RJH CONSULTANTS, INC.

GEOTECHNICAL AND
WATER RESOURCES ENGINEERING

BREACH INUNDATION MAPPING REPORT

LONG LAKE DAM

ROUTT COUNTY, COLORADO

Submitted to
City of Steamboat Springs
P.O. Box 775088
Steamboat Springs, Colorado 80477

Submitted by
RJH Consultants, Inc.
9800 Mt. Pyramid Court, Suite 330
Englewood, Colorado 80112
303-225-4611
www.rjh-consultants.com

December 2013
Project 13117

G. George Solvensky, P.E.
Project Manager

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SECTION 1 - INTRODUCTION

1.1 Purpose

The purpose of this Breach Inundation Mapping Report (Report) is to present the results of the dam breach analysis and inundation limits for a simulated failure of Long Lake Dam (Project). This evaluation was prepared in accordance with the Colorado Office of the State Engineer (SEO) *Rules and Regulations for Dam Safety and Construction* (Rules) (SEO, 2007) and *Guidelines for Dam Breach Analysis* (Guidelines) (SEO, 2010).

The simulated breach analysis was performed to support inundation mapping for the Long Lake Dam Emergency Action Plan (EAP) and these analytical methods are only appropriate for these purposes. The actual flood inundation limits from a dam breach for Long Lake Dam depend on actual dam failure flood conditions and may differ from areas shown on the Report mapping. The models documented in this Report should not be used for other purposes.

1.2 Objectives

The objectives of this simulated dam breach analysis are as follows:

- Develop dam breach parameters and a dam breach hydrograph for a “sunny-day” failure event.
- Route the dam breach peak flow through the downstream drainage.
- Develop dam breach inundation limits.
- Evaluate dam breach inundation parameters (i.e., depth, velocity, etc.) at critical locations throughout the downstream drainage.

1.3 Project Location and Background

Long Lake Dam is located approximately 8 miles east of Steamboat Springs in Routt County, Colorado. The site is located in Section 22 and 23, Township 6 North, Range 83 West of the 6th Principal Meridian. The dam is located on Fish Creek and impounds a reservoir with a storage capacity of approximately 357 acre-feet (ac-ft), and is supplied by direct inflow from Fish Creek. The Project location is shown on Figure 1.1.

According to documents provided by the SEO, the earthen embankment dam was originally constructed in 1942 and was rehabilitated in 2000. The rehabilitation consisted of removing and replacing a portion of the existing embankment with homogeneous cohesive material, installing a granular cutoff collar, and installing a new 24-inch-diameter outlet works.

Based on the location of the Project and review of available data, the flood routing model and inundation mapping were developed using 2-foot topography provided by the City of Steamboat Springs (Steamboat Springs) and supplemented with cross section data from the Federal Emergency Management Agency (FEMA) Flood Insurance Study (FIS) effective hydraulic models (FEMA, 2005). A further discussion of topographic mapping and cross section data is provided in Section 4.4.

Inundation mapping for this Report was developed using National Agriculture Imagery Program (NAIP) 1-meter resolution aerial photography as figure backgrounds.

1.4 Scope of Services

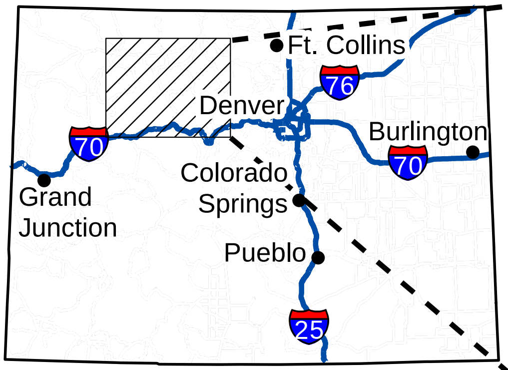
RJH Consultants, Inc. (RJH) performed the following tasks for this evaluation:

- Obtained digital topographic data, aerial photography, and other information that describes the downstream drainage.
- Developed dam breach parameters for a simulated failure of Long Lake Dam.
- Developed a hydrologic model to evaluate the dam breach hydrograph.
- Developed a hydraulic model to evaluate dam breach water surface elevations, velocities, and inundation limits in the downstream drainage.
- Developed inundation maps.
- Prepared this Report.

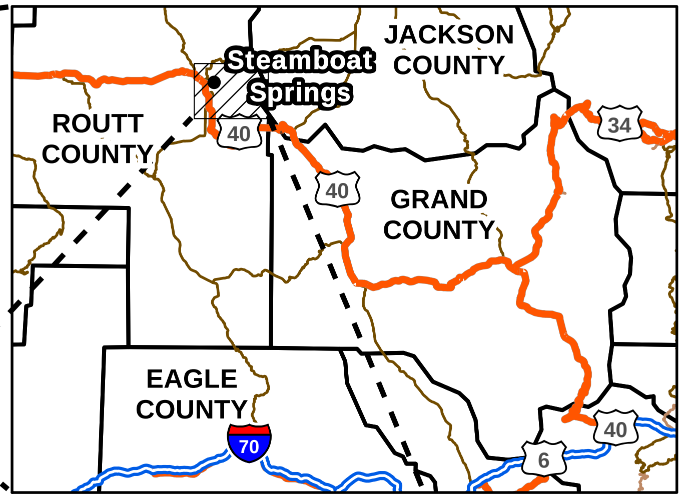
1.5 Authorization and Project Personnel

RJH performed the work described in this Report in accordance with the terms and conditions of our contract with Steamboat Springs for Engineering Services for Dam Inundation Mapping dated September 4, 2013. The following RJH personnel are responsible for the work described in this Report:

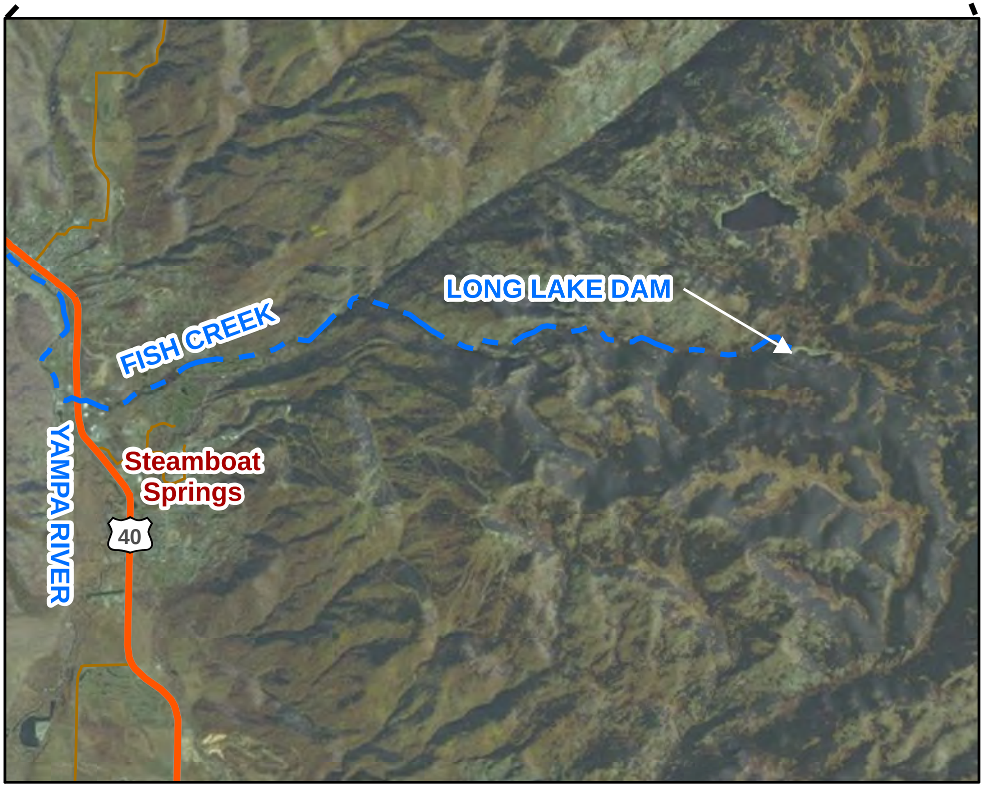
Project Manager	George Slovensky, P.E.
Project Engineer	Eric Hahn, P.E.
Technical Review	Korey Kadrmas, P.E.



PROJECT VICINITY MAP
(NOT TO SCALE)



PROJECT LOCATION MAP
(NOT TO SCALE)



SITE LOCATION MAP
(NOT TO SCALE)

RJH CONSULTANTS, INC.	LONG LAKE DAM BREACH INUNDATION MAPPING REPORT	SITE LOCATION AND VICINITY MAPS
	PROJECT NO. 13117	DECEMBER 2013 **Figure 1.1**

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SECTION 2 - PROJECT DESCRIPTION

2.1 Dam and Reservoir Characteristics

Long Lake Dam is a small, high hazard, earth embankment dam with a crest at about elevation (El.) 9858.0. The upstream slope is about 2 horizontal to 1 vertical (H:V) and the downstream slope is about 2H:1V. The crest is approximately 480 feet long. The reservoir has a storage capacity of about 357 ac-ft at about maximum normal pool El. 9852.7. The maximum normal pool of the reservoir is controlled by an earth-cut spillway channel that discharges to Fish Creek, located to the north of the reservoir.

Key characteristics of the dam and reservoir are provided in Table 2.1.

TABLE 2.1
DAM AND RESERVOIR CHARACTERISTICS

Active Storage Volume	357 ac-ft
Surface Area at Normal Pool	57 acres
Dam Crest Elevation	9858.0 feet
Natural Ground Elevation Below Crest	9835.0 feet (approx.)
Spillway Crest Elevation	9852.7 feet
Maximum Normal Water Surface Elevation	9852.7 feet

2.2 Drainage Characteristics

Long Lake Dam is located on Fish Creek about 9 miles upstream of its confluence with the Yampa River in the limits of Steamboat Springs. Additional information regarding the drainage characteristics of the downstream channels is provided in Section 4.2.

SECTION 3 - BREACH HYDROGRAPH ESTIMATION

3.1 General

A simulated dam breach was evaluated for a "sunny-day" scenario with the reservoir at maximum normal pool elevation with no base flow. The :sunny-day" failure was assumed to result from a piping failure. No base flow was selected because anticipated base flows would be negligible compared to peak breach flows. RJH developed the breach analysis using the "simple" level of breach analysis structure in accordance with the SEO Guidelines. The simple approach was selected because it a) generally produces conservative flood limits that are appropriate for an EAP, and b) the results of the breach analysis are not anticipated to change the hazard classification. The simple breach analysis approach as applied to this study consists of the following components:

- Breach Parameter Estimate: Empirical methods.
- Breach Hydrograph Estimation: Parametric hydrologic model (HEC-HMS).
- Breach Hydrograph Routing: None (conservative for EAP support).
- Hydraulics at Critical Sections: Steady state hydraulics (HEC-RAS).

3.2 Breach Parameter Estimation Methods

RJH evaluated breach parameters using the Froelich (2008) method in accordance with recommendations in the SEO Guidelines for a small-size dam with a "high" storage intensity. Input parameters were developed based on available data from the design drawings and previous SEO inspections. Documentation of the breach parameter analysis is provided in Appendix A and the results are summarized in Table 3.1.

TABLE 3.1
SUMMARY OF BREACH PARAMETER ESTIMATES – SUNNY-DAY FAILURE

Average Breach Width, B_{avg}	61 feet
Bottom Breach Width, B_b	48 feet
Breach Formation Time, t_f	0.66 hour
Breach Side Slopes, z (ZH:1V)	0.7

3.3 Breach Hydrograph Development

The simulated dam breach hydrograph was developed using the U.S. Army Corps of Engineers' (USACE) HEC-HMS Version 3.5 computer software (USACE, 2009). The dam breach parameters shown in Table 3.1 were used in the HEC-HMS program to model the temporal development of the breach and resulting outflow. The HEC-HMS breach hydrograph model resulted in a peak breach outflow of 5,052 cubic feet per second (cfs) and a total breach outflow volume of 356.6 ac-ft. HEC-HMS model input/output, including the breach hydrograph, is provided in Appendix B.

SECTION 4 - DAM BREACH FLOOD ROUTING

4.1 General

RJH performed dam breach analyses to support the development of inundation maps that identify potential inundation limits for a simulated failure of Long Lake Dam. The peak breach flow was routed downstream on Fish Creek to the confluence point with the Yampa River where breach flows became less than the FEMA FIS 100-year discharge. During an actual dam failure, flooding will vary depending on actual conditions including the location, size, depth, rate of breach development, downstream backwater effects, local flood conditions, and seasonal variations within the channel. The erosion resistance of downstream flow-control areas will also affect the flooding characteristics. Because of these factors, the actual inundation limits may vary from those shown on the referenced inundation figures.

4.2 Roughness Values

Manning's "n" values are a measure of channel roughness and resistance to flow and will impact the routing of the dam breach peak flow. Manning's "n" values also vary depending on the roughness of the channel and overbanks, and with the depth of flow and type of flow event. Deeper flows will be less affected by a given obstruction than shallower flows. RJH assigned roughness values to representative sections of the floodplain downstream based on a) Manning's n values used in the FEMA FIS, b) field visit observations, c) aerial photographs, d) published references that provide a description and pictures of stream channels with a recommended typical "n" value, and e) through engineering experience and judgment.

RJH divided the downstream drainage into two segments with relatively homogenous hydraulic roughness characteristics (XS = river cross section):

- **XS -0.0 TO XS -6.30 (FISH CREEK):** The main channel of this stream reach generally consists of a steep mountain stream with large boulders and minimal vegetation. A Manning's "n" value of 0.08 was selected for the main channel, based on the FEMA FIS effective model and confirmed with field visit observations and published references for similar stream channels. The overbanks consist of some areas with thick pine trees and brush with interspersed areas of rock, gravel, and short native grasses. A Manning's "n" value of 0.08 was selected for the overbanks based primarily on aerial photography, field visit observations and published references for similar overbank areas.

- **XS -6.30 TO XS -9.23 (FISH CREEK):** The main channel of this stream reach generally consists of a steep mountain stream with gravel, cobbles, some boulders, and minimal vegetation. A Manning's "n" value of 0.06 was selected for the main channel, based on the FEMA FIS effective model and confirmed with field visit observations and published references for similar stream channels. The overbanks vary from thick pine trees and brush, to commercial/residential developed areas, to a golf course area. Manning's "n" values between 0.08 to 0.10 were selected for the thick pine tree and brush areas based primarily on field visit observations and published references for similar overbank areas. A Manning's "n" value of 0.06 was selected for the developed areas, based on the FEMA FIS effective model and confirmed with field visit observations and published references for similar stream channels. A Manning's "n" value of 0.05 was selected for the golf course areas based on field visit observations and published references for similar overbank areas.

Documentation of the Manning's "n" analysis is provided in Appendix C.

4.3 Dam Breach Flood Routing

The dam breach hydrograph will attenuate as it travels downstream because of the effects of storage and dispersion within the downstream channel. RJH did not evaluate the attenuation of the dam breach hydrograph for Long Lake. In our opinion, attenuation would be minimal along Fish Creek because the main channel is very steep and breach flows would generally be contained within the narrow cross section geometry for a majority of the reach. Disregarding the impacts of attenuation is conservative for the purpose of developing inundation maps.

4.4 Dam Breach Flood Hydraulic Analysis and Mapping

Dam breach inundation limits were developed using the USACE HEC-RAS Version 4.1.0 computer software. A steady-flow HEC-RAS model was developed to hydraulic analysis of the peak dam breach flow of 5,052 cfs. Water surface elevations, velocities, and other hydraulic parameters were computed at each cross section using the model.

A total of 55 cross sections were used to model Fish Creek and the Yampa River. Cross sections are labeled as the distance in river miles from Fish Creek Dam downstream to the cross section location. For example, XS -1.046 is located 1.046 miles downstream from the toe of the dam.

The HEC-RAS model and inundation mapping were developed using 2-foot topography provided by Steamboat Springs. In the city limits, the 2-foot topography was supplemented with surveyed cross section data from the FEMA FIS hydraulic models to better define the main river channel. The 2-foot topography and FIS data generally corresponded well.

Six identified roads, railroads, and pedestrian trails cross Fish Creek. RJH included the following crossings in the HEC-RAS model:

- **STEAMBOAT BOULEVARD BRIDGE (XS -6.76):** Bridge data obtained from field measurements by RJH.
- **PEDESTRIAN BRIDGE (XS -6.803):** Bridge data obtained from field measurements by RJH.
- **ROLLINGSTONE DRIVE BRIDGE (XS -8.89):** Bridge data obtained from field measurements by RJH.
- **HIGHWAY 40 BRIDGE (XS -9.1):** Bridge data obtained from FEMA effective model.
- **RAILROAD BRIDGE (XS -9.22):** Bridge data obtained from FEMA effective model.

RJH assumed that the two most upstream bridges (Steamboat Boulevard bridge and Pedestrian bridge) would be blocked with flood debris and overtop. RJH did not include a small pedestrian bridge located near XS -7.3 because we concluded during the site visit that this structure would likely be washed away by the large breach flows.

4.5 Results

Flood inundation limits for the sunny-day failure event are shown on Figures 4.1 through 4.6. Hydraulic modeling output is provided in Appendix D. Flooding was mapped to the confluence of Fish Creek and the Yampa River where the peak breach flow of 5,052 cfs is less than the estimated 100-year flow of 8,250 cfs in the Yampa River. At this location breach flows would be contained within the regulatory 100-year floodplain.

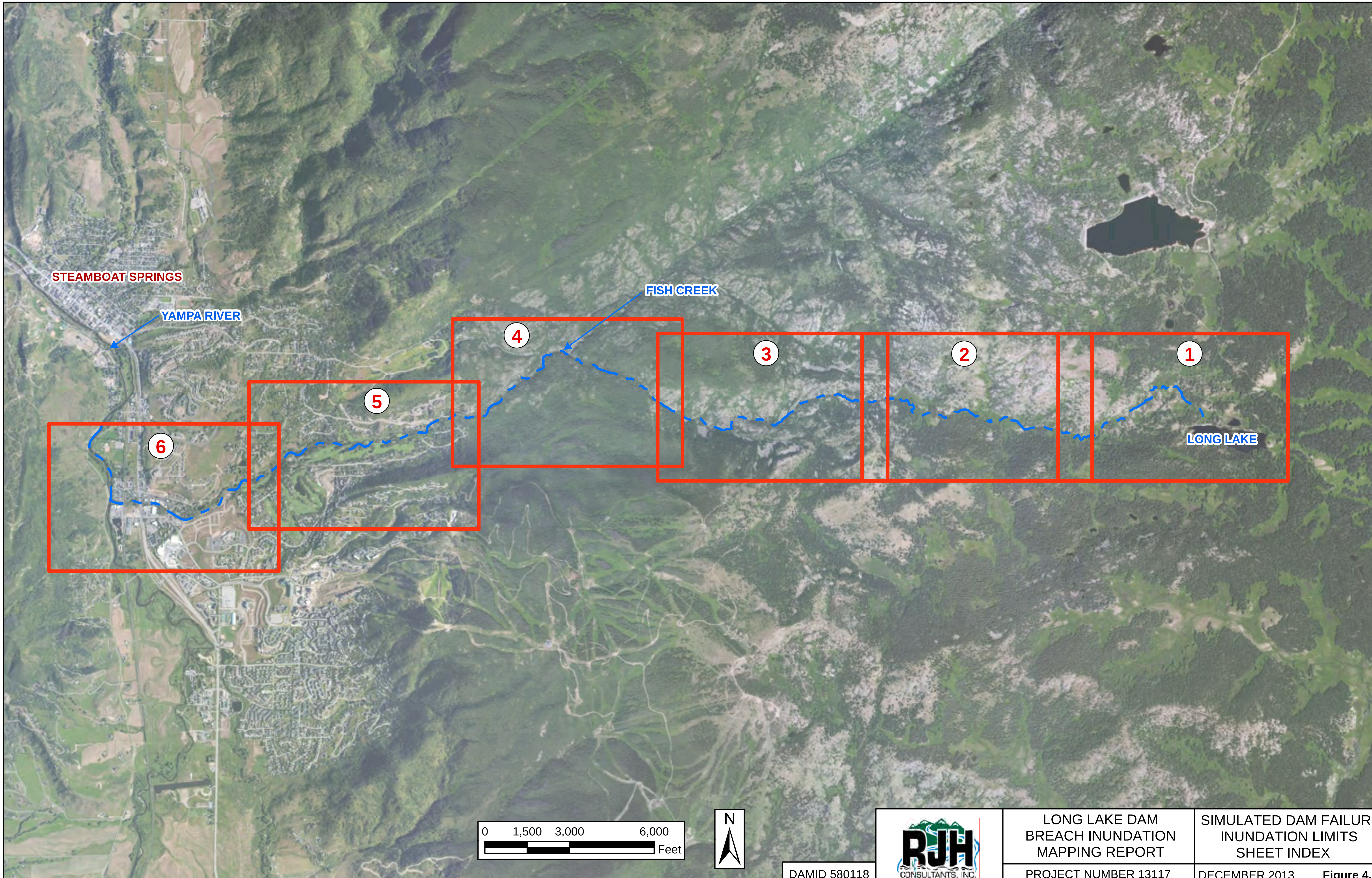
Table 4.1 presents the following floodwave information for the simulated "sunny-day" failure at specific cross section locations: peak floodwave discharge, peak floodwave velocity, maximum water surface elevation (stage), and peak floodwave arrival time (elapsed time for the peak breach flow to travel from the dam to the referenced cross section).

TABLE 4.1
SIMULATED SUNNY-DAY FAILURE

Cross Section (Stream Miles Below Dam)	Peak Flood Wave Discharge (cfs)	Peak Flood Wave Velocity(1) (ft/s)	Maximum Water Surface Elevation(2) (ft)	Peak Flood Wave Arrival Time (HR:MIN)	Notes:
-0.136	5,052	10.2	9829.45	0:00	Downstream of dam
-0.594	5,052	12.0	9755.45	0:04	
-1.046	5,052	9.6	9634.06	0:07	
-1.442	5,052	9.3	9569.68	0:11	
-1.645	5,052	12.6	9523.04	0:13	
-1.983	5,052	3.8	9467.89	0:16	
-2.407	5,052	11.2	9435.86	0:21	
-2.708	5,052	4.1	9397.97	0:25	
-3.039	5,052	7.0	9367.74	0:30	
-3.249	5,052	26.1	9277.00	0:31	
-3.478	5,052	13.0	9212.75	0:32	
-3.741	5,052	23.5	9097.82	0:33	
-4.081	5,052	21.6	8854.17	0:35	
-4.356	5,052	28.8	8546.44	0:36	
-4.673	5,052	11.1	8310.73	0:37	
-4.774	5,052	23.8	8247.85	0:38	
-4.978	5,052	14.9	8149.82	0:39	
-5.177	5,052	27.0	8017.68	0:39	
-5.361	5,052	27.7	7770.97	0:40	
-5.521	5,052	14.5	7668.70	0:41	Fish Creek Falls
-5.611	5,052	13.5	7454.07	0:41	Confluence Fish Creek/Middle Fork Fish Creek
-5.859	5,052	21.3	7347.52	0:42	
-6.105	5,052	11.4	7288.41	0:44	
-6.300	5,052	13.4	7247.73	0:45	
-6.501	5,052	16.1	7188.45	0:46	Upstream limits of Steamboat Springs
-6.699	5,052	2.2	7161.17	0:48	
-6.753	5,052	4.3	7159.95	0:50	Steamboat Blvd. bridge
-6.766	5,052	6.8	7151.51	0:50	
-6.802	5,052	3.0	7145.00	0:51	Pedestrian bridge
-6.806	5,052	7.9	7140.87	0:51	

Cross Section (Stream Miles Below Dam)	Peak Flood Wave Discharge (cfs)	Peak Flood Wave Velocity(1) (ft/s)	Maximum Water Surface Elevation(2) (ft)	Peak Flood Wave Arrival Time (HR:MIN)	Notes:
-6.854	5,052	11.0	7131.99	0:51	
-7.007	5,052	10.3	7111.76	0:52	
-7.238	5,052	14.8	7074.23	0:54	
-7.625	5,052	13.3	6999.00	0:56	
-7.946	5,052	15.2	6931.17	0:58	
-8.120	5,052	11.5	6894.93	0:60	
-8.352	5,052	10.1	6855.87	1:01	
-8.536	5,052	7.0	6829.06	1:03	
-8.778	5,052	5.6	6800.88	1:07	
-8.882	5,052	3.3	6791.18	1:09	Rollingstone Dr. bridge
-8.896	5,052	5.7	6788.78	1:09	
-8.975	5,052	5.5	6780.42	1:10	
-9.043	5,052	6.8	6775.93	1:11	
-9.091	5,052	6.6	6771.80	1:12	Highway 40 bridge
-9.127	5,052	12.6	6764.25	1:13	
-9.212	5,052	3.9	6756.60	1:14	Railroad bridge
-9.225	5,052	4.9	6755.00	1:14	
-9.342	5,052	15.9	6742.84	1:15	Confluence of Yampa River/Fish Creek
-9.474	5,052	5.4	6740.90	1:16	
-9.883	5,052	6.9	6729.40	1:23	End of Study

Notes:
1. Average velocity of cross section.
2. NAVD 1988



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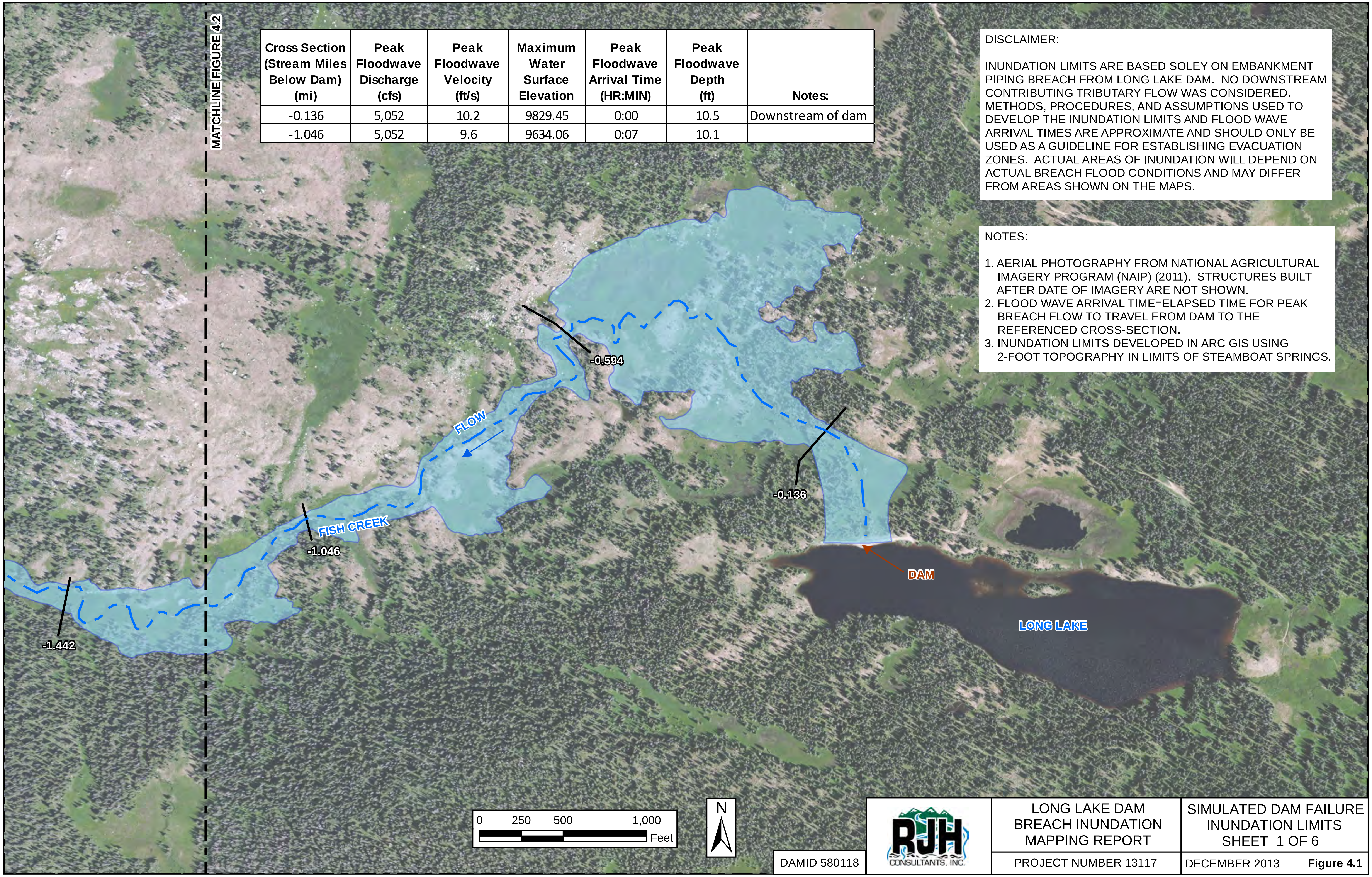
Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)	Notes:
-0.136	5,052	10.2	9829.45	0:00	10.5	Downstream of dam
-1.046	5,052	9.6	9634.06	0:07	10.1	

DISCLAIMER:

INUNDATION LIMITS ARE BASED SOLEY ON EMBANKMENT PIPING BREACH FROM LONG LAKE DAM. NO DOWNSTREAM CONTRIBUTING TRIBUTARY FLOW WAS CONSIDERED. METHODS, PROCEDURES, AND ASSUMPTIONS USED TO DEVELOP THE INUNDATION LIMITS AND FLOOD WAVE ARRIVAL TIMES ARE APPROXIMATE AND SHOULD ONLY BE USED AS A GUIDELINE FOR ESTABLISHING EVACUATION ZONES. ACTUAL AREAS OF INUNDATION WILL DEPEND ON ACTUAL BREACH FLOOD CONDITIONS AND MAY DIFFER FROM AREAS SHOWN ON THE MAPS.

NOTES:

1. AERIAL PHOTOGRAPHY FROM NATIONAL AGRICULTURAL IMAGERY PROGRAM (NAIP) (2011). STRUCTURES BUILT AFTER DATE OF IMAGERY ARE NOT SHOWN.
2. FLOOD WAVE ARRIVAL TIME=ELAPSED TIME FOR PEAK BREACH FLOW TO TRAVEL FROM DAM TO THE REFERENCED CROSS-SECTION.
3. INUNDATION LIMITS DEVELOPED IN ARC GIS USING 2-FOOT TOPOGRAPHY IN LIMITS OF STEAMBOAT SPRINGS.



DAMID 580118	RJH CONSULTANTS, INC.	LONG LAKE DAM BREACH INUNDATION MAPPING REPORT	SIMULATED DAM FAILURE INUNDATION LIMITS SHEET 1 OF 6
		PROJECT NUMBER 13117	DECEMBER 2013 **Figure 4.1**

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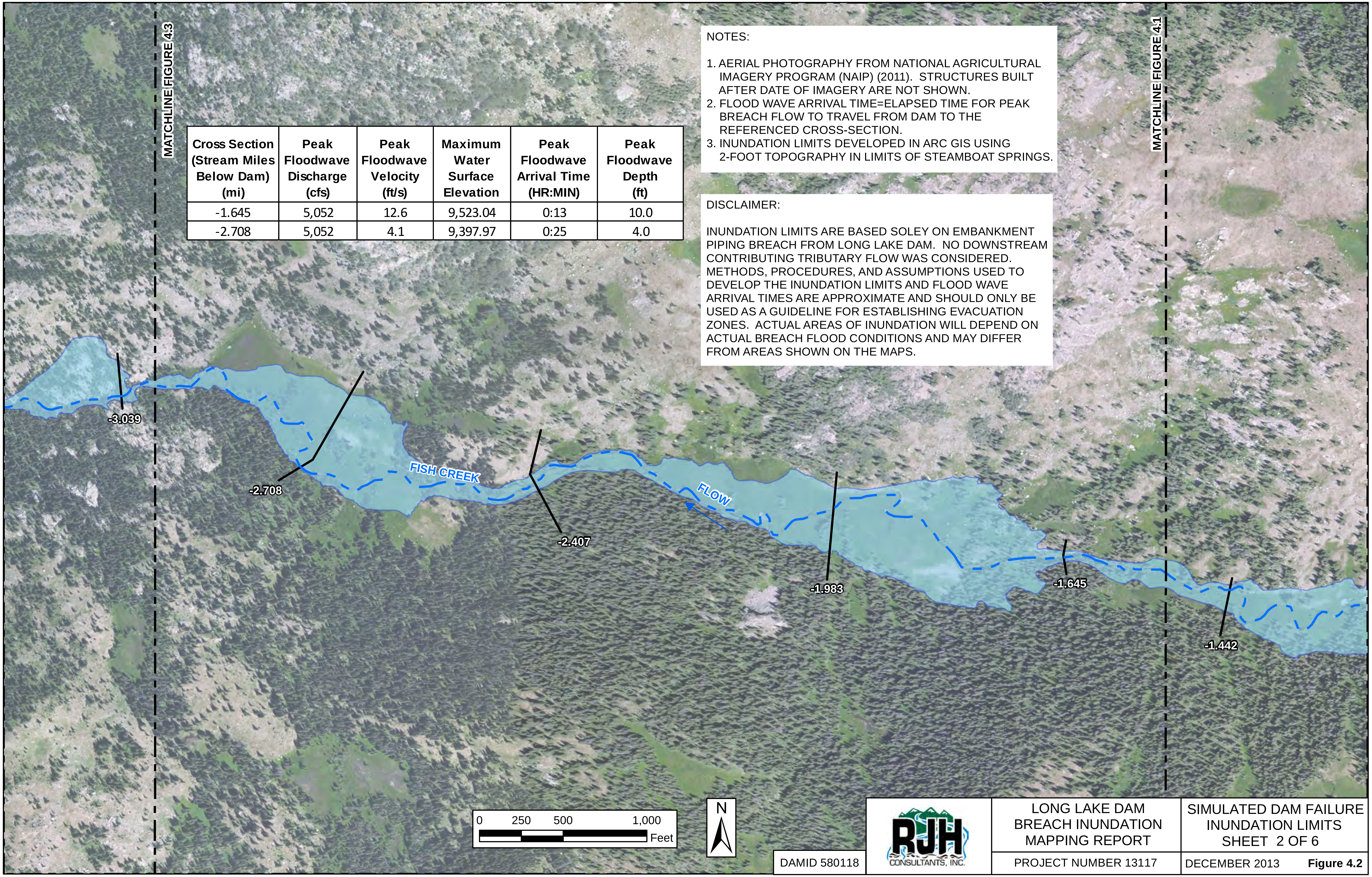

Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)
-1.645	5,052	12.6	9,523.04	0:13	10.0
-2.708	5,052	4.1	9,397.97	0:25	4.0

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DAMID 580118	RJH CONSULTANTS, INC.	LONG LAKE DAM BREACH INUNDATION MAPPING REPORT	SIMULATED DAM FAILURE INUNDATION LIMITS SHEET 2 OF 6
		PROJECT NUMBER 13117	DECEMBER 2013 Figure 4.2

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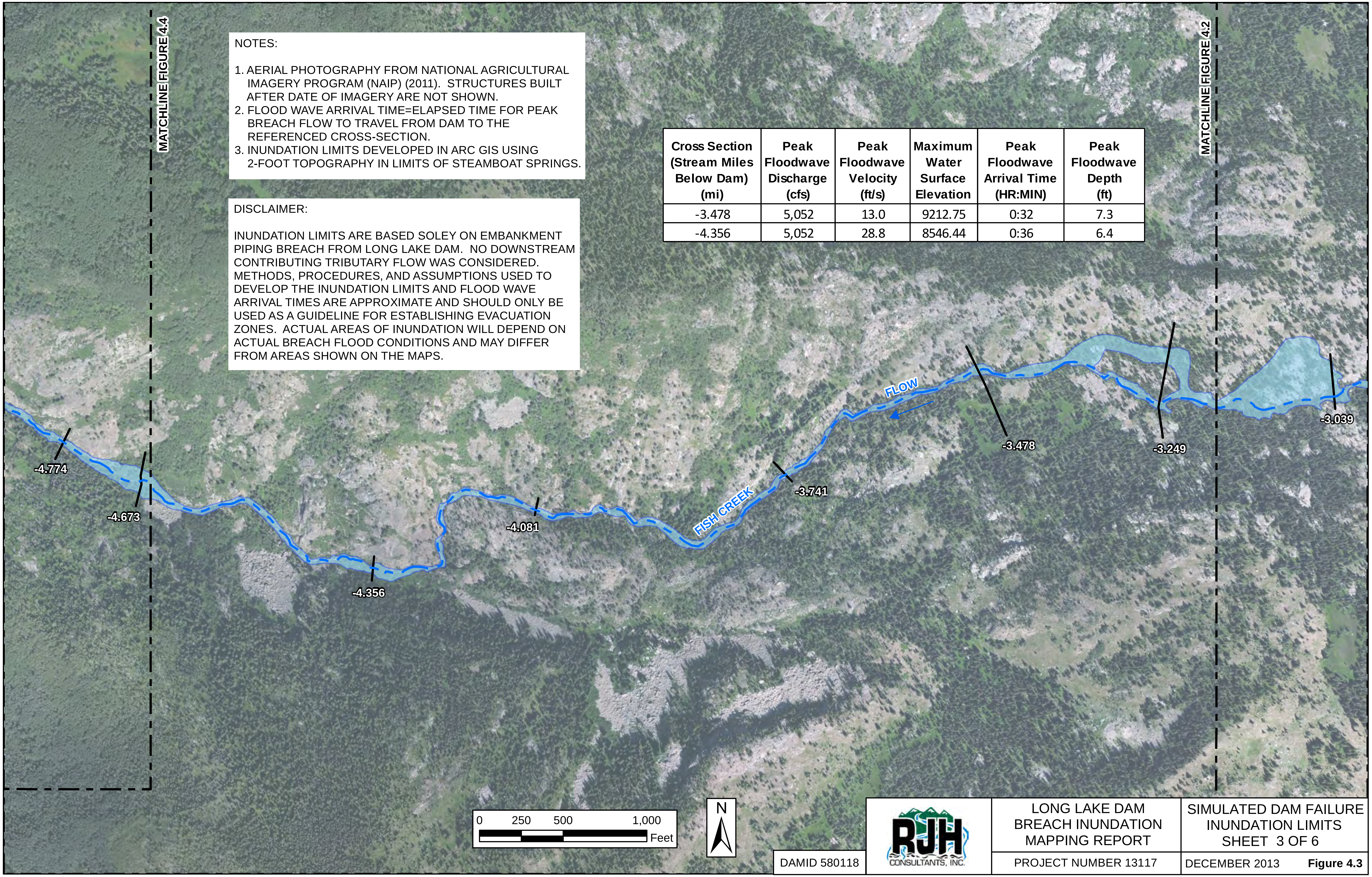

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Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)
-3.478	5,052	13.0	9212.75	0:32	7.3
-4.356	5,052	28.8	8546.44	0:36	6.4

DAMID 580118

RJH CONSULTANTS, INC.

LONG LAKE DAM
BREACH INUNDATION
MAPPING REPORT

PROJECT NUMBER 13117

SIMULATED DAM FAILURE
INUNDATION LIMITS
SHEET 3 OF 6

DECEMBER 2013

Figure 4.3

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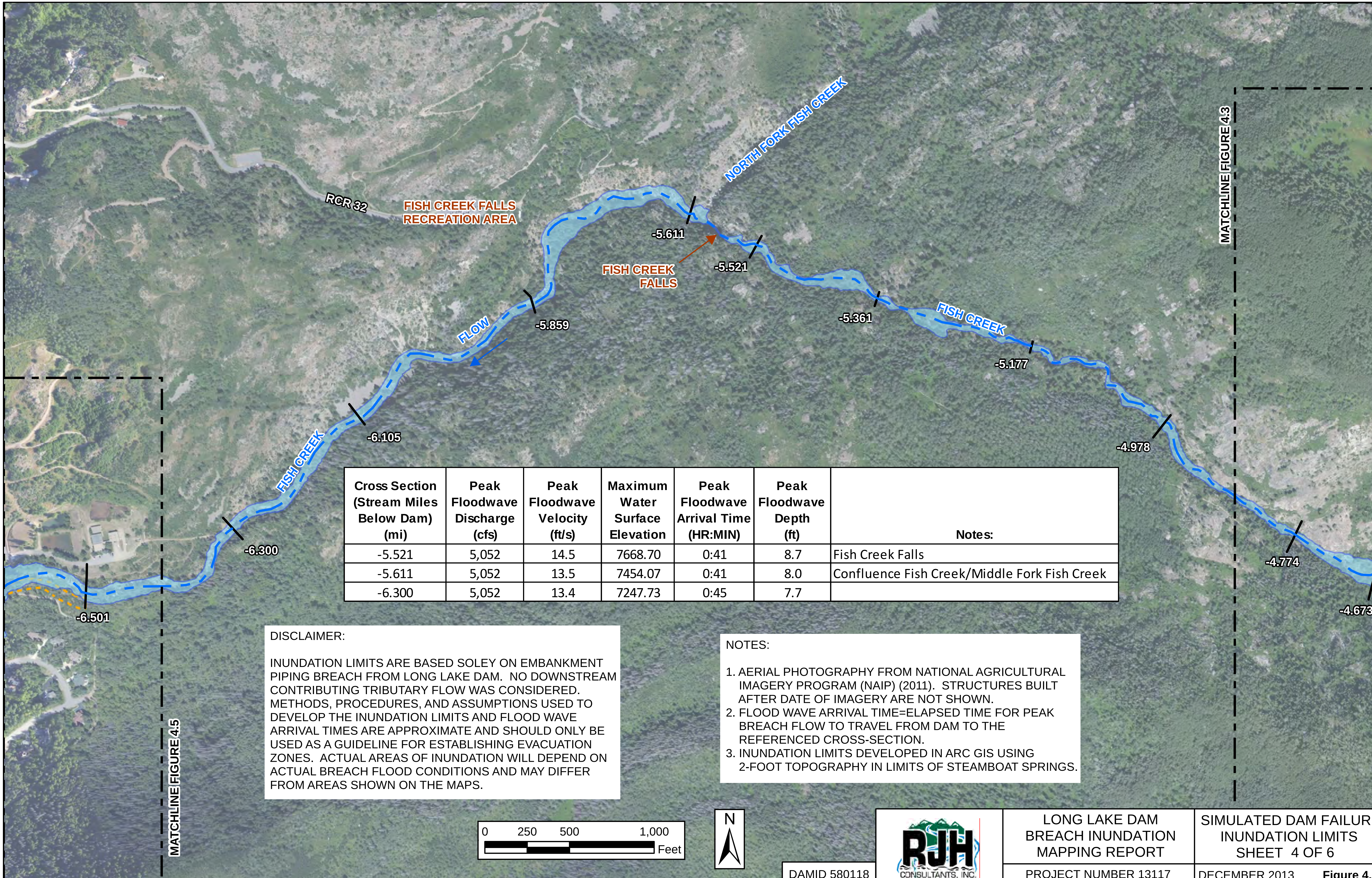

Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)	Notes:
-5.521	5,052	14.5	7668.70	0:41	8.7	Fish Creek Falls
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2. FLOOD WAVE ARRIVAL TIME=ELAPSED TIME FOR PEAK BREACH FLOW TO TRAVEL FROM DAM TO THE REFERENCED CROSS-SECTION.
3. INUNDATION LIMITS DEVELOPED IN ARC GIS USING 2-FOOT TOPOGRAPHY IN LIMITS OF STEAMBOAT SPRINGS.

