Hamilton Reservoir Dam Breach Inundation Mapping Larimer County, CO

Prepared for:

Platte River Power Authority
2000 East Horsetooth Road
Fort Collins, CO 80525-2942

Prepared by:

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Project No. 110295
March 2014

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Project No. 110295

March 31, 2014

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1.0 INTRODUCTION

1.1 Study Purpose

The Platte River Power Authority (PRPA) requested Engineering Analytics, Inc. (EA) estimate the flood inundation extent for a simulated breach of the Rawhide Dam at Hamilton Reservoir (Reservoir). The Reservoir is owned and operated by the PRPA. This study meets the regulations and guidelines set forth by the State of Colorado Office of the State Engineer (SEO) for breach inundation mapping. In-stream and overbank erosion hazards or creek instabilities that may occur during flooding are not accounted for in this study.

1.2 Location

The Reservoir is located in Sections 5, 6, 8, and 9, Township 10 North, Range 68 West of the Sixth Principal Meridian in eastern Larimer County, Colorado. A vicinity map depicting the location of the Reservoir and the surrounding area is presented in Figure 1-1. The general characteristics of the Hamilton Reservoir are listed in Table 1-1.

2.0 JURISDICTIONAL STATUS AND SIZE

The Reservoir is a jurisdictional dam as classified by the SEO and thus subject to the regulations and authority of the State Engineer. The State Engineer has classified the Rawhide Dam as an existing High Hazard, Large dam.

3.0 BREACH INUNDATION MODELING

3.1 Introduction

The Reservoir dam breach modeling was conducted in accordance with procedures and analytical methods presented in the Guidelines for Dam Breach Analysis (Colorado, 2010). The "Advanced" level as described in Colorado (2010) was used for the breach modeling. The "Advanced" level of analysis includes: estimating breach parameters using empirical equations and using a hydrologic model for both the breach hydrograph estimation and breach hydrograph routing.

3.2 Breach Parameter Estimation

The geometric parameters for the Reservoir that are summarized in Table 3-1 were obtained from a dam inspection report conducted by the SEO (2011) and reservoir storage data provided by PRPA. The minimum embankment crest elevation for the Reservoir is 5,680 feet. The toe elevation for the Reservoir is 5,590 feet. The spillway water level (5,670.5 feet) was used as the water level at the time of failure for the analysis. The elevation-storage relationship of the Reservoir was calculated by EA based on surface area-volume relationship data is shown on Table 3-2.

According to Colorado (2010), the appropriate empirical model to estimate the breach geometry and failure time is dependent on the storage intensity (SI). The SI for a dam is calculated by dividing the volume of the water (Vw) in acre-feet by the height of water in the reservoir (Hw) in feet. The volume of the Reservoir is 16,308 acre-feet at the emergency spillway elevation. Considering a water level of 5,670.5 feet and a base elevation of 5,590 feet, the Hw of the dam is 80.5 feet. Engineering Analytics used these variables to calculate an SI of 202.6 for the Rawhide Dam. Since the SI is greater than 20, the Rawhide Dam is considered a large dam. The Guidelines for Dam Breach Analysis (Colorado, 2010) recommends the appropriate empirical model to estimate breach geometry and failure time for a large dam is the Froehlich (2008) method since it yields conservative, but reasonable results.

Using the Froehlich (2008) method yields a piping hole width of 156.8 feet and a breach formation time of 0.92 hours for the Rawhide Dam. The results of the analysis are shown in Table 3-3.

3.3 Breach Hydrograph Estimation and Flood Characteristics

In accordance with the "Advanced" level of analysis EA used the River Analysis System (HEC-RAS) to model both the breach hydrograph and flood characteristics for the dam breach simulation. The HEC-RAS software is designed to perform one-dimensional steady and unsteady flow simulations to solve a wide range of problems, including flood hydrology (US Army Corps of Engineers, 2010). The HEC-RAS 4.1.0 software was used to simulate dam failure, obtain the outflow hydrographs, and route the resulting flood downstream. Critical cross-sections were drawn perpendicular to the simulated flowpath at sensitive locations. Additional cross-sections were also drawn to stabilize the models. The ground surface elevations for each cross-section were obtained from an electronic digital elevation model obtained from the USGS National Map Viewer (2013). A Manning's n value of 0.045 was used for the overland flow portions near the Reservoir and a value of 0.035 was used for the flowpath downstream of the Cache la Poudre River to estimate flow along natural stream channels. This Manning's n was obtained from information published by the Federal Emergency Management Agency (2012).

The hydrologic flowpath, banks and cross-sections were constructed in HEC-GeoRAS before importing the parameters into the HEC-RAS models. The flowpaths from the breach of the dam were digitized on an electronic topographic map from the simulated dam breach location to the South Platte River east of the City of Greeley. An unsteady HEC-RAS model was constructed to simulate failure of the Rawhide Dam.

