the goal of extending the high lake stage through the growing season, while allowing for a winter drawdown. In 1997, the Natural Resources and Conservation

Service (NRCS) designed a water control structure that was to be placed downstream of the Eloika Lake Road. This structure would maintain the lake elevation at 1907 feet from April to October and then lower the Lake to 1903 feet in the late fall through winter.

For this study, our understanding of the Eloika Lake landowner objectives is to similarly extend the period of higher lake levels into the fall and to understand the influence of the Eloika Lake Road culverts on the lake level dynamics. However, a winter drawdown is no longer a primary goal. More specifically, in the desired future condition, the lake water surface elevation would be maintained at a level at least 2 feet higher than the current average low lake elevation. In keeping with these objectives, for this study, a new low flow lake elevation of 1907 feet was used for modeling purposes. The previously designed NRCS control structure, as proposed, required active operator participation for it to function through the target range of flows. At high flows, all check boards in the structure must be removed or an unacceptable increase in lake water surface elevation would occur. It is our further understanding that the current Eloika Lake landowner objectives are to explore treatments that will function passively and will not rely on regular operator intervention.

Given these lake management objectives, regulating lake levels as described has several practical considerations that provide boundary conditions for this analysis. The Eloika Lake outlet conveys annual peak flows each year generally in the months of April through June. During this period, lake levels typically range between 1907 feet and 1909.6 feet. Even higher lake levels are likely during low frequency flood events. From a lake shore owner perspective, it is anticipated that any measure to manage lake levels at the outlet should not significantly increase lake levels during normal high magnitude flows. Some increase during these conditions may be acceptable, but the actual acceptable rise will be an issue to be addressed prior to final design of an outlet structure. From a regulatory standpoint, it will likely not be acceptable for a control structure to increase the 100 year flood elevation. These lake elevation rise criteria present limitations to passive lake level control options that will be discussed in following sections of this report.

The following provides a summary of boundary conditions used for this analysis:

- No increase / rise in lake elevations during the 100 year flow conditions
- Small increase allowable for ordinary high flows. (Assume < 0.5 feet)
- Lake level during low flow conditions maintained at 1907 feet through the growing season
- Lake level control must be passive system requiring no regular manual operation

4. METHODS

To evaluate channel hydraulics, a 1-dimensional water surface profile model of the Eloika Lake outlet to a point downstream of the Eloika Lake Road was constructed using HEC RAS version 4.1. On June 14th, 10 cross sections upstream of the Eloika Lake Road Culverts and 3 cross sections downstream of the road were surveyed. These cross sections were used to generate physical data for the model. A streambed and water surface longitudinal profiles were also surveyed to identify significant slope breaks in the channel that may act as outlet controls to lake levels.

5. HYDROLOGY

On June 14th, 2011 the Eloika Lake outlet was discharging approximately 120 cubic feet per second (cfs) and was flowing near the bankfull condition, which exceeds levels that would typically be expected for this date as a result of an unusually wet spring. Figure 1 shows a photo of a surveyed cross section as well as a plot of the cross section showing the water surface elevation relative to the top of the channel banks. Discharges higher than 120 cfs would likely result in overbank / floodplain flows. On June 14th, the corresponding Eloika Lake water surface elevation was 1906.7 feet, which is close to the desired summer stage in the lake.