DAMID 580118	RJH CONSULTANTS, INC.	LONG LAKE DAM BREACH INUNDATION MAPPING REPORT	SIMULATED DAM FAILURE INUNDATION LIMITS SHEET 4 OF 6
		PROJECT NUMBER 13117	DECEMBER 2013 **Figure 4.4**

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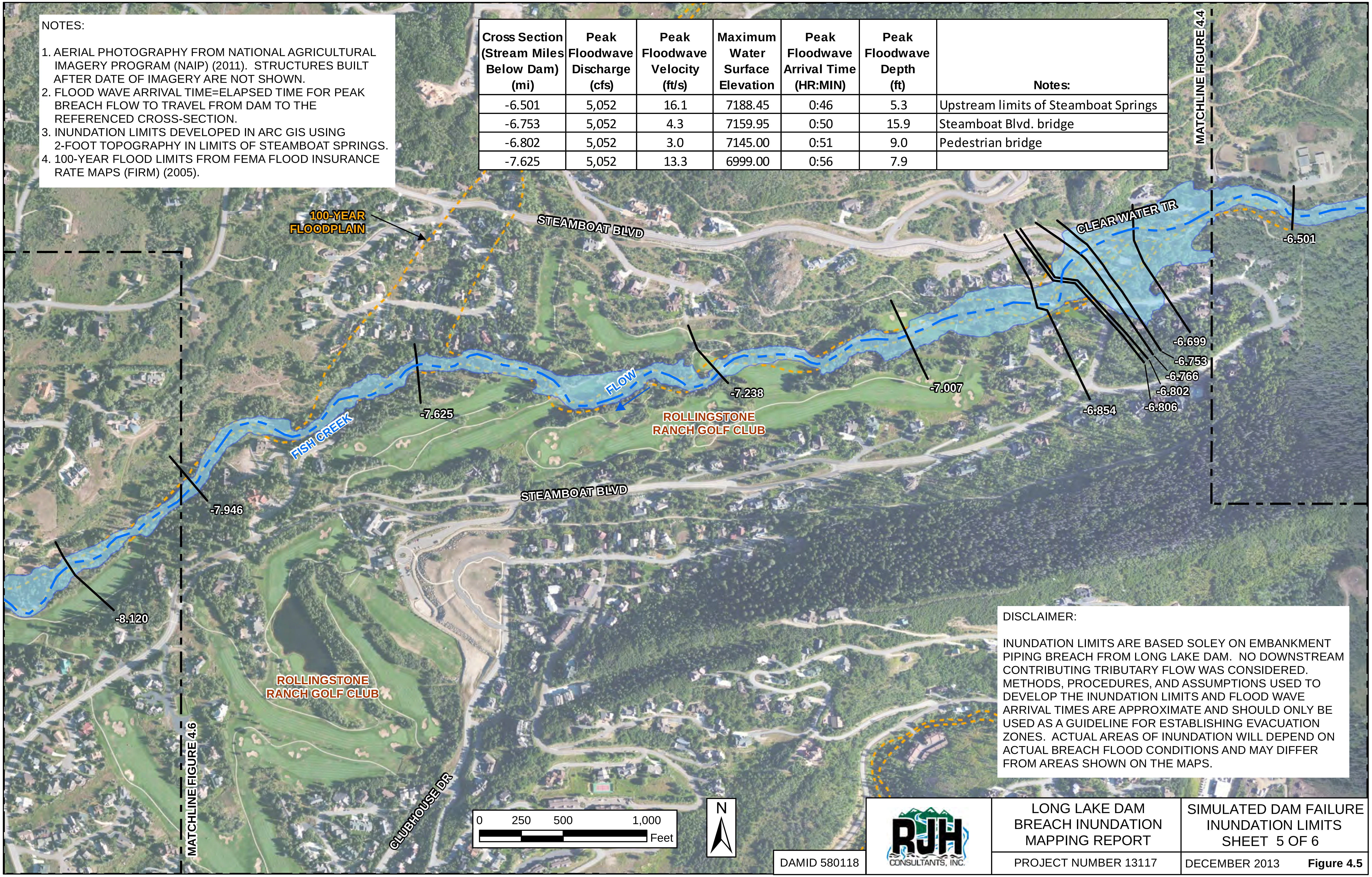
3. INUNDATION LIMITS DEVELOPED IN ARC GIS USING 2-FOOT TOPOGRAPHY IN LIMITS OF STEAMBOAT SPRINGS.
4. 100-YEAR FLOOD LIMITS FROM FEMA FLOOD INSURANCE RATE MAPS (FIRM) (2005).

Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)	Notes:
-6.501	5,052	16.1	7188.45	0:46	5.3	Upstream limits of Steamboat Springs
-6.753	5,052	4.3	7159.95	0:50	15.9	Steamboat Blvd. bridge
-6.802	5,052	3.0	7145.00	0:51	9.0	Pedestrian bridge
-7.625	5,052	13.3	6999.00	0:56	7.9	



DISCLAIMER:

INUNDATION LIMITS ARE BASED SOLEY ON EMBANKMENT PIPING BREACH FROM LONG LAKE DAM. NO DOWNSTREAM CONTRIBUTING TRIBUTARY FLOW WAS CONSIDERED. METHODS, PROCEDURES, AND ASSUMPTIONS USED TO DEVELOP THE INUNDATION LIMITS AND FLOOD WAVE ARRIVAL TIMES ARE APPROXIMATE AND SHOULD ONLY BE USED AS A GUIDELINE FOR ESTABLISHING EVACUATION ZONES. ACTUAL AREAS OF INUNDATION WILL DEPEND ON ACTUAL BREACH FLOOD CONDITIONS AND MAY DIFFER FROM AREAS SHOWN ON THE MAPS.

DAMID 580118

RJH CONSULTANTS, INC.

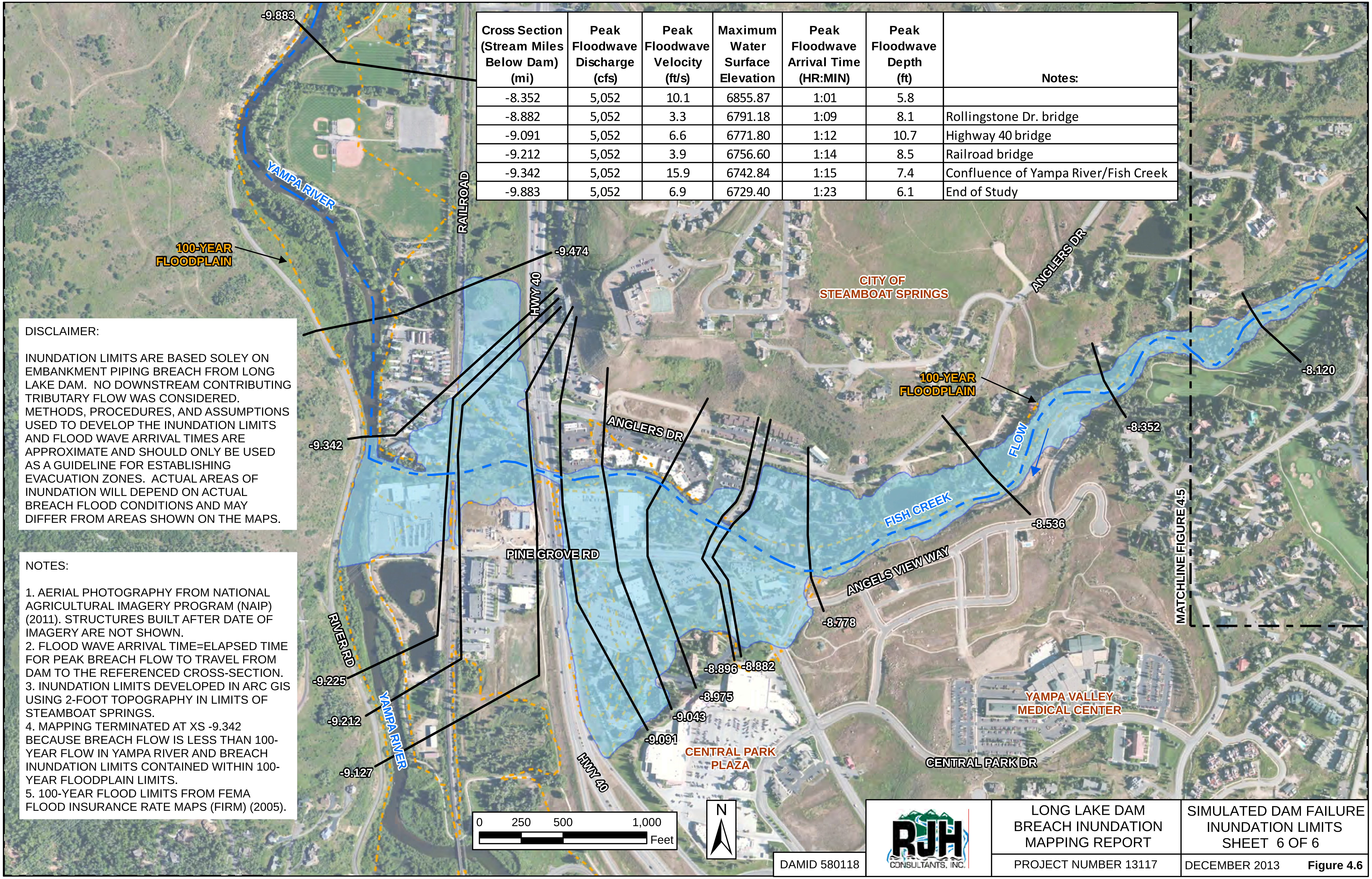
LONG LAKE DAM BREACH INUNDATION MAPPING REPORT

PROJECT NUMBER 13117

SIMULATED DAM FAILURE INUNDATION LIMITS SHEET 5 OF 6

DECEMBER 2013 **Figure 4.5**

P:\13117 - SteamboatEngineering\GIS\Long Lake\Figures.mxd



Cross Section (Stream Miles Below Dam) (mi)	Peak Floodwave Discharge (cfs)	Peak Floodwave Velocity (ft/s)	Maximum Water Surface Elevation	Peak Floodwave Arrival Time (HR:MIN)	Peak Floodwave Depth (ft)	Notes:
-8.352	5,052	10.1	6855.87	1:01	5.8	
-8.882	5,052	3.3	6791.18	1:09	8.1	Rollingstone Dr. bridge
-9.091	5,052	6.6	6771.80	1:12	10.7	Highway 40 bridge
-9.212	5,052	3.9	6756.60	1:14	8.5	Railroad bridge
-9.342	5,052	15.9	6742.84	1:15	7.4	Confluence of Yampa River/Fish Creek
-9.883	5,052	6.9	6729.40	1:23	6.1	End of Study

DISCLAIMER:

INUNDATION LIMITS ARE BASED SOLEY ON EMBANKMENT PIPING BREACH FROM LONG LAKE DAM. NO DOWNSTREAM CONTRIBUTING TRIBUTARY FLOW WAS CONSIDERED. METHODS, PROCEDURES, AND ASSUMPTIONS USED TO DEVELOP THE INUNDATION LIMITS AND FLOOD WAVE ARRIVAL TIMES ARE APPROXIMATE AND SHOULD ONLY BE USED AS A GUIDELINE FOR ESTABLISHING EVACUATION ZONES. ACTUAL AREAS OF INUNDATION WILL DEPEND ON ACTUAL BREACH FLOOD CONDITIONS AND MAY DIFFER FROM AREAS SHOWN ON THE MAPS.

NOTES:

1. AERIAL PHOTOGRAPHY FROM NATIONAL AGRICULTURAL IMAGERY PROGRAM (NAIP) (2011). STRUCTURES BUILT AFTER DATE OF IMAGERY ARE NOT SHOWN.
2. FLOOD WAVE ARRIVAL TIME=ELAPSED TIME FOR PEAK BREACH FLOW TO TRAVEL FROM DAM TO THE REFERENCED CROSS-SECTION.
3. INUNDATION LIMITS DEVELOPED IN ARC GIS USING 2-FOOT TOPOGRAPHY IN LIMITS OF STEAMBOAT SPRINGS.
4. MAPPING TERMINATED AT XS -9.342 BECAUSE BREACH FLOW IS LESS THAN 100-YEAR FLOW IN YAMPA RIVER AND BREACH INUNDATION LIMITS CONTAINED WITHIN 100-YEAR FLOODPLAIN LIMITS.
5. 100-YEAR FLOOD LIMITS FROM FEMA FLOOD INSURANCE RATE MAPS (FIRM) (2005).

P:\13117 - Steamboat\Engineering\GIS\Long Lake\Figures.mxd

DAMID 580118	RJH CONSULTANTS, INC.	LONG LAKE DAM BREACH INUNDATION MAPPING REPORT	SIMULATED DAM FAILURE INUNDATION LIMITS SHEET 6 OF 6
		PROJECT NUMBER 13117	DECEMBER 2013 Figure 4.6

SECTION 5 - CONCLUSIONS

Based on the results of this evaluation, RJH offers the following conclusions:

1. Dam breach parameters for a simulated failure of Long Lake Dam are as follows:

Average Breach Width, B_f	61 feet
Bottom Breach Width, B_b	48 feet
Breach Formation Time, t_f	0.66 hour
Breach Side Slopes, z (zH:1V)	0.7

2. The dam breach hydrograph peak flow is 5,052 cfs and the total breach volume is 356.6 ac-ft.

3. Simulated floodwave velocities in the downstream channel ranged from about 2 to 28 feet per second (fps) and peak depths ranged from about 4 to 16 feet.

4. Peak floodwave arrival times at key locations are as follows:

Location	Time (Hr:Min)
Upstream limits of Steamboat Springs (XS -6.501)	0:46
Steamboat Blvd. bridge (XS -6.76)	0:50
Pedestrian bridge (XS -6.802)	0:51
Rollingstone Dr. bridge (XS -8.89)	1:09
Highway 40 bridge (XS -9.1)	1:12
Railroad bridge (XS -9.22)	1:14
Confluence of Yampa River/Fish Creek (XS -9.342)	1:15

5. The breach inundation mapping was terminated at the confluence of Fish Creek and the Yampa River. The peak breach flow will be 5,052 cfs, which is less than the estimated 100-year flow of 8,250 cfs in the Yampa River at this location.

SECTION 6 - LIMITATIONS

The information presented in this Report is suitable for use in evaluating simulated breach scenarios at Long Lake Dam and corresponding floodwave inundation mapping in the drainage channel downstream of the dam. Future modifications to the Report analyses and inundation mapping will be required in accordance with periodic updates of EAP documents and will need to consider development and current conditions within the downstream floodplain. The information presented in this Report is based on RJH's understanding of the dam Project features, drainage basin characteristics, available information, and current computer model capabilities. The analyses and inundation mapping presented in the Report are based, in part, upon the level of detail of the available topographic information. Variations in the conditions of the drainage channel and impacted structures are possible and future modifications may be necessary if more detailed input data becomes available.

RJH has endeavored to conduct our professional services for this Project in a manner consistent with a level of care and skill ordinarily exercised by members of the engineering profession currently practicing in Colorado under similar conditions as this Project. RJH makes no other warranty, expressed or implied.

This work has been prepared for the exclusive use of the City of Steamboat Springs and the SEO for specific application to Long Lake Dam in Routt County, Colorado.

SECTION 7 - REFERENCES

Colorado Office of the State Engineer (SEO) (2007). *Rules and Regulations for Dam Safety and Dam Construction*.

Colorado Office of the State Engineer (SEO) (2010). *Guidelines for Dam Breach Analysis*.

Federal Emergency Management Agency (FEMA) (2005). *Flood Insurance Study Routt County Colorado and Unincorporated Areas*.

APPENDIX A

DAM BREACH PARAMETERS

RJH CONSULTANTS, INC.

Client: Steamboat Springs
Subject: Long Lake Dam

Project: 13117 Page: 1/12
Date: 10/17/13 By: EMH
Checked: 10/17/13 By: TEO
Approved: 11/1/13 By: GGS

REQUIRED - Develop dam breach parameters for Long Lake Dam

ASSUMPTIONS -
1) Use Colorado SEO "Guidelines for Dam Breach Analysis" (Feb 2010) (SEO) ✓
2) Use elevation-capacity information provided by SEO ✓
3) Use the simple-level analysis methodology per the scope of work from owner and SEO ✓
4) Sunny-day piping failure ✓
5) Use Long Lake Dam As-Built survey by Steamboat Springs Utilities ✓
6) Use 2012 SEO Inspection Report ✓

SUMMARY -
- Avg. Breach Width, $B_{avg} = 60.7'$ ✓✓
- Breach Bottom Width, $B_b = 47.8'$ ✓✓
- Breach side slopes, $z = 0.7$ ✓✓
- Breach bottom elev. = 9839.6 ✓✓
- Breach piping elev. = 9848.8 ✓✓ (mid pt. of 19.4' Breach Ht.) (see p3)
- Piping coefficient = 0.6 ✓ ok (conservative)
- Time to failure, $T_f = 0.66$ hours ✓✓

RJH CONSULTANTS, INC.	Project 13117 Page 2/12
	Date 10/17/13 By EMH
Client Steamboat Springs	Checked 10/17/13 By TEO
Subject Long Lake Dam	Approved 11/1/13 By GGS

ANALYSIS -

- SEO guidelines specify the use of emperical equations to estimate dam breach parameters for a simple-level analysis. Use the Froehlich equations which require the following input parameters[(1)]

1) Height of water above breach, H_w

- assume sunny-day failure at maximum normal pool (El. 9852.7) (see p. 6)

- assume average bottom elev. of breach is average of downstream invert of outlet works (El. 9838.2) and upstream toe of dam (~El. 9841.0) (see p. 5-6)

  = El. 9839.6

$H_w = 9852.7 - 9839.6$

$H_w = \underline{13.1'}$

2) Volume of water at time of failure, V_w

$V_w = \underline{357 \text{ ac-ft}}$ (see p. 5, 7)

3) Reservoir surface area at H_w

$A_w = \underline{57 \text{ ac}}$ (SEO Inspection Report) (p. 8)

4) Height of breach, H_b

- Dam crest El. 9858.0

$H_b = 9858.0 - 9839.6$

$H_b = \underline{18.4'}$

(1) DAM SIZE = "SMALL" (100 AF < 357 AF < 4000 AF & HE < 50 ft). STORAGE INTENSITY (SI) = 357 AF / 13.1 ft ≅ 27 = "HIGH". BASED ON TBL 3 (P. 15) OF SEO GUIDELINES FOR DAM BREACH ANALYSIS, METHOD = FROEHLICH FOR BOTH GEOMETRY & FAILURE TIME.

Client: Steamboat Springs			
Subject: Long Lake Dam			
Project: 13117	Page: 3/12	Date: 10/17/13	By: EMH
Checked: 10/17/13	By: TEO	Approved: 11/1/13	By: GGS

RJH CONSULTANTS, INC.

ANALYSIS -

5) $K_o = 1.0$ ✓✓ for piping (see p. 11)

6) $z = 0.7H:1V$ ✓✓ for piping (see p. 11)

- Use SEO spreadsheet to compute dam breach parameters (see p. 4.) using Froehlich method. Results are summarized as follows:
  - $B_{avg} = 60.7'$ ✓✓
  - $B_y = 47.8'$ ✓✓
  - $T_f = 0.66$ hours ✓✓

- Other required input parameters include
  - Breach bottom elev = 9839.6 ✓
  - Piping Coefficient = 0.6 ✓ (typical orifice coefficient)
  - Piping elev = set at mid-point of final breach height (see p. 12)

$$= \frac{9858.0 + 9839.6}{2} \checkmark$$

$$= 9848.8 \checkmark$$

√TEO 10/17/13
√GGS 11/1/13

RJH Consultants, Inc.
Fish Creek and Long's Lake Dam Breach Mapping
Project No. 13117
Prepared by: E. Hahn 10/18/2013
Checked by:
Approved by:

ESTIMATION OF DAM BREACH PARAMETERS USING THE FROEHLICH 2008 METHOD

PROJECT: Long Lake Dam

BREACH INPUT PARAMETERS:

Select Failure Mode From Drop-Down Menu:	PIPING	
Height of water over base elevation of breach (H_w) =	13.1 ✓✓	Feet
Volume of water in the reservoir at the time of failure (V_w) =	357.0 ✓✓	Acre-Feet
Reservoir Surface Area at Hw (A_s) =	57.0 ✓✓	Acres
Height of breach (H_b) =	18.4 ✓✓	Feet
Failure Mode Factor (K_o) =	1 ✓✓	
Breach Side-Slope Ratio (Z_b) =	0.7 ✓✓	Z(H):1(V)
Dam Size Class:	Small ✓✓	Assumes Full Reservoir At Time of Breach.

CALCULATED BREACH CHARACTERISTICS:

Average Breach Width (B_{avg}) =	60.7 ✓	Feet
Bottom Width of Breach (B_b) =	47.8 ✓	Feet
Breach Formation Time (T_f) =	0.66 ✓	Hours
Storage Intensity (SI) =	27.3 ✓	Acre Feet/Foot
Predicted Peak Flow (Q_p) =	6539	Cubic Feet per Second

✓✓

RESULTS CHECK:

Average Breach Width Divided by Height of Breach (B_{avg}/H_b) =	3.30	If $(B_{avg}/H_b) > 0.6$, Full Breach Devlopment is Anticipated ✓✓
Erosion Rate (ER), Calculated as (B_{avg}/T_f) =	91.6	
Erosion Rate Divided by Height of Water Over Base of Breach (ER/H_w) =	7.0	If $1.6 < (ER/H_w) < 21$, Erosion Rate is Assumed Reasonable ✓

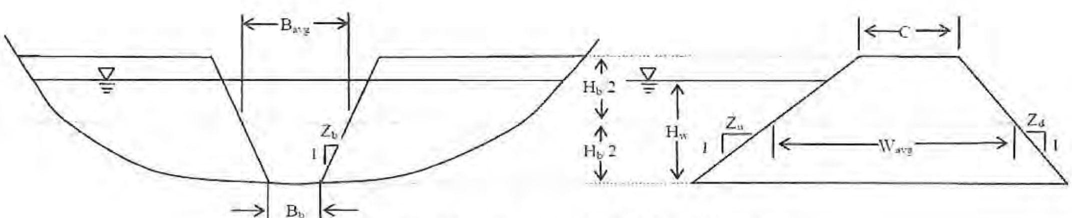


Figure 1- Breach Variable Definition Sketch

5/12

✓TEO 10/17/13
✓GGS 11-1-13

LONG LAKE RESERVOIR
ID 3522
GAGE ROD CONVERSION TO ELEVATION BASED ON 2003 LETTER

	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
✓**9841**								38.5	40.6	42.7
9842	44.8	46.9	49	51.1	53.2	55.3	57.4	60	62.2	64.5
9843	66.8	69.1	71.4	73.7	76	78.3	80.6	83	85.4	87.8
9844	90.2	92.5	94.9	97.3	99.7	102	104.4	107	109.5	112
9845	114.5	117	119.5	122	124.5	127	129.6	133	135.8	138.6
9846	141.4	144.1	146.9	149.6	152.4	155.1	157.9	161	163.8	166.6
9847	169.5	172.3	175.1	178	180.8	183.6	186.5	190	193.1	196.2
9848	199.3	202.4	205.5	208.6	211.7	214.8	217.9	221	224.1	227.2
9849	230.3	233.4	236.5	239.6	242.7	245.8	248.9	252	255.3	258.7
9850	262.1	265.5	268.8	272.1	275.5	278.8	282.1	286	289.5	293
9851	296.5	300	303.5	307	310.5	314	317.5	321	324.6	328.2
9852	331.8	335.3	338.8	342.3	345.8	349.3	352.8	357 ✓✓	360.9	364.8
9853	368.7	372.6	376.5	380.4	384.3	388.2	392.1	396.6		

ELEVATION = 9800 + GAGE HT

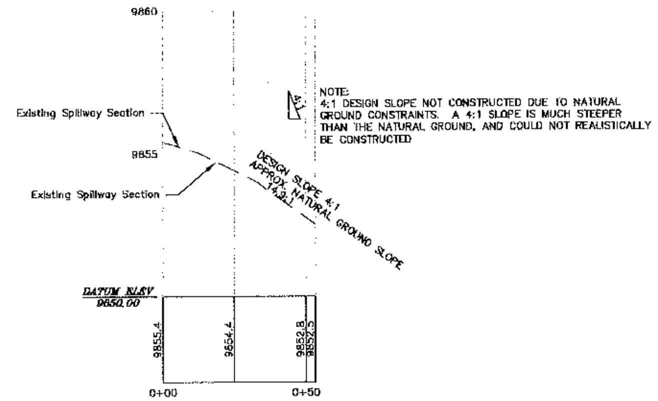
OLD GAGE HT	ELEV
2	9841.7
3	9842.7
4	9843.7
5	9844.7
6	9845.7
7	9846.7
8	9847.7
9	9848.7
10	9849.7
11	9850.7
12	9851.7
13	9852.7
14	9853.7

SPILLWAY AT 13 FT ON OLD GAGE AND 9852.7 ✓ ELEVATION (FROM 2003 LETTER)

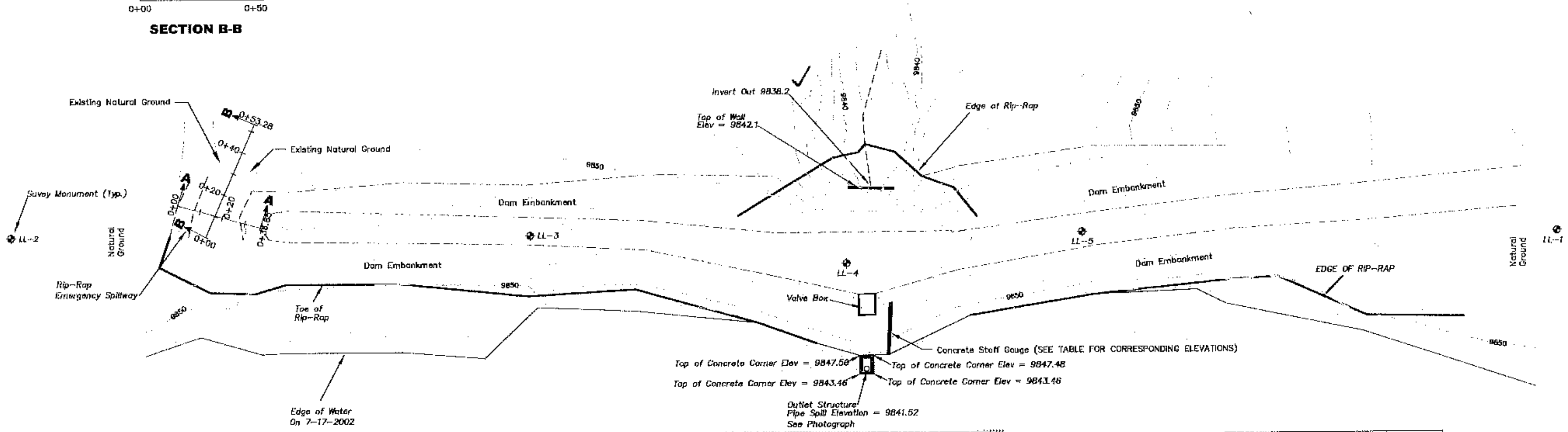
Per SEO: Crest El. = 9858.0 ✓✓
max NWL = 9852.7 ✓✓

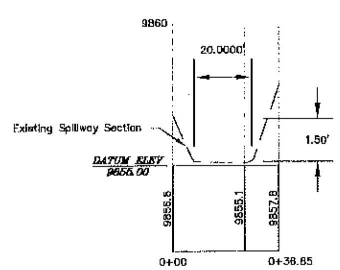
✓ GGS 11/1/13
✓ TEO 10/17/13
6/12

LONG LAKE DAM AS–BUILT SURVEY DETAILS

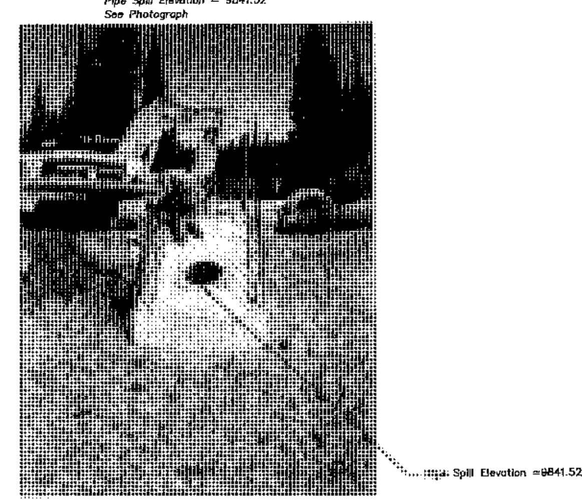


SECTION B-B





SECTION A-A



SURVEY MONUMENT TABLE			
DESCRIPTION	NORTH	EAST	ELEV
LL-1	5000	5000	9856.000
LL-2	5000	4329.8	9860.173
LL-3	5000	4554.91	9857.129
LL-4	4987.48	4691.94	9859.036
LL-5	5000.69	4794.19	9857.859

CONCRETE STAFF GAUGE ELEVATIONS	
STAFF GAUGE FOOT MARK	ELEV
17	9858.35
16	9857.40
15	9856.39
14	9855.39
13	9854.40
12	9853.41
11	9852.43
10	9851.43
9	9850.44
8	9849.47
7	9848.49

✓

GRAPHIC SCALE

(IN FEET)
1 inch = 30 ft.

NOTES

1. TOPOGRAPHIC INFORMATION PROVIDED BY EMERALD MT. SURVEYS.
2. TOPOGRAPHIC INFORMATION PROVIDED PRIOR TO RE–GRADING OF CREST. THE CREST HAS BEEN REGRADED TO DRAIN TOWARDS THE RESERVOIR.

GREG L. BUXTON, P.E.
PROJECT DESIGN ENGINEER

DATE
DESIGN 8–8–02
DRAWN GLB 8–8–02
SURVEY 8–8–02

REVISIONS		
NO.	DESCRIPTION	DATE

City of Steamboat Springs
Water & Sewer
PO BOX 775088
STEAMBOAT SPRINGS, CO
(970) 871–6303 FAX (970) 871–8851

CITY OF STEAMBOAT UTILITIES
LONG LAKE DAM
FEATURE SURVEY

SHEET NO. 1

✓ TEO 10/17/13 7/12
✓ GGS 11/1/13

Eric Hahn

To: George Slovensky
Subject: RE: Steamboat - Long Lake

From: Miller - DNR, Dana [mailto:dana.miller@state.co.us]
Sent: Thursday, October 17, 2013 10:18 AM
To: George Slovensky; Jon Snyder
Subject: Re: Steamboat - Long Lake

Hi George,

Here is the best I have, which I think should suffice. Attached is a capacity table from the file. The crest elevation of the dam is 9858, with 5.3 feet of freeboard to the emergency spillway on the southwest side of the reservoir. There is another auxiliary spillway left of the dam that has 4 feet of freeboard.

The normal full elevation of the reservoir should be about 9852.7, at a capacity of around 357 ac-ft. Our database lists the capacity as 395, and my guess is that someone had overlooked the fact that the other spillway is lower and actually spills before the one closer to the dam.

For your purposes, please assume normal full capacity of the reservoir would be at elevation 9852.7.

Please let me know if I can answer any other questions.

I sincerely appreciate your patience!

Dana

Dana S. Miller, P.E.
Div 6 Dam Safety Field Engineer, CO Division of Water Resources
505 Anglers Dr. Suite 101, Steamboat Springs, CO 80487
ph (970) 879-0272 ext. 6014, fx (970) 879-1070, hm (719) 221-1227
www.water.state.co.us

✓ TEO 10/17/13 ✓ GGS 11/1/13 8/12

INSPECTOR: DSM

ENGINEER'S INSPECTION REPORT

OFFICE OF THE STATE ENGINEER - DIVISION OF WATER RESOURCES - DAM SAFETY BRANCH 1313 SHERMAN STREET, ROOM 818, DENVER, CO 80203, (303) 866-3581

DAM NAME:	LONG LAKE	T: 060N R: 0830W S: 23		COUNTY:	ROUTT	DATE OF INSPECTION:	8/21/2012
DAM ID:	580118 YRCompl: 1942	DAM HEIGHT(FT):	20.0	SPILLWAY WIDTH(FT):	100.0	PREVIOUS INSPECTION:	9/12/2011
CLASS:	High hazard	DAM LENGTH(FT):	480.0	SPILLWAY CAPACITY(CFS):	297.0	NORMAL STORAGE (AF):	396.0
DIV:	6 WD: 58	CRESTWIDTH(FT):	14.0	FREEBOARD (FT):	3.5	SURFACE AREA(AC):	57.0 ✓
EAP:	10/18/2010	CRESTELEV(FT):	9858.0	DRAINAGE AREA (AC.):	700.0	OUTLET INSPECTED:	7/26/2000

CURRENT RESTRICTION: -- NONE --

OWNER:	CITY OF STEAMBOAT SPRINGS	OWNER REP.:	CHUCK ANDERSON, PUBLIC WORKS DIRECTOR
ADDRESS:	P. O. BOX 775088	CONTACT NAME:	JOE ZIMMERMAN
	STEAMBOAT SPRINGS CO 80477-5088	CONTACT PHONE:	(970) 871-8209

INSPECTION PARTY: Joe Zimmerman, Jon Snyder — Dana Miller

REPRESENTING: City of Steamboat Springs — State Engineer's Office

FIELD CONDITIONS OBSERVED

WATER LEVEL: BELOW DAM CREST ___ FT. Below Spillway ~4.5 FT. GAGE ROD READING 9.2

GROUND MOISTURE CONDITION: [✓] DRY [ ] WET [ ] SNOWCOVER OTHER ___

DIRECTIONS: MARK AN X FOR CONDITIONS FOUND AND UNDERLINE WORDS THAT APPLY

UPSTREAM SLOPE

PROBLEMS NOTED: [ ] (0)NONE [ ] (1)RIPRAP - MISSING, SPARSE, DISPLACED, WEATHERED [✓] (2) WAVE EROSION - WITH SCARPS

[ ] (3) CRACKS WITH DISPLACEMENT [ ] (4) SINKHOLE [ ] (5) APPEARS TOO STEEP [ ] (6) DEPRESSIONS OR BULGES [ ] (7) SLIDES

[ ] (8) CONCRETE FACING - HOLES, CRACKS, DISPLACED, UNDERMINED [✓] (9) OTHER rodent activity

Minor erosion at the high water line on the right portion of the dam. Rock protection at and below high water line with rock/soil/weeds above. A willow or two was noted. Rodent activity did not appear as prevalent this year as last, but was still active. Somewhat uneven water line.

CONDITIONS OBSERVED: [ ] Good [X] Acceptable [ ] Poor

CREST

PROBLEMS NOTED: [✓] (10) NONE [ ] (11 RUTS OR PUDDLES [ ] (12) EROSION [ ] (13) CRACKS - WITH DISPLACEMENT [ ] (14) SINKHOLES

[ ] (15) NOT WIDE ENOUGH [ ] (16) LOW AREA [ ] (17) MISALIGNMENT [ ] (18) IMPROPER SURFACE DRAINAGE [ ] (19) OTHER

Good, gravelly surface with almost no vegetation. Good camber noted on the crest. Cross slope is flat to upstream.

CONDITIONS OBSERVED: [X] Good [ ] Acceptable [ ] Poor

DOWNSTREAM SLOPE

PROBLEMS NOTED: [✓] (20) NONE [ ] (21) LIVESTOCK DAMAGE [ ] (22) EROSION OR GULLIES [ ] (23) CRACKS - WITH DISPLACEMENT [ ] (24) SINKHOLE

[ ] (25) APPEARS TOO STEEP [ ] (26) DEPRESSIONS OR BULGES [ ] (27) SLIDE [ ] (28) SOFT AREAS [ ] (29) OTHER

Steeper in the center near the maximum section over the outlet pipe. Slope looks good. Vegetation on the left side noted last year as a water-seeking plant was dead or dying, perhaps an indication that water was not available from melting snowpack this year vs. the plant potentially getting water from the reservoir. No movement detected in the slope; even the rocks above the headwall appeared solid. Vegetation is coming in nicely - a little patchy - on the right side, which was most recently disturbed and rebuilt. One or two seedlings were noted.

CONDITIONS OBSERVED: [X] Good [ ] Acceptable [ ] Poor

SEEPAGE

PROBLEMS NOTED: [ ] (30) NONE [ ] (31) SATURATED EMBANKMENT AREA [ ] (32) SEEPAGE EXITS ON EMBANKMENT

[✓] (33) SEEPAGE EXITS AT POINT SOURCE [ ] (34) SEEPAGE AREA AT TOE [ ] (35) FLOW ADJACENT TO OUTLET [ ] (36) SEEPAGE INCREASED / MUDDY

DRAIN OUTFALLS SEEN [ ] No [✓] Yes Show location of drains on sketch and indicate amount and quality of discharge. [ ] (37) FLOW INCREASED / MUDDY [✓] (38) DRAIN DRY / OBSTRUCTED

[ ] (39) OTHER

Seepage along the base of the hillside on the right side with wet soil and standing water, but no flow of water detected. Seepage historically noted on the left side of the outlet channel downstream, was dry during the inspection. The lower toe drains on the left and right were running a trickle, with iron ochre noted in the right drain. The upper drain on the right was dry.

CONDITIONS OBSERVED: [ ] Good [X] Acceptable [ ] Poor

Table 1 - Tiered Dam Breach Analysis Structure

Level of Analysis	Breach Parameter Estimation (Size/Shape and Failure Time)	Breach Hydrograph Estimation	Breach Hydrograph Routing	Hydraulics at Critical Section(s)
Screening	Empirical Equations	Peak Breach Discharge from SMPDBK	Empirical Routing Equations or Nomographs	Normal Depth
Simple ✓	Empirical Equations ✗	Parametric Model (HEC-1 or HEC-HMS)	Hydrologic Model (HEC-1 or HEC-HMS)	Steady-State Hydraulics (HEC-RAS)
Intermediate	Empirical Equations	Parametric Model HEC-1 or HEC-HMS	Unsteady Hydraulic Model (HEC-RAS)	Peak Water Surface Profile (Unsteady HEC-RAS)
Advanced	Empirical Equations	Parametric Model (HEC-RAS or DAMBRK)	Unsteady Hydraulic Model (HEC-RAS)	Peak Water Surface Profile (Unsteady HEC-RAS)

The hydraulic conditions at critical locations downstream of the dam can usually be determined with normal depth calculations as long as steady, uniform flow is a valid assumption (i.e. no significant backwater effects in the vicinity of the section).

Because the screening level of analysis is very conservative, it can be used to determine if further analysis is required. It is expected that, if the hydraulics calculated at critical locations indicate a specific hazard classification with a screening-level analysis, then more sophisticated analyses would not likely result in a higher hazard classification. So if a screening analysis indicates a Low Hazard, no further analysis is required. If the screening analysis indicates High or Significant Hazard, a more accurate, less conservative approach may show a lower hazard classification and additional analysis may be warranted to demonstrate this depending on the situation.

Note that the screening level of analysis does not lead to inundation maps which are required for Significant and High Hazard dams. The minimum level of analysis required to develop inundations maps is the next level: Simple.

6.2 Simple

The Simple level of analysis is slightly more sophisticated than the screening analysis. Results of the Simple level of analysis may provide the necessary conclusion, or may indicate that the intermediate or advanced approach is warranted. This analysis uses the recommended empirical methods to determine the breach parameters and then uses a hydrologic parametric model (HEC-HMS or HEC-1) to compute a breach hydrograph. The hydrologic tool can then be used to route the flood downstream to critical locations. At that point, a steady-state hydraulic model can be used to calculate the hydraulic conditions where required.

Erosion rate (ER) guidelines of $1 < ER/H_w < 21$, where $ER=B_{avg}/T_f$, can be used as check of the methods and the parameters adjusted accordingly. Table 3 summarizes the generally appropriate empirical methods for varying dam sizes and storage intensities. This is only a guide and engineering judgment is needed on a case-by-case basis considering the ER/H_w and B_{avg}/H_b guidelines mentioned above.

Table 3 - Guide of Appropriate Empirical Methods for Various Dam Sizes and Storage-Intensities

Dam Size	Storage Intensity $(SI) = V_w/H_w$		
	Low ($SI < 5$)	**Medium** ($5 < SI < 20$)	**High** ($SI > 20$) ✓✓
Minor	*MacDonald & Langridge-Monopolis with Washington State failure time. Froehlich for Overtopping.	*MacDonald & Langridge-Monopolis with Washington State failure time. Froehlich for Overtopping.	*MacDonald & Langridge-Monopolis with Washington State failure time. Froehlich for Overtopping.
Small ✓✓	*MacDonald & Langridge-Monopolis with Washington State failure time and possibly Froehlich (case-by-case). Froehlich for Overtopping.	Froehlich and possibly *MacDonald & Langridge-Monopolis with Washington State failure time (case-by-case).	Froehlich for geometry and failure time. ✓✓
Large	Froehlich. The side slopes may need to be adjusted to yield a reasonable bottom width.	Froehlich and possibly *MacDonald & Langridge-Monopolis with Washington State failure time (case-by-case).	Froehlich and possibly *MacDonald & Langridge-Monopolis with Washington State failure time (case-by-case).
Comments	Parameters likely need to be adjusted with judgment on a case-by-case basis – may need to be modeled as piping hole for Small and Minor dams.	Both Froehlich and *MacDonald & Langridge-Monopolis seem to work for Small and Large dams in the middle range of SI. Engineering judgment is needed on a case-by-case basis.	It is important to look at valley and dam constraints as the computed parameters may exceed the valley width and/or dam length.
References	Froehlich (2008) MacDonald & Langridge-Monopolis (1984) Washington State (2007)		

* Where the MacDonald & Langridge-Monopolis Method is referenced as a recommendation, this only applies for embankments constructed of cohesive materials. The Washington State Method is preferred for cohesionless earthen embankments.