The outflow hydrograph was calculated in the HEC-RAS model using the following parameters: initial water elevation of 5,670.5 feet, top elevation of 5,680 feet, bottom elevation of 5,590 feet, piping elevation of 5,590 feet, and a piping coefficient of 0.5. The breach development time was 0.92 hours. A pilot flow of 1,000 ft^3/s was used as to stabilize the model. A summary of parameters used for the dam break portion of the HEC-RAS model are shown in Table 3-4.

The results from the HEC-RAS model at critical cross-sections are shown in Table 3.5. The results show a peak discharge of 229,295 ft^3/s at the breach location, which attenuated to a peak flow rate east of the junction with the South Platte River of 23,031 ft^3/s at RS 1718. Although the peak discharge at this location exceeds the maximum average flow of the South Platte River, it is less than the maximum observed streamflow. United States Geological Survey (USGS) stream gage number 06754000 is located approximately 0.5 miles downstream of RS 1718. A peak observed streamflow of 31,500 ft^3/sec was measured at this stream gage (USGS, 2013) and is less than the simulated peak discharge. The annual peak streamflows recorded at this USGS stream gage are included in Appendix B. The results of the unsteady HEC-RAS models are also included in Appendix B.

Engineering Analytics also used HEC-RAS to estimate the velocity, depth of flow through the cross-sections and the floodplain extents throughout the flood channel. The unsteady model consisted of ninety (90) cross-sections for the simulation. An in-line structure was placed at river station RS 359958 to simulate a piping failure of the Rawhide Dam

A summary of the results of the unsteady flow model are shown in Table 3-5. The complete HEC-RAS output tables are located in Appendix B.

3.4 Summary

Failure of the Rawhide Dam was evaluated using the results from the breach analysis and hydraulic modeling of the inundation zone. A list of potential critical structures and their elevations were selected using the topographic map, digital elevation model, and aerial photograph. Figure 3-1 shows the critical and non-critical cross-sections in and along the inundation zone. The inundation zone was exported from the HEC-RAS models and plotted onto a topographic map and aerial photograph. The inundation maps are included as Figure 3-2 through Figure 3-6. Table 3-5 summarizes each critical location and corresponding peak discharge estimates, peak flood wave elevations, peak flood wave depths, peak flood wave arrival times and velocities.

Table 3-6 lists the critical cross-sections and gives a description of each location. The critical cross-sections are associated with schools, railroads, road crossings and residential/municipal areas. The results of the HEC-RAS models indicate surface flooding from the Reservoir toward the south and to the east of Greeley. Flooding of residences, schools, municipal areas, roads, railroad bridges, and Interstate I-25 is anticipated. Although the discharge of the peak flood wave exceeds the highest monthly average at the South Platte River, this rate is less than observed historical peak flood discharges.