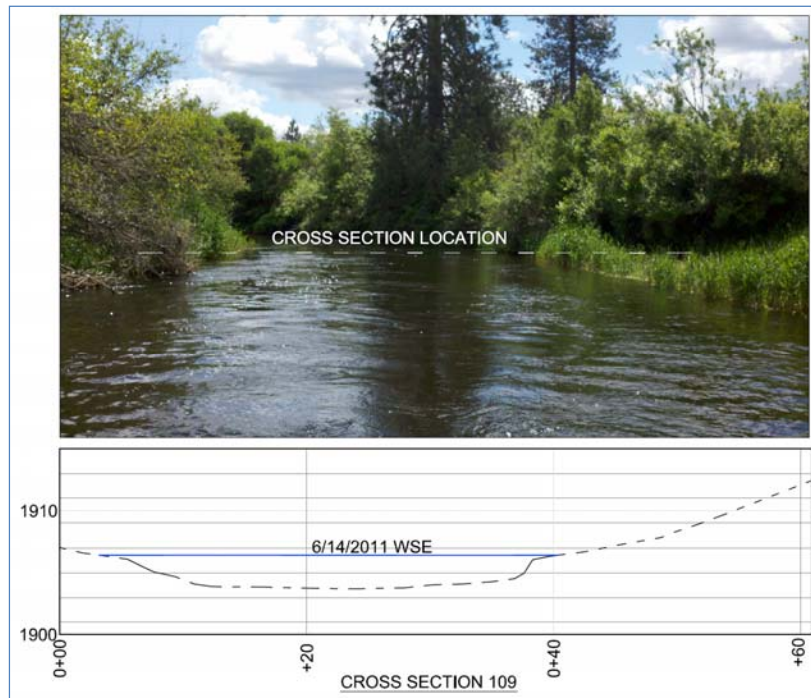


FIGURE 1. TYPICAL SURVEYED CROSS SECTION

Hydrology data is limited for the Eloika Lake outlet; however, the June 2009 *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility* report does offer a limited period of record for inlet and outlet flows. This analysis is not intended to be a detailed flood study and, as such, a full hydrological analysis was not conducted. While the available hydrology data is insufficient to develop a complete outlet hydrograph, for the purpose of this study, a general understanding of base flow conditions, the typical magnitude of ordinary high flows, and the 100 year discharge are of primary importance. Four flow rates were adopted for the analysis. These flows were estimated from data reported in the June 2009 *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility* report and through a direct discharge measurement on June 14th, 2011. A summary of outlet hydrology and adopted modeling flows is presented in Table 1. A value for a 100 year discharge is also indicated in the table as reported in the NRCS 1997 *Eloika Lake Water Control Structure Design* report.

Table 1. Adopted Modeling Flows

	Flow (cfs)	Model Flow (cfs)	Source
Base Flow	5 to 10	10	Eloika Lake Feasibility Study ¹
Ordinary Annual Peak	200 to 260	260	Eloika Lake Feasibility Study ¹
Measured Discharge 6/14/11	120	120	6/14/11 Measurement
100 Year Discharge	1434	1434	NRCS Report ²

6. MODEL SCENARIOS

Five scenarios were modeled to assess the influence of the Eloika Lake Road culvert and to test the effectiveness of several potential outlet control structures. A description of the modeled scenarios are as follows:

- 1) Scenario 1 - Existing Conditions. Existing channel and culvert geometry was modeled over the range of adopted flows. This model was calibrated using water surface elevations at each cross section as surveyed on 6/14/2011.
- 2) Scenario 2 – This modeling scenario used the same flow rates as Scenario I but modeled the flows as if the Eloika Lake Road crossing did not exist.
- 3) Scenario 3 – Modeled the existing channel and culvert geometry as in Scenario I, but used a downstream control scenario consistent to that which would occur if the NRCS designed control structure were installed at its proposed location downstream of the Eloika Lake Road.
- 4) Scenario 4 – Modeled the existing channel geometry with a roughened channel control in the first four channel cross sections near the lake outlet. This iteration hypothesizes that the Eloika Lake channel can be sufficiently roughened to maintain higher lake levels during summer base flows. Roughness of a channel

can be accomplished by adding coarse material to the streambed. The degree to which a channel's roughness can be increased is practically limited as the addition of coarse material sufficient to appreciably affect channel roughness will, at some point, excessively obstruct the channel. For this scenario, an increased roughness was applied to cross sections 109 through 112. A Manning's roughness value consistent with published values for boulder bed streams ($n=0.08$) was used in the analysis. Additionally, to illustrate the limitations of this measure, a Manning's roughness value of $n = 0.2$ was also modeled. A channel roughness of 0.2 would be all but impossible to achieve in the Eloika Lake outlet channel without substantially reducing channel area and conveyance.

- 5) Scenario 5 – This scenario modeled a base flow step pool channel near the lake outlet with a high flow cross channel spanning apron that would seasonally act as a high flow weir. This structural measure would be placed in the lake portion of the outlet just upstream of the active outlet channel. The base flow step pool channel will accommodate seasonal low flows, provide fish passage and maintain a minimum lake level. The broad apron will accommodate flood flows while maintaining shallow depth over the structure. Additional cross sections were added to the model upstream of cross section 112 to simulate the geometry of this control feature. For this model, the structure is idealized as a broad crested weir with a low flow notch representing the base flow channel. Weir and notch widths were determined through an iterative process using the “no rise” and “minimal rise” criteria as the test. As a consequence, to accommodate flood flows, the cross section of this structure would be significantly wider than the actual outlet channel.