7.1.1.1 Piping Failure Considerations with Empirical Methods

For Small and Minor dams with low storage intensities (SI less than 5) that are built with cohesive soils, it is possible that a piping failure could occur and drain the reservoir without fully breaching the dam (i.e. collapsing the crest). This situation is evident when the MacDonald & Langridge-Monopolis and Washington State empirical method for establishing the breach parameters shows that the volume eroded (V_{er}) results in a corresponding B_{avg}/H_b of less than about 0.5. This phenomenon is common for Small dams with a volume less than 100 AF and SI less than about 2.5, and Minor dams when SI is less than about 1.5. When this occurs, it is possible to calculate the maximum piping-hole size (assumed to be square) from the volume of embankment eroded. This piping-only failure mode does not apply to dams

Table 2 – Summary of Recommended Empirical Equations (English Units)

Breach Parameters	MacDonald & Langridge-Monopolis (1984)	Washington (2007)	Froehlich (2008)
Volume Eroded V_{er} **(yd³)**	$V_{er} = 3.264BFF^{0.77}$ (best fit all data)	$V_{er} = 3.75BFF^{0.77}$ (cohesionless dams)	
	$V_{er} = 0.714BFF^{0.852}$ (rockfill)	$V_{er} = 2.5BFF^{0.77}$ (cohesive dams)	
Average Breach Width B_{avg} **(ft)**	$B_{avg} = \frac{V_{er}}{(H_b \times W_{avg})}$		$B_{avg} = 8.239K_oV_w^{0.32}H_b^{0.04}$ K_o=1.0 for piping K_o=1.3 for overtopping
Breach Side slopes Z_b **(H:V)**	2.0:1		0.7:1 - piping 1.0:1 - overtopping
Breach Development Time T_f **(hr)**	$T_f = 0.016V_{er}^{0.364}$	$T_f = 0.02V_{er}^{0.36}$ (cohesionless)	$T_f = 3.664\sqrt{\frac{V_w}{gH_b^2}}$
		$T_f = 0.036V_{er}^{0.36}$ (cohesive)	

Suggested Methods to Validate the Parameters Calculated using Empirical Methods:

On a case by case basis, judgment is needed with the predicted parameters calculated using the recommended methods presented here. There are a few general tools used to validate the predicted parameters:

1. An estimate of linear erosion rate can be used to check the validity of the failure time. Linear erosion rate (ER) is defined as the B_{avg}/T_f. Von Thun and Gillette (1990) suggests the minimum allowable erosion rate related to the height of the water above the breach bottom, can be empirically defined as $4H_w$ and the maximum erosion rate related to the water depth is $200 + 4H_w$. However, the data set used to develop the empirical parameters suggest a minimum ER of $1.6H_w$. **If the T_f, B_{avg}, and H_w computed by the empirical methods listed above produces an ER/H_w much less than 1.6, then either the T_f is too long or B_{avg} is too small** and adjustments are needed or a different method selected. Likewise, the maximum ER/H_w in the data set was only 21, which is considerably less than upper limit defined by Von Thun and Gillette (1990) (greater than 200). The average ER/H_w computed from the database was 6.7. **Therefore, if the ER/H_w ratio is greater than 21, then the parameters are considered suspect.**

2. Von Thun and Gillette (1990) suggests that B_{avg}/H_w cannot be less than 2.5. However, the data set, especially for piping, shows B_{avg}/H_w less than 2.5 in many instances. In fact, it is near 1.0 in several cases and less than 1.0 in a few instances. The minimum B_{avg}/H_w for the data set was 0.6 and the minimum B_{avg}/H_b was 0.5. This ratio is highly dependent on storage-intensity ($SI = V_w/H_w$) and with a relatively small reservoir volume relative to the dam height (low storage intensity), the reservoir evacuates quickly and does not allow for the breach to widen. Piping failure of a dam with a very low storage-intensity may evacuate the reservoir through the piping hole without a full rectangular or trapezoidal breach forming. Paquir, et.al, (post 1995) suggested that the piping hole width has to reach 2/3 of the dam height above the bottom of the pipe before the roof of the piping hole collapses

decrease in the reservoir level with higher flows occurring during the piping stage of the failure. As such, the peak of the breach hydrograph usually occurs during the piping mode of failure as opposed to during the weir flow mode. **To resolve this issue when modeling a piping failure breach with HEC-HMS, it is recommended that the starting piping elevation should always be set at the mid-point of the final breach height.** This will ensure that the head is always measured from the center of the pipe/dam. A comparison of HEC-HMS results (with the starting elevation set at the center elevation of the reservoir) to HEC-RAS results (with a piping failure starting at the bottom of the reservoir) showed similar peaks and time to peaks in the resulting breach hydrographs.

The HEC-1 model simulates a dam breach by assuming weir flow through a trapezoidal section that progresses linearly from no breach at the top of the dam to the specified final parameters at the bottom of the breach in the time T_f. The piping portion of a failure is not considered and the only progression available is linear. Therefore, the results may not be valid for a piping failure of a smaller reservoir when the piping portion may be significant enough to impact the final hydrograph.

Due to the above issues, caution should be exercised when using HEC-1 and HEC-HMS to simulate a piping failure, especially when the final results at a critical location downstream indicate a borderline situation between hazard ratings. However, because of their simplicity and ease of use, both models are valuable for simulating an overtopping breach for a simple or intermediate analysis. Also, for a simple or intermediate analysis of a piping failure, HEC-1 can be useful for a larger reservoir when the piping portion of the failure is not as significant and HEC-HMS can be useful if the starting piping elevation is set at mid-height of the reservoir behind dam.

7.2.2.2 Hydraulic Models

The latest versions of the HEC-RAS model include algorithms to model both overtopping and piping breaches. HEC-RAS uses hydraulic principles through cross sections upstream and downstream of the dam to define how the reservoir drains during the formation of a dam breach. The dam crest is modeled as an inline weir and either a piping failure or overtopping failure is simulated with enlargement of the breach occurring over time as defined by a specified breach progression. Flow through the piping hole is calculated as orifice flow and flow through the breach is calculated as weir flow. The water surface profile upstream of the dam is back-calculated using unsteady momentum and hydraulic principles for each time step and the resulting drawdown through the hole and/or breach produces an outflow hydrograph. Resulting water levels for each time step downstream of the dam are used to model potential backwater effects and the weir and orifice coefficients are automatically adjusted for submergence, if necessary. HEC-RAS can also model a piping failure that does not progress to the point of collapsing the crest. In this scenario, the piping hole is simulated as a sluice gate.

Compared to HEC-HMS, the HEC-RAS program models a dam failure, especially a piping failure, more correctly and accurately for the following reasons:

1. Modeling a dam failure using hydraulic principles is usually more accurate than a hydrologic model because the modeler can more accurately simulate the shape of the reservoir, tailwater effects, and drawdown effects. Put simply, a dam failure is more accurately defined as a hydraulic process than a hydrologic one. HEC-RAS has the capability to model the pipe with an initial piping elevation set at the bottom of the dam (most piping failure situations); the piping hole is modeled as a rectangular hole, which is more consistent with the final trapezoidal shaped breach section, thereby reducing discontinuity. The bottom width of the hole enlarges proportionally to the final bottom width according to the selected progression, as does the height of the hole toward the final breach depth. This will make the hole height/width ratio greater than one if the final breach parameters chosen show

APPENDIX B

HEC-HMS HYDROLOGIC MODEL RESULTS

RJH CONSULTANTS, INC.

Project 1317 Page 1/4
Date 9/23/13 By EMH
Client Steamboat Springs Checked 10/17/13 By TEO
Subject Long Lake Dam Approved 11/5/13 By GGS

REQUIRED - Develop a HEC-HMS hydrologic model to develop the dam breach hydrograph

ASSUMPTIONS -

1) Use RJH Dam Breach Parameters analysis dated 10/17/13. ✓
2) No downstream channel routing will be performed ✓ OK
3) Use USACE HEC-HMS Version 3.5 ✓
4) Use SEO Elevation-Capacity data ✓
5) Evaluate a sunny-day piping failure ✓

ANALYSIS -

- The HEC-HMS model consists of the reservoir ✓
- Model input is shown on p. 2-3 ✓
- Model output is shown on p. 4 ✓

Summary -

- Dam breach hydrograph shown on p. 4 ✓
- Peak dam breach outflow = 5,052 cfs ✓

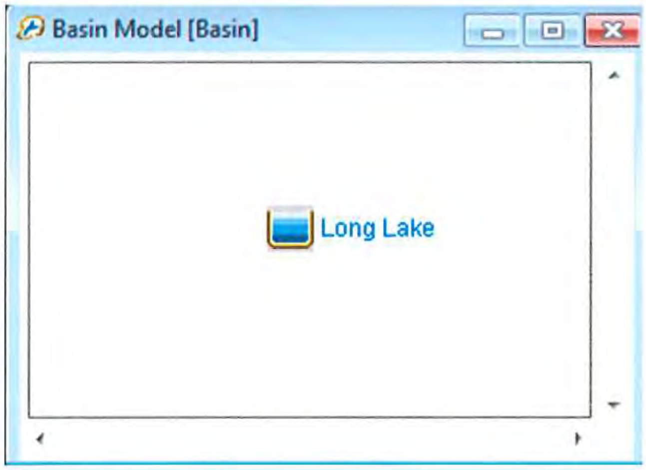
2/4

✓ TEO 10/17/13
✓ GGS 11/5/13

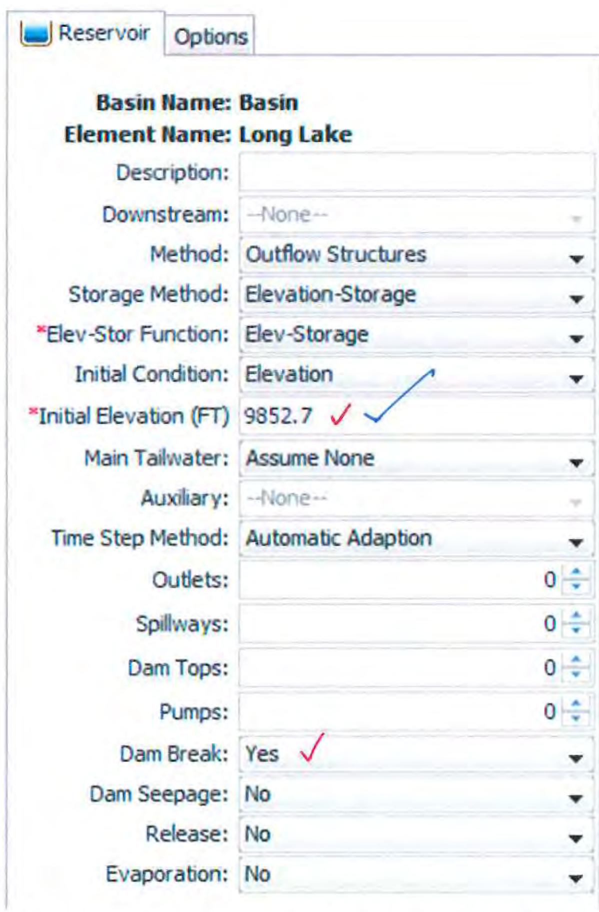
Long Lake Dam Breach Inundation Study
Project No. 13117

HEC-HMS

Schematic



Reservoir Parameters



✓TEO 10/17/13
✓GGS 11/5/13

Breach Parameters

Reservoir | Dam Break | Options

Basin Name: Basin
Element Name: Long Lake

Method:	Piping Breach ✓
Direction:	Main
*Top Elevation (FT)	9858 ✓✓
*Bottom Elevation (FT)	9839.6 ✓✓
*Bottom Width (FT)	48 ✓✓
*Left Slope (xH:1V)	0.7 ✓✓
*Right Slope (xH:1V)	0.7 ✓✓
*Piping Elevation (FT)	9848.8 ✓✓
*Piping Coefficient:	0.6 ✓ ok conservative
*Development Time (HR)	0.66 ✓✓
Trigger Method:	Elevation
*Trigger Elevation (FT)	9852.6 ✓
Progression Method:	Linear

✓

Elevation-Capacity

Paired Data | Table | Graph

Elevation (FT)	Storage (AC-FT)
9839.0	0.0 ✓
9841.0	0.1 ✓
9842.0	44.8 ✓
9843.0	66.8 ✓
9844.0	90.2 ✓✓
9845.0	114.5 ✓
9846.0	141.4 ✓
9847.0	169.5 ✓
9848.0	199.3 ✓✓
9849.0	230.3 ✓
9850.0	262.1 ✓
9851.0	296.5 ✓
9852.0	331.8 ✓
9852.7	357.0 ✓
9853.0	368.7 ✓✓
9858.0	570.0 ok

✓

√TEO 10/17/13
√GGS 11/5/13

Results

Summary Results for Reservoir "Long Lake"

Project: Long Lake
Simulation Run: Breach Reservoir: Long Lake

Start of Run:	01Jan2000, 00:00	Basin Model:	Basin
End of Run:	01Jan2000, 06:00	Meteorologic Model:	Met
Compute Time:	17Oct2013, 16:08:32	Control Specifications:	Control

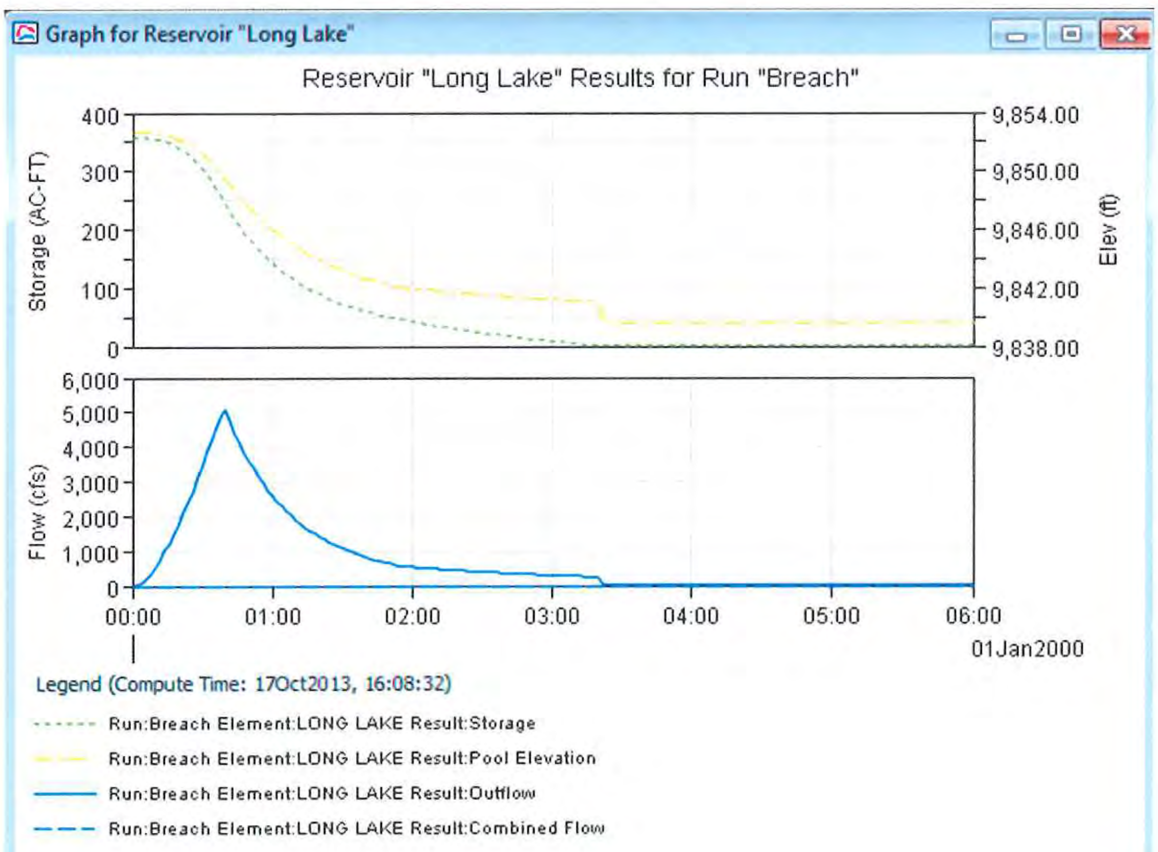
Volume Units: IN AC-FT

Computed Results

Peak Inflow :	0.0 (CFS)	Date/Time of Peak Inflow :	01Jan2000, 00:00
Peak Outflow :	5051.8 (CFS) ✓	Date/Time of Peak Outflow :	01Jan2000, 00:40 ✓
Total Inflow :	0.0 (AC-FT)	Peak Storage :	357.0 (AC-FT) ✓
Total Outflow :	356.6 (AC-FT) ✓	Peak Elevation :	9852.7 (FT) ✓

✓

Breach Hydrograph



✓

APPENDIX C

MANNING'S N VALUES

REQUIRED - Evaluate Manning's n values for the downstream drainage

ASSUMPTIONS -
1) Use FEMA effective hydraulic models for Fish Creek and Yampa River ✓
2) Use photographs from site visit October 2013 ✓
3) Use USDA NAIP Aerial Imagery (2011). ✓
4) Use FEMA Flood Insurance Study Routt County Colorado and Unincorporated Areas (2005). ✓
5) Use V.T. Chow Open Channel Hydraulics (1959) Table of Manning's n values as shown in T.L. Sturm Open Channel Hydraulics (2001). ✓

ANALYSIS -

- RJH will generally use Manning's n values as presented in the FEMA effective models
  ↳ The intent of this evaluation is to confirm that these Manning's n values are appropriate and adjust where required ✓✓

- Fish Creek (Dam to XS - 6.30)
  - Main channel consists of a steep mountain stream with large boulders and minimal vegetation (see p. 4) ✓
  - FEMA model used n = 0.08 for upper reaches of Fish Creek main channel ✓
  - From Sturm:

	Min.	Avg.	Max.	
- Mountain stream w/ large boulders ✓	0.04 ✓	0.05 ✓	0.07 ✓	(see p. 6) ✓

  - Increase Sturm significant presence of large boulders ✓

ANALYSIS -

- use n=0.08 for main channel → FEMA model confirmed ✓✓
- overbanks consist of some areas of thick pine trees and brush with some areas of rock/gravel and native grasses interspersed (see p. 4) ✓
  - FEMA model used n=0.10 for upper reaches of Fish Creek overbanks ✓
  - From Sturm:

	Min.	Avg.	Max.
- Trees, heavy stand of timber ✓	0.08 ✓	0.10 ✓	0.12 ✓ (see p. 7) ✓

  - use n=0.08 ✓✓OK to account for interspersed areas of native grass/rocky areas ✓ (n=0.10 used in a few select areas of densely forested areas) ✓

- Fish Creek (XS -6,30 to -9,225)

- Main channel consists of a steep mountain stream with gravel, cobbles, and boulders (see p. 5) ✓
  - FEMA model used n=0.06 for main channel ✓
  - From Sturm:

	Min.	Avg.	Max.
- Mountain stream w/ cobbles and large boulders ✓	0.04 ✓	0.05 ✓	0.07 ✓

  - use n=0.06 ✓OK for main channel → FEMA model confirmed ✓✓
- Overbanks vary from areas with thick pine trees and brush to commercial/residential developed areas to a golf course ✓
  - Use n=0.08 ✓✓ for areas with pine trees and brush (see above) ✓✓
  - Use n=0.06 ✓✓ for developed areas (same as FEMA model) ✓✓

ANALYSIS -

- For golf course/native grass areas:

  - From Sturm:

	Min.	Avg.	Max	
- Pasture/grass	0.03	0.035	0.05	(see p.6 7)

- use n = 0.05 at higher end of range to account for some site features and scattered trees that would increase roughness

✓ TEO 11/1/13
✓ GGS 11/5/13

Fish Creek – Aerial photograph ✓

Fish Creek near XS -7.5 ✓

5/7
✓TEO 11/1/13
✓GGS 11/5/13

Fish Creek near XS -8.8 ✓

Fish Creek near XS -9.2 ✓

✓TEO 11/1/13
✓GGS 11/5/13 6/7

Type of Channel and Description	Minimum	Normal	Maximum
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
D. Natural Streams			
D–1. Minor streams (top width at flood stage < 100 ft)			
a. Streams on plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
→ 2. Bottom: cobbles with large boulders	0.040	0.050	0.070 ✓
D–2. Flood plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035

(continued)

Sturm

✓TEO 11/1/13
✓GGS 11/5/13 717

TABLE 4-1 (Continued)

Type of Channel and Description	Minimum	Normal	Maximum
2. High grass	0.030	0.035	0.050 ✓
b. Cultivated areas			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120 ✓
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
D-3. Major streams (top width at flood stage > 100 ft). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	. . .	0.060
b. Irregular and rough section	0.035	. . .	0.100

Source: Chow 1959. Used with permission of Chow estate.

Chow (1959) presented methods by Horton, Einstein and Banks, and Lotter for obtaining a composite value of Manning's n for a single channel; that is, for the main channel only of a compound channel or a canal with laterally varying roughness. The Horton method is based on the assumption that the velocities in each wetted-perimeter subsection are equal to one another as well as equal to the mean velocity of the whole cross section. The resulting composite value of Manning's n, denoted n_c, is given by

$$n_c = \left[\frac{\sum_{i=1}^{N} P_i n_i^{3/2}}{P} \right]^{2/3} \tag{4.27}$$

in which P_i, n_i = wetted perimeter and Manning's n of any section i; P = wetted perimeter of the entire cross section; and N = total number of sections into which

Sturm

APPENDIX D

HEC-RAS MODEL RESULTS

Client Steamboat Springs
Subject Long Lake Dam

Project 13117 Page 1/33
Date 10/30/13 By EMH
Checked 11/4/13 By TEO
Approved 11/11/13 By GGS

REQUIRED - Develop a HEC-RAS model to route the peak dam breach flow through the downstream drainage (Fish Creek from the dam to the Yampa River).

ASSUMPTIONS 1) Use Manning's n evaluation by RJH dated 10/30/13. ✓ ✓

2) Use peak flow = 5,052 cfs from RJH HEC-HMS hydrologic model. ✓✓

3) Develop HEC-RAS sections in ArcGIS using the HEC-GeoRAS extension & 2-ft topography provided by the City of Steamboat Springs and supplement with channel topography from the FEMA effective hydraulic model as appropriate. ✓✓

4) Use bridge data from FEMA effective hydraulic model, where available, and field measurements by RJH elsewhere. ✓✓

5) The upstreammost two bridges will be modeled as blocked from dam breach debris. ✓✓

ANALYSIS

- Cross-sections were developed for Fish Creek from the dam to the Yampa River (approx. 9.3 miles) ✓

- The following bridges were modeled:

- Steamboat Blvd - based on field measurements by RJH (XS-6.76) (modeled as blocked) ✓✓

- Pedestrian Bridge just downstream of Steamboat Blvd. bridge - based on field measurements by RJH (XS-6.803) (modeled as blocked) ✓✓

- Rollingstone Blvd - based on field measurements by RJH (XS-8.89) ✓✓

- Hwy 40 - based on data from FEMA effective model (XS-9.1) ✓✓

- Railroad bridge just downstream of Hwy 40 bridge - based on data from FEMA effective model (XS-9.22) ✓✓

- Manning's n values were input from RJH 10/30/13 manning's n evaluation. ✓✓

RJH CONSULTANTS, INC.

Project 13117 Page 2/33
Date 10/30/13 By EMH
Client Steamboat Springs
Checked 11/4/13 By TEO
Subject Long Lake Dam
Approved 11/11/13 By GGS

ANALYSIS –

- Normal depth was used for the downstream boundary condition (at Yampa River) and critical depth for upstream boundary condition ✓✓

- See HEC-RAS results on p. 3-33 ✓

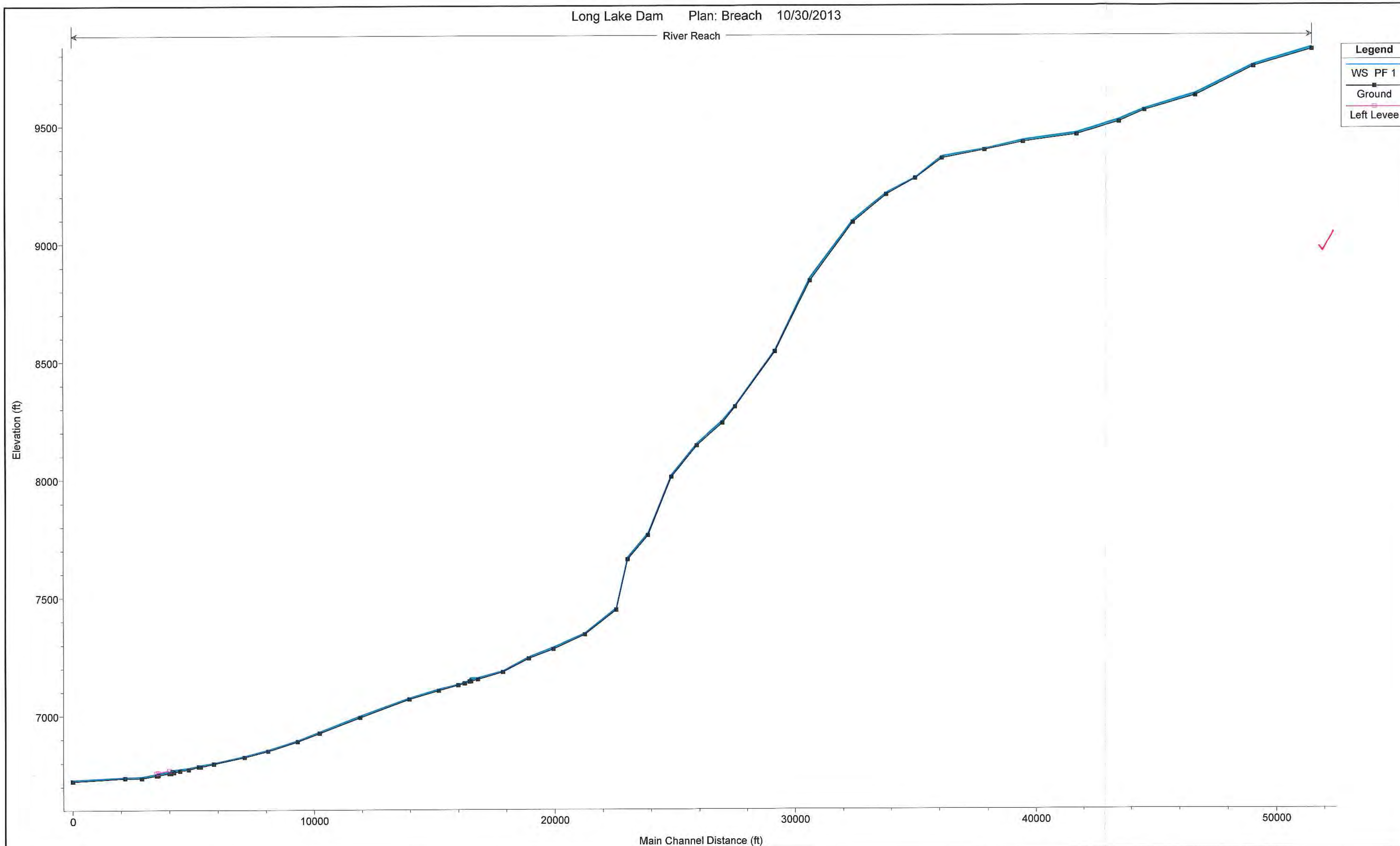
- QA/QC
  - Check in Arc GIS
  - Cross-Section Layout ✓
  - Reach Lengths ✓
  - Check in HEC-RAS
  - Reach lengths ✓
  - Manning's n values ✓
  - Flow Data ✓
  - Cross-Section topography ✓
  - Bridge Data ✓
  - General Model Performance ✓

✓ TEO 11/4/13 3/33
✓ GGS 11/11/13

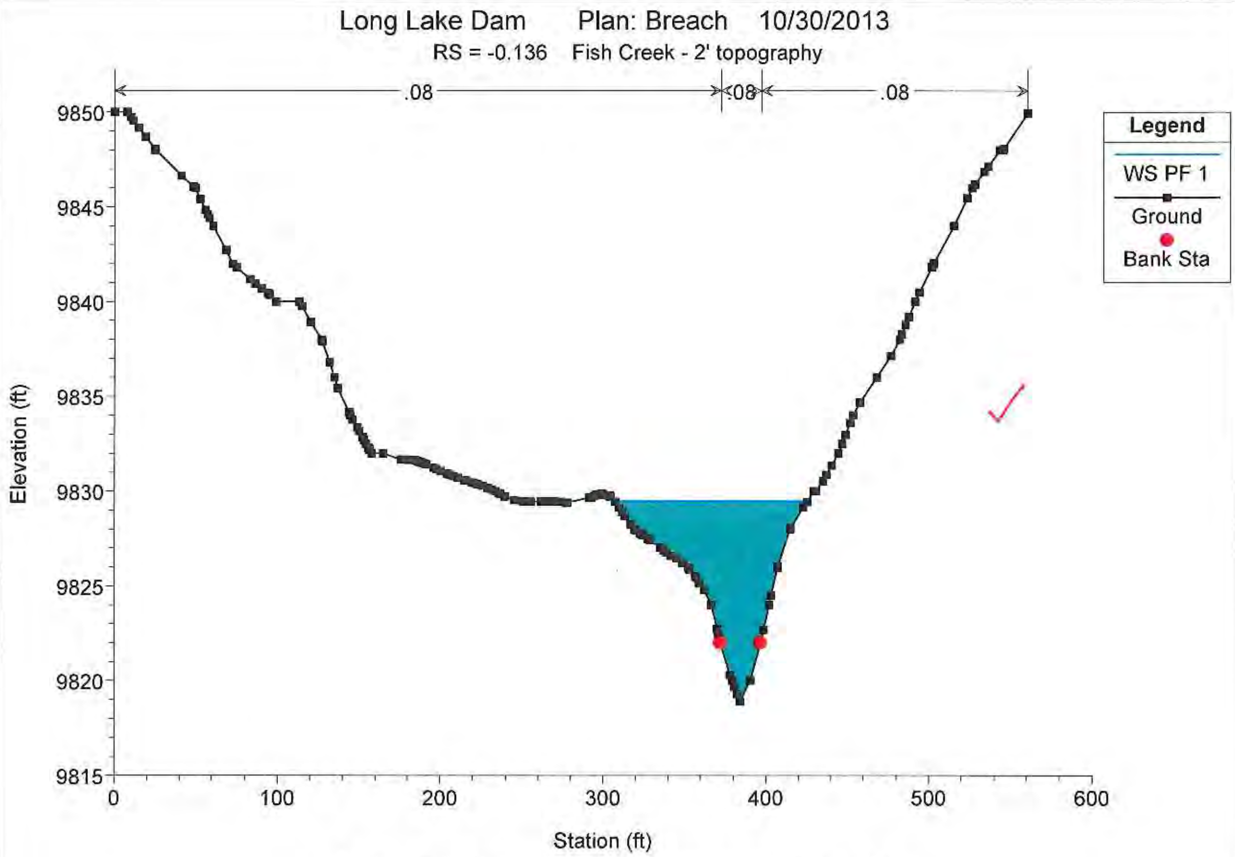
HEC-RAS Plan: Breach - Ste River: River Reach: Reach Profile: Breach

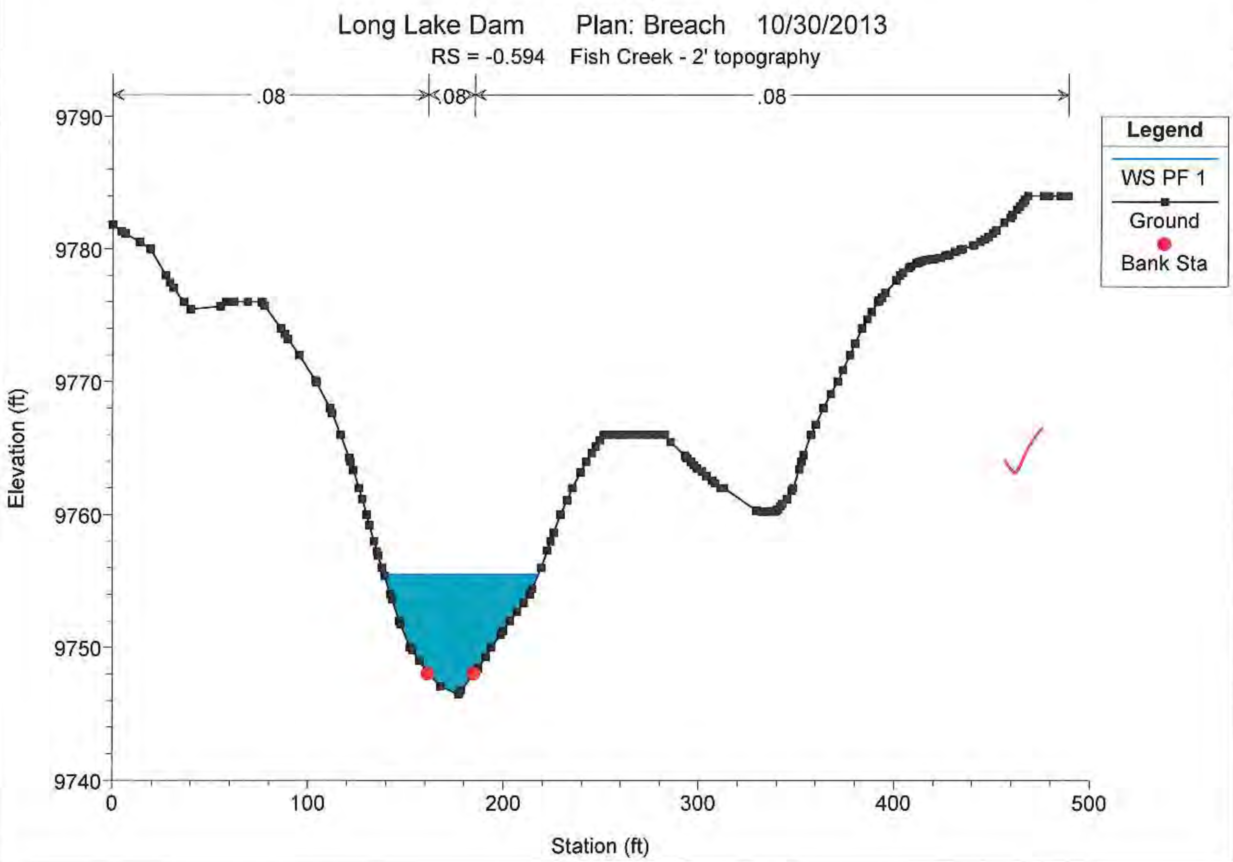
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl	Vel Total
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)		(ft/s)
Reach	-0.136	Breach	5052.00	9818.91	9829.45	9829.45	9831.75	0.032591	14.36	496.11	127.03	0.84	10.18
Reach	-0.594	Breach	5052.00	9746.47	9755.45	9755.45	9758.09	0.039964	15.11	421.69	78.89	0.92	11.98
Reach	-1.046	Breach	5052.00	9624.00	9634.06	9633.03	9635.67	0.026237	12.76	527.54	97.04	0.75	9.58
Reach	-1.442	Breach	5052.00	9562.00	9569.68	9569.59	9571.20	0.045011	12.16	544.63	161.37	0.90	9.28
Reach	-1.645	Breach	5052.00	9513.04	9523.04	9523.04	9525.96	0.041549	16.92	401.61	69.07	0.96	12.58
Reach	-1.983	Breach	5052.00	9460.00	9467.89	9465.79	9468.14	0.007244	5.27	1328.30	370.87	0.37	3.80
Reach	-2.407	Breach	5052.00	9428.02	9435.86	9435.86	9438.19	0.041783	13.67	450.40	100.73	0.92	11.22
Reach	-2.708	Breach	5052.00	9394.00	9397.97	9396.95	9398.23	0.015487	4.63	1244.16	536.89	0.48	4.06
Reach	-3.039	Breach	5052.00	9358.77	9367.74	9367.74	9368.99	0.024525	12.04	717.76	239.75	0.73	7.04
Reach	-3.249	Breach	5052.00	9274.90	9277.00	9279.02	9287.83	1.241147	22.29	193.56	138.34	3.70	26.10
Reach	-3.478	Breach	5052.00	9205.46	9212.75	9212.75	9215.61	0.045517	14.15	390.10	70.75	0.96	12.95
Reach	-3.741	Breach	5052.00	9088.00	9097.82	9101.27	9108.51	0.157497	30.48	214.96	38.47	1.77	23.50
Reach	-4.081	Breach	5052.00	8840.00	8854.17	8857.07	8863.17	0.124590	30.77	233.68	32.71	1.48	21.62
Reach	-4.356	Breach	5052.00	8540.00	8546.44	8550.08	8561.85	0.415319	36.83	175.56	51.64	2.69	28.78
Reach	-4.673	Breach	5052.00	8306.00	8310.73	8311.13	8312.84	0.073759	12.83	454.37	149.20	1.12	11.12
Reach	-4.774	Breach	5052.00	8238.00	8247.85	8251.24	8258.53	0.146985	29.60	212.32	34.29	1.74	23.79
Reach	-4.978	Breach	5052.00	8141.68	8149.82	8150.75	8153.83	0.067341	18.07	339.84	67.79	1.17	14.87
Reach	-5.177	Breach	5052.00	8008.64	8017.68	8021.53	8031.38	0.259098	37.81	187.33	38.50	2.28	26.97
Reach	-5.361	Breach	5052.00	7762.00	7770.97	7775.04	7785.03	0.252136	37.64	182.59	34.17	2.26	27.67
Reach	-5.521	Breach	5052.00	7660.00	7668.70	7670.01	7673.16	0.079581	20.30	347.91	90.91	1.28	14.52
Reach	-5.611	Breach	5052.00	7446.10	7454.07	7454.07	7457.21	0.044889	14.88	373.34	61.45	0.96	13.53
Reach	-5.859	Breach	5052.00	7342.00	7347.52	7349.93	7355.17	0.165589	22.67	237.25	54.62	1.73	21.29
Reach	-6.105	Breach	5052.00	7280.00	7288.41	7287.91	7290.73	0.031537	13.19	444.63	75.68	0.81	11.36
Reach	-6.300	Breach	5052.00	7240.00	7247.73	7247.73	7250.70	0.049341	15.30	376.47	64.30	1.00	13.42
Reach	-6.501	Breach	5052.00	7183.10	7188.45	7189.82	7193.18	0.059369	18.02	312.94	77.00	1.39	16.14
Reach	-6.699	Breach	5052.00	7152.16	7161.17	7157.24	7161.27	0.001386	3.79	2342.43	398.61	0.23	2.16
Reach	-6.753	Breach	5052.00	7144.00	7159.95	7159.45	7160.25	0.025910	5.61	1169.37	701.20	0.76	4.32
Reach	-6.76		Inl Struct										
Reach	-6.766	Breach	5052.00	7143.02	7151.51	7151.51	7152.26	0.072981	8.68	744.52	504.49	1.24	6.79
Reach	-6.802	Breach	5052.00	7136.00	7145.00	7141.50	7145.20	0.001805	4.41	1704.78	330.57	0.26	2.96
Reach	-6.803		Inl Struct										
Reach	-6.806	Breach	5052.00	7134.28	7140.87	7140.87	7142.36	0.017563	10.53	642.25	231.83	0.77	7.87
Reach	-6.854	Breach	5052.00	7128.00	7131.99	7132.71	7134.55	0.069964	14.52	458.05	203.45	1.41	11.03
Reach	-7.007	Breach	5052.00	7104.58	7111.76	7111.76	7113.77	0.020916	12.17	490.58	124.48	0.85	10.30
Reach	-7.238	Breach	5052.00	7068.10	7074.23	7075.65	7078.22	0.043029	16.47	342.13	85.84	1.19	14.77
Reach	-7.625	Breach	5052.00	6991.10	6999.00	6999.66	7002.74	0.032266	16.19	379.70	80.10	1.07	13.31
Reach	-7.946	Breach	5052.00	6925.10	6931.17	6932.25	6935.17	0.050537	16.23	332.44	87.12	1.27	15.20
Reach	-8.120	Breach	5052.00	6889.92	6894.93	6895.26	6897.21	0.033731	12.49	440.15	128.50	1.03	11.48
Reach	-8.352	Breach	5052.00	6850.10	6855.87	6856.06	6857.74	0.031088	12.09	500.96	165.49	0.99	10.08
Reach	-8.536	Breach	5052.00	6824.10	6829.06	6828.74	6829.88	0.021671	8.51	719.03	279.41	0.79	7.03
Reach	-8.778	Breach	5052.00	6796.10	6800.88	6800.88	6801.51	0.025232	8.43	896.74	588.55	0.84	5.63
Reach	-8.882	Breach	5052.00	6783.10	6791.18	6790.54	6791.47	0.004822	5.74	1512.12	812.75	0.40	3.34
Reach	-8.89		Bridge										
Reach	-8.896	Breach	5052.00	6784.00	6788.78	6788.78	6789.49	0.023153	8.95	881.56	656.19	0.81	5.73
Reach	-8.975	Breach	5052.00	6772.10	6780.42	6780.34	6781.17	0.011923	8.53	913.57	652.91	0.62	5.53
Reach	-9.043	Breach	5052.00	6767.10	6775.93	6775.93	6776.98	0.015040	9.12	747.84	337.93	0.69	6.76
Reach	-9.091	Breach	5052.00	6761.10	6771.80	6767.70	6772.49	0.005071	6.63	762.37	686.04	0.42	6.63
Reach	-9.1		Bridge										
Reach	-9.127	Breach	5052.00	6756.80	6764.25	6764.25	6766.74	0.029056	12.69	402.47	543.59	0.97	12.55
Reach	-9.212	Breach	5052.00	6748.10	6756.60	6755.83	6756.95	0.005697	5.77	1290.19	1309.89	0.44	3.92
Reach	-9.22		Bridge										
Reach	-9.225	Breach	5052.00	6746.70	6755.00	6755.00	6755.74	0.009441	8.04	1036.33	1382.35	0.57	4.87
Reach	-9.342	Breach	5052.00	6735.40	6742.84	6743.83	6746.77	0.026263	15.92	317.39	71.40	1.33	15.92
Reach	-9.474	Breach	5052.00	6735.54	6740.90	6739.35	6741.36	0.004592	5.71	940.55	312.20	0.49	5.37
Reach	-9.883	Breach	5052.00	6723.30	6729.40	6728.04	6730.19	0.006000	7.26	732.45	191.92	0.58	6.90