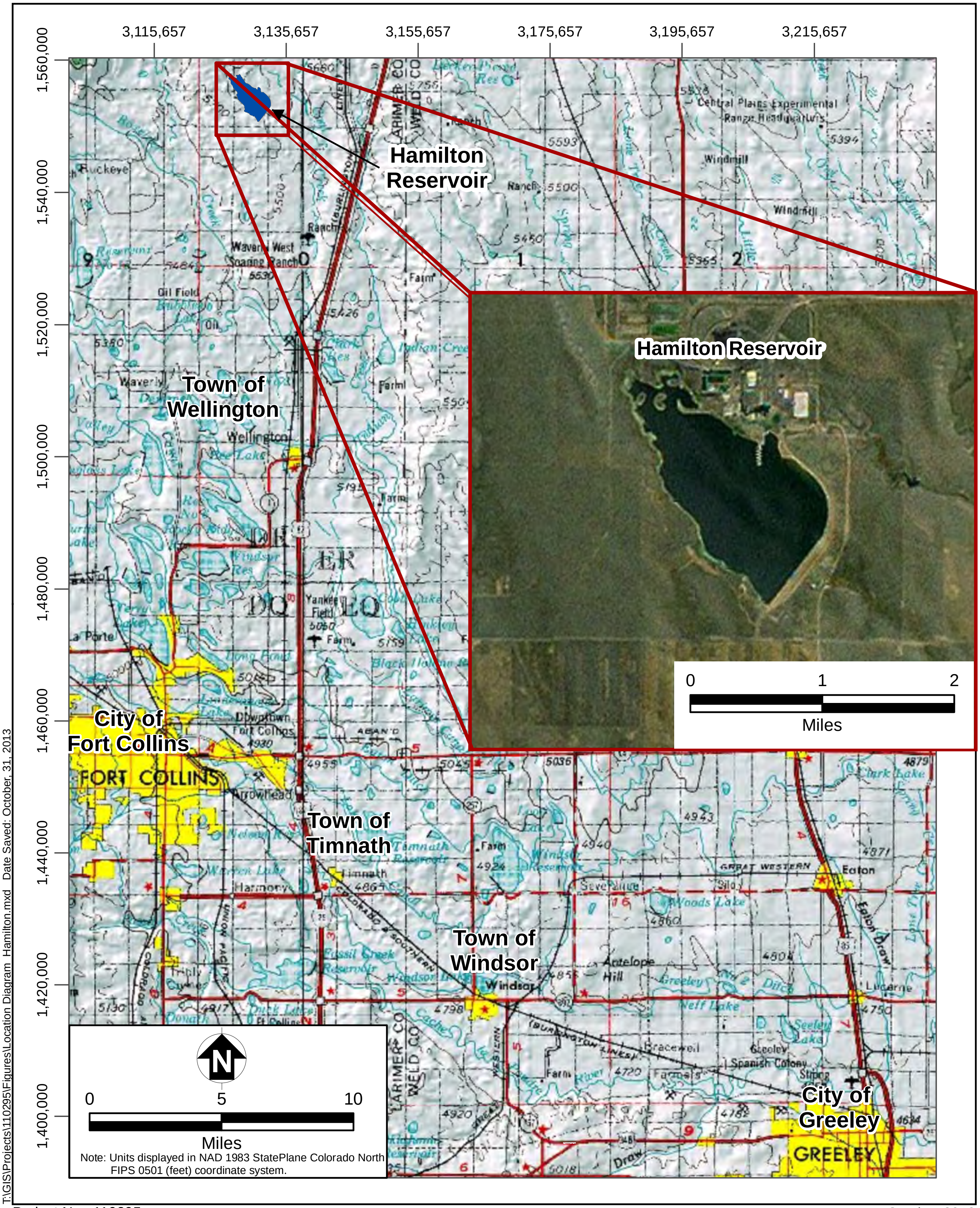
4.0 CONCLUSIONS

Engineering Analytics was asked by the Platte River Power Authority to model the flood inundation zone resulting from dam failure of the existing Rawhide Dam. Following the rules and regulations provided by the State of Colorado Office of the State Engineer, Engineering Analytics estimated the inundation zone for the Hamilton Reservoir. The inundation zone was estimated utilizing geometric and soil parameters and is depicted on Figures 3-2 through 3-6.

5.0 STANDARD OF CARE