7. RESULTS

7.1. Influence of the Eloika Lake Road Culverts

The Eloika Lake Road culverts could potentially influence lake levels in two primary ways:

- The Eloika Lake outlet channel is very flat in gradient. Therefore, the invert elevation at which the culverts were installed may act as a minimum lake elevation control.
- If the culverts are undersized, backwater conditions will occur and lake levels will be controlled by the culvert hydraulics.

7.1.1. Base Flow Lake Level Elevation Control

Drawing Sheet M3 shows a longitudinal streambed and water surface profile of the Eloika Lake outlet channel from Eloika Lake to a point approximately 100 feet downstream of the Eloika Lake Road culverts. Potential stream bed and culvert controls

are indicated along the profile. In general, the outlet channel is very flat in gradient; however, there is a significant slope change between stations 5+00 and 7+28. This segment of channel is steeper than other reaches by an order of magnitude. The minimum channel bed elevation at 7+28 is 1904.165 feet. While the majority of the outlet channel is composed of small gravel and sand, in this steeper reach the stream bed consists of coarse gravel and cobble, creating a stable elevation control. By comparison, the upstream culvert invert was installed at an elevation of 1902.684 feet. Given the apparent stability of the control at station 7+28, it is clear that the Eloika Lake Road culvert does not create a low lake elevation control. There are potentially other upstream controls at stations 11+65 (Elev. 1904.0 feet) and 13+76 (1904.1 feet), but given that these points are slightly lower than the stream bed at 7+28 and that the channel is composed of more erodible sand and small gravel, the station 7+28 stream bed is likely a more reliable control. The June 2009 *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility* report notes that historical minimum lake levels range from about 1904.3 feet to 1904.8 feet, which also supports the conclusion that the low water control is not provided by the culvert. Additional support for this conclusion is provided in Table 2, which details the HEC RAS model results comparing Scenario 1 (Existing Conditions) and Scenario 2 (Free Flow / No Culvert). Under base flow (10 CFS) conditions there is no change in the lake water surface elevation between the two scenarios.

**Table 2. Change in Lake Water Surface Elevations
Between Scenario 1 and 2**

Eloika Lake Water Surface Elevation (WSE) at Cross Section 112			
Discharge (CFS)	WSE Scenario 1	WSE Scenario 2	Change Δ
	(ft)	(ft)	(ft)
10	1904.67	1904.67	0.00
120	1906.68	1906.67	-0.01
260	1907.85	1907.81	-0.04
1434	1913.46	1911.81	-1.65

Positive Δ values indicate an increase in the WSE from existing conditions

7.1.2. Backwater Effects

On June 14th, 2011, at a discharge of 120 cfs, the Eloika Lake Road culverts were operating under outlet control conditions indicating that they were not creating upstream backwater that would support an artificially high lake level. A comparison of results from modeling scenarios 1 and 2 is shown in Table 2. The modeling results indicate that the culverts exert little to no influence on lake elevation at a discharge of 120 cfs or at ordinary high flows. However, as flows increase, the culverts exert an increasing influence on lake levels, and, at the 100 year discharge, the culverts appear to be the controlling influence on lake water surface elevations.

7.2. NRCS Control Structure

In the June 2009 *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility* report, some questions were raised related to the effect the proposed NRCS control structure would have on flooding around the Eloika Lake outlet and along the outlet channel. Presumably, if the NRCS structure were managed as outlined in the design report, then all check boards would be removed during flood conditions and the structure would result in no increase in upstream flood elevations. At base flows, in order to affect lake levels, check boards would by definition be in place and would increase water surface elevations in the Eloika Lake outlet. Under Scenario 3, the existing channel geometry was modeled under base flow conditions and the downstream boundary condition was set to simulate a condition where structure check boards were in place, such that the water surface elevation at the control structure was 1907 feet. To test the sensitivity of the boundary condition, the simulation was run again using a downstream boundary condition of 1906.5 feet. Table 3 presents water surface elevations under both scenarios at cross section 100 (structure location) and at cross section 112 at the lake outlet.