√TEO 11/4/13 4/33
GGOS 11/11/13

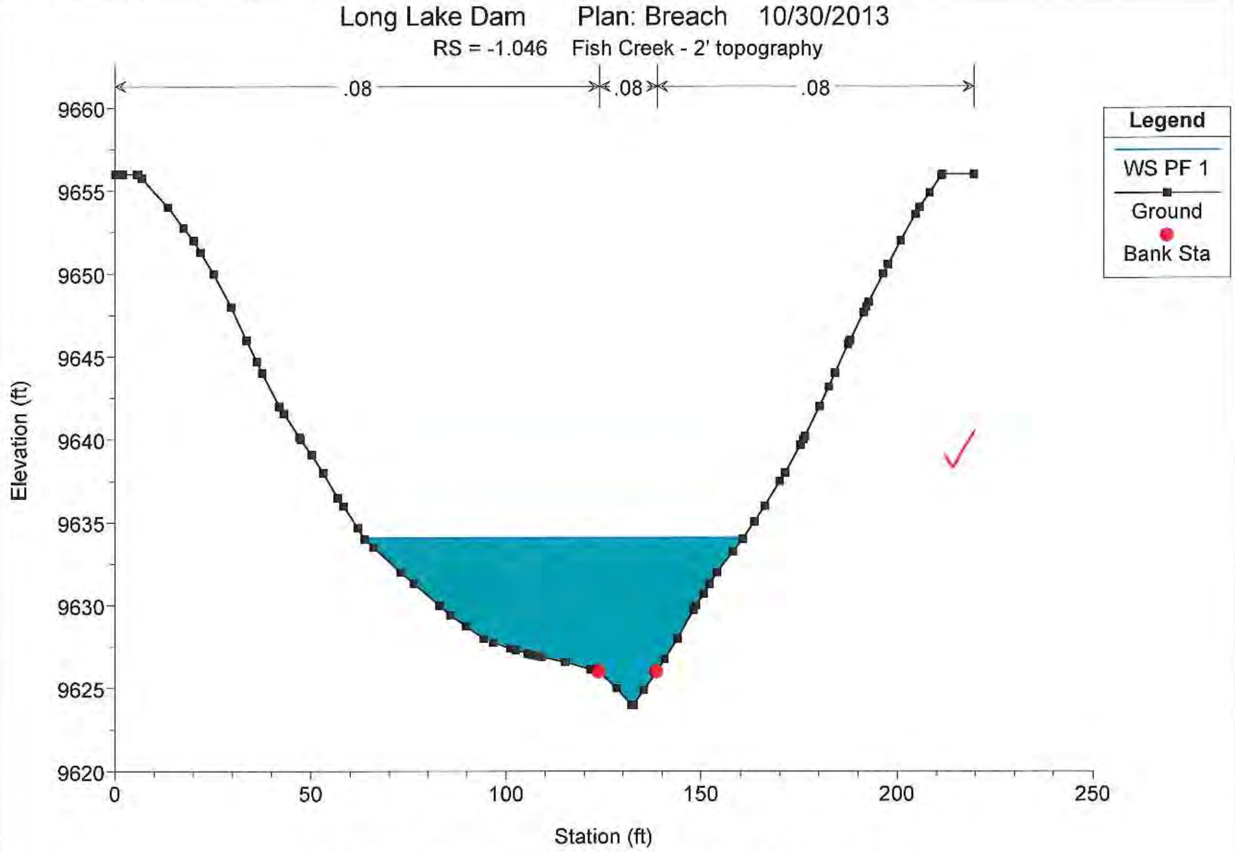


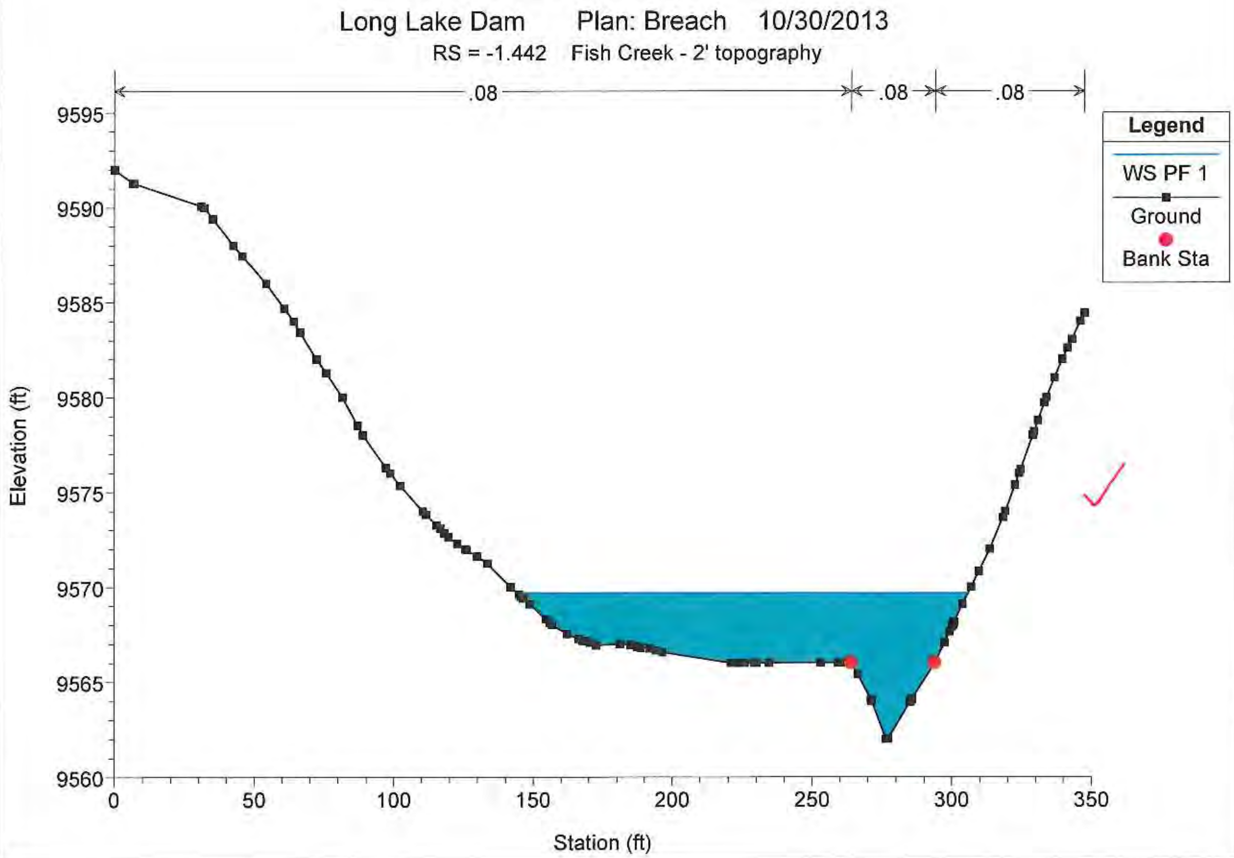
√TEO 11/4/13 5/33
GGS 11/11/13



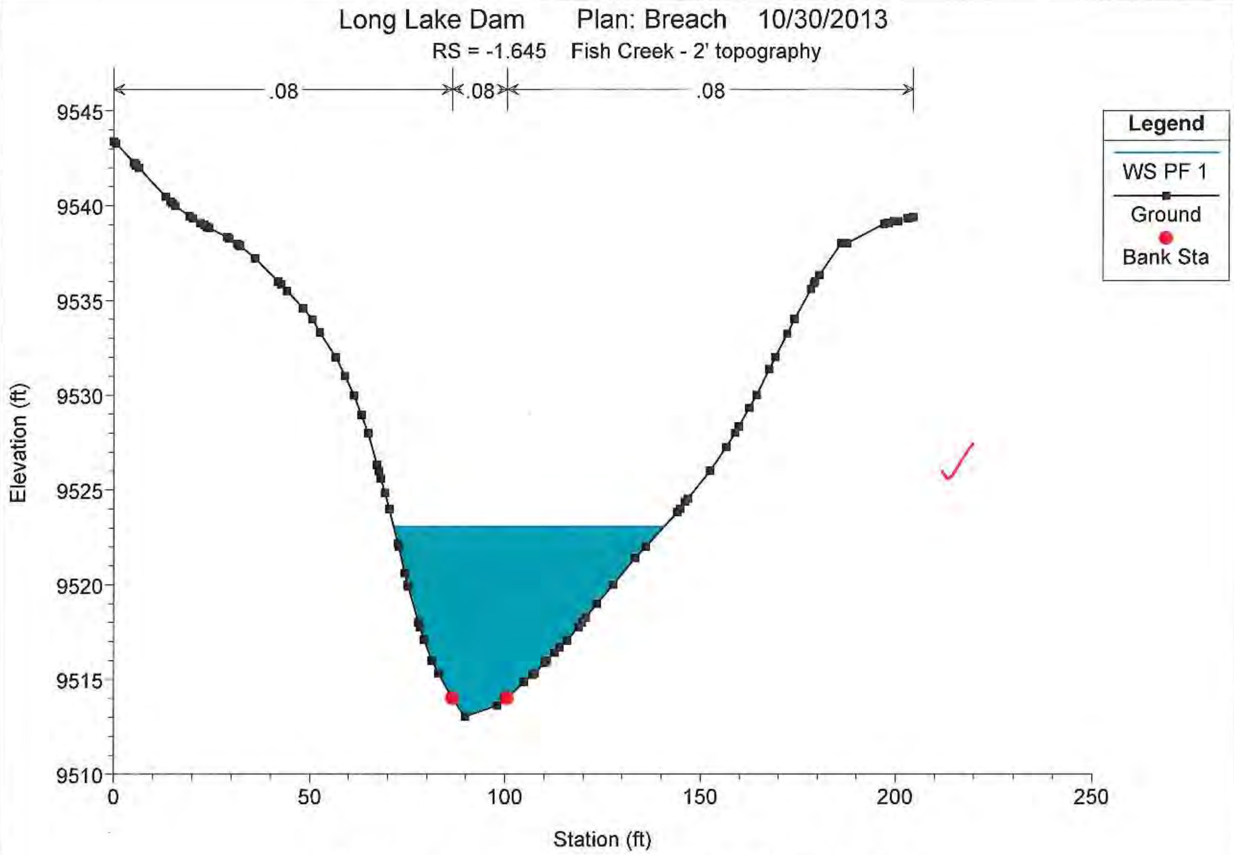


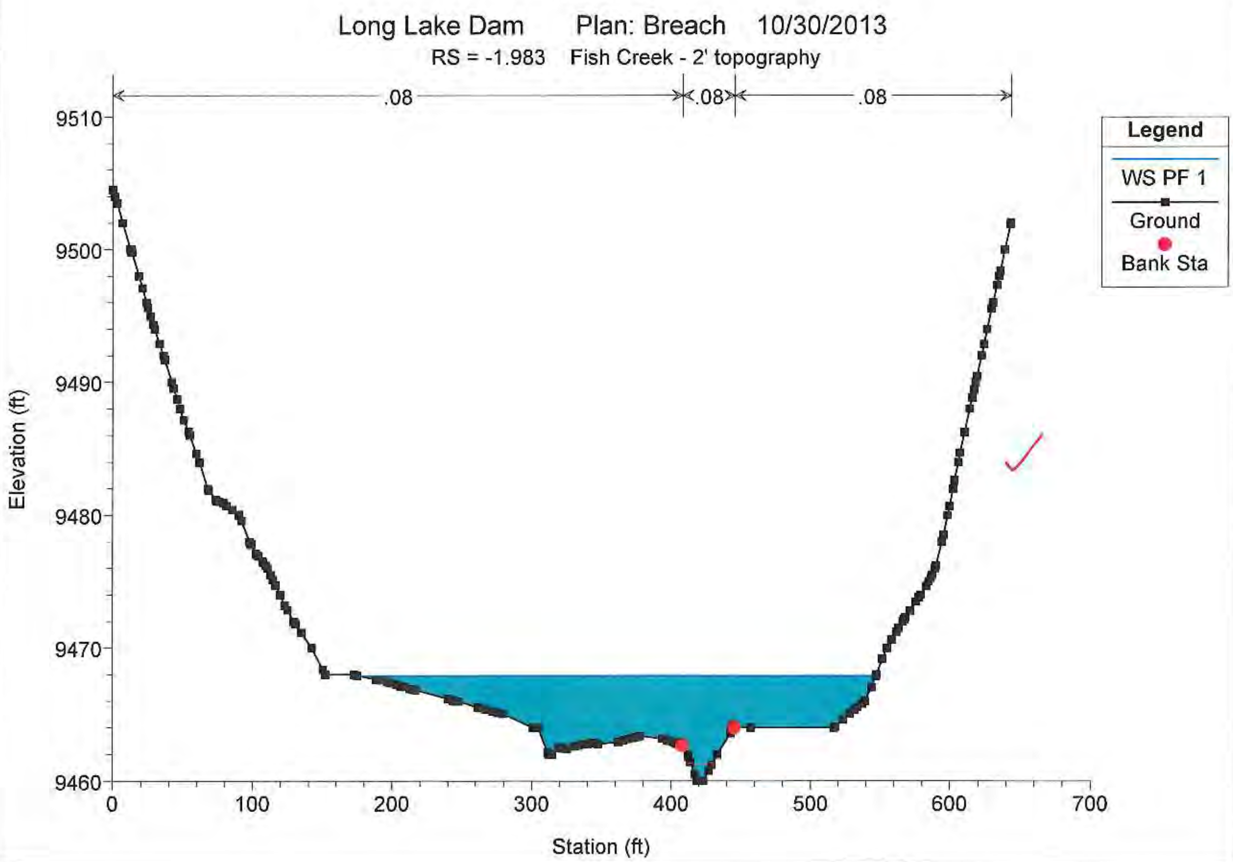
✓TEO 11/4/13 6/33
GGS 11/11/13



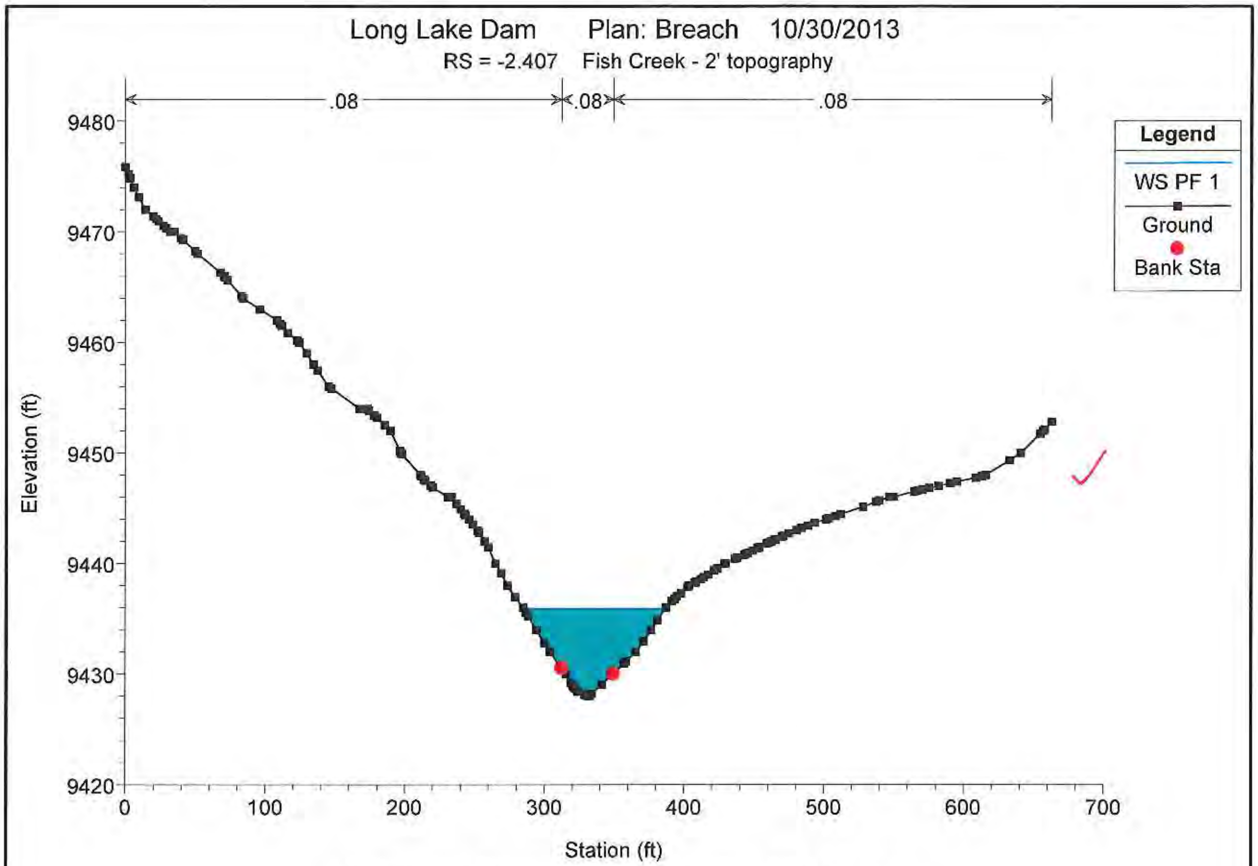


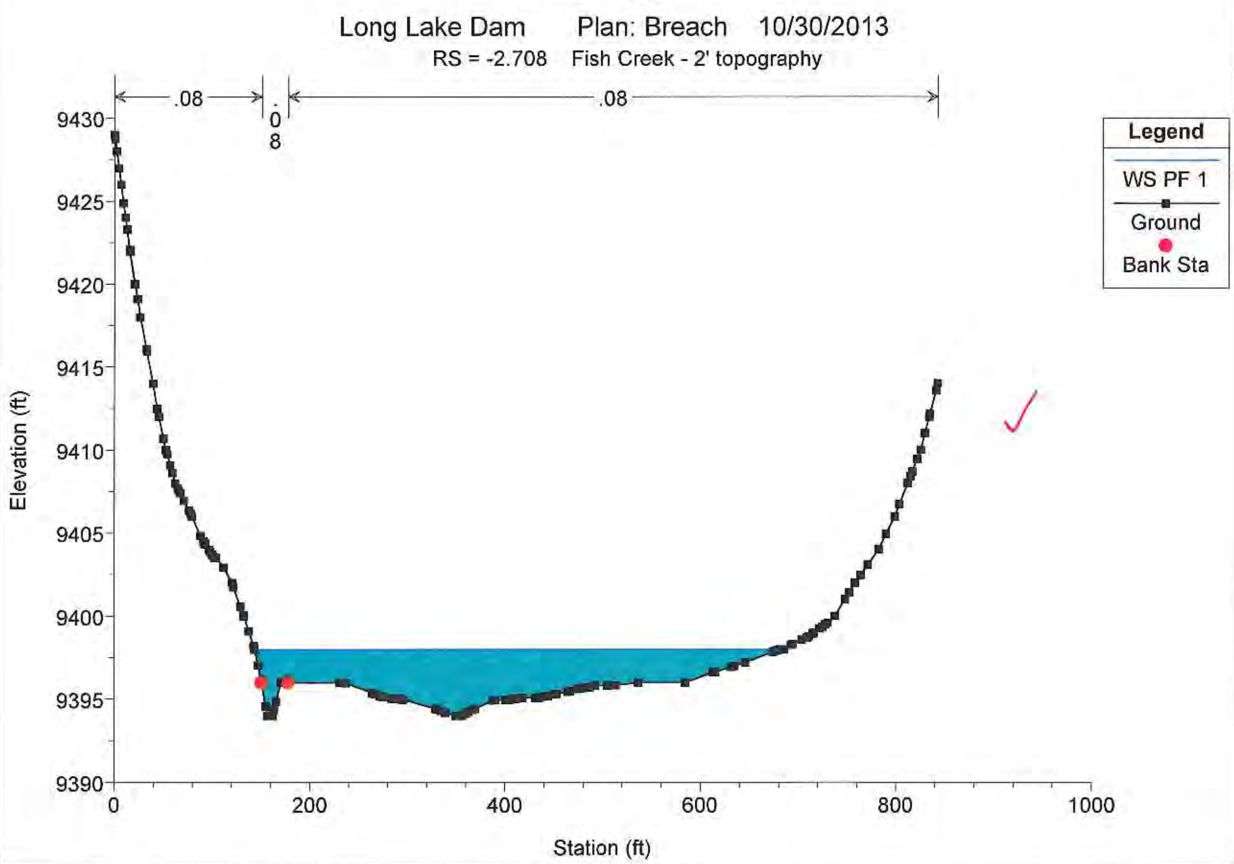
✓ TEO 11/4/13 7/33
GGS 11/11/13



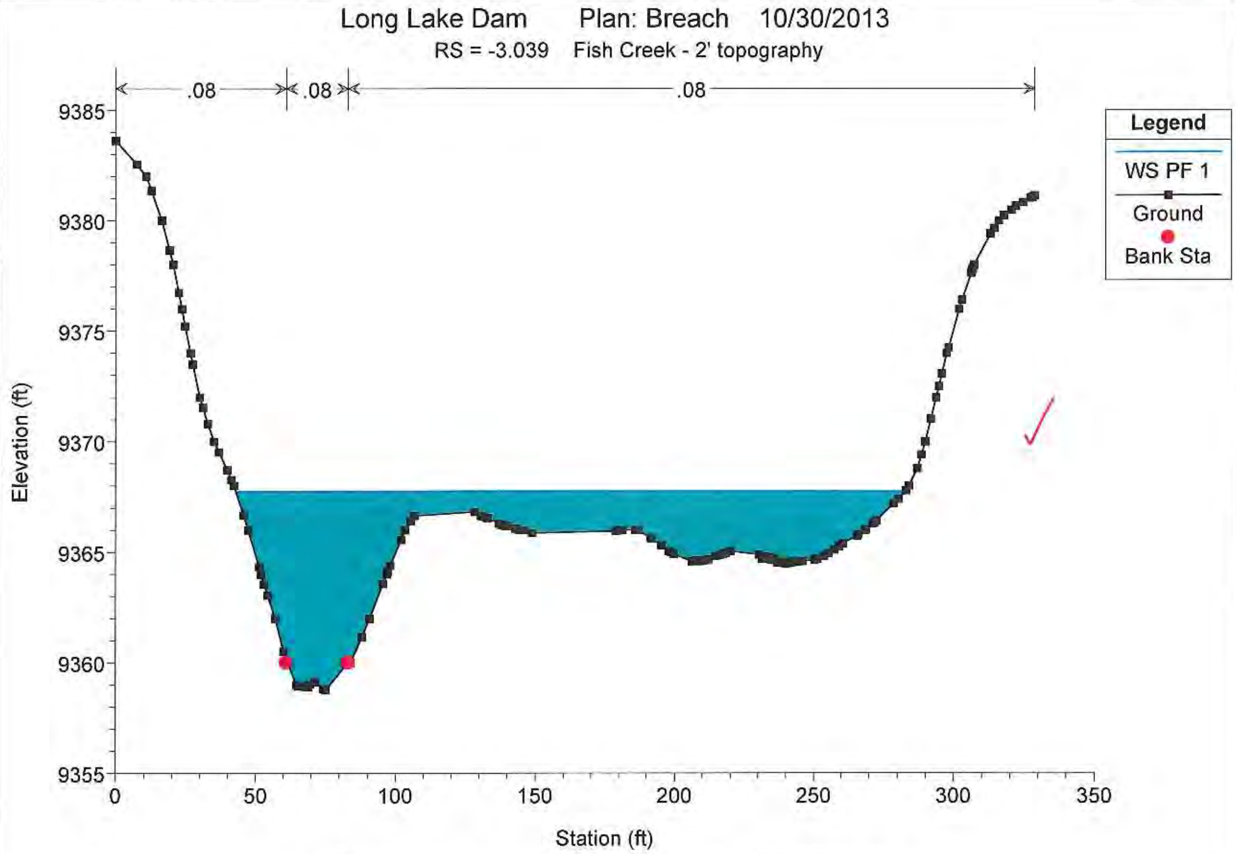


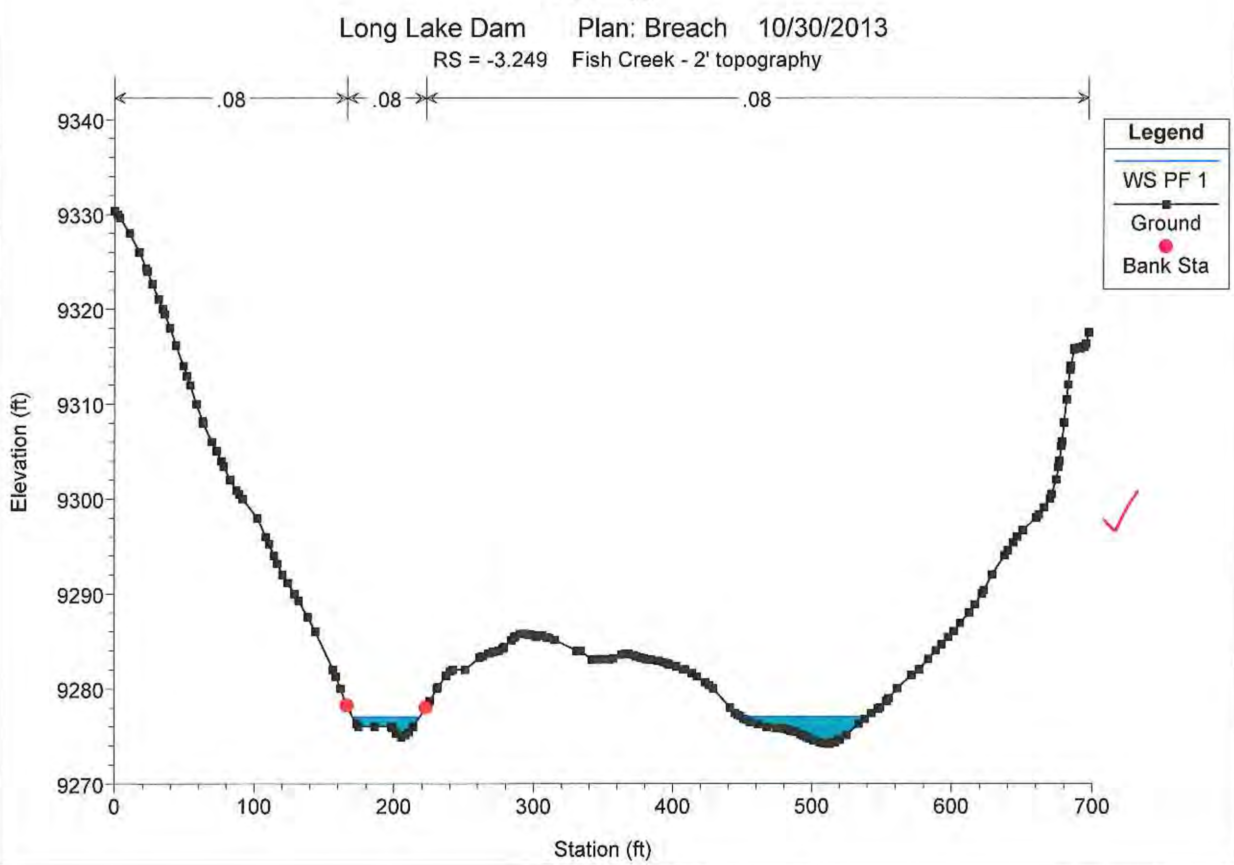
√TEO 11/4/13 8/33
GGS 11/11/13

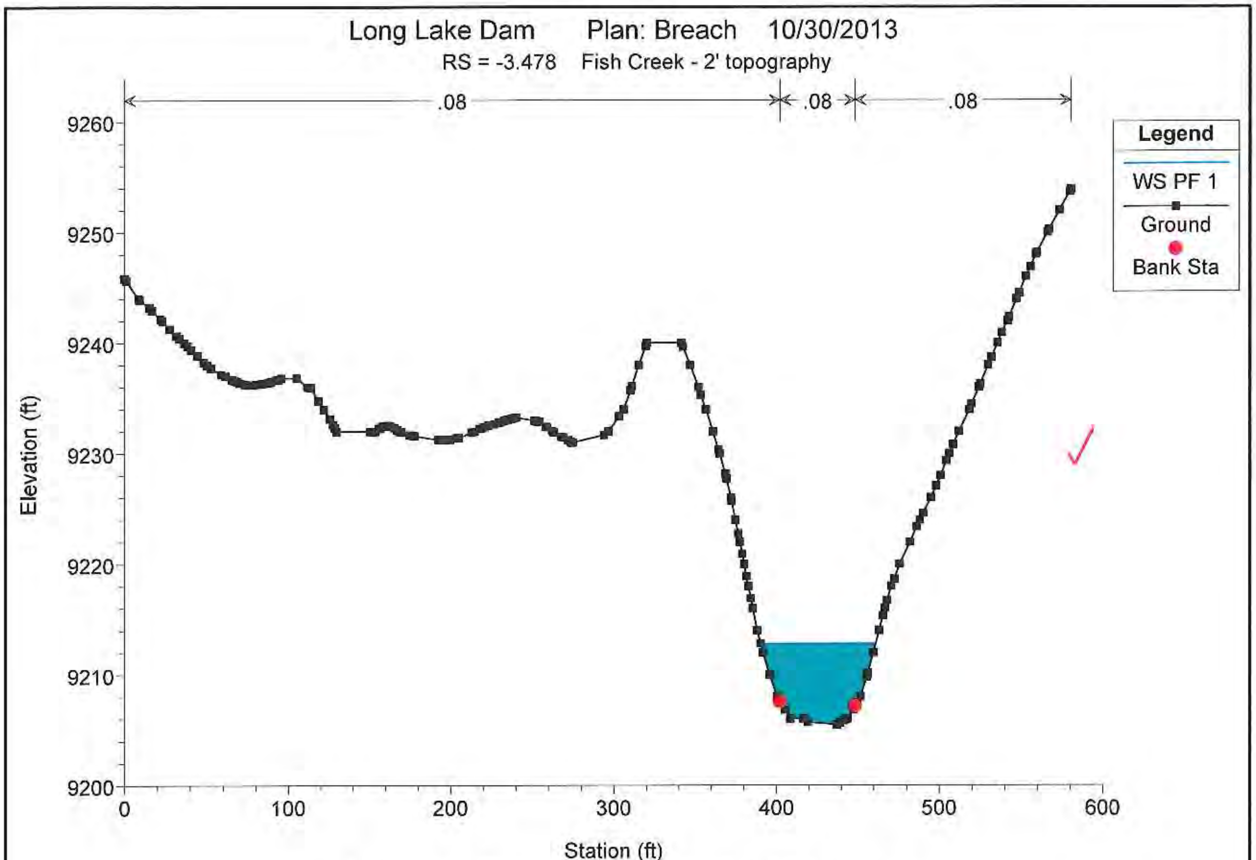


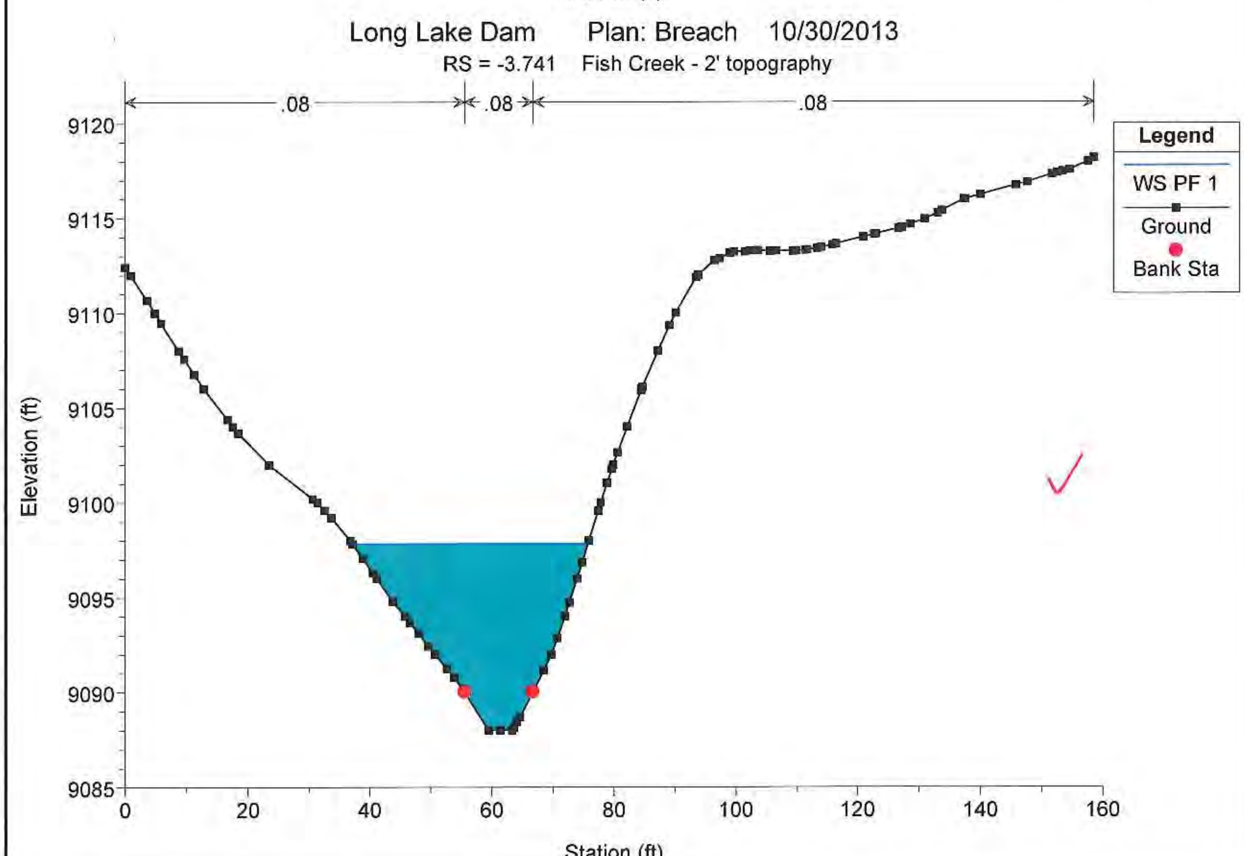


✓ TEO 11/4/13
GGS 11/11/13

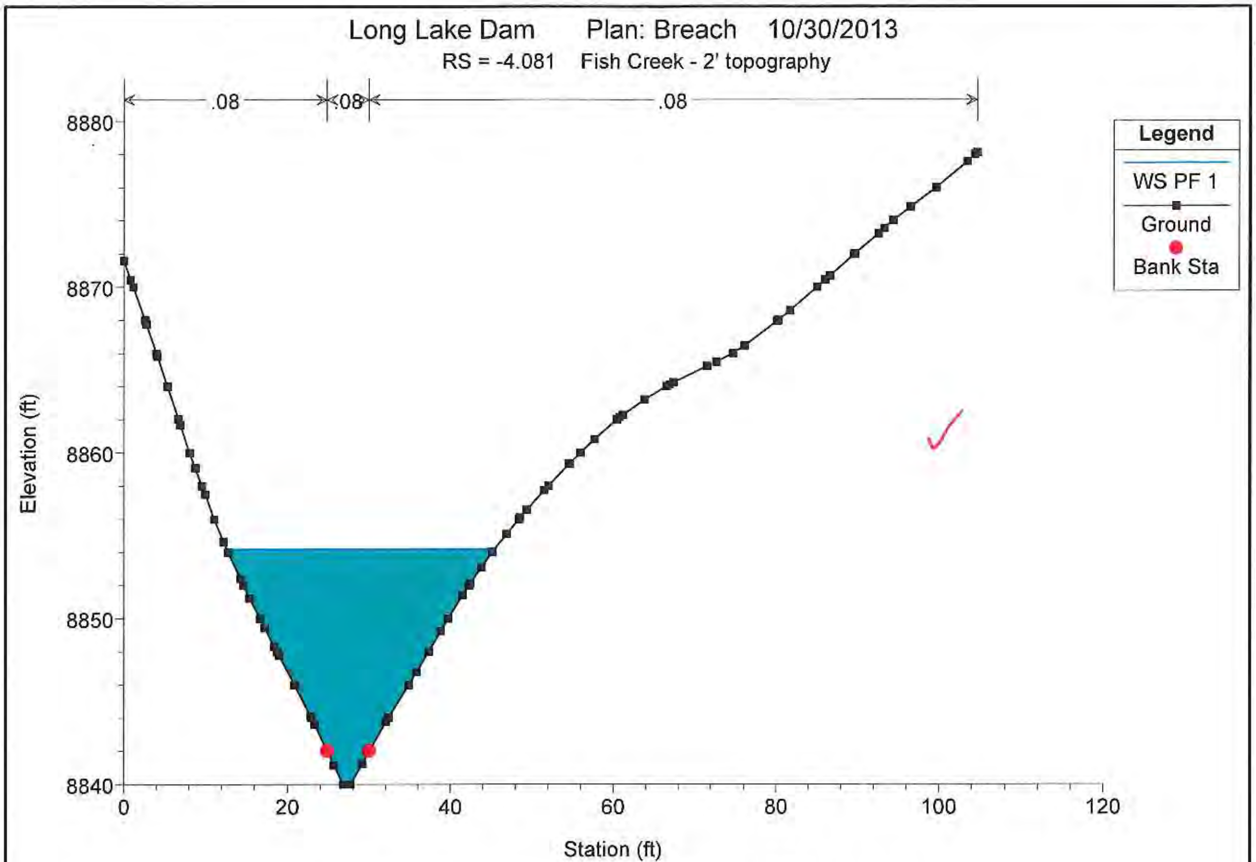


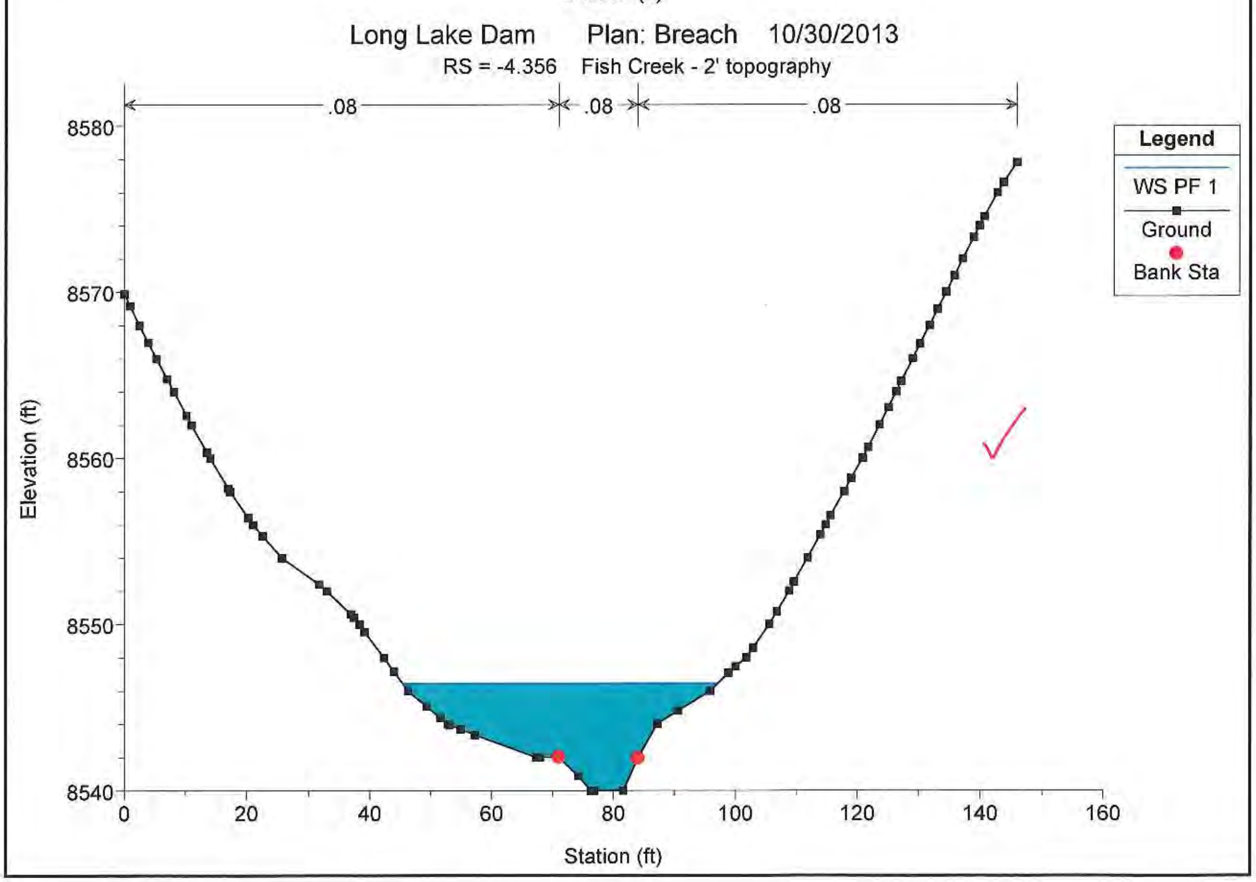



Long Lake Dam Plan: Breach 10/30/2013
RS = -3.478 Fish Creek - 2' topography
.08
.08
.08
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
9260
9250
9240
9230
9220
9210
9200
0
100
200
300
400
500
600
Station (ft)
✓

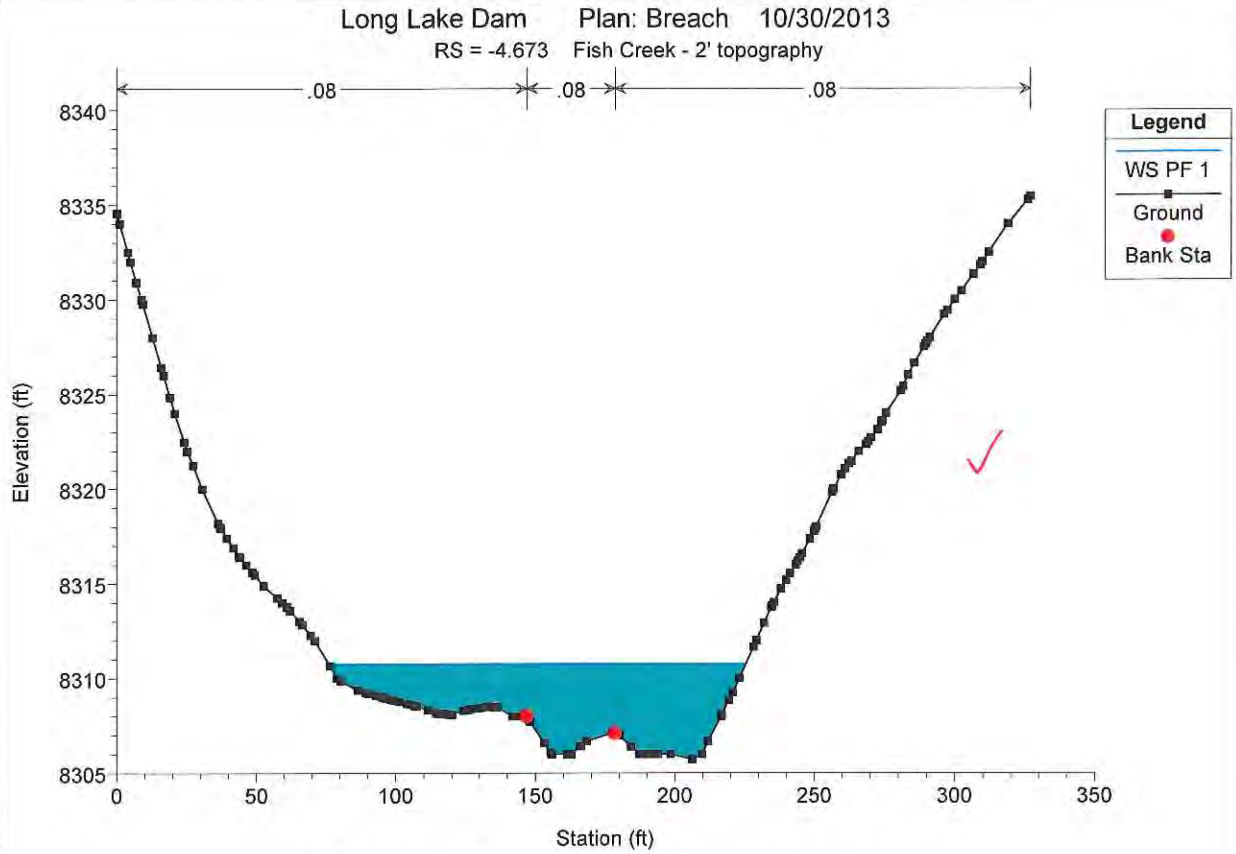

Long Lake Dam Plan: Breach 10/30/2013
RS = -3.741 Fish Creek - 2' topography
.08
.08
.08
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
9120
9115
9110
9105
9100
9095
9090
9085
0
20
40
60
80
100
120
140
160
Station (ft)
✓