The recommendations and information contained in this report represent our professional opinions and judgment based in part on our investigations, engineering studies, and information provided by others. These opinions were arrived at in accordance with currently accepted engineering procedures at this time and location. Other than this, no warranty, either expressed or implied, is intended.

FIGURES



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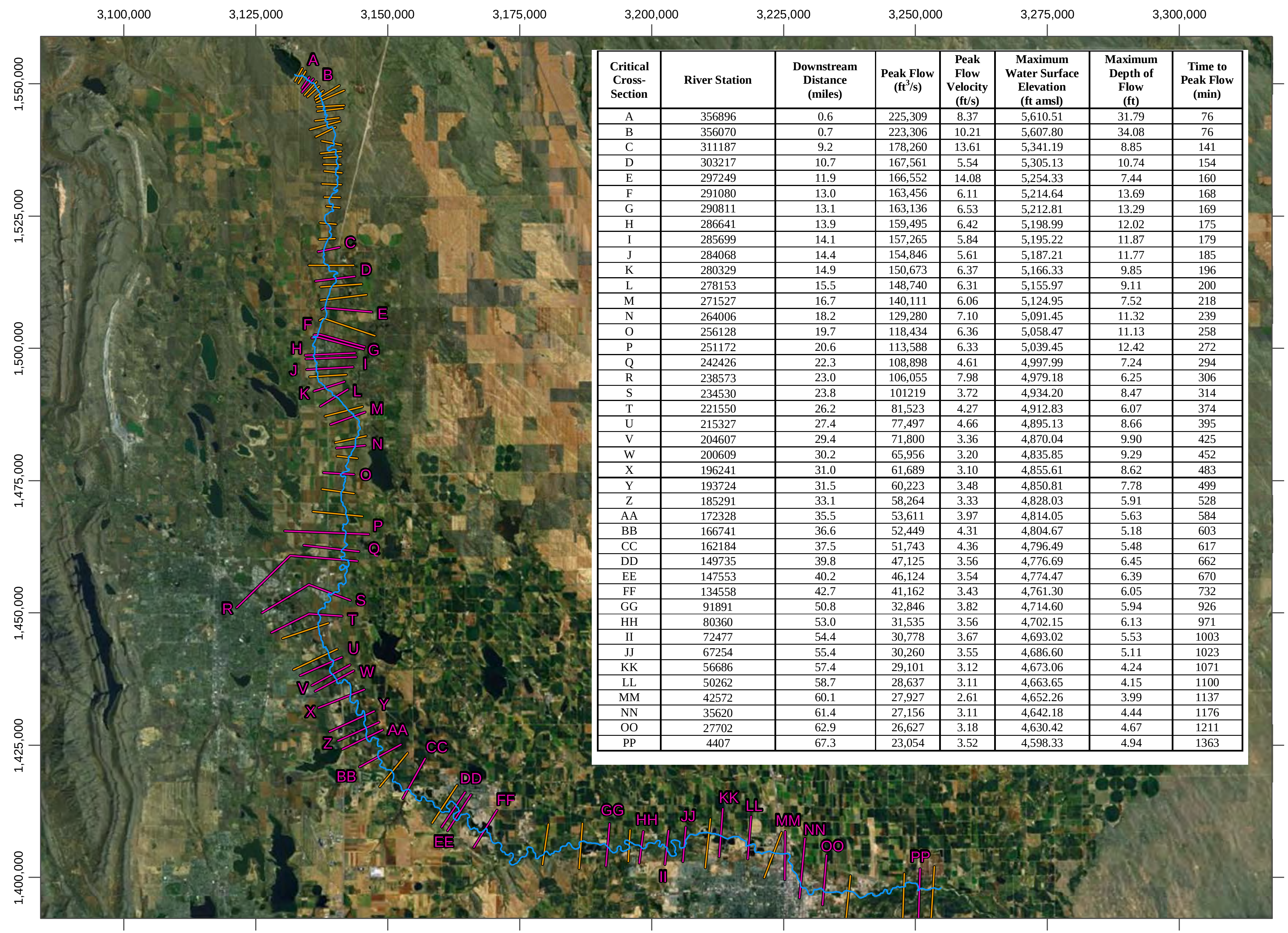
Project No. 110295