Table 3. Scenario 3 Water Surface Elevations at the Lake and at the Structure

Model Scenario	WSE at Base Flow (10 cfs) Boundary condition - known water surface 1907' (ft)	Δ (ft)	WSE at Base Flow (10 cfs) Boundary condition - known water surface 1906.5' (ft)	Δ (ft)
Scenario 3 - NRCS Structure at Cross Section 100	1907.0	0.0	1906.5	0.0
Scenario 3 - NRCS Structure Cross Section 112 - at Lake Outlet	1907.0		1906.5	

The take away message from this analysis is that, under base flow conditions, the water surface elevation at the NRCS structure would have to be set at the desired lake elevation to exert a controlling influence. This condition has a number of implications that make the proposed structure location less than desirable. On June 14th, 2011, the outlet channel was flowing at or near bankfull condition. At the proposed structure location, the corresponding water surface elevation was 1905.596 feet. Fixing the downstream (NRCS Structure) water surface elevation at 1907 feet, as would be required during base flow conditions, would cause sustained flooding of much of the Eloika Lake outlet floodplain through the growing season. Figure 2 shows the 10 cfs water surface elevation at modeled cross section 106 with all check boards in place at the NRCS structure. Under this scenario, approximately 1 foot of water would inundate the floodplain and over time would likely result in a conversion (loss) of the riparian vegetation community. Additionally, the fluvial nature of the outlet channel would be seasonably converted to lacustrine habitat. The Scenario 3 model runs suggest that the

extent of prolonged flooding would occur to varying degrees all the way to the lake. However, flooding between stations 1+80 and 6+50 would extend across the entire floodplain.

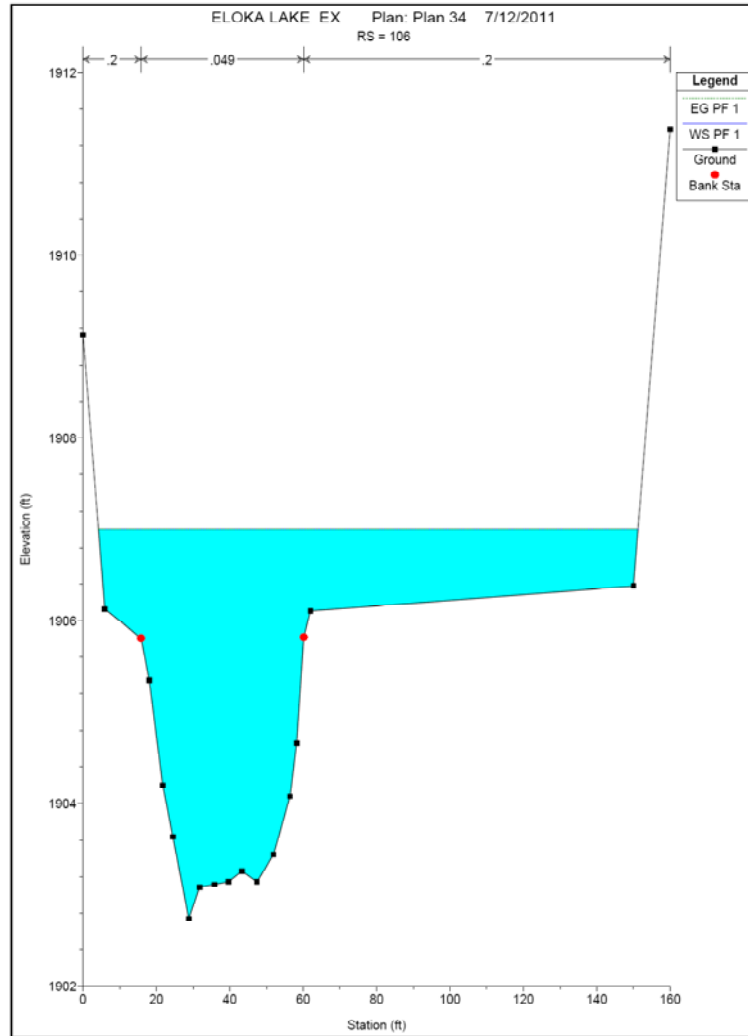


FIGURE 2. CROSS SECTION 106 AT 10 CFS WITH CHECK BOARDS IN PLACE

7.3. Lake Level Control Measures at the Lake Outlet

One of the primary objectives of this study is to identify passive controls that can accomplish the lake level management objectives. Previous recommendations for managing lake levels relied on a certain level of manual operation for optimal system function. For example, the NRCS control structure downstream of the Eloika Lake Road would require check boards to be added and removed as outlet discharge changed. The intent of this analysis is to explore opportunities to passively control lake levels within the desired elevation tolerances through “bioengineered” methods. The term