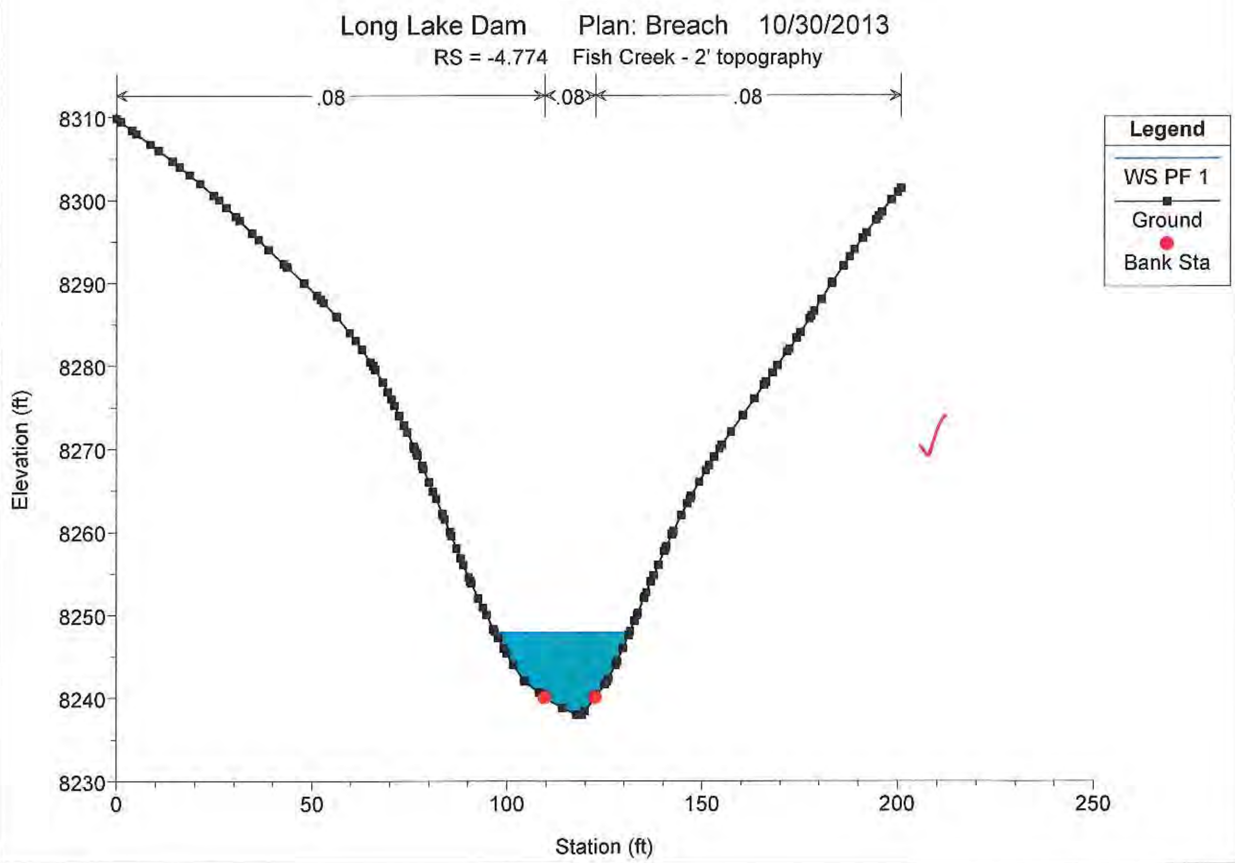
√ TEO 11/4/13 11/33
GGS 11/11/13



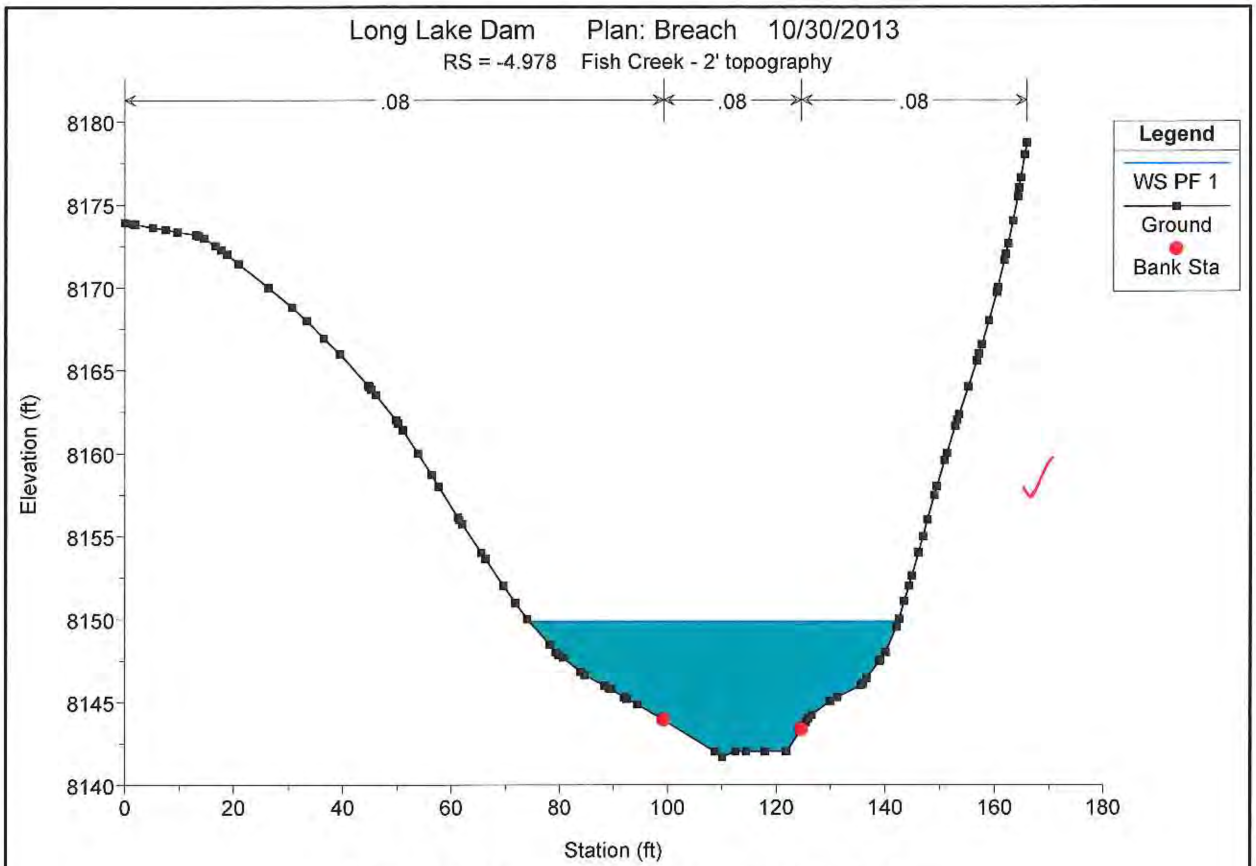


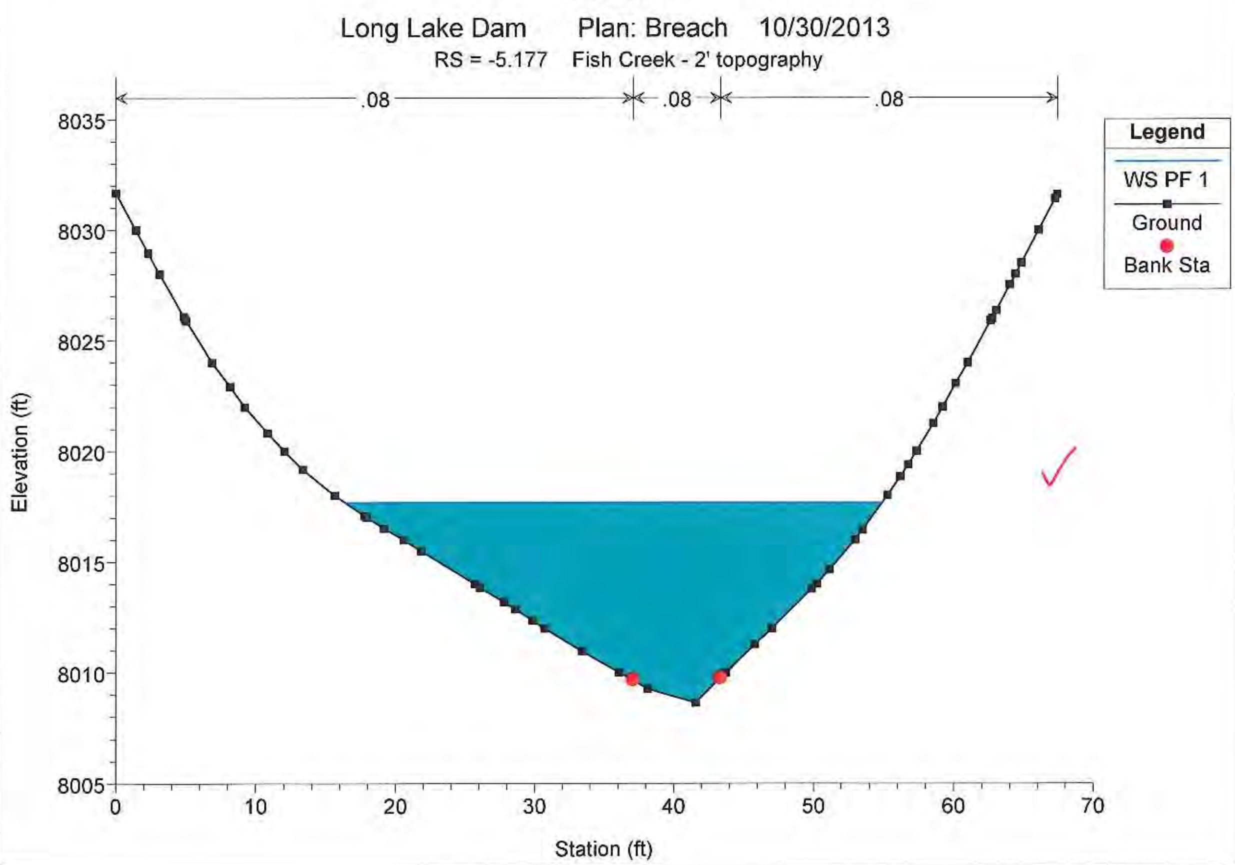
√TEO 11/4/13 12/33
GGOS 11/11/13



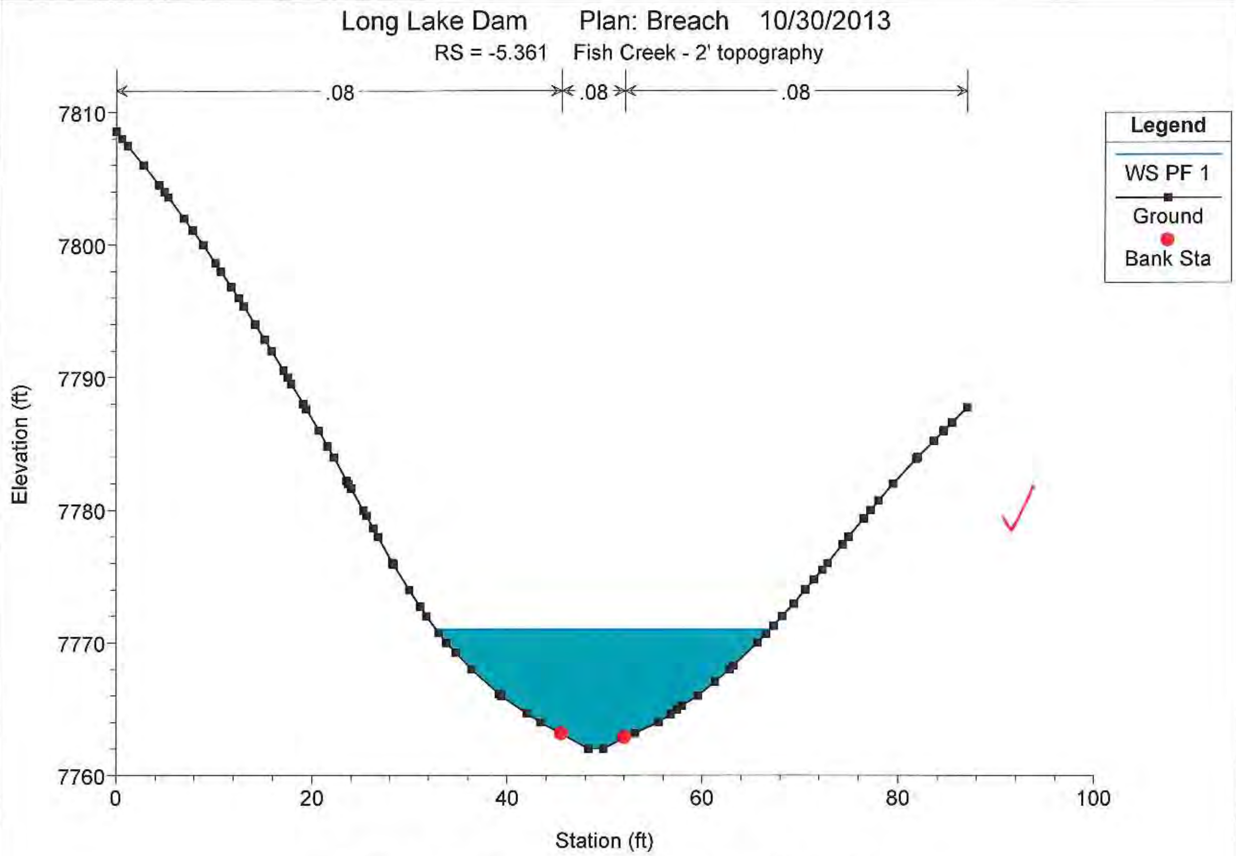


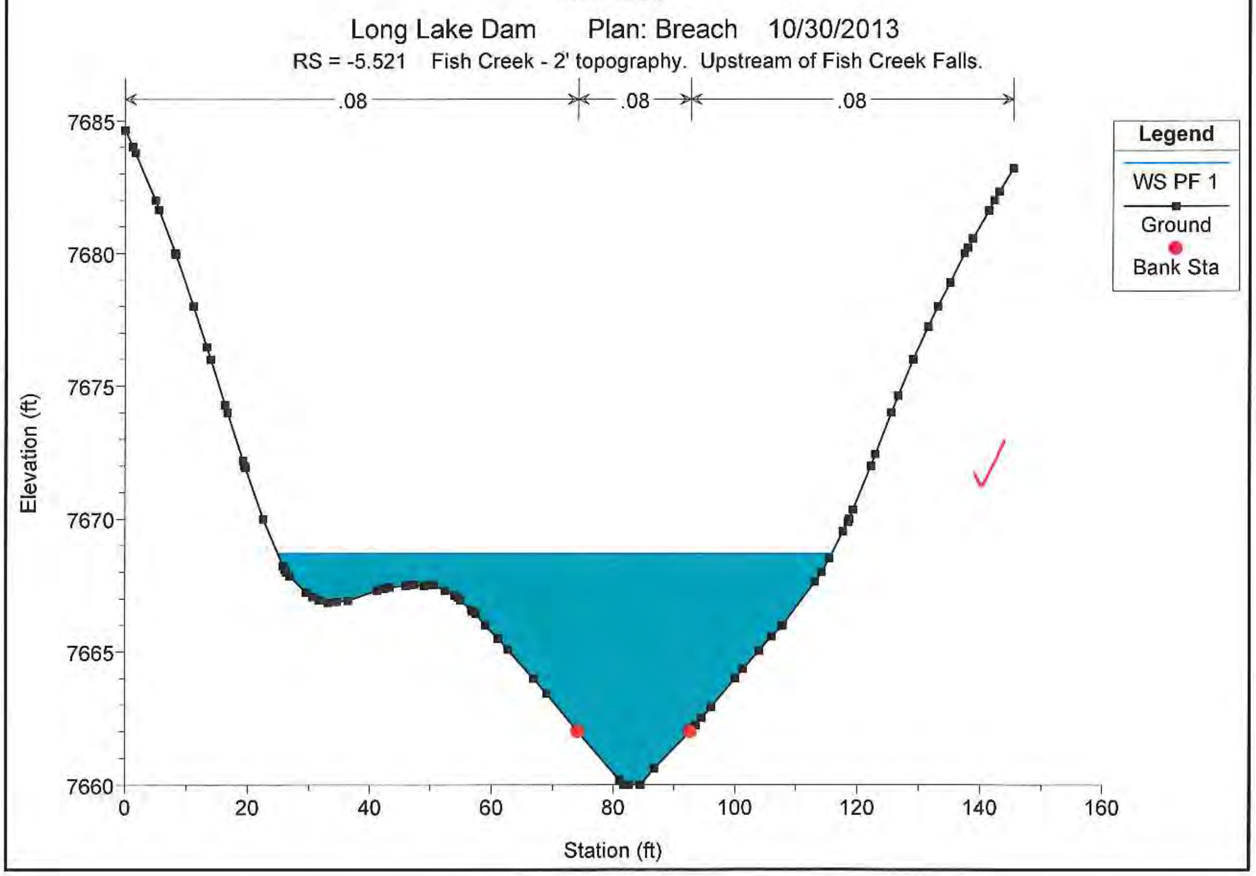
✓ TEO 11/4/13 13/33
GGOS 11/11/13



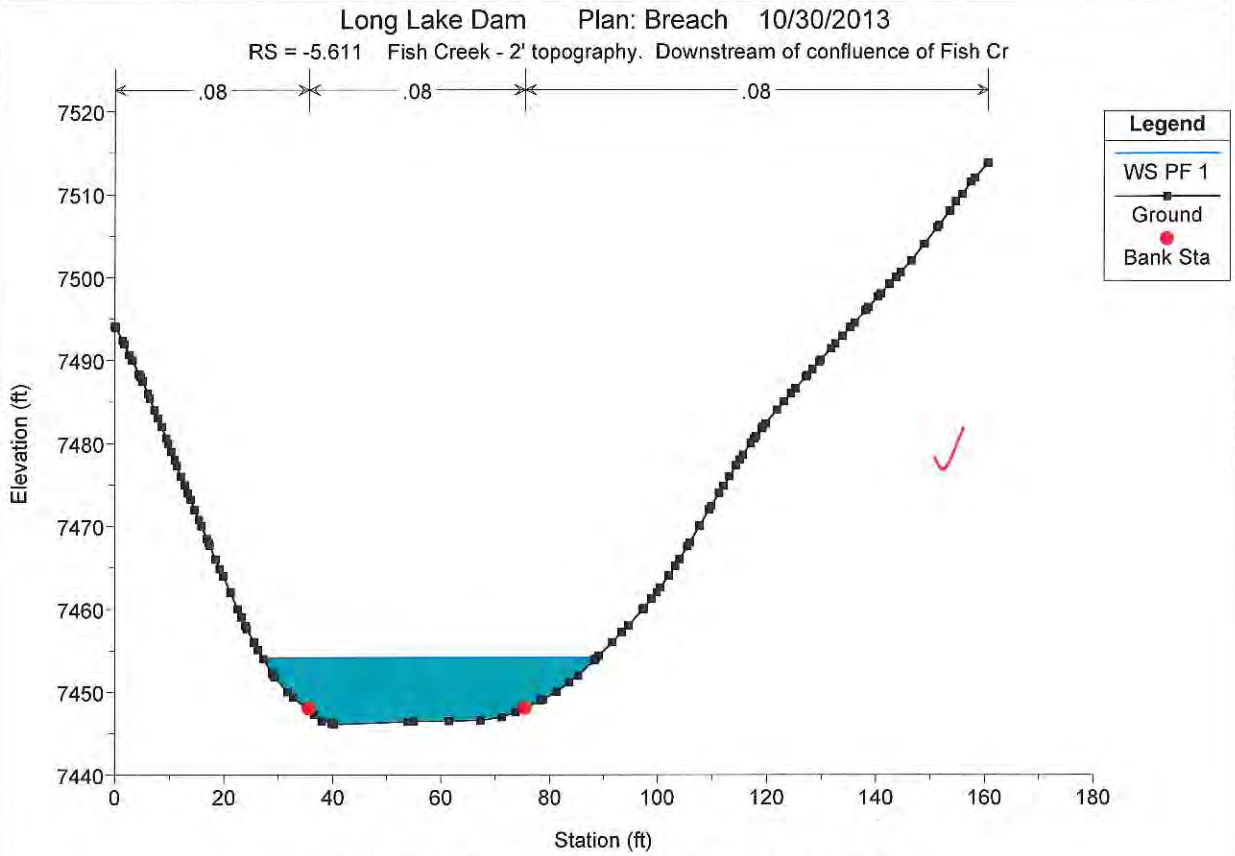


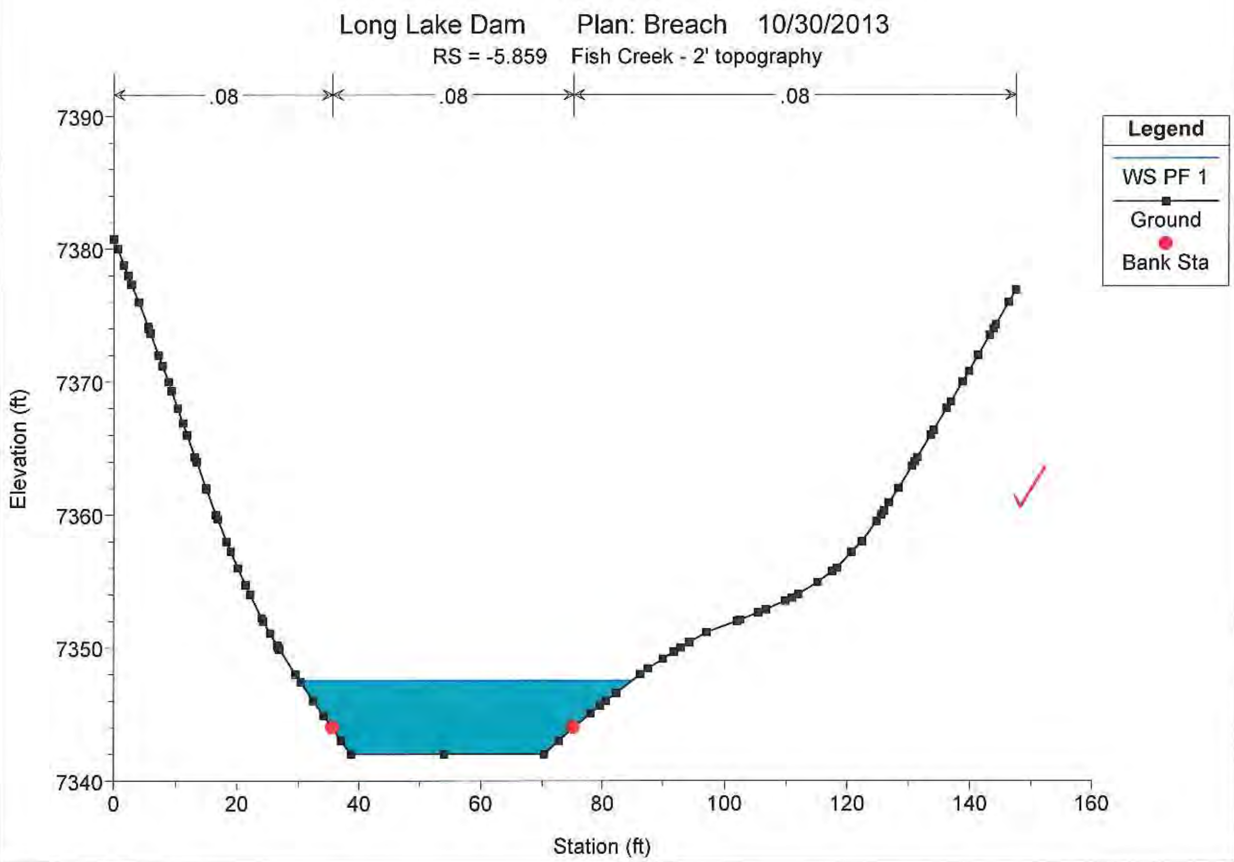
✓TEO 11/4/13 14/33
GGS 11/11/13



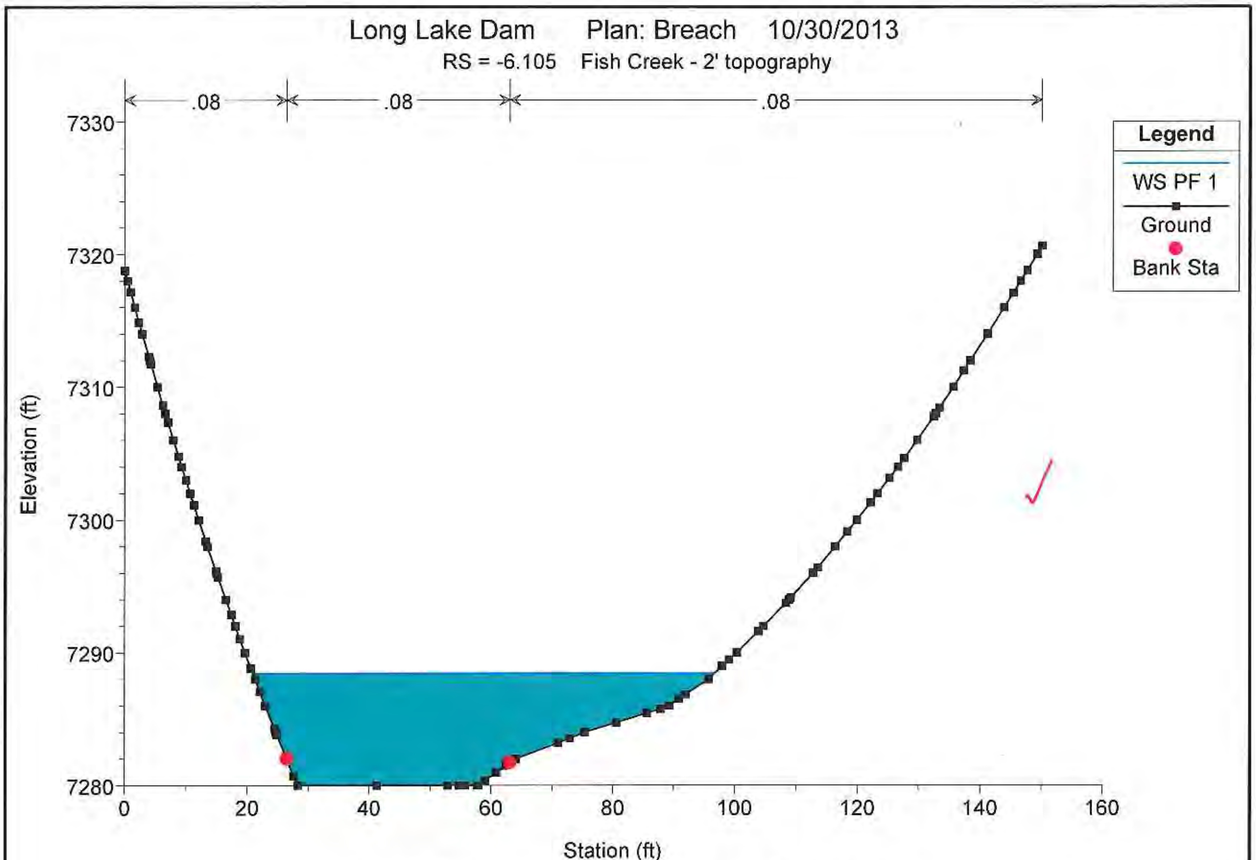


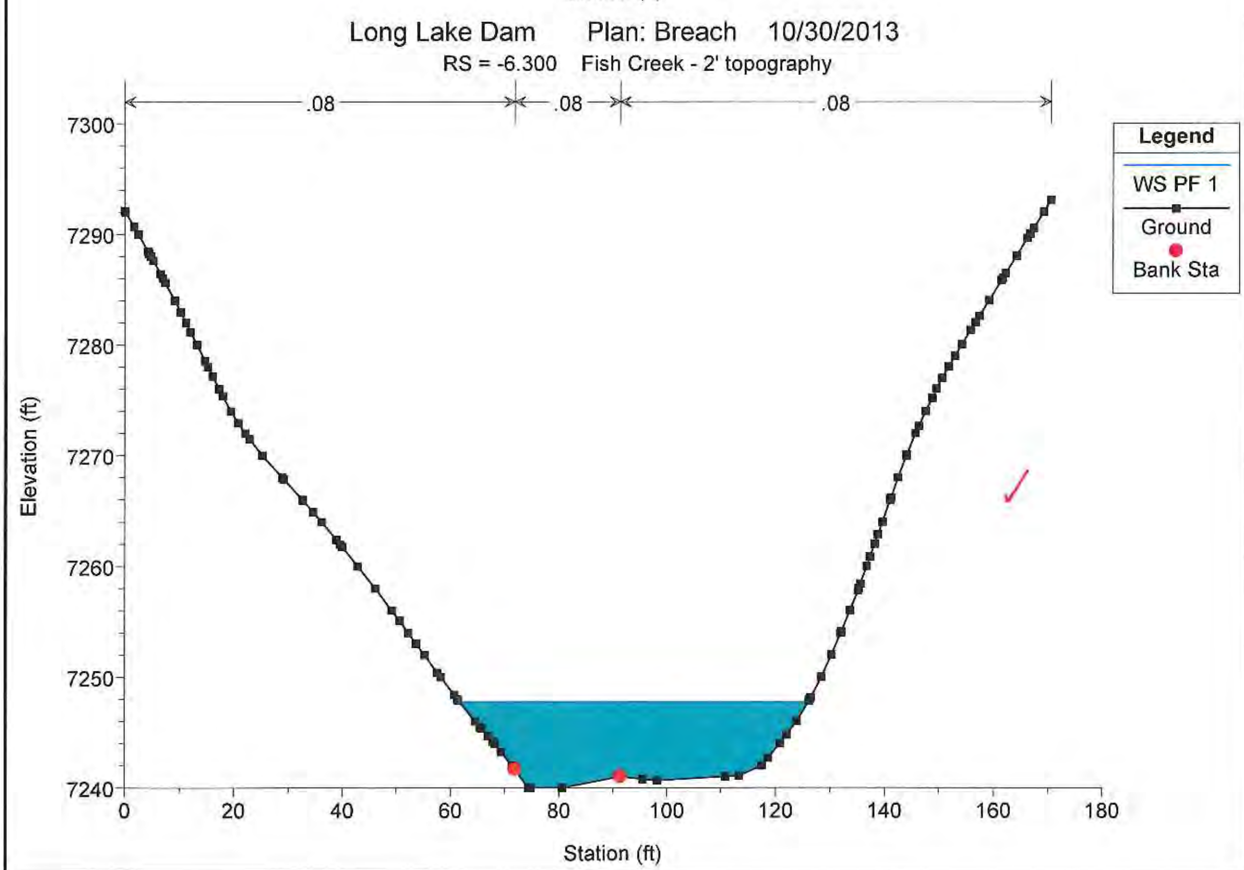
√TEO 11/4/13
GGS 11/11/13



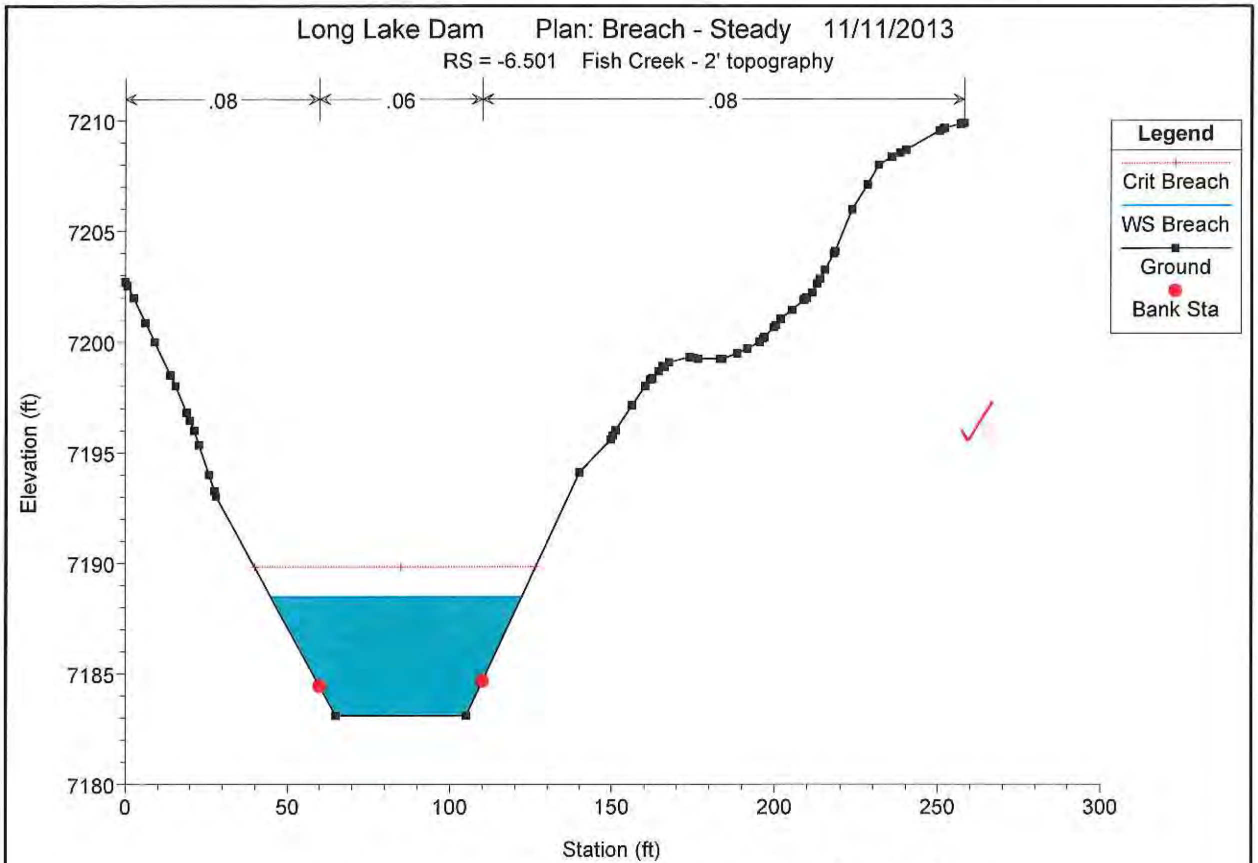


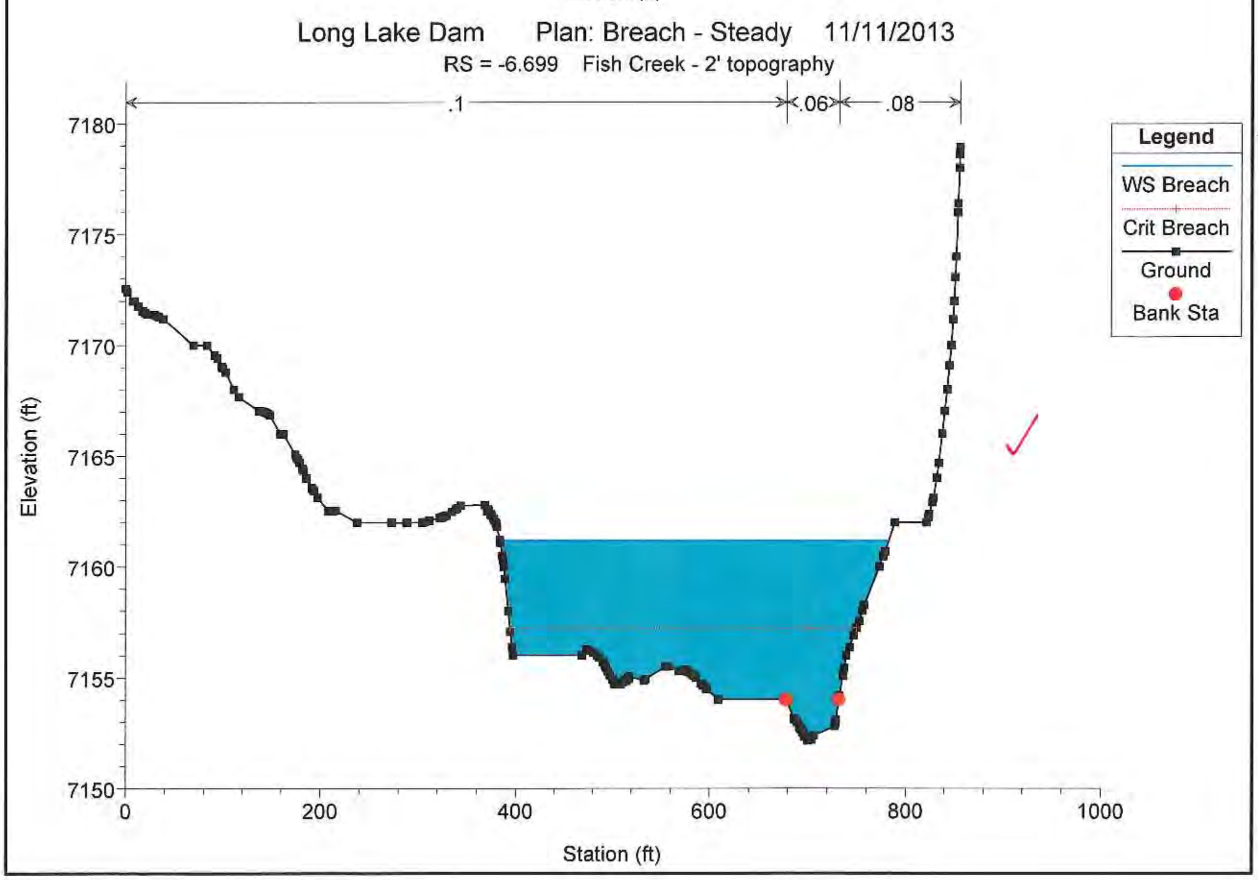
√TEO 11/4/13
GGS 11/11/13



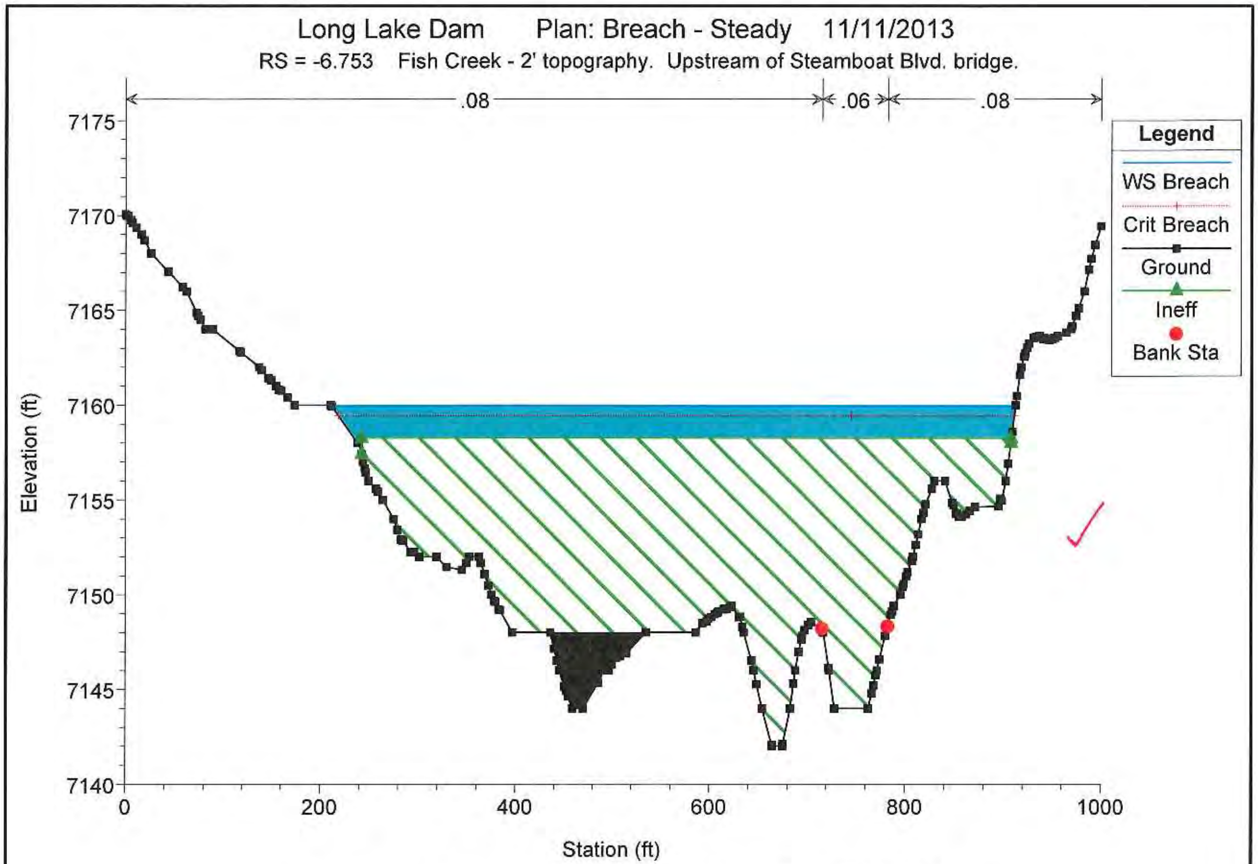


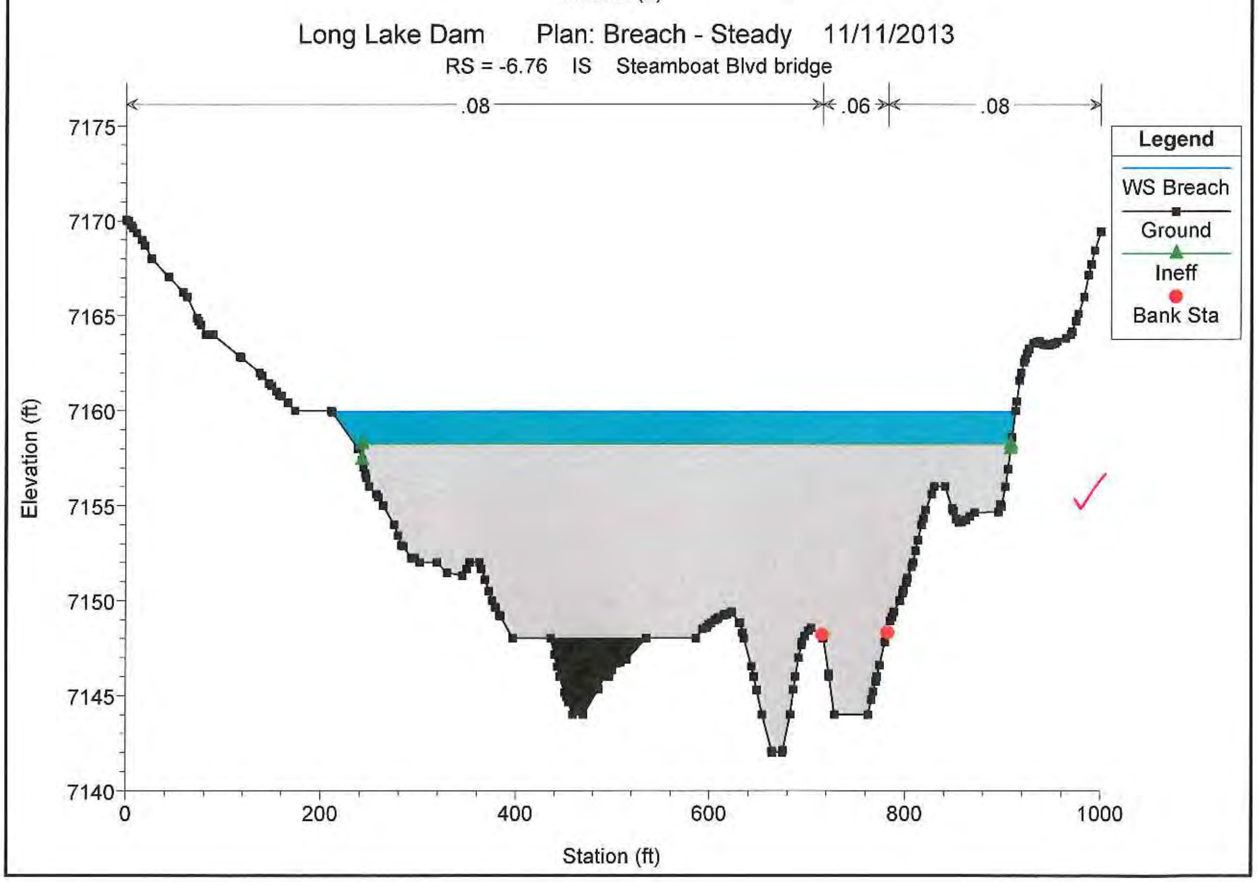
✓TEO 11/11/13
GGS 11/11/13



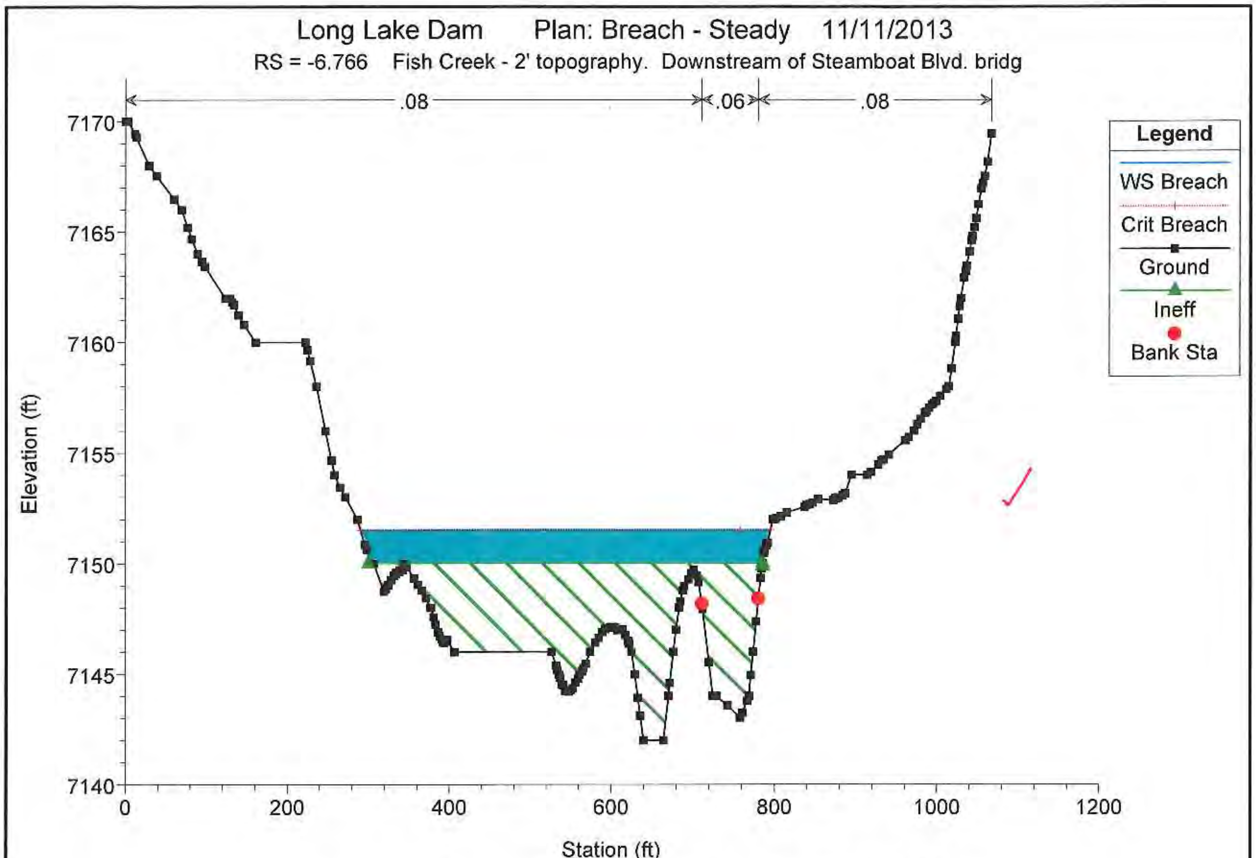


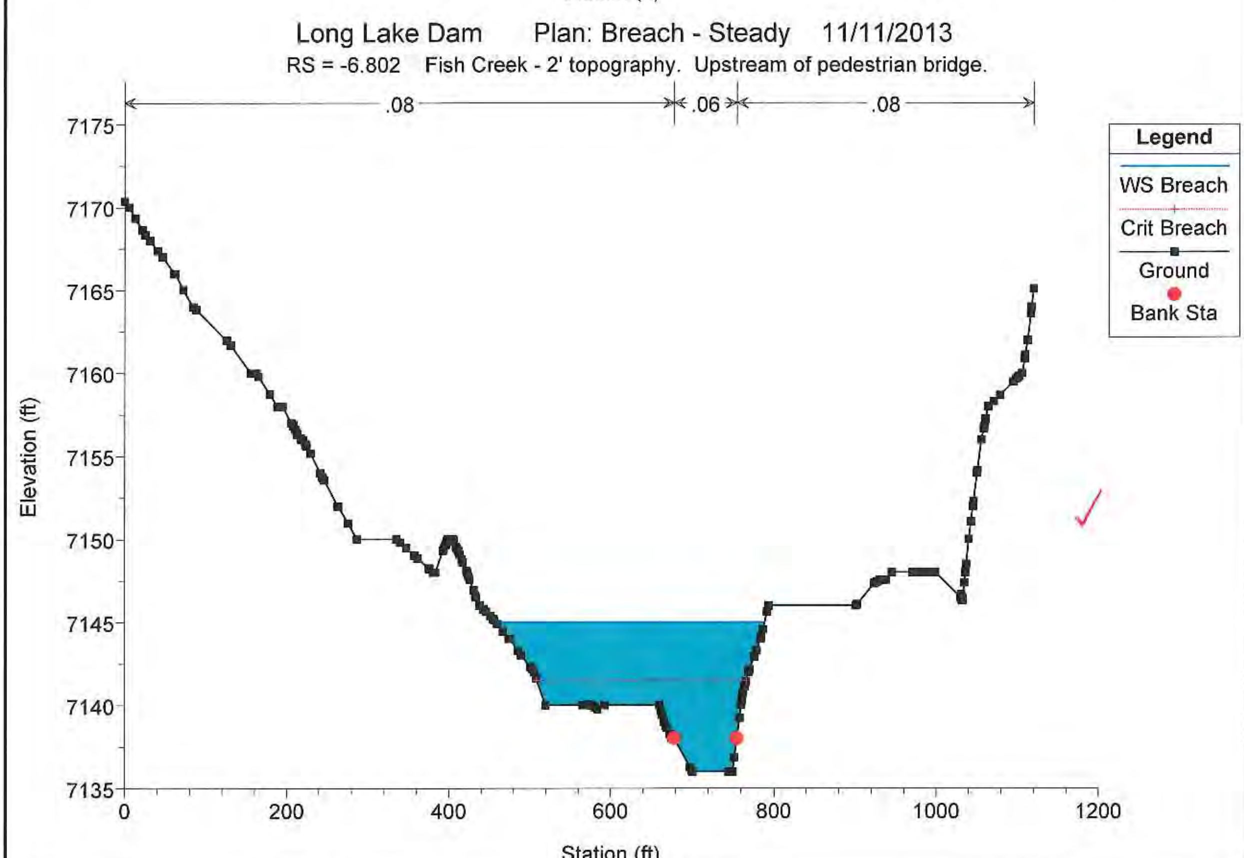
√TEO 11/11/13 18/33