October 2013

Engineering Analytics, Inc.

FIGURE 1-1
VICINITY MAP
HAMILTON RESERVOIR
LARIMER COUNTY, COLORADO



Critical Cross-Section	River Station	Downstream Distance (miles)	Peak Flow (ft^3/s)	Peak Flow Velocity (ft/s)	Maximum Water Surface Elevation (ft amsl)	Maximum Depth of Flow (ft)	Time to Peak Flow (min)
A	356896	0.6	225,309	8.37	5,610.51	31.79	76
B	356070	0.7	223,306	10.21	5,607.80	34.08	76
C	311187	9.2	178,260	13.61	5,341.19	8.85	141
D	303217	10.7	167,561	5.54	5,305.13	10.74	154
E	297249	11.9	166,552	14.08	5,254.33	7.44	160
F	291080	13.0	163,456	6.11	5,214.64	13.69	168
G	290811	13.1	163,136	6.53	5,212.81	13.29	169
H	286641	13.9	159,495	6.42	5,198.99	12.02	175
I	285699	14.1	157,265	5.84	5,195.22	11.87	179
J	284068	14.4	154,846	5.61	5,187.21	11.77	185
K	280329	14.9	150,673	6.37	5,166.33	9.85	196
L	278153	15.5	148,740	6.31	5,155.97	9.11	200
M	271527	16.7	140,111	6.06	5,124.95	7.52	218
N	264006	18.2	129,280	7.10	5,091.45	11.32	239
O	256128	19.7	118,434	6.36	5,058.47	11.13	258
P	251172	20.6	113,588	6.33	5,039.45	12.42	272
Q	242426	22.3	108,898	4.61	4,997.99	7.24	294
R	238573	23.0	106,055	7.98	4,979.18	6.25	306
S	234530	23.8	101219	3.72	4,934.20	8.47	314
T	221550	26.2	81,523	4.27	4,912.83	6.07	374
U	215327	27.4	77,497	4.66	4,895.13	8.66	395
V	204607	29.4	71,800	3.36	4,870.04	9.90	425
W	200609	30.2	65,956	3.20	4,835.85	9.29	452
X	196241	31.0	61,689	3.10	4,855.61	8.62	483
Y	193724	31.5	60,223	3.48	4,850.81	7.78	499
Z	185291	33.1	58,264	3.33	4,828.03	5.91	528
AA	172328	35.5	53,611	3.97	4,814.05	5.63	584
BB	166741	36.6	52,449	4.31	4,804.67	5.18	603
CC	162184	37.5	51,743	4.36	4,796.49	5.48	617
DD	149735	39.8	47,125	3.56	4,776.69	6.45	662
EE	147553	40.2	46,124	3.54	4,774.47	6.39	670
FF	134558	42.7	41,162	3.43	4,761.30	6.05	732
GG	91891	50.8	32,846	3.82	4,714.60	5.94	926
HH	80360	53.0	31,535	3.56	4,702.15	6.13	971
II	72477	54.4	30,778	3.67	4,693.02	5.53	1003
JJ	67254	55.4	30,260	3.55	4,686.60	5.11	1023
KK	56686	57.4	29,101	3.12	4,673.06	4.24	1071
LL	50262	58.7	28,637	3.11	4,663.65	4.15	1100
MM	42572	60.1	27,927	2.61	4,652.26	3.99	1137
NN	35620	61.4	27,156	3.11	4,642.18	4.44	1176
OO	27702	62.9	26,627	3.18	4,630.42	4.67	1211
PP	4407	67.3	23,054	3.52	4,598.33	4.94	1363