“bioengineered” in this context is defined as structural measures using natural materials and vegetation to create a functional lake level control with a naturalized aesthetic.

The challenge of a passive system is in devising a control that will increase lake water surface elevations at base flow while minimally increasing lake levels during ordinary high flows and not at all during a 100 year flood. The previously proposed NRCS structure would have had a 40 foot crest width, which can be set to an elevation of 1907 feet for control of summer lake levels. The range between base flows and average annual flows is such that the 40 foot crest width would result in an unacceptable water surface elevation increase during seasonally high flows, therefore necessitating manual removal of check boards. Given that the Eloika Lake outflow channel’s width near the lake ranges from 35 feet to 42 feet, by logical deduction, a permanent passive control structure within the outlet channel similarly will not meet the “no rise” criteria.

To illustrate the limitations of controls in the outlet channel and to offer a potential solution, a variety of control structures were considered. Considered measures included installation of in-channel barbs, increasing channel roughness in a reach near the outlet and installation of a cross channel step pool type structure further into the lake portion of the outlet.

7.3.1. Barbs

A barb is a low profile, sloping stone sill angled in an upstream direction. Barbs are generally used to stabilize eroding banks but they do have the effect of increasing channel roughness. While barbs were considered, they were not further modeled because it was clear that the small localized backwater affect created by barbs would be insignificant during seasonal low flows and would have little effect on lake levels. In order for barbs to begin to affect lake levels at low flows their protrusion into the channel would be such that the rise in lake water surface elevations at higher flows would be unacceptable.

7.3.2. Roughened Channel

As previously stated, intuitively passive outlet controls placed within the Eloika Lake outlet channel will likely not function within the parameters outlined in Section 3. A 1-dimensional water surface elevation model was constructed to illustrate the limitations of in-channel solutions. In this model, existing channel geometry was used but the channel roughness was increased in the first four cross sections nearest the lake. This simulation is representative of any type of control that would increase channel bed and bank roughness. Tables 4 and 5 present the model results for a Manning’s roughness of $n = 0.08$ and $n = 0.2$, respectively, which reflect an increase from the existing condition ($n = 0.049$).

Table 4. Scenario 1 and 4 Comparison (n = 0.08)

Eloika Lake Water Surface Elevation (WSE) at Cross Section 112			
Discharge (CFS)	WSE Scenario 1	WSE Scenario 4 (n = 0.08)	Change Δ
	(ft)	(ft)	(ft)
10	1904.67	1904.85	0.18
120	1906.68	1907.04	0.36
260	1907.85	1908.27	0.42
1434	1913.46	1913.70	0.24

Positive Δ values indicate an increase in the WSE from existing conditions

Table 5. Scenario 1 and 4 Comparison (n = 0.2)

Eloika Lake Water Surface Elevation (WSE) at Cross Section 112			
Discharge (CFS)	WSE Scenario 1	WSE Scenario 4 (n = 0.2)	Change Δ
	(ft)	(ft)	(ft)
10	1904.67	1905.32	0.65
120	1906.68	1908.03	1.35
260	1907.85	1909.29	1.44
1434	1913.46	1914.26	0.80

Positive Δ values indicate an increase in the WSE from existing conditions

Under both scenarios, during base flow conditions, there is an insufficient lake level increase to meet the base flow lake management target. It is also clear that even if flow resistance could be increased sufficiently to achieve the low flow management target, the resulting increase in water surface elevation associated with flood flows would be unacceptable. These results suggest that, given the range of flows that must be accommodated, in channel structural measures are not likely to be viable options to passively control lake levels within the management range.