GGS 11/11/13





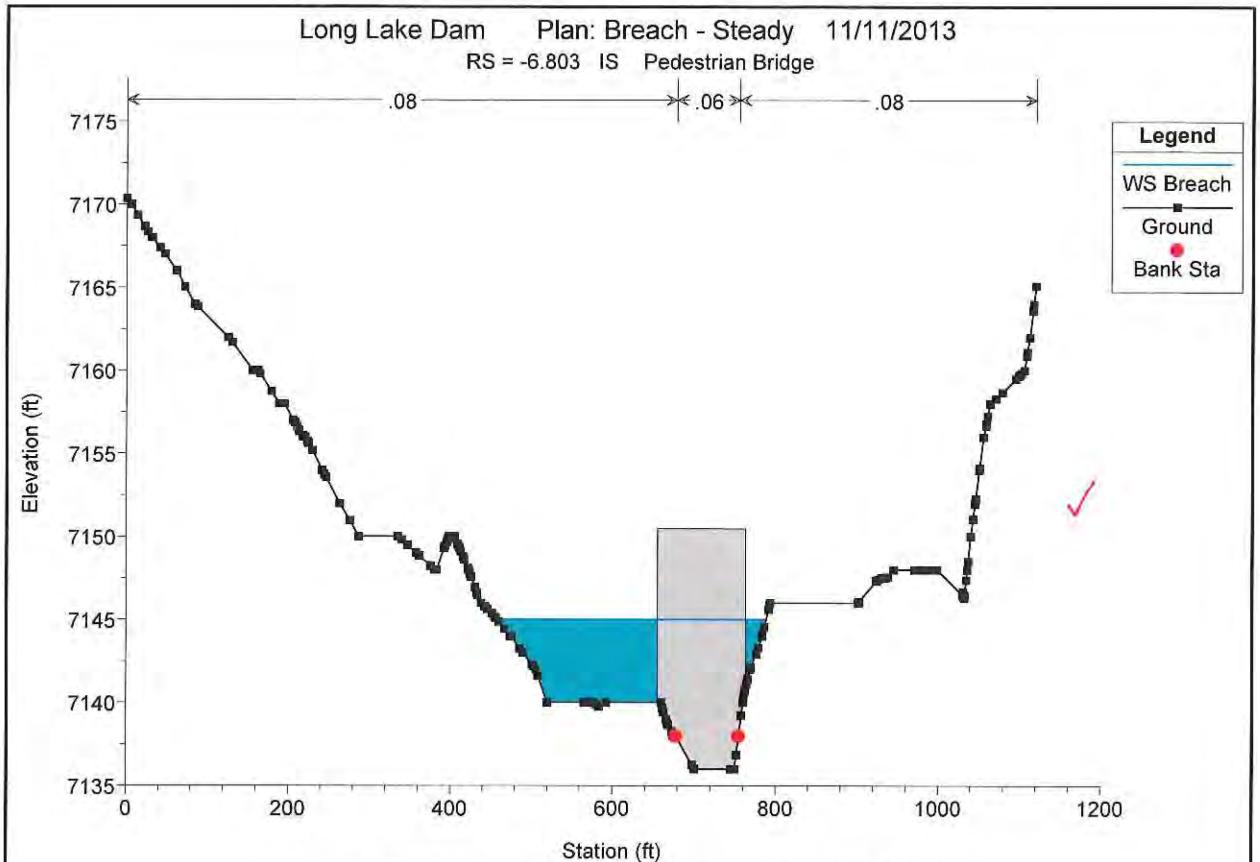
✓ TEO 11/11/13
GGS 11/11/13

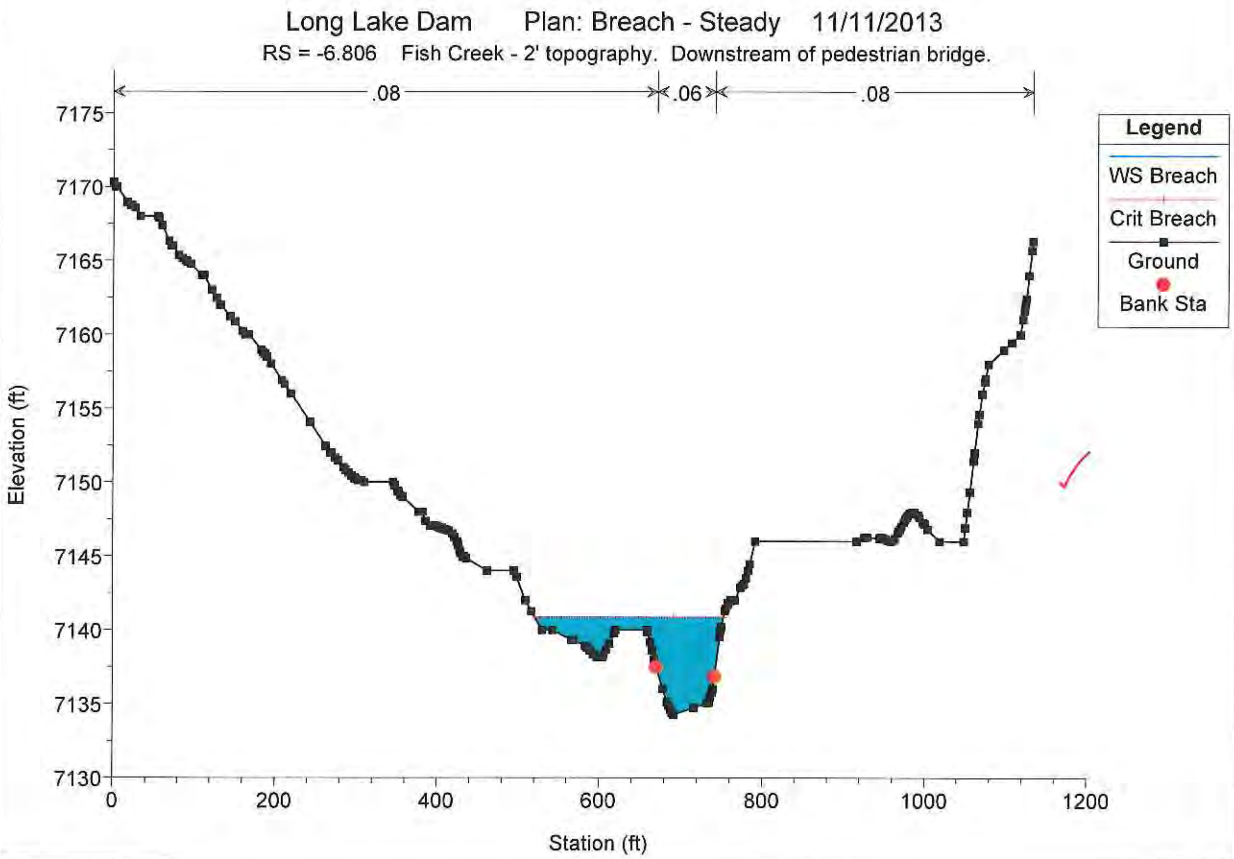




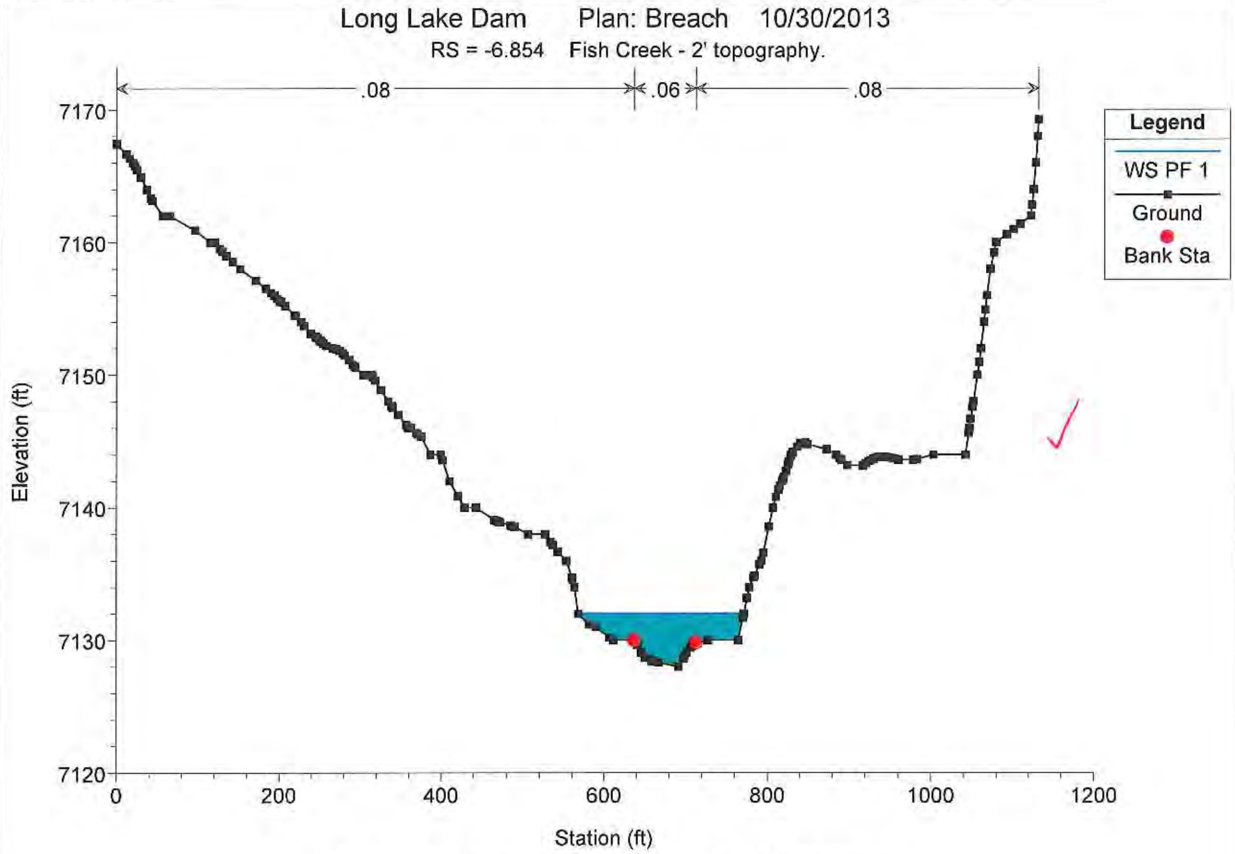
20133

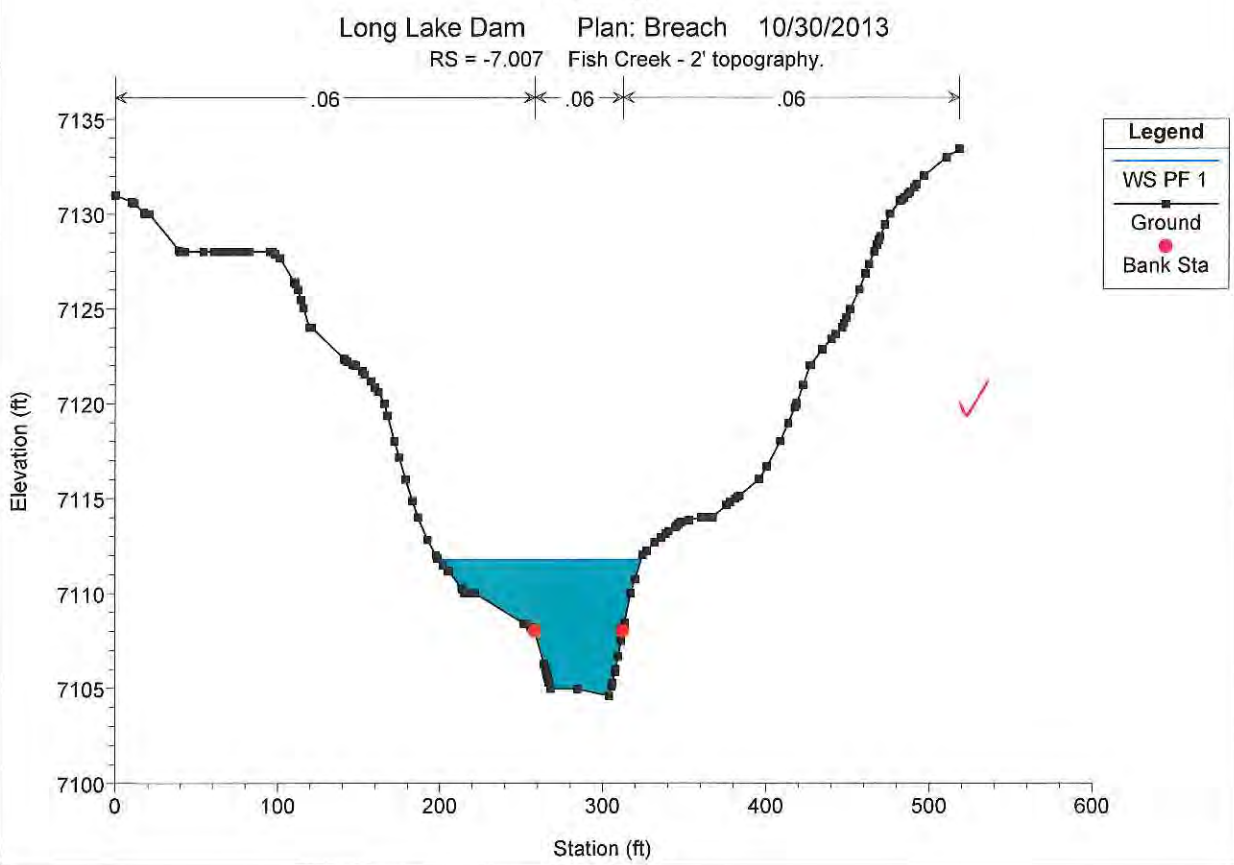
✓ TEO 11/11/13
GGS 11/11/13

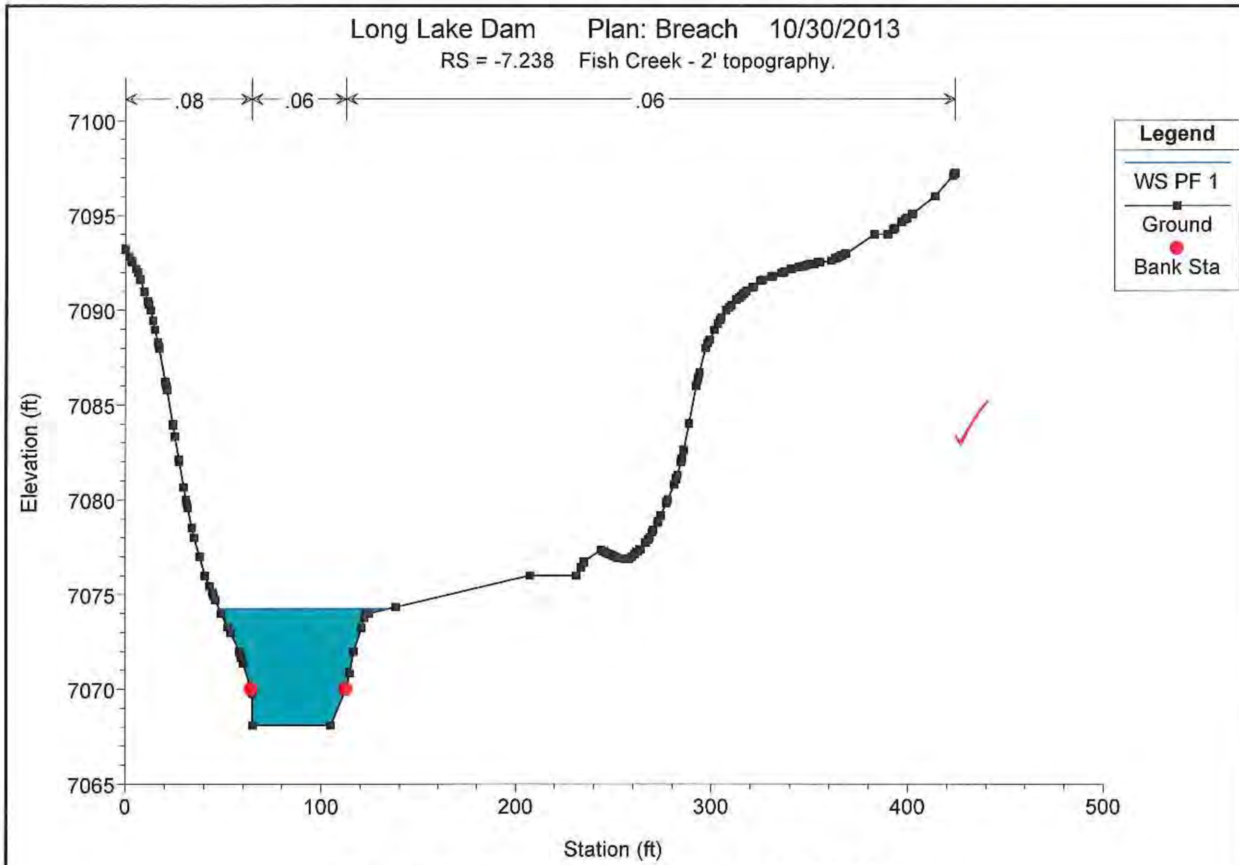


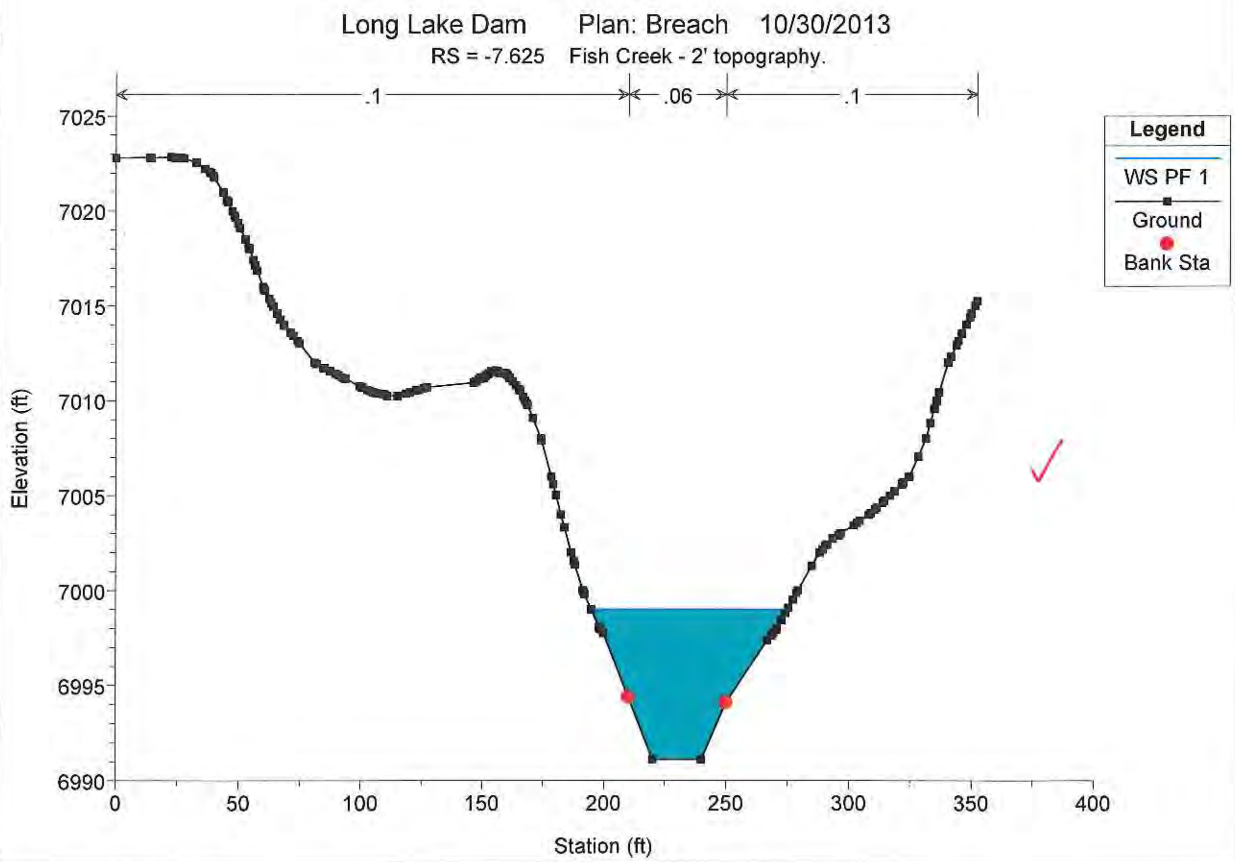


√TEO 11/4/13
GGS 11/11/13



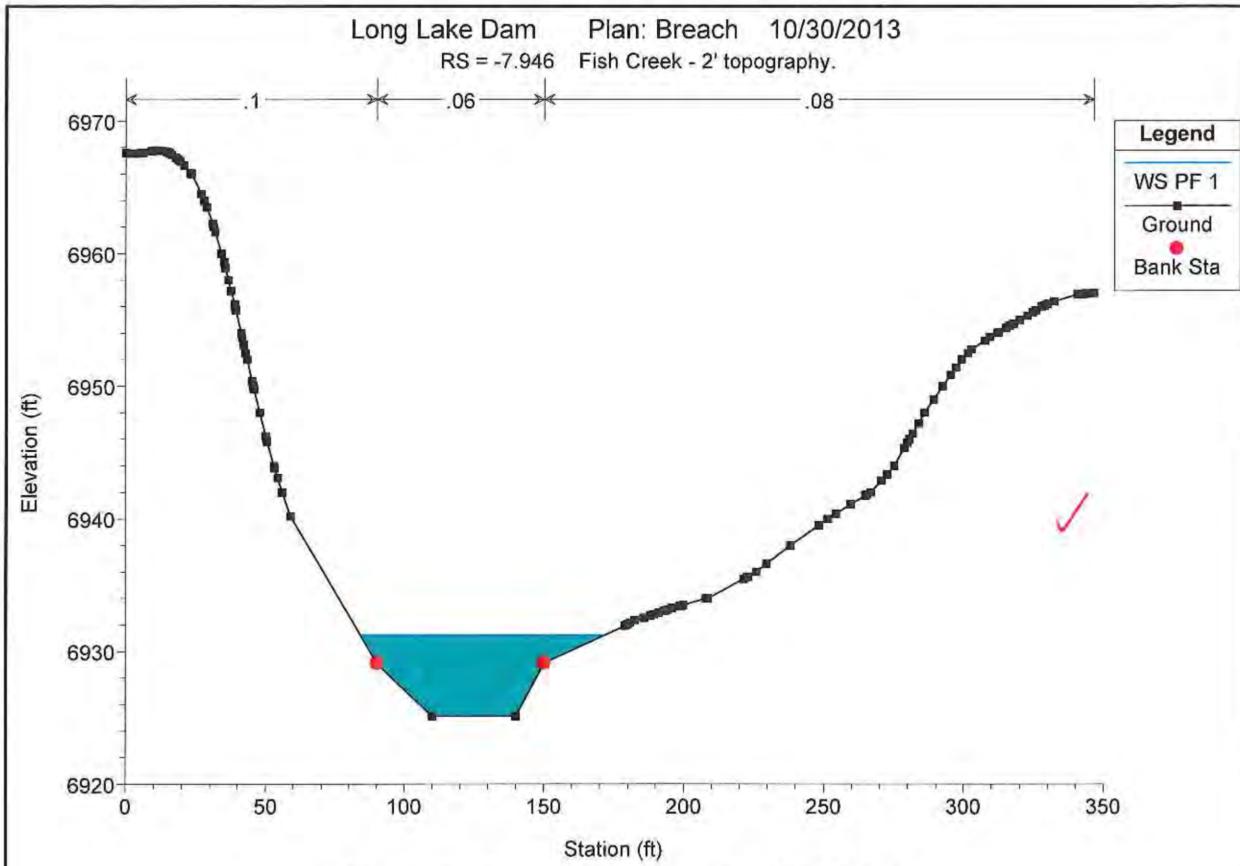


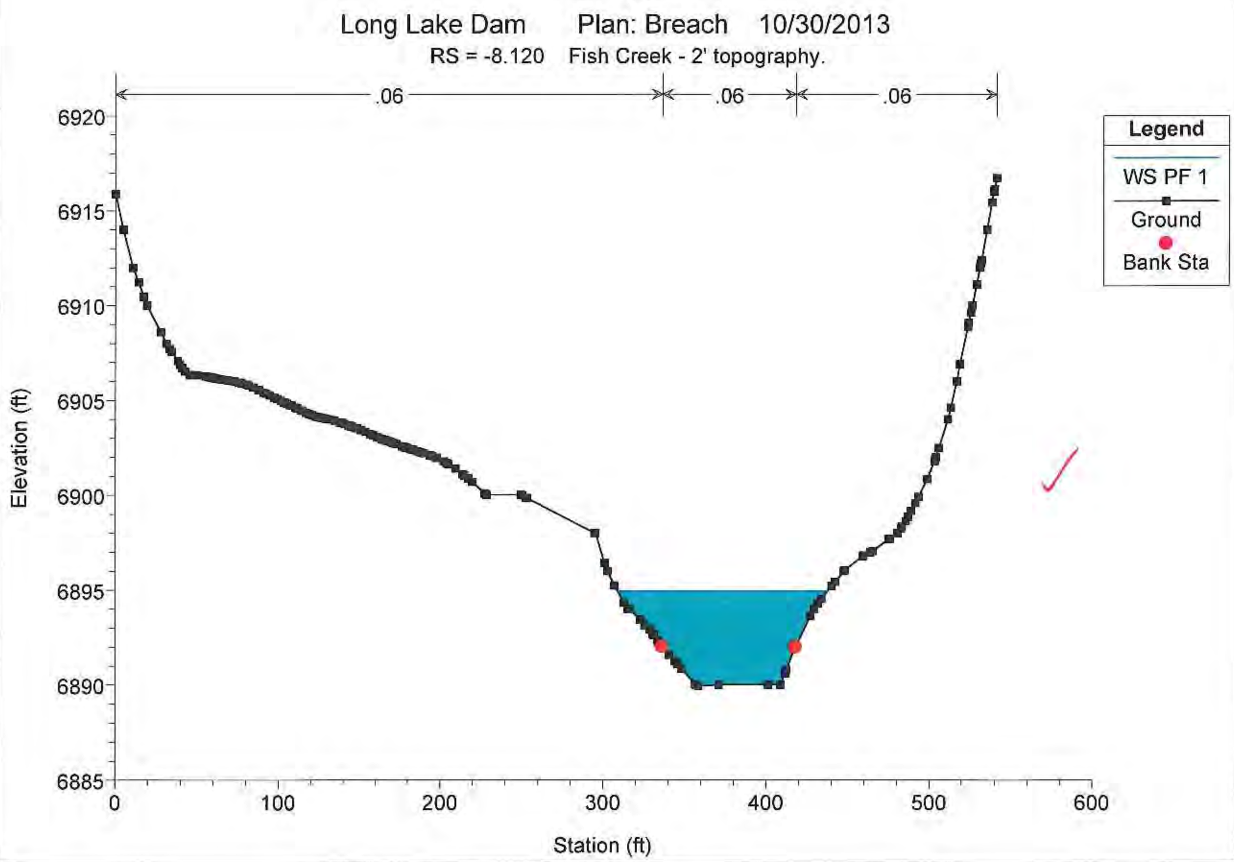

Long Lake Dam Plan: Breach 10/30/2013
RS = -7.238 Fish Creek - 2' topography.
.08
.06
.06
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)
7065
7070
7075
7080
7085
7090
7095
7100
0
100
200
300
400
500


Long Lake Dam Plan: Breach 10/30/2013
RS = -7.625 Fish Creek - 2' topography.
.1
.06
.1
Legend
WS PF 1
Ground
Bank Sta
Elevation (ft)
Station (ft)
6990
6995
7000
7005
7010
7015
7020
7025
0
50
100
150
200
250
300
350
400