EXPLANATION

- Hamilton Reservoir
- Flow Paths Used In HEC-RAS Simulation
- Cross-Section Line
- A — Critical Cross-Section Line With Identifier

N

0 5 10

Miles

Note: Units displayed in NAD 1983 StatePlane Colorado North FIPS 0501 (feet) coordinate system.

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Project No. 110295

October 2013

Engineering Analytics, Inc.

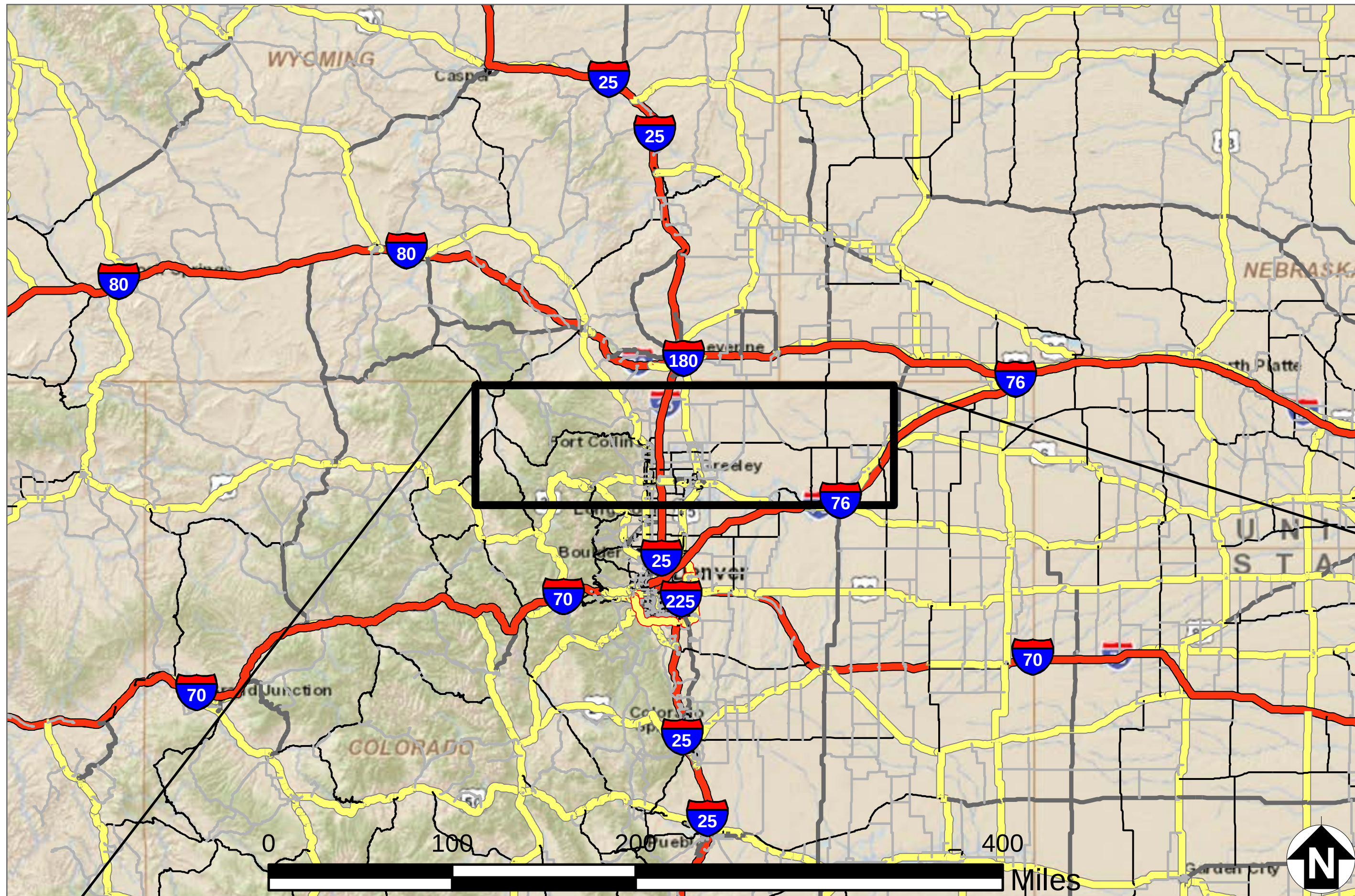
FIGURE 3-1
HEC-RAS CROSS-SECTIONS
HAMILTON RESERVOIR
LARIMER COUNTY, COLORADO

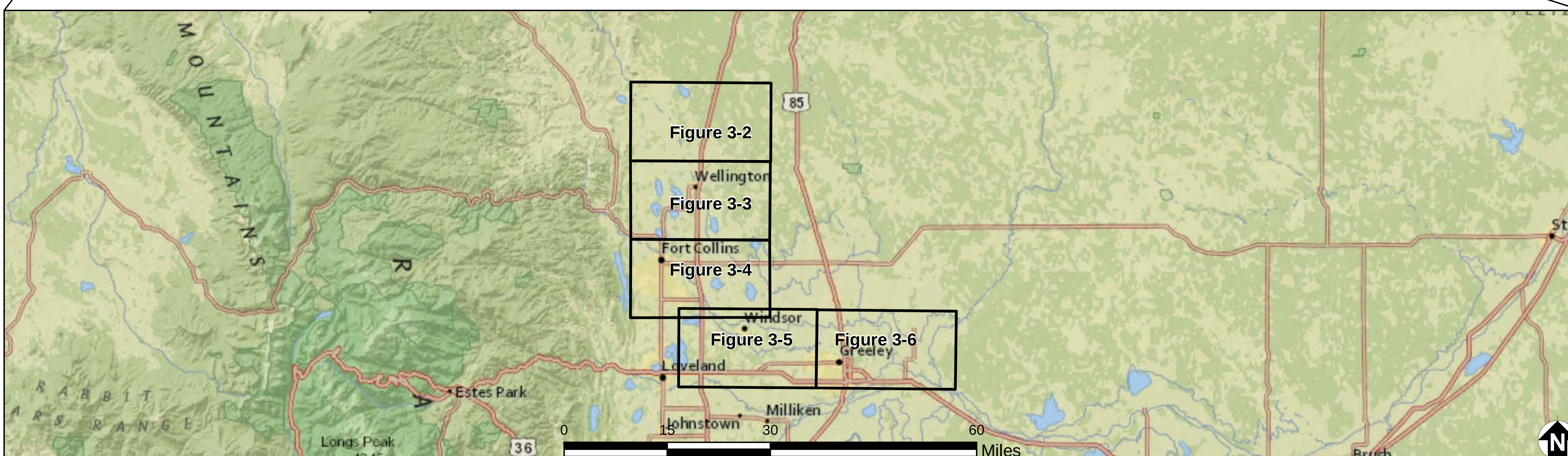
HAMILTON RESERVOIR (RAWHIDE DAM)
Emergency Action Plan
Dam Failure Inundation Maps

Prepared for
Platte River Power Authority

Engineering Analytics, Inc.