7.3.3. In-Lake Control Structure with Low Flow Step Pool Channel

Due to low base flows seasonally available at the Eloika Lake outlet, a full lake outlet spanning structure will likely be necessary to passively achieve the lake level management goals. A full spanning structure would effectively reset the controlling elevation at the lake outlet to a higher elevation. Since this type of structure would permanently increase the controlling lake bed elevation, the structure must be sufficiently wide to convey flood flows at shallow flow depths. Conceptually, a naturalized (bioengineered) form of this measure may consist of a broad rock weir with a smaller base flow notch configured as a step pool system to accommodate lower flows and provide for fish passage. Given the relatively small base flow, the notch would be narrow with respect to the lake's cross section while the broader crest of the weir would equal the width of the lake section. The broad weir crest would accommodate larger

magnitude flows by spreading the flows at shallow depths, thereby minimizing the upstream rise in lake levels.

In order to model this type of structure, it was idealized in the HEC RAS model as a notched broad crested weir. This structure was adjusted through several iterations to a relatively narrow base flow notch, such that, under base flow conditions, the upstream lake level was maintained near 1907 feet. For this modeled scenario, a notch width of 4.0 feet with a depth of 1 foot was found to achieve the management objective. The notch crest was set at 1906 feet while the broader weir was set at 1907 feet. The weir crest was found to perform adequately with a width of 150 feet. This large width necessitates locating the structure within the lake portion of the outlet, as shown on Sheet M2. An additional benefit of placing the structure within the lake would be to minimize perennial flooding of the hay field to the south of the outlet. On Sheet M2, the cross hatched area shows low ground that allows flooding of the field when the lake water surface elevation approaches 1907 feet. If a structure were placed nearer the outlet channel, the field to the south would remain perennially flooded.

Table 6 shows a comparison of modeling results for the described structure configuration and the existing condition. The desired base flow water surface rise is clearly achieved and as outlet discharges increase through the ordinary high water and up to the 100 year discharge, the structures relative effect on lake stage decrease, which is also a desired management condition. These model results show that a fully spanning structure of this type will exert control on lake water surface levels at flows less than the average annual flood but will exert only minimal control during flows of higher magnitude. During high magnitude flows the Eloika Lake Road culverts exert a controlling influence and effectively mute the hydraulic influence of the modeled control structure. Figure 3 shows water surface profiles for each discharge. The visible lack of backwater upstream of the culverts at low flow and the considerable backwater for the 100 year discharge, indicates a transition from no influence to a controlling influence of the culverts.

Table 6. Scenario 1 and Scenario 5 Comparison

Eloika Lake Water Surface Elevation (WSE)			
Discharge (CFS)	WSE Scenario 1 (ft)	WSE Scenario 5 (ft)	Change Δ (ft)
10	1904.67	1907.01	2.34
120	1906.68	1907.41	0.73
260	1907.85	1907.94	0.09
1434	1913.46	1913.58	0.12

Positive Δ values indicate an increase in the WSE from existing conditions

This evaluation was completed to demonstrate the potential effectiveness of this type of structure in meeting lake elevation management goals. The modeled configuration is a simple representation of this type of structure; however, there are a variety of possible notch configurations and weir plan forms that would function well. A final design process for an Eloika Lake control structure would explore optimal configurations.