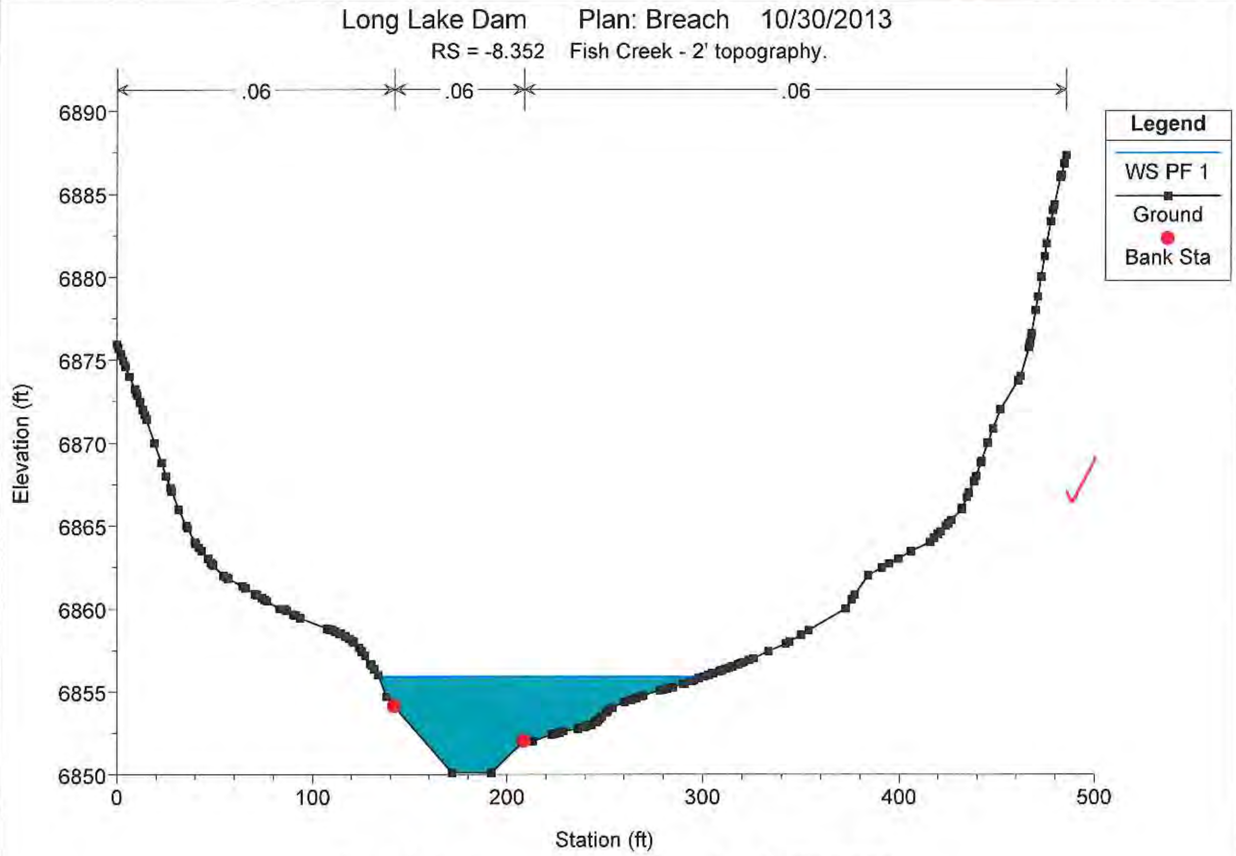
√TEO 11/4/13

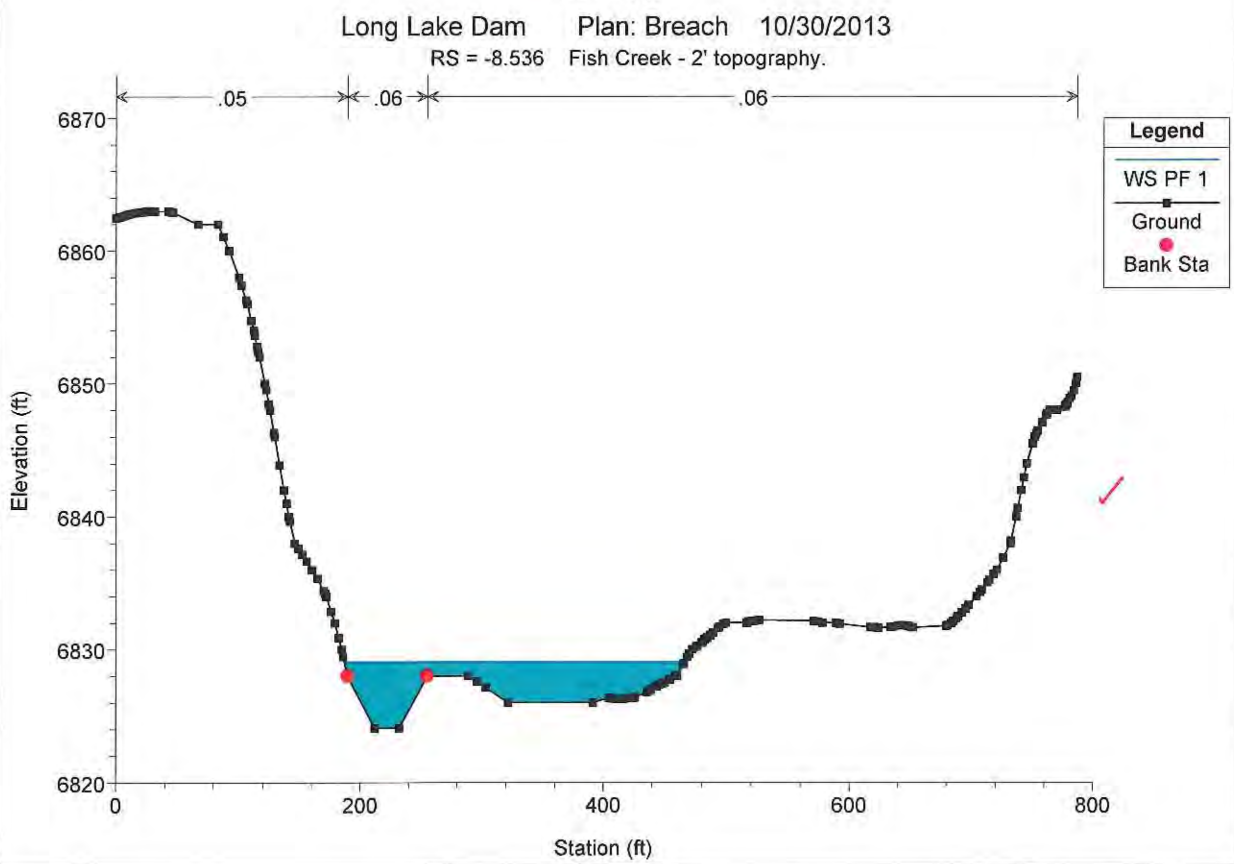
GGS 11/11/13





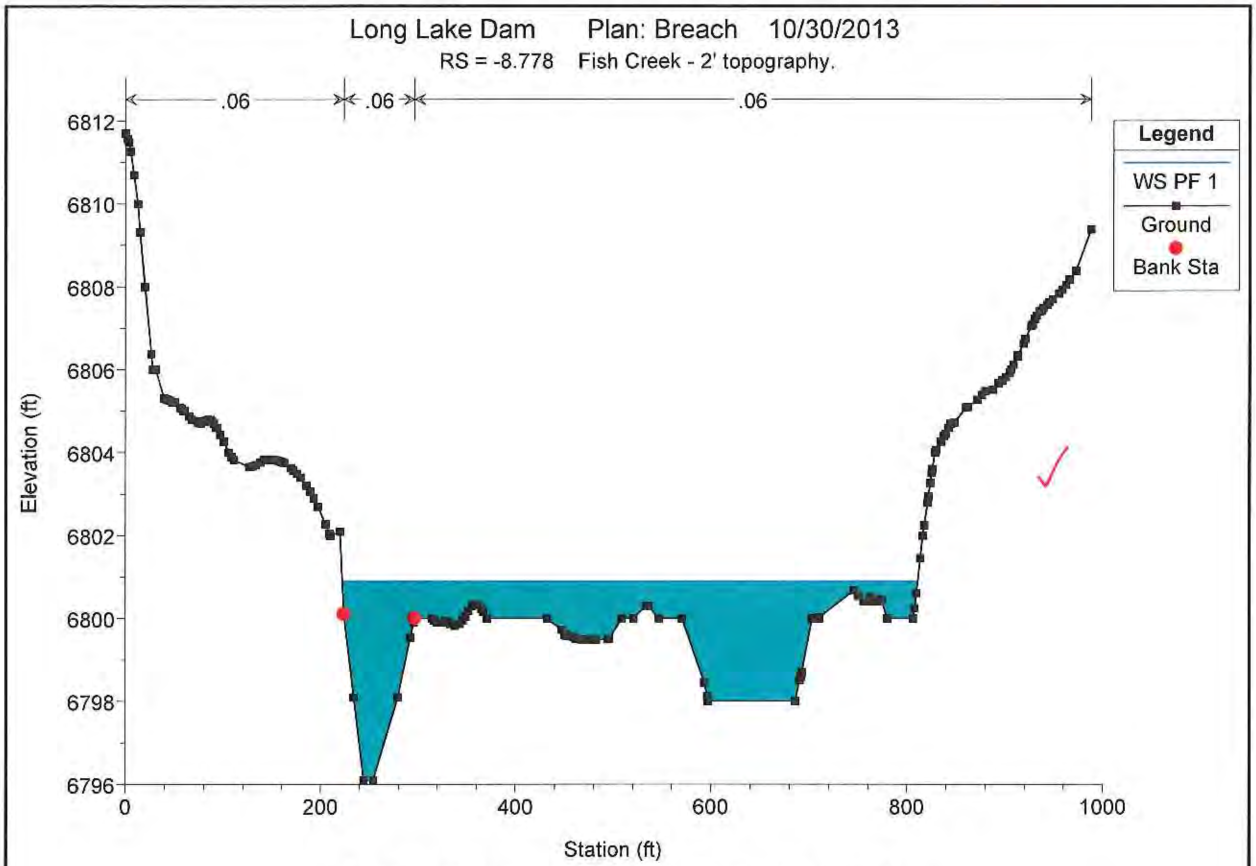
✓TEO 11/4/13
GGS 11/11/13

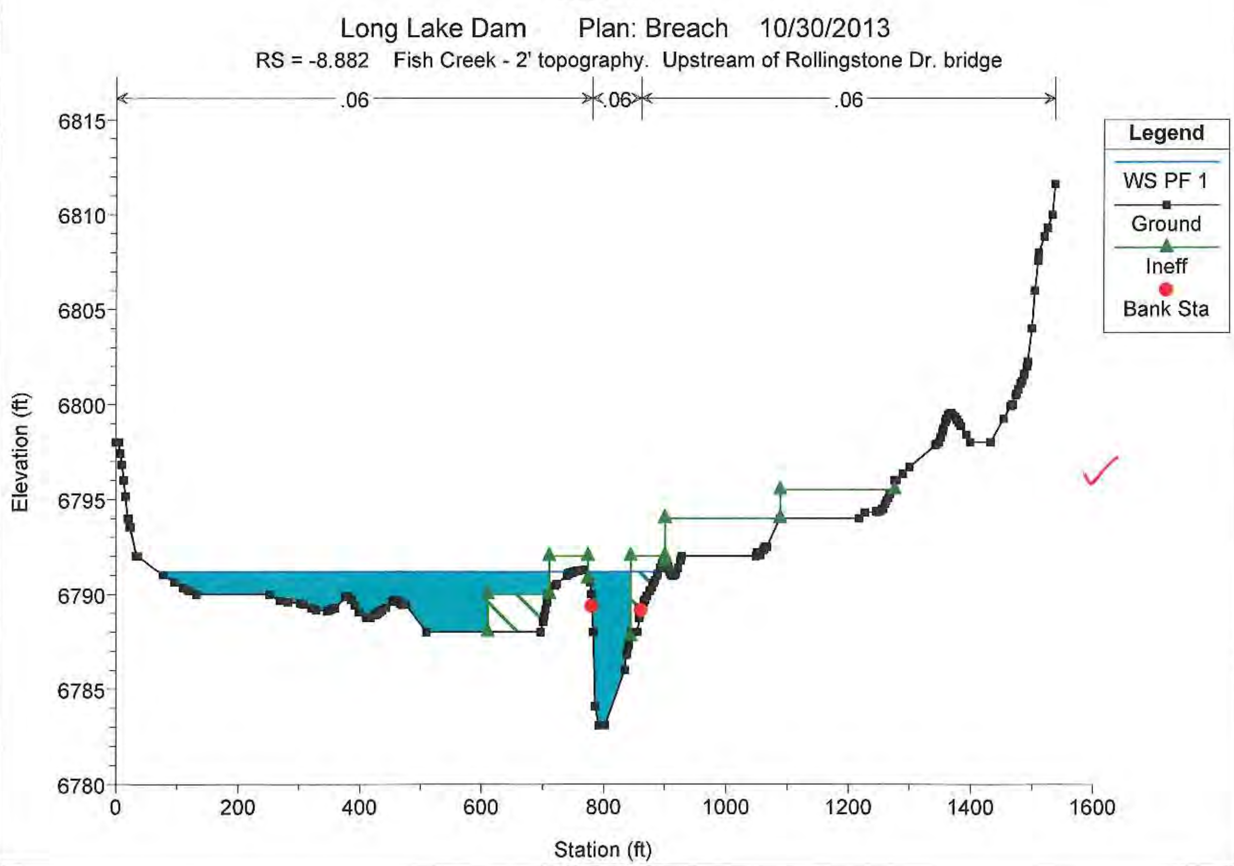




✓TEO 11/4/13 25/33

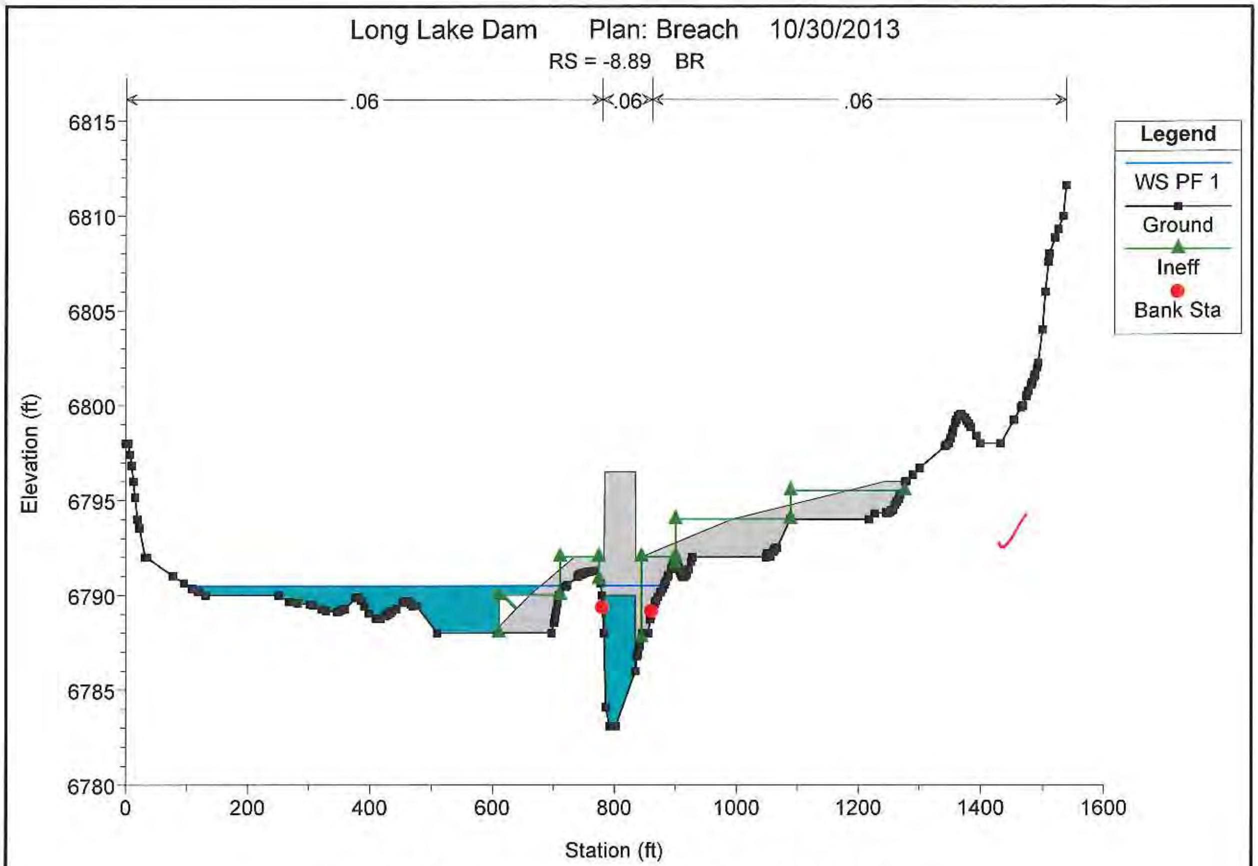
GGS 11/11/13

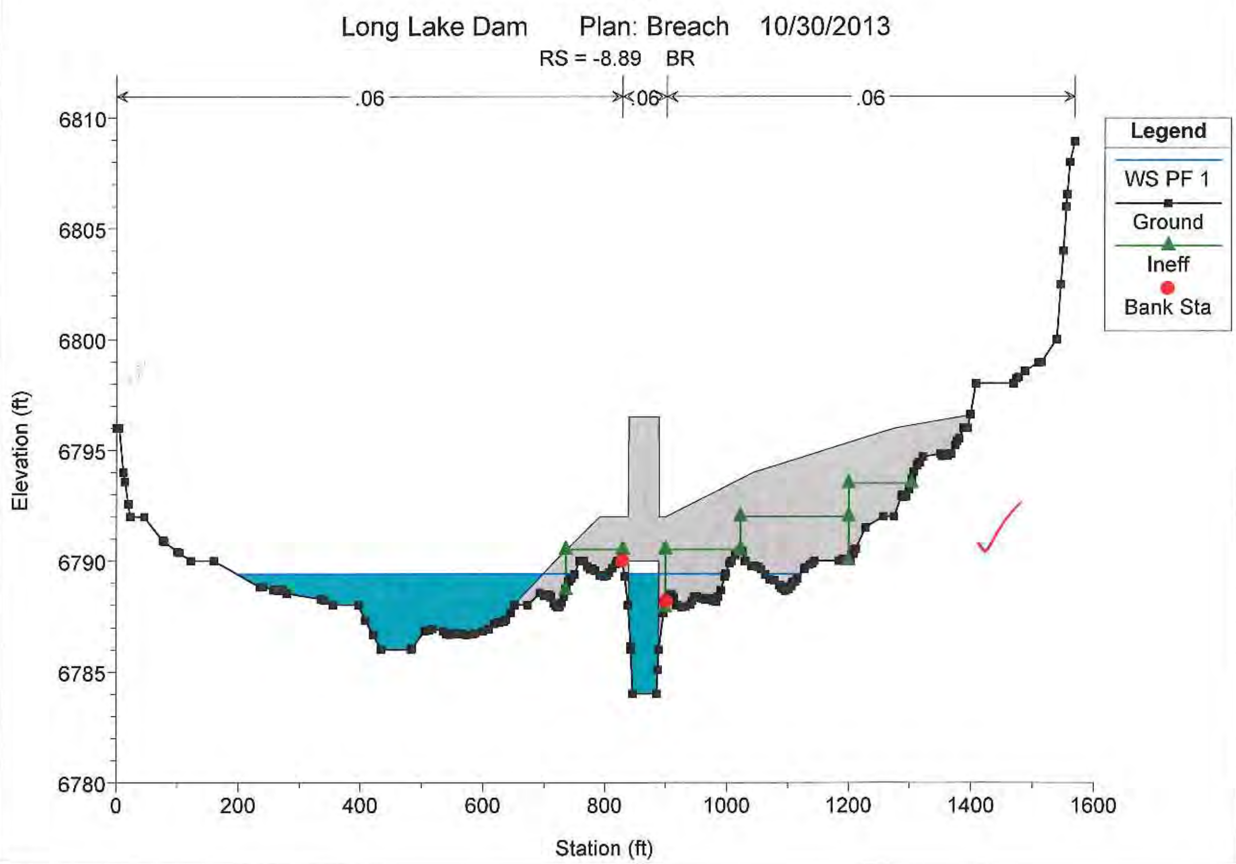




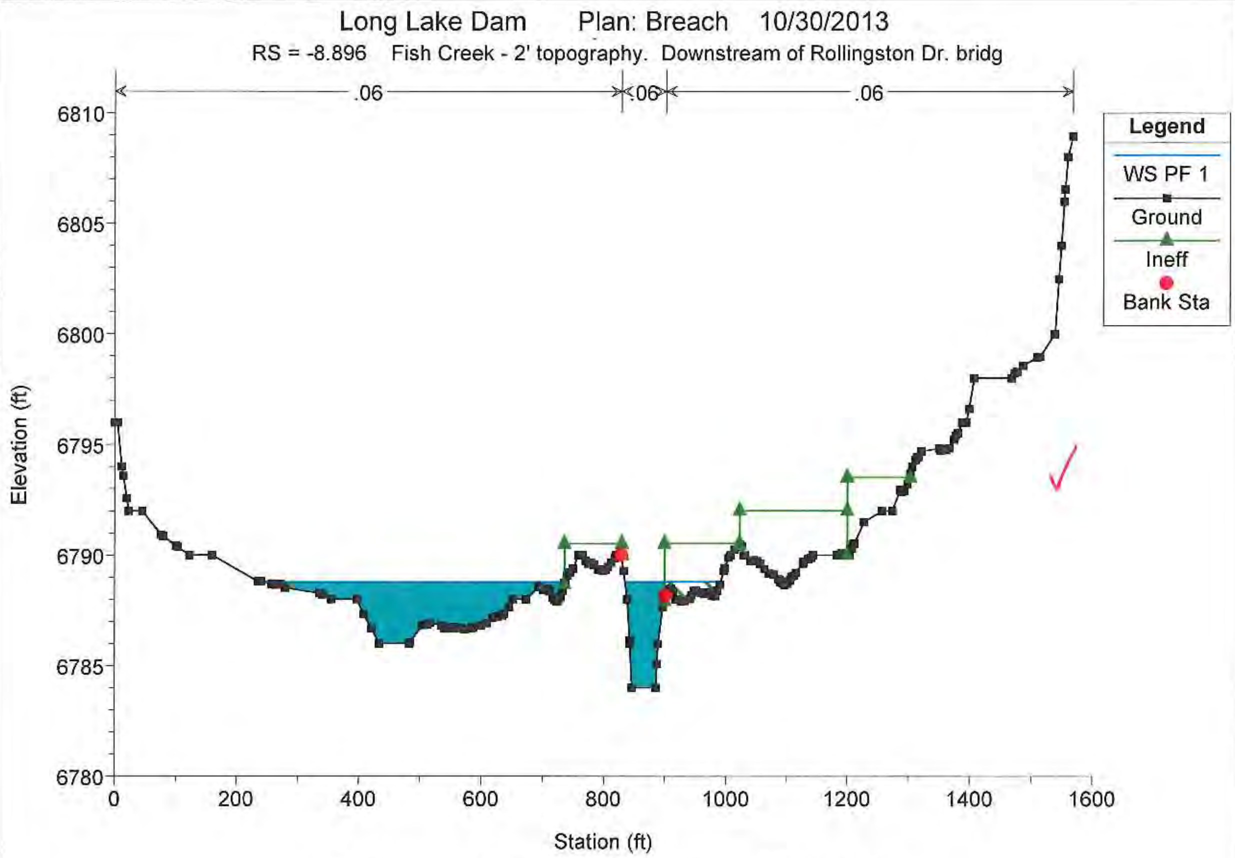
√TEO 11/4/13

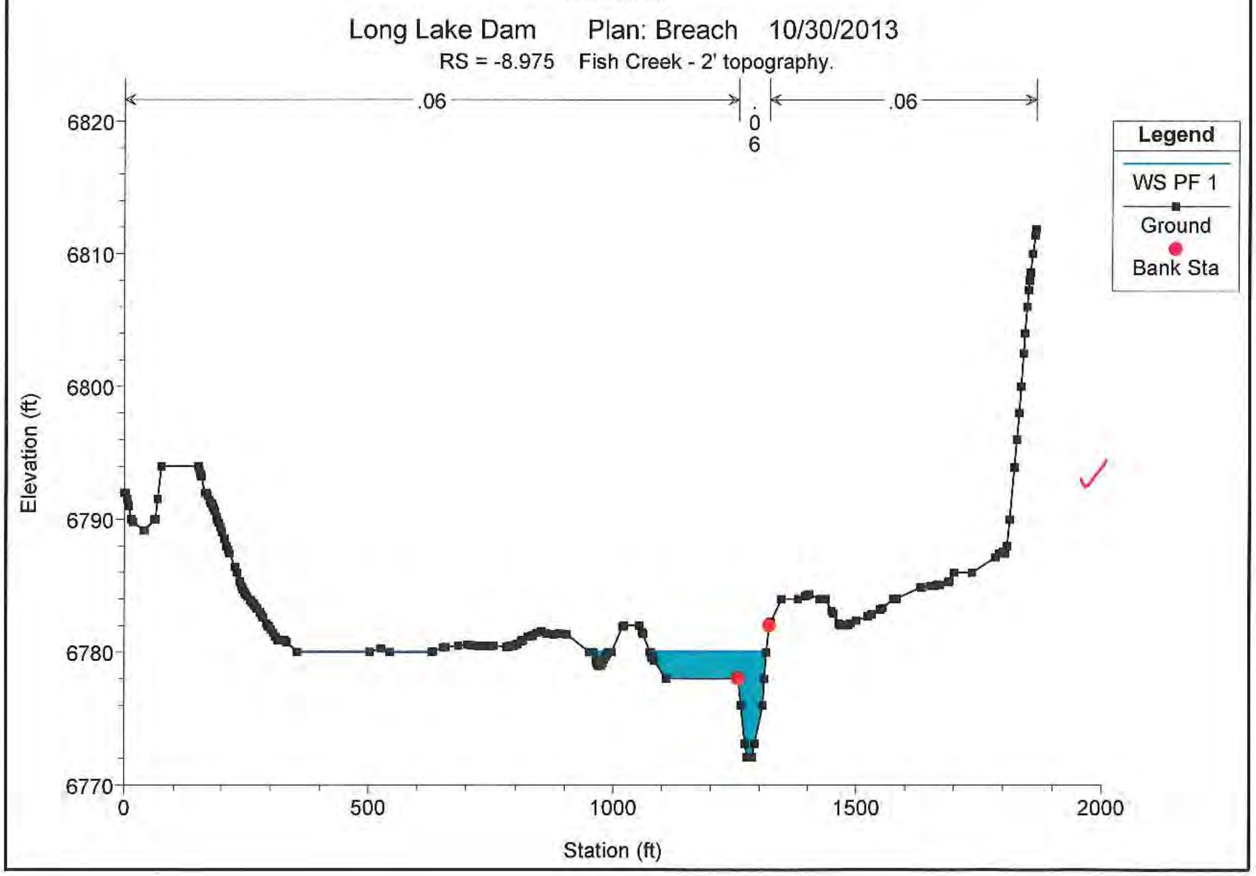
GGOS 11/11/13





√TEO 11/4/13
GGS 11/11/13





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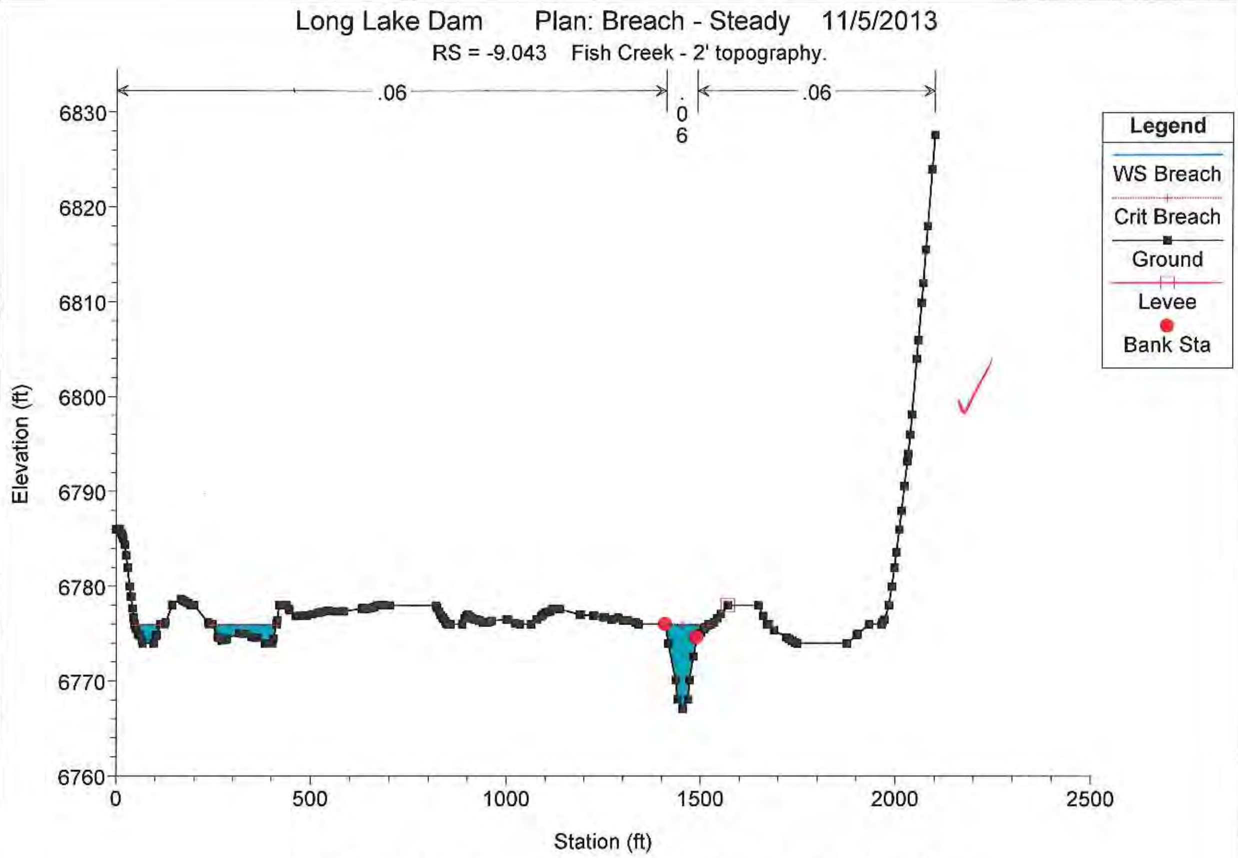
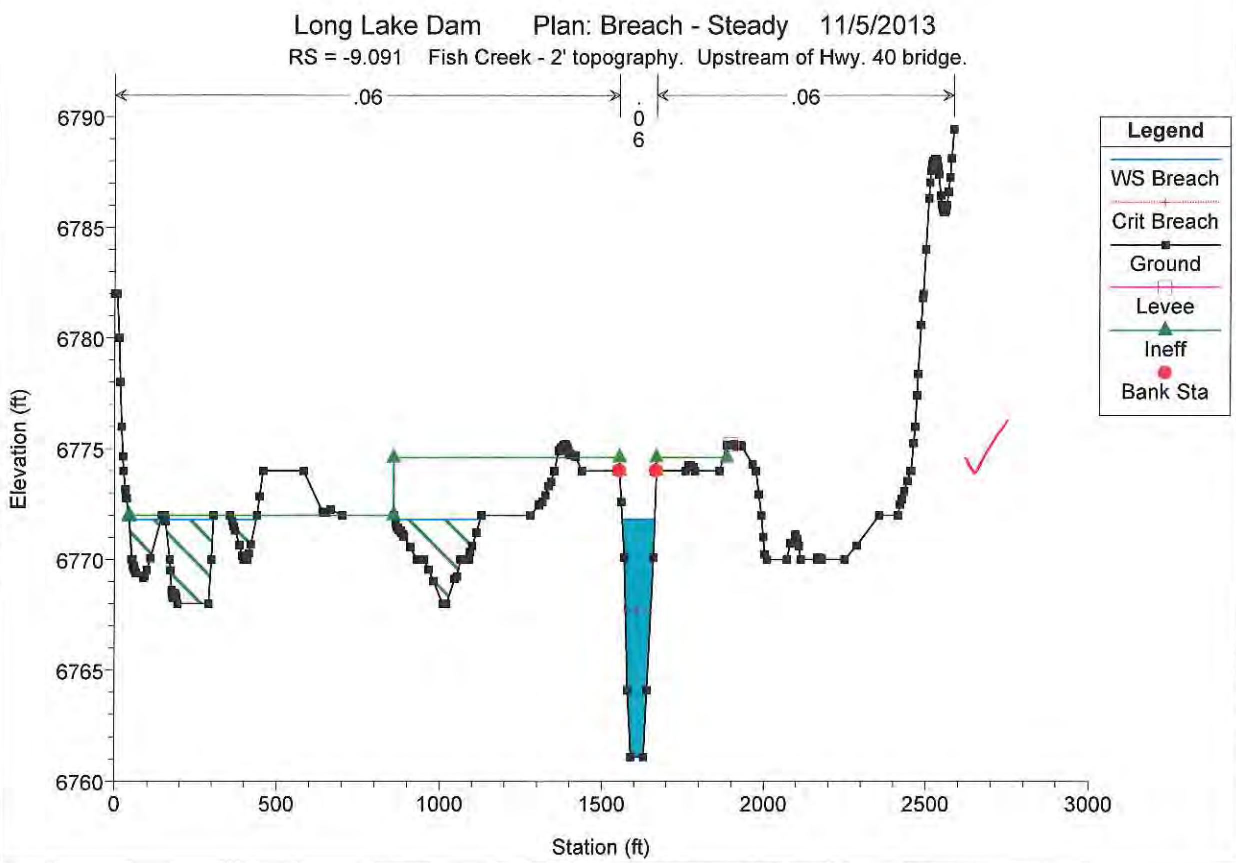
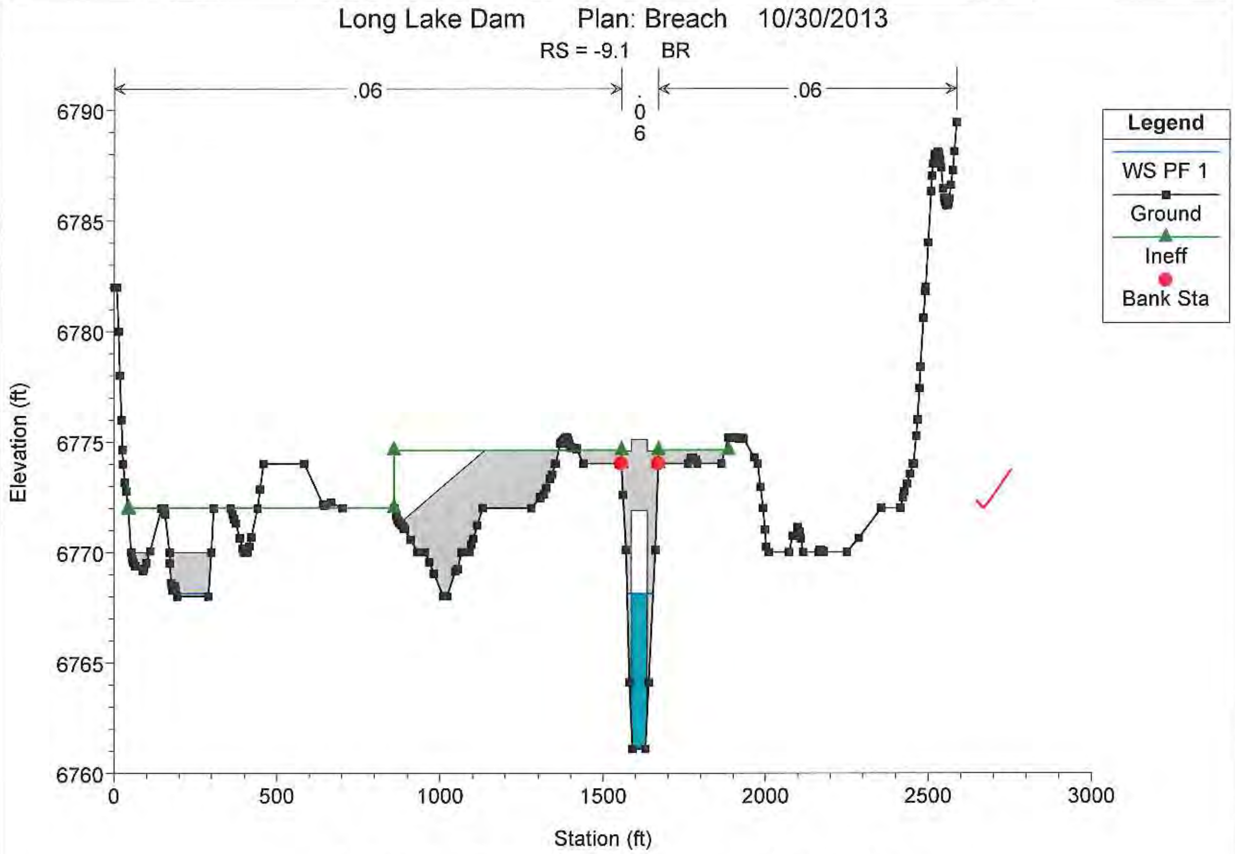
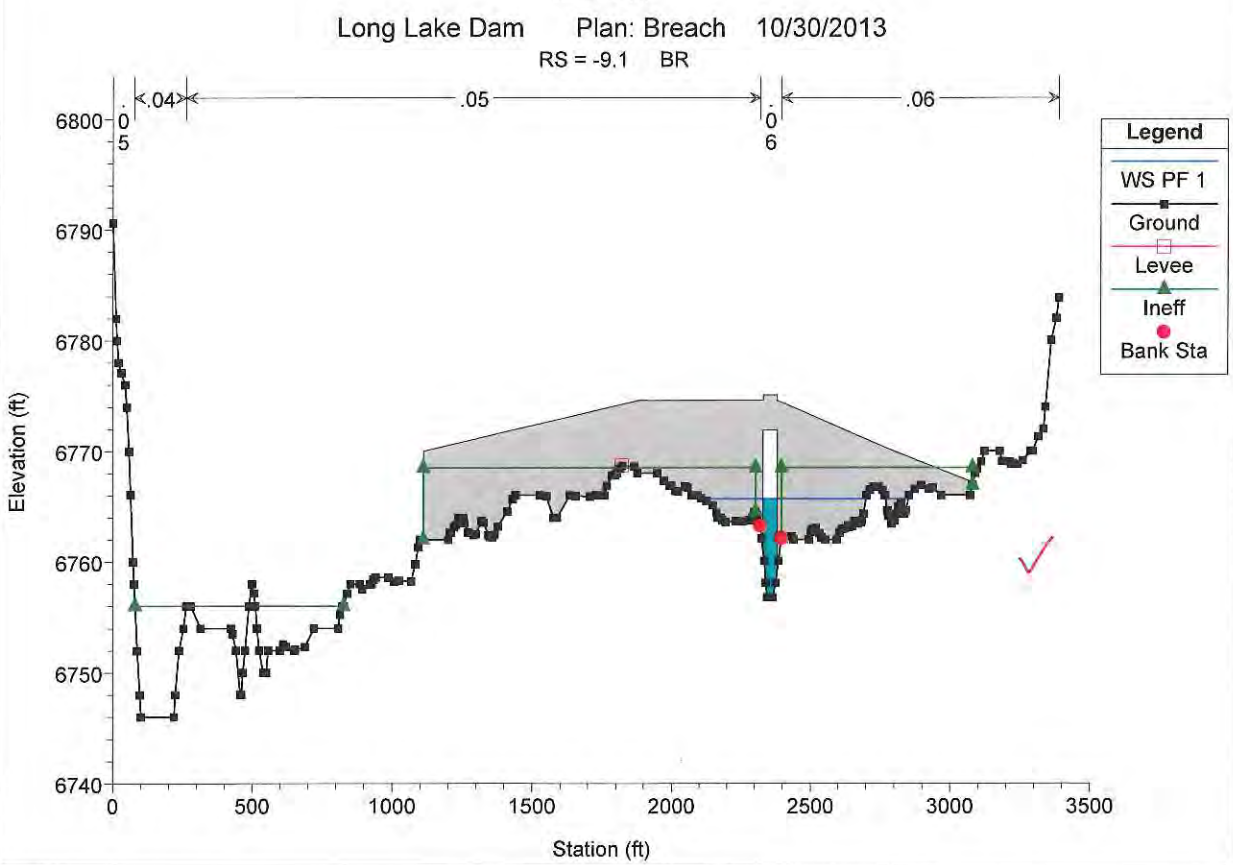
✓TEO 11/4/13
GGS 11/11/13





✓ TEO 11/4/13
GGS 11/11/13





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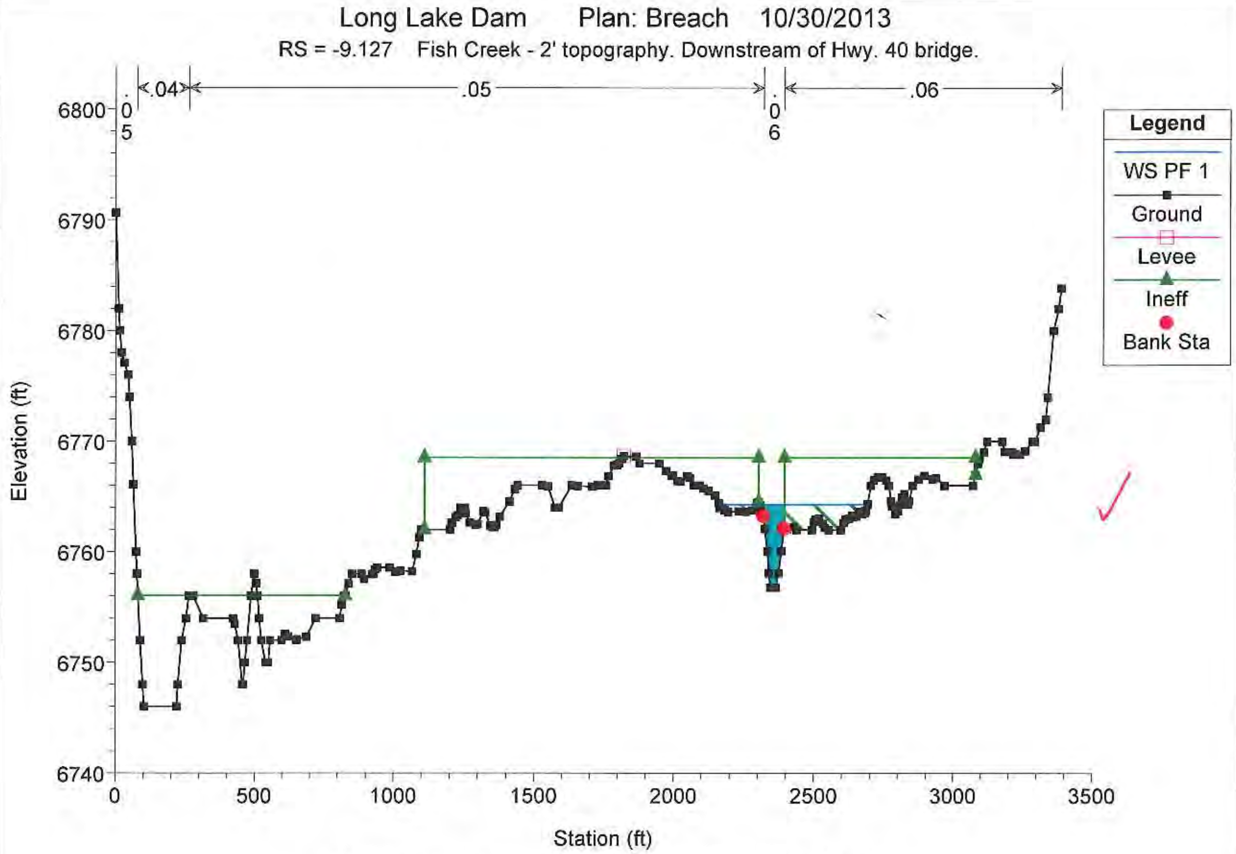