Project No.: 110295
February 2014





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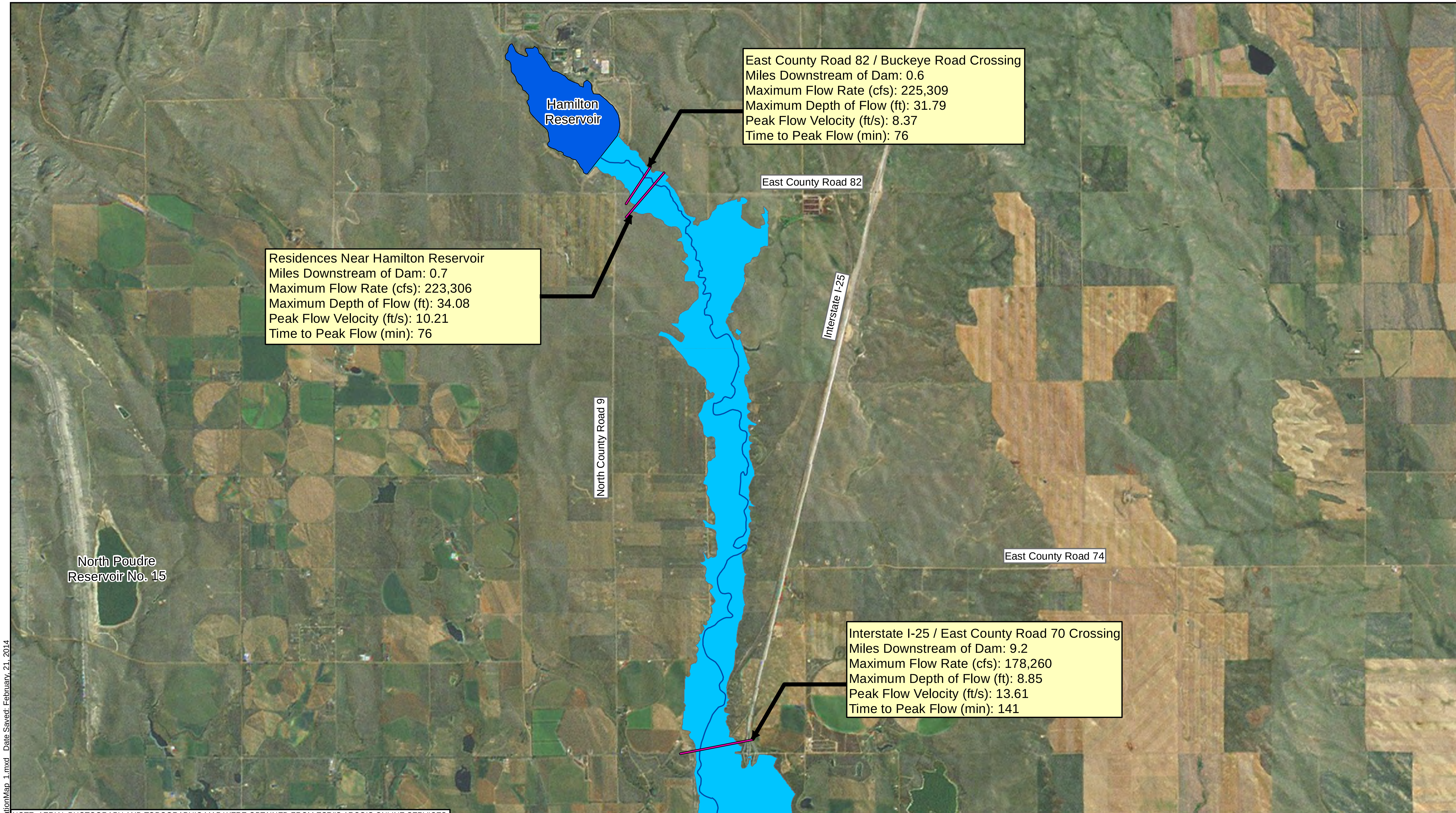
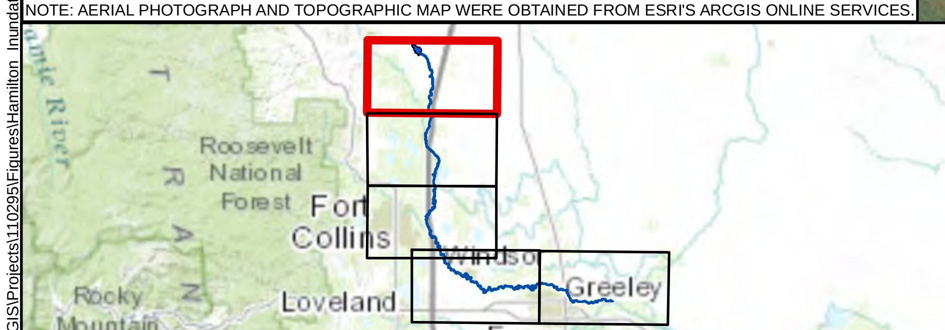


NOTE: AERIAL PHOTOGRAPH AND TOPOGRAPHIC MAP WERE OBTAINED FROM ESRI'S ARCGIS ONLINE SERVICES.



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EXPLANATION

- Approximate Extent of Inundation Area
- Flow Path Used In HEC-RAS Simulation
- Critical Cross Section Line