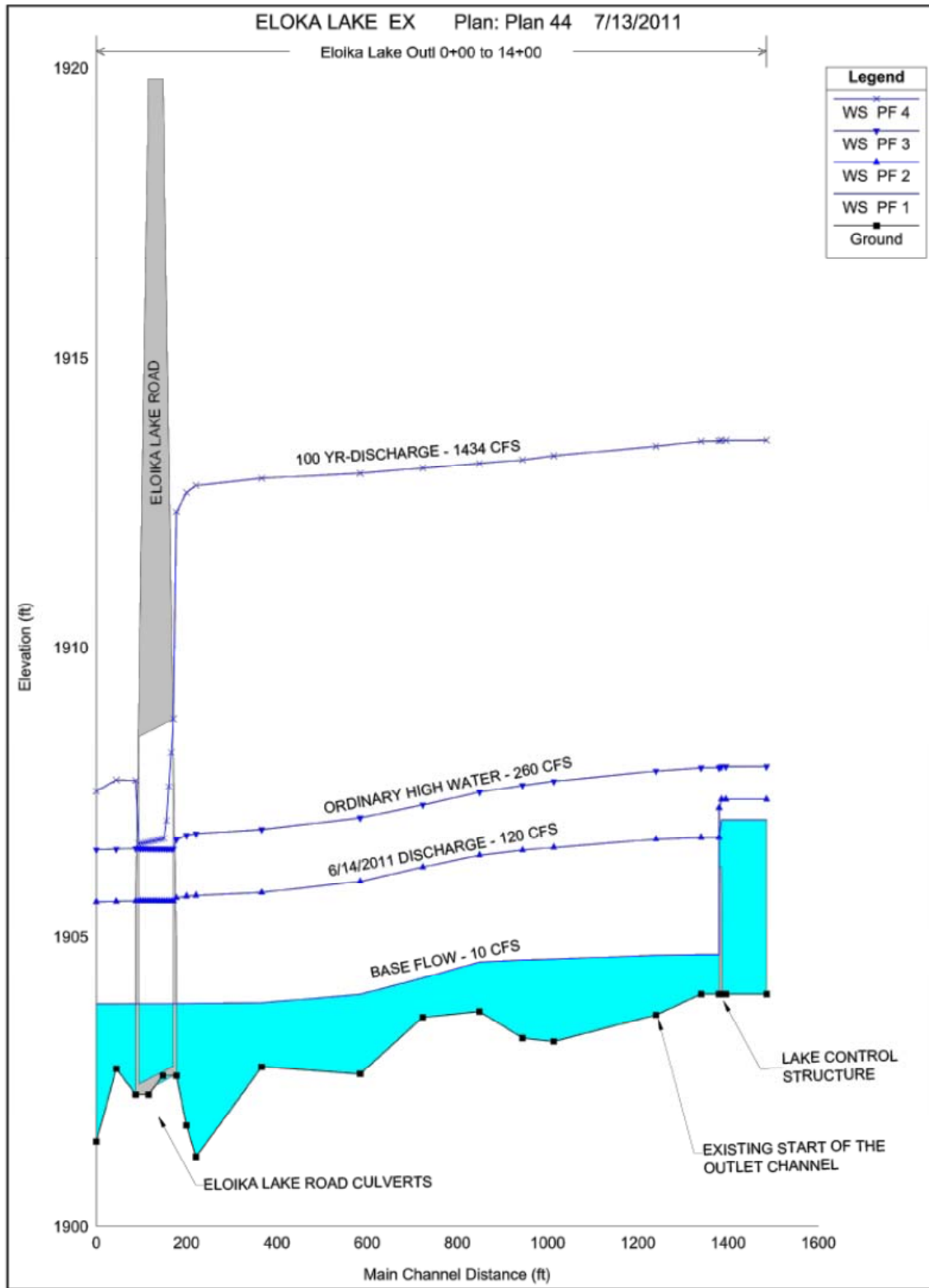


FIGURE 3. WATER SURFACE PROFILES WITH LAKE CONTROL STRUCTURE IN-PLACE

8. REFERENCES

Natural Resources Conservation Service (NRCS). (April 1997). *Eloika Lake Water Control Structure: Final Design Report*. Spokane County, Washington: Stephen G. Durgin

PBS&J. (June 2009). *Eloika Lake In-Depth Surface Water Storage and Wetland Restoration Feasibility*. Spokane County, Washington.

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APPENDIX A

Project Site Drawings

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1 VICINITY MAP

NOTE:
AERIAL PHOTOGRAPH BACKGROUND 2005



2 PROJECT SITE LOCATION
SCALE: 1" = 1000'

SHEET
M1

VICINITY AND SITE LOCATION MAP
ELOIKA LAKE OUTLET STUDY
SPOKANE COUNTY CONSERVATION DISTRICT
SPOKANE, WA

DATE: 6/21/11
CHKD: TC
DRAWN: TC
PROJ. No.: 584-003
PO Box 582 Livingston, MT
59047 (406) 222 7600





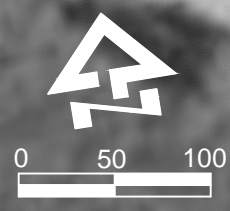
LOW GROUND ELEVATION - WATER FLOWS INTO ADJACENT FIELD / WETLAND NEAR A LAKE ELEVATION OF 1907'