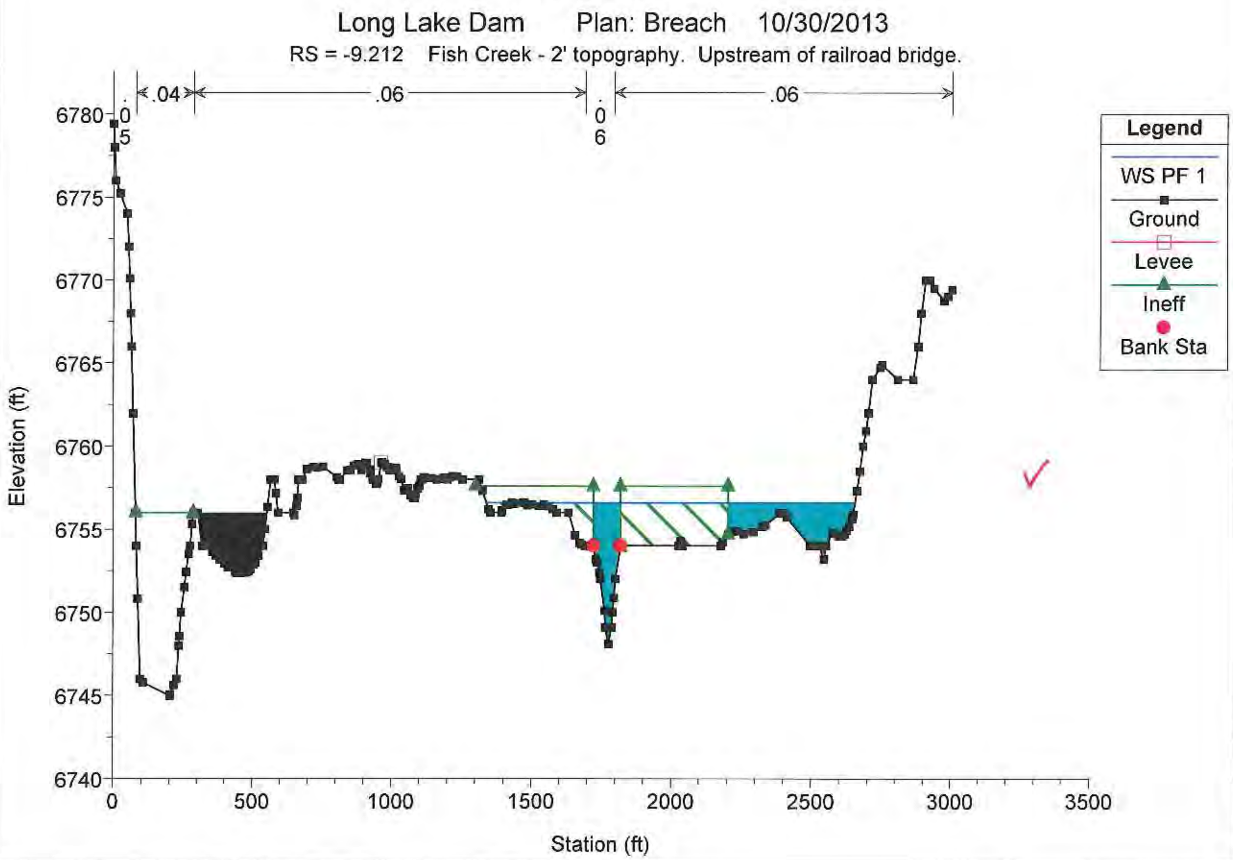

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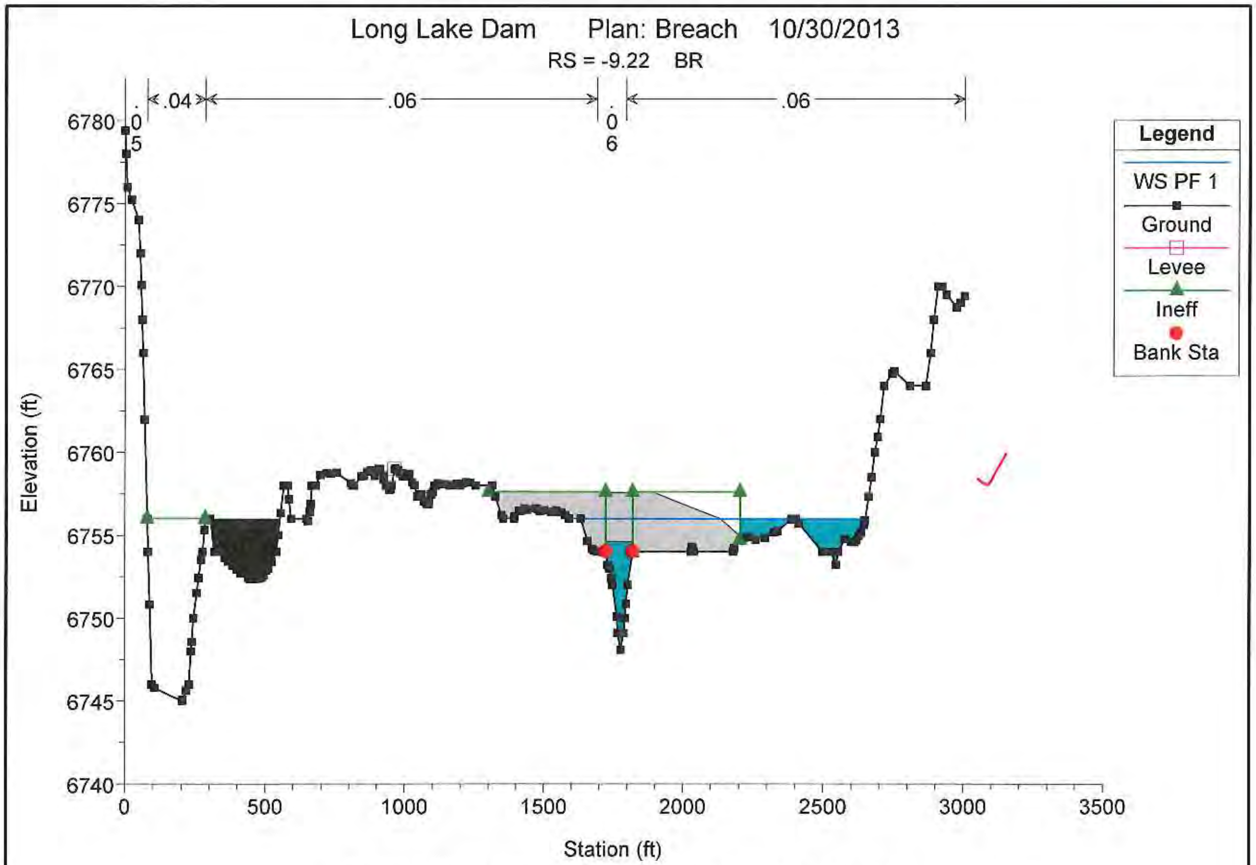
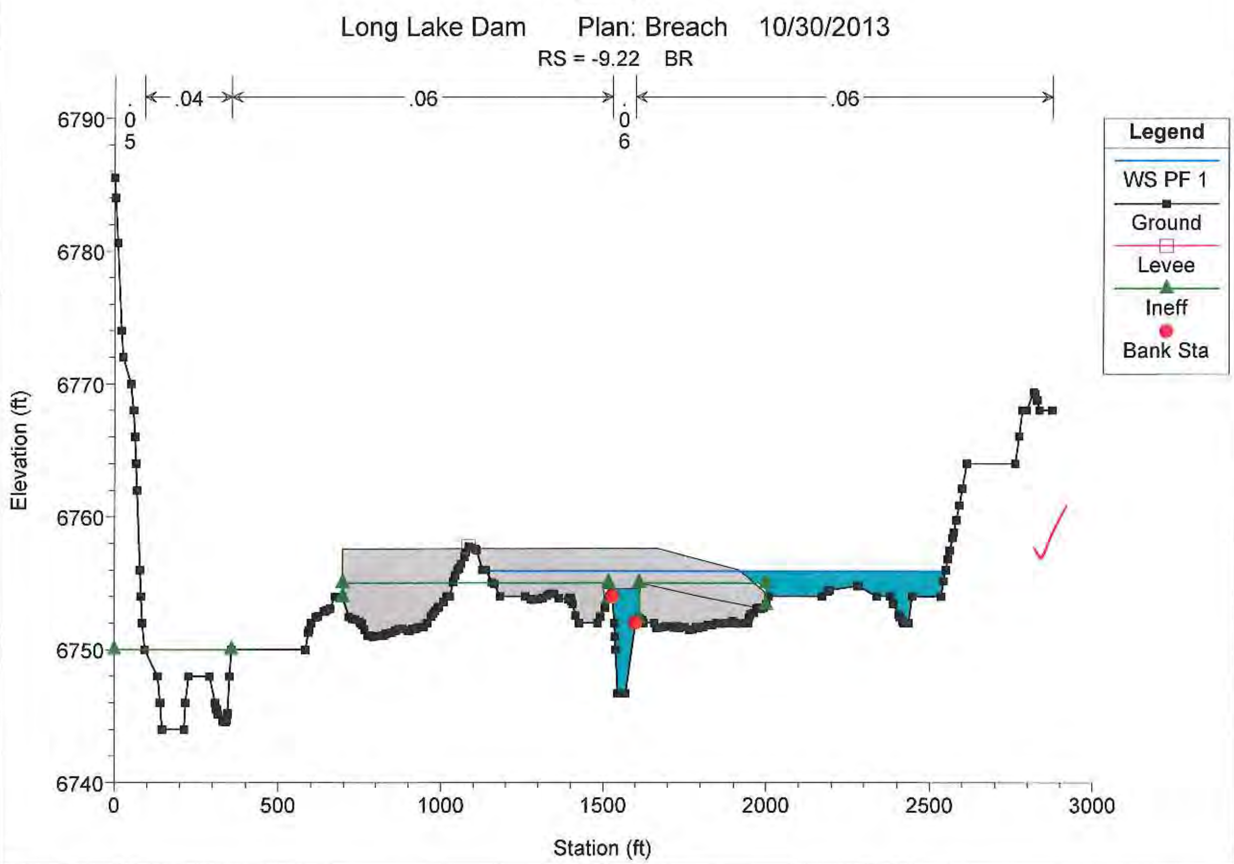
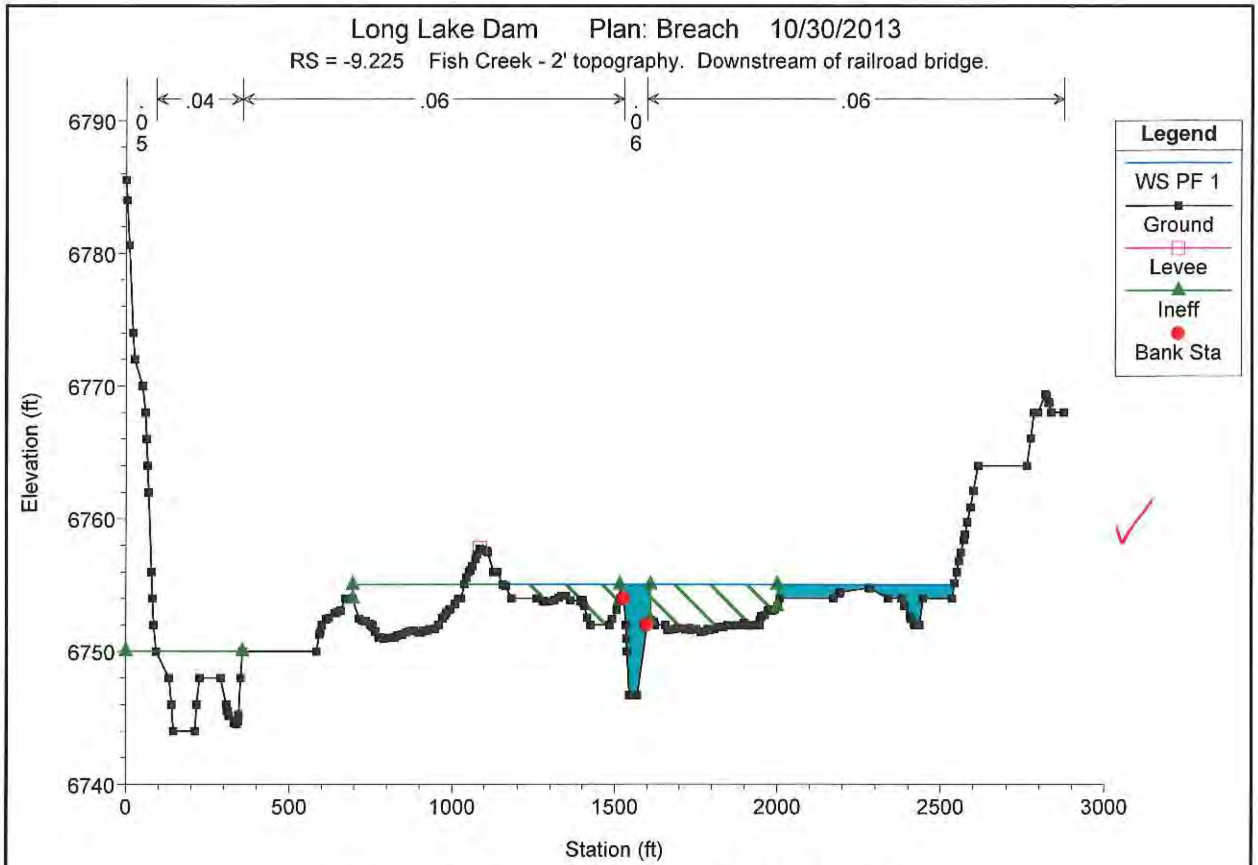
√TEO 11/4/13
GGS 11/11/13

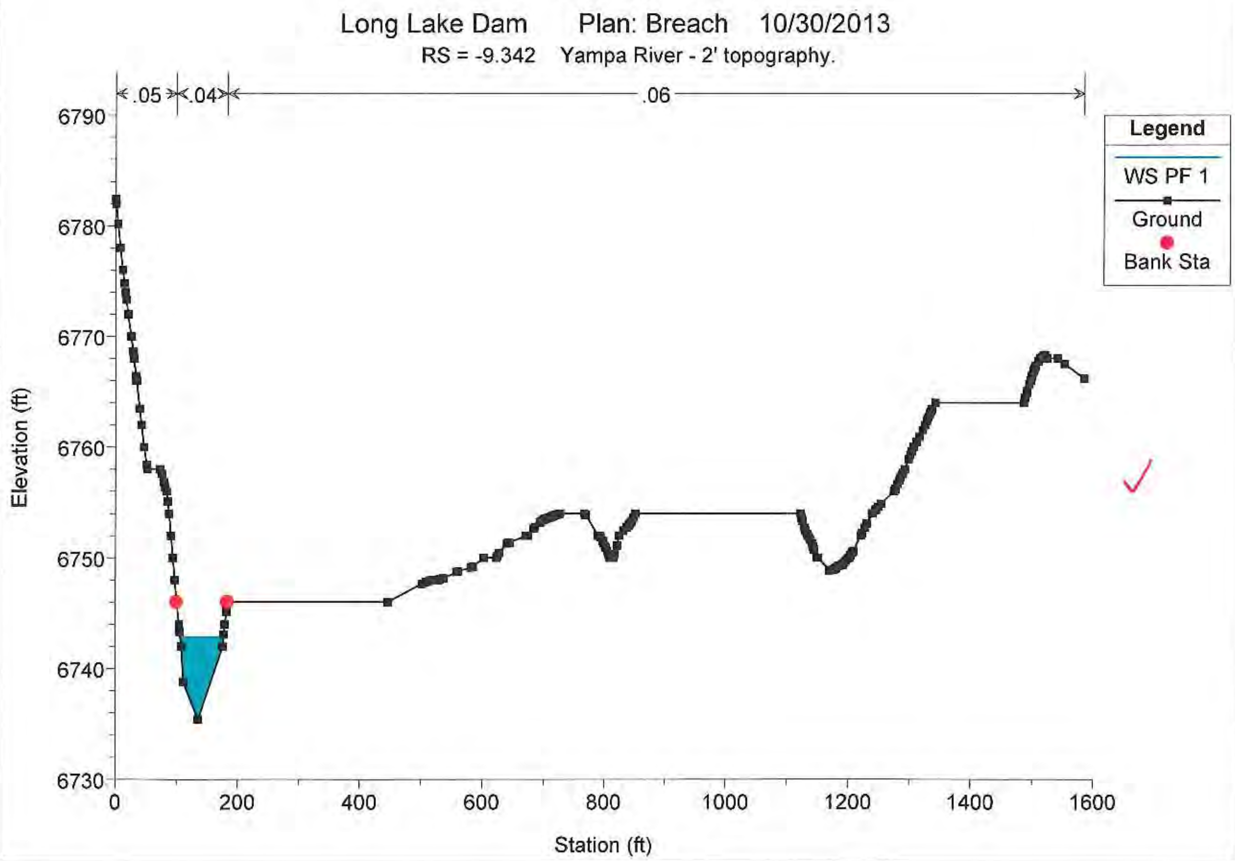




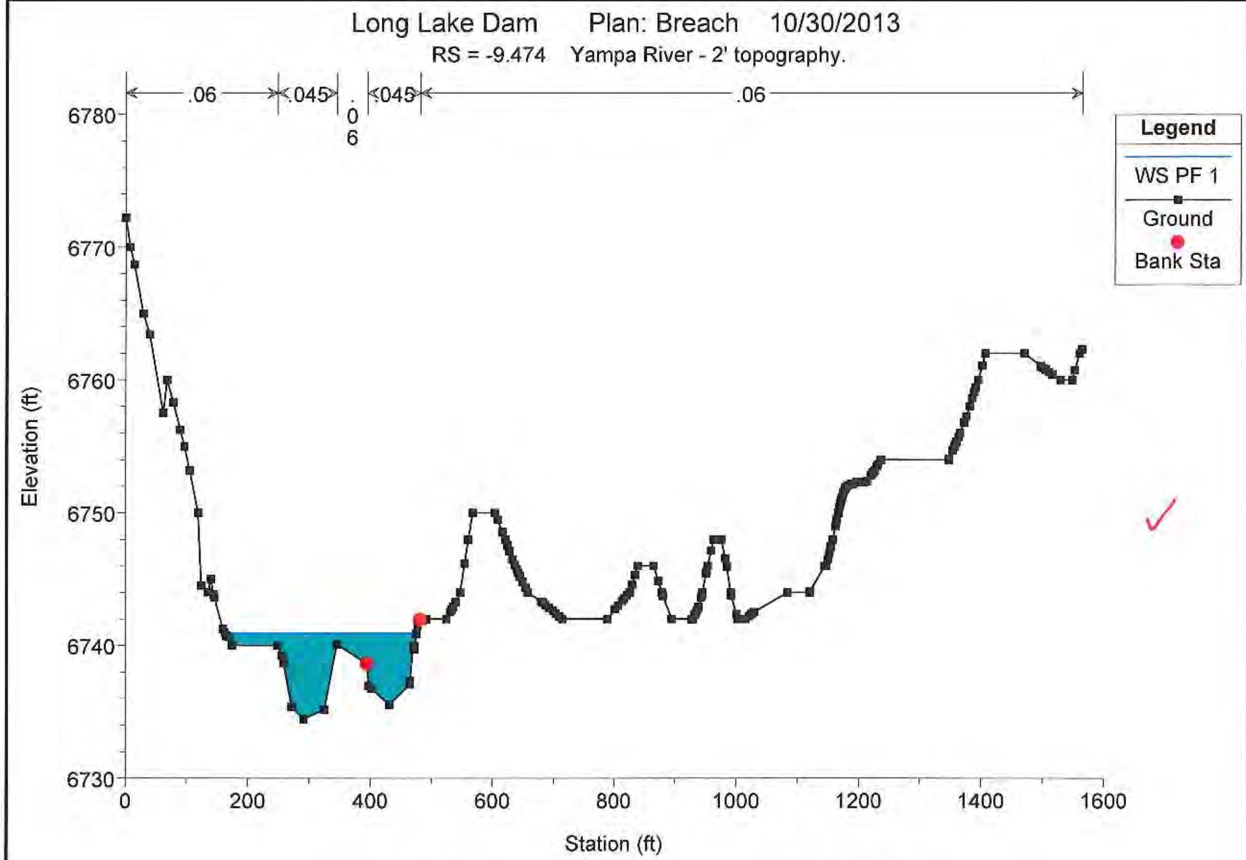
√ TEO 11/4/13

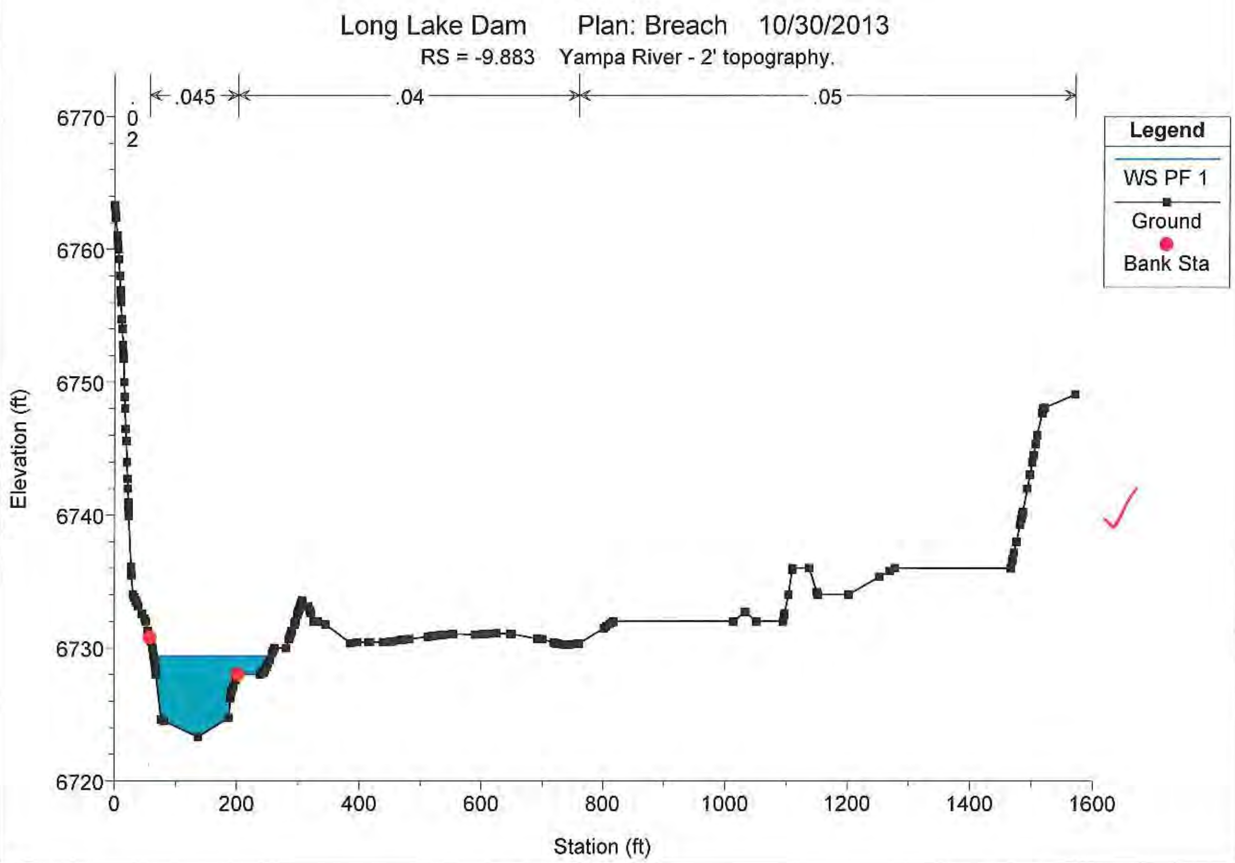
GGS 11/11/13





✓ TEO 11/4/13
GGS 11/11/13



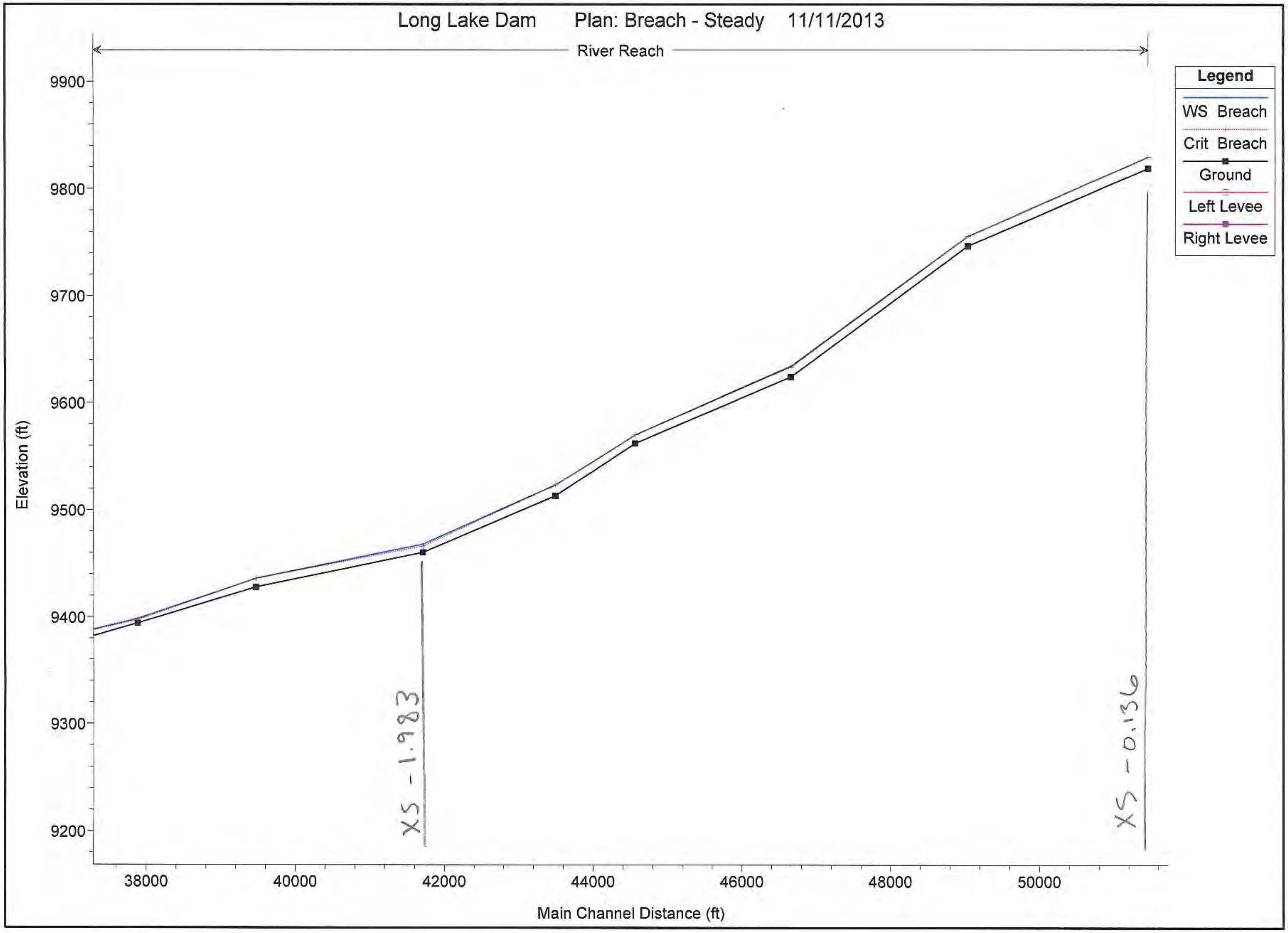


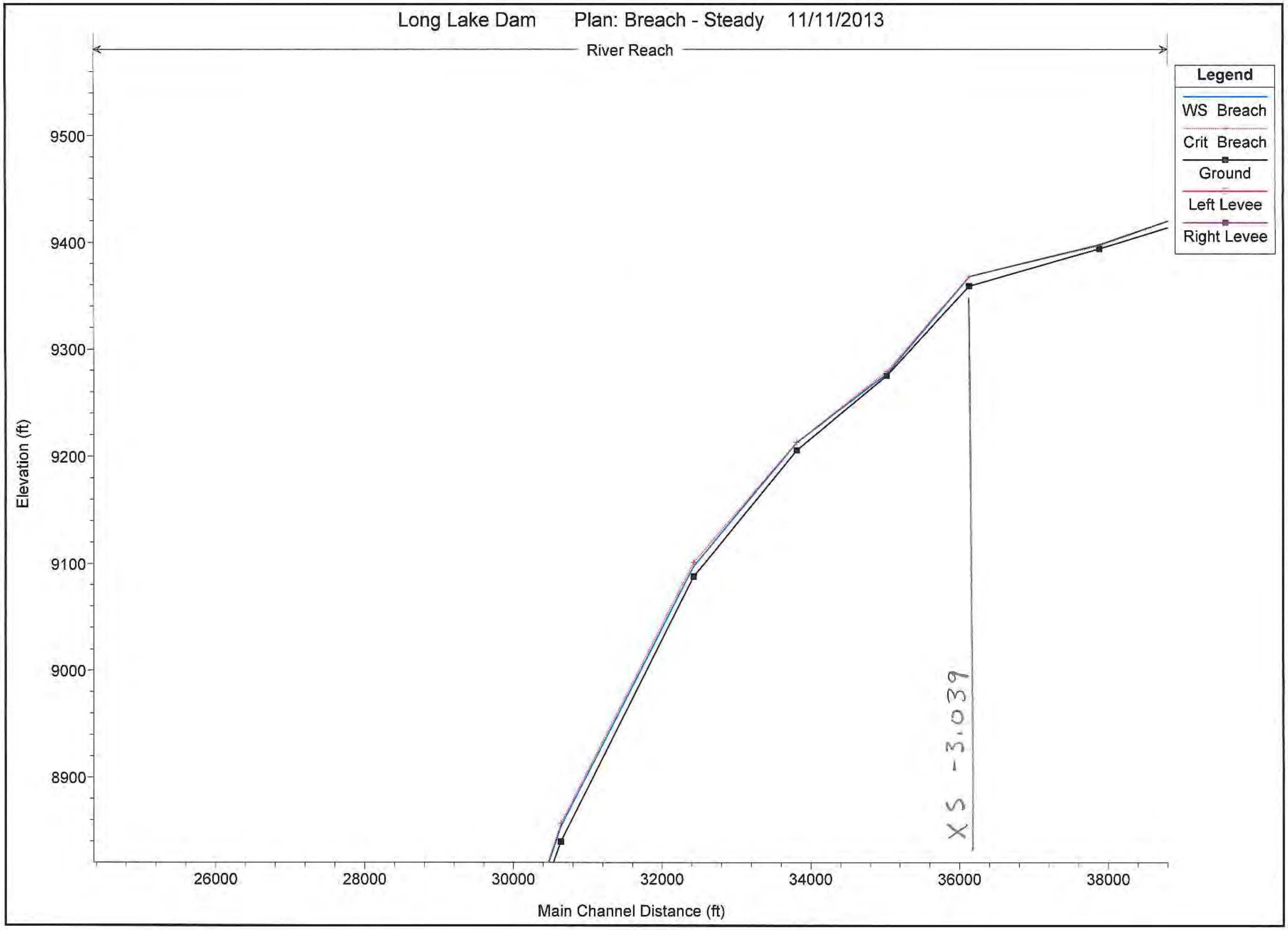
RJH CONSULTANTS, INC.

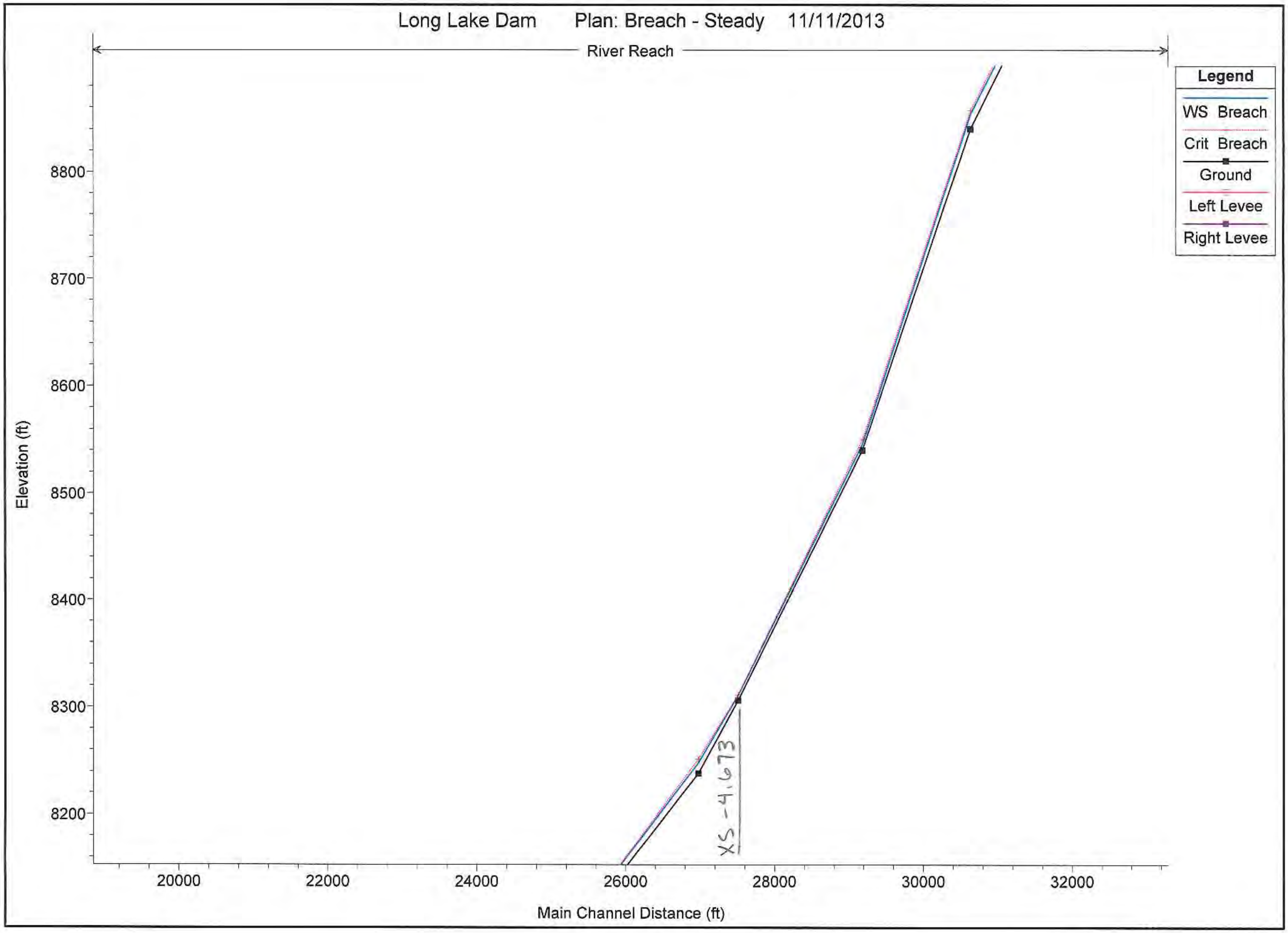
Client	Steamboat Springs	Project 13133	Page —
Subject	Long Lake Dam	Date —	By —
		Checked	By
		Approved	By

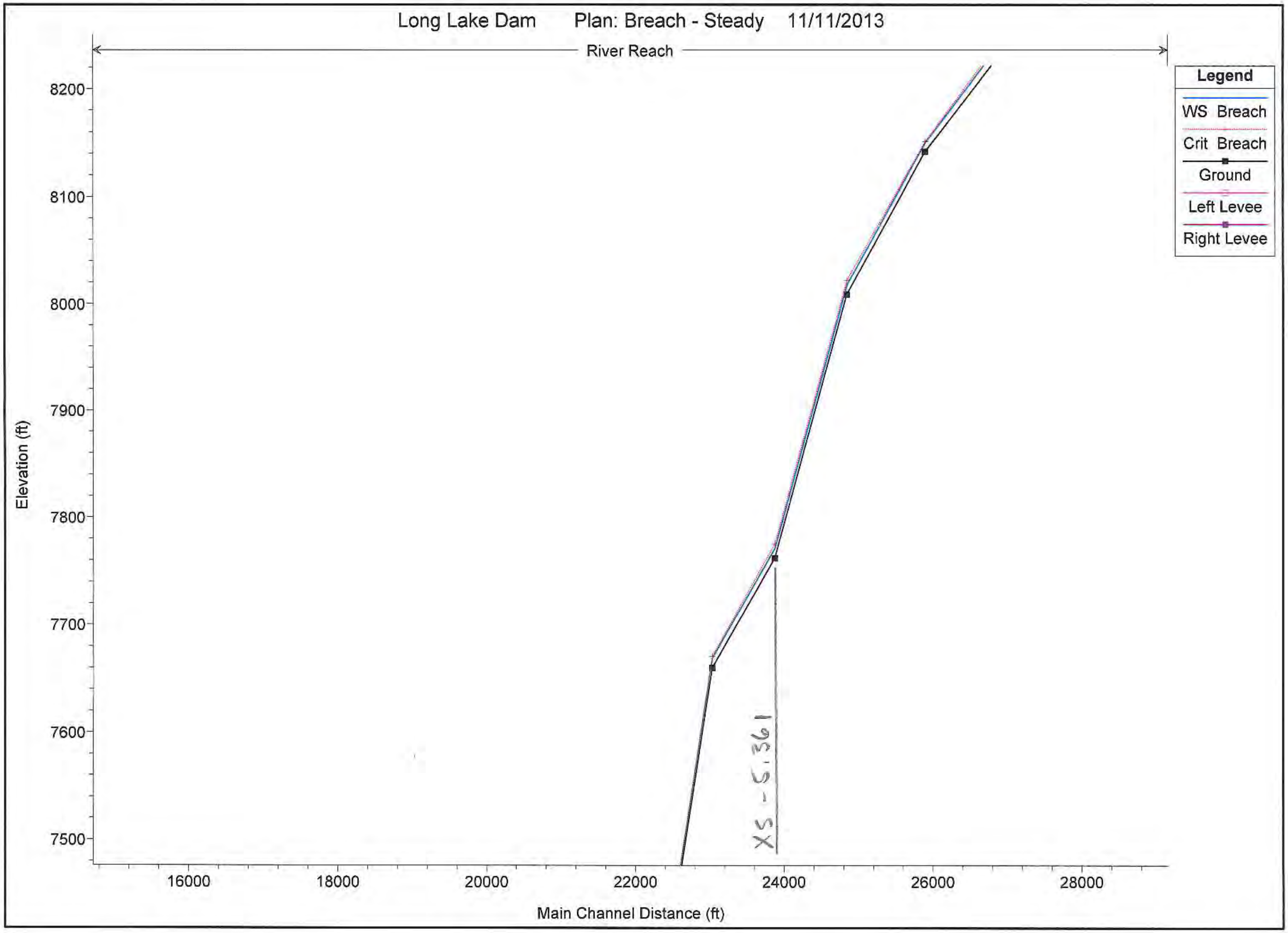
Attachment 1

Detailed HEC-RAS Profile

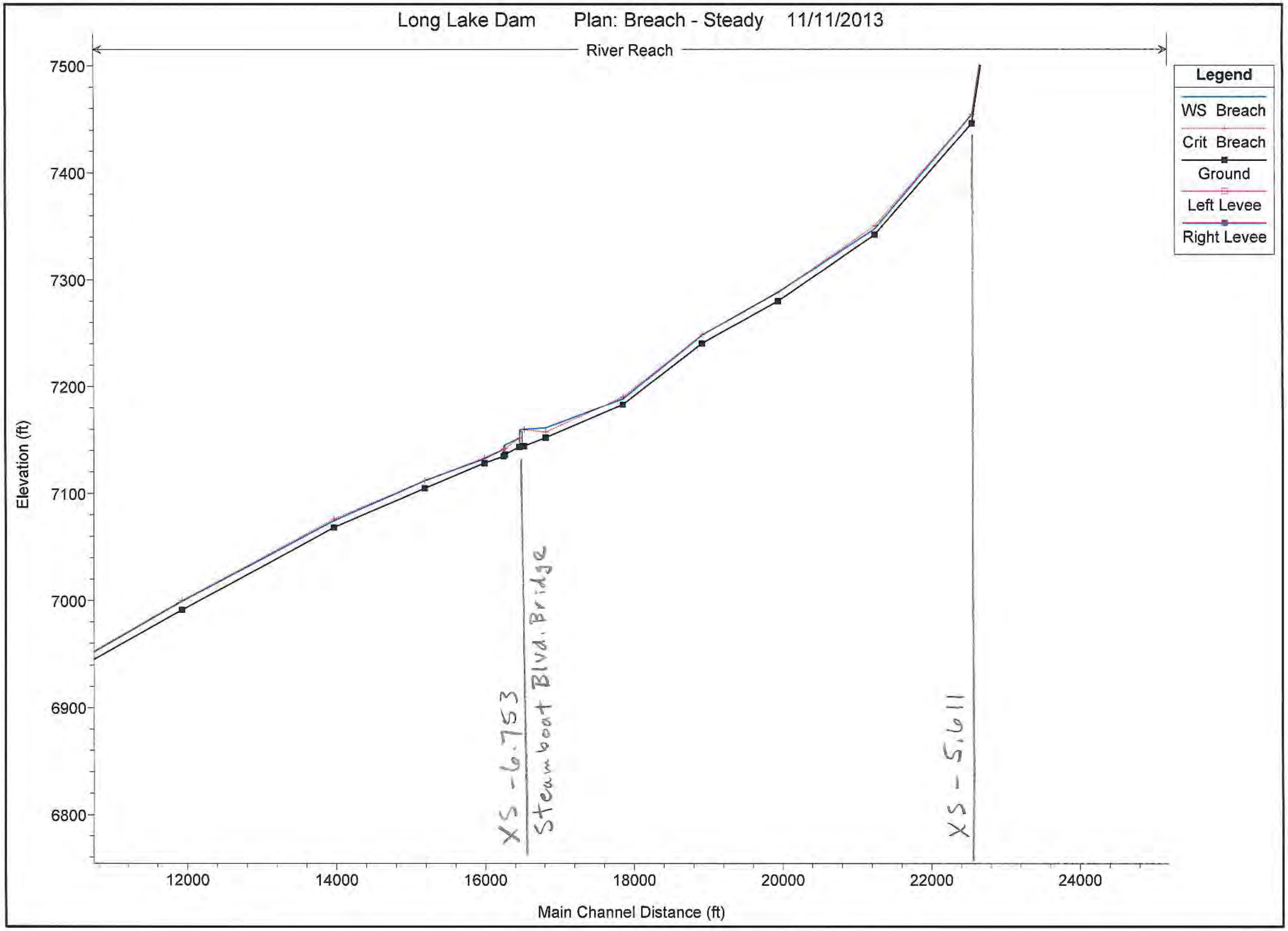

Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
Elevation (ft)
9900
9800
9700
9600
9500
9400
9300
9200
38000
40000
42000
44000
46000
48000
50000
Main Channel Distance (ft)
XS - 1.983
XS - 0.136


Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
9500
9400
9300
9200
9100
9000
8900
Elevation (ft)
26000
28000
30000
32000
34000
36000
38000
Main Channel Distance (ft)
XS -3.039

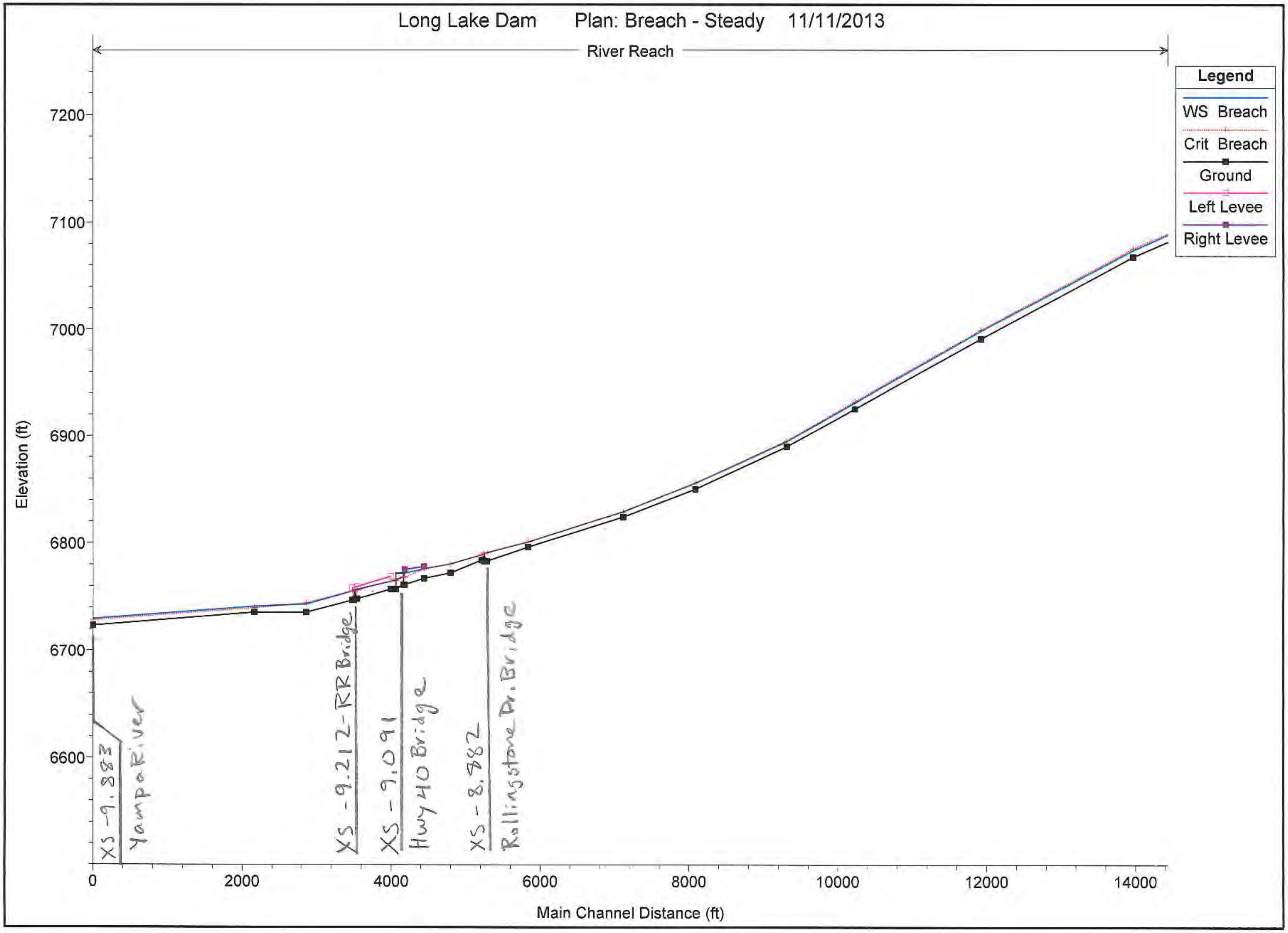

Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
Elevation (ft)
8800
8700
8600
8500
8400
8300
8200
20000
22000
24000
26000
28000
30000
32000
Main Channel Distance (ft)
XS -4.673



Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
Elevation (ft)
8200
8100
8000
7900
7800
7700
7600
7500
16000
18000
20000
22000
24000
26000
28000
Main Channel Distance (ft)
XS - 5,361



Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
7500
7400
7300
7200
7100
7000
6900
6800
Elevation (ft)
12000
14000
16000
18000
20000
22000
24000
Main Channel Distance (ft)
XS -6.753
Steamboat Blvd. Bridge
XS - 5.611


Long Lake Dam Plan: Breach - Steady 11/11/2013
River Reach
Legend
WS Breach
Crit Breach
Ground
Left Levee
Right Levee
Elevation (ft)
7200
7100
7000
6900
6800
6700
6600
Main Channel Distance (ft)
0
2000
4000
6000
8000
10000
12000
14000
XS -9.883
YampaRiver
XS -9.212-RR Bridge
XS -9.091
Hwy 40 Bridge
XS - 8.882
Rollingstone Dr. Bridge