NOTES:
 XS # - SURVEYED CROSS SECTION
 CP 1 - APPARENT PROPERTY CORNER - TOP OF REBAR
 CP2 - SPOKANE COUNTY CONSERVATION DISTRICT (SCCD) REBAR CONTROL POINT
 CP3 - SCCD CONTROL POINT A - TOP OF RIVER LEFT CULVERT WINGWALL

SHEET
M2

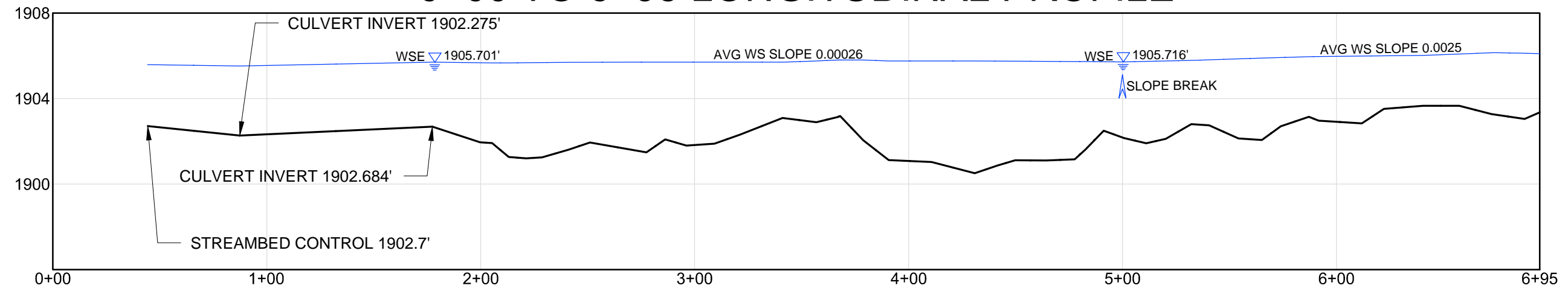
CHANNEL ALIGNMENT AND CROSS SECTION LOCATION
 ELOIKA LAKE OUTLET STUDY
 SPOKANE COUNTY CONSERVATION DISTRICT
 SPOKANE, WA

DATE: 6/21/11
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 DRAWN: TC
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 PO Box 582 Livingston, MT 59047 (406) 222 7600

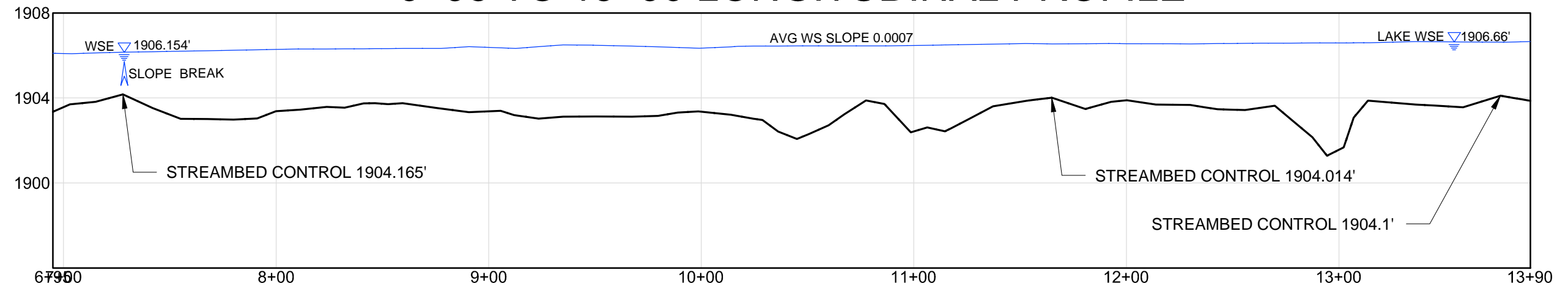


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6+95 TO 13+90 LONGITUDINAL PROFILE



LONGITUDINAL PROFILE
ELOIKA LAKE OUTLET STUDY
SPOKANE COUNTY CONSERVATION DISTRICT
SPOKANE, WA

DATE: 6/21/11
CHKD: TC
DRAWN: TC
PROJ. No.: 584-003
PO Box 582 Livingston, MT 59047 (406) 222 7600