N

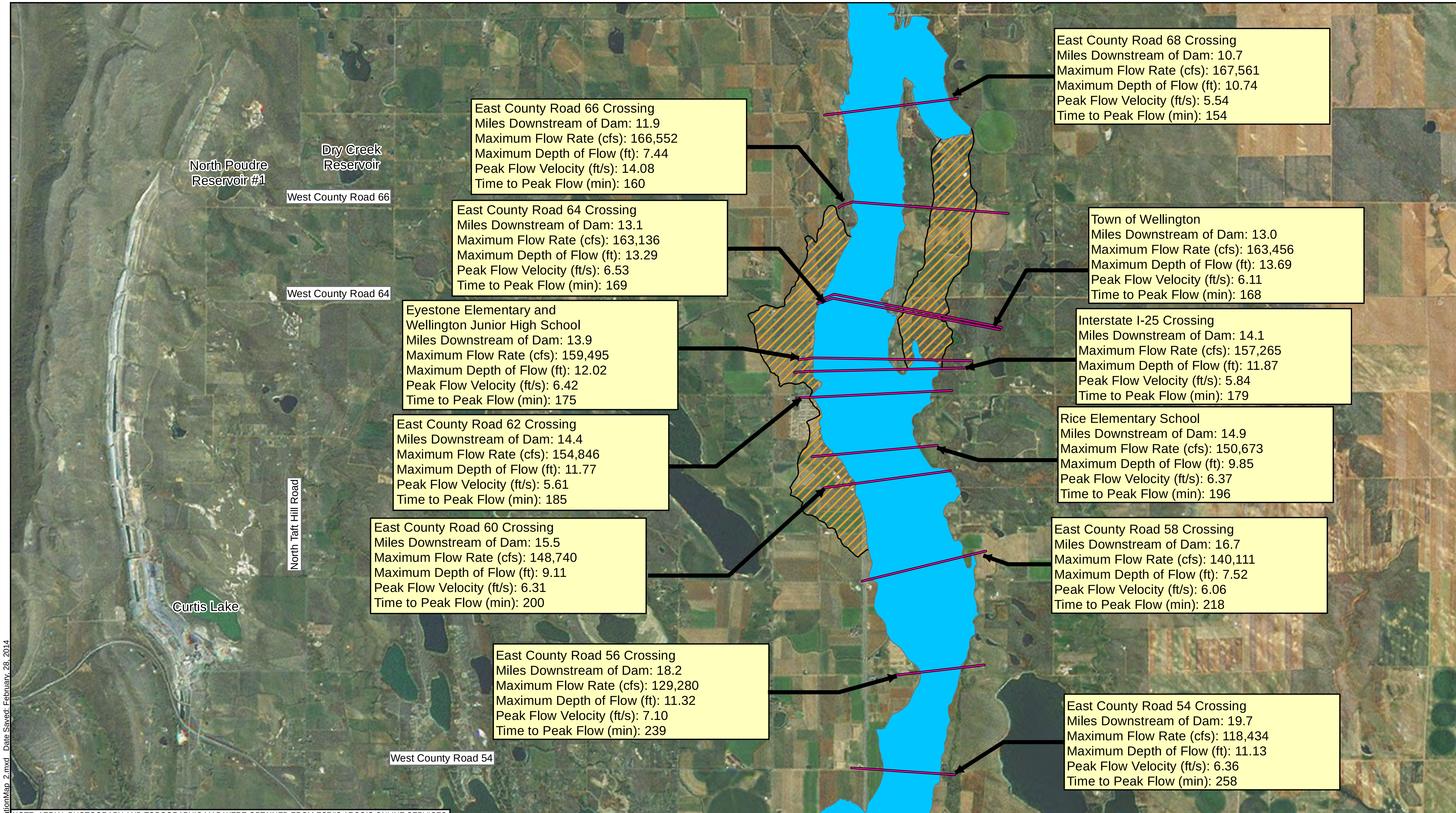
0 1 2 4

Miles

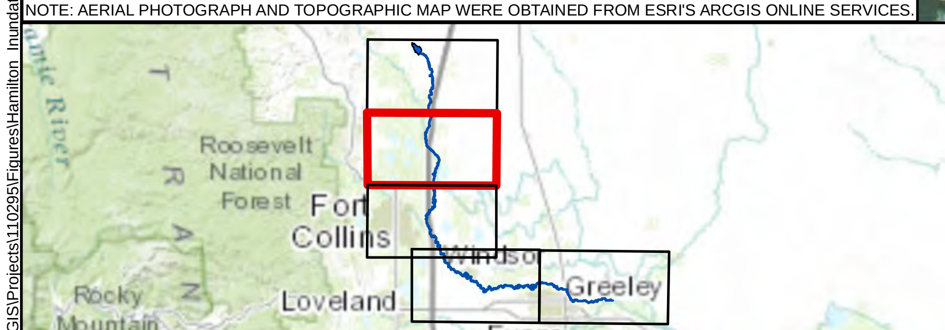
Engineering Analytics, Inc.

HAMILTON RESERVOIR
(RAWHIDE DAM)
Emergency Action Plan
Dam Failure Flood Inundation Map

Date: February 2014	Project No.: 110295	FIGURE 3-2



NOTE: AERIAL PHOTOGRAPH AND TOPOGRAPHIC MAP WERE OBTAINED FROM ESRI'S ARCGIS ONLINE SERVICES.



EXPLANATION

- Approximate Extent of Inundation Area
- Potential Inundation Area
- Flow Path Used In HEC-RAS Simulation
- Critical Cross Section Line

N

0 1 2 4

Miles

Engineering Analytics, Inc.

HAMILTON RESERVOIR
(RAWHIDE DAM)
Emergency Action Plan
Dam Failure Flood Inundation Map

Date: February 2014	Project No.: 110295	FIGURE 3-3

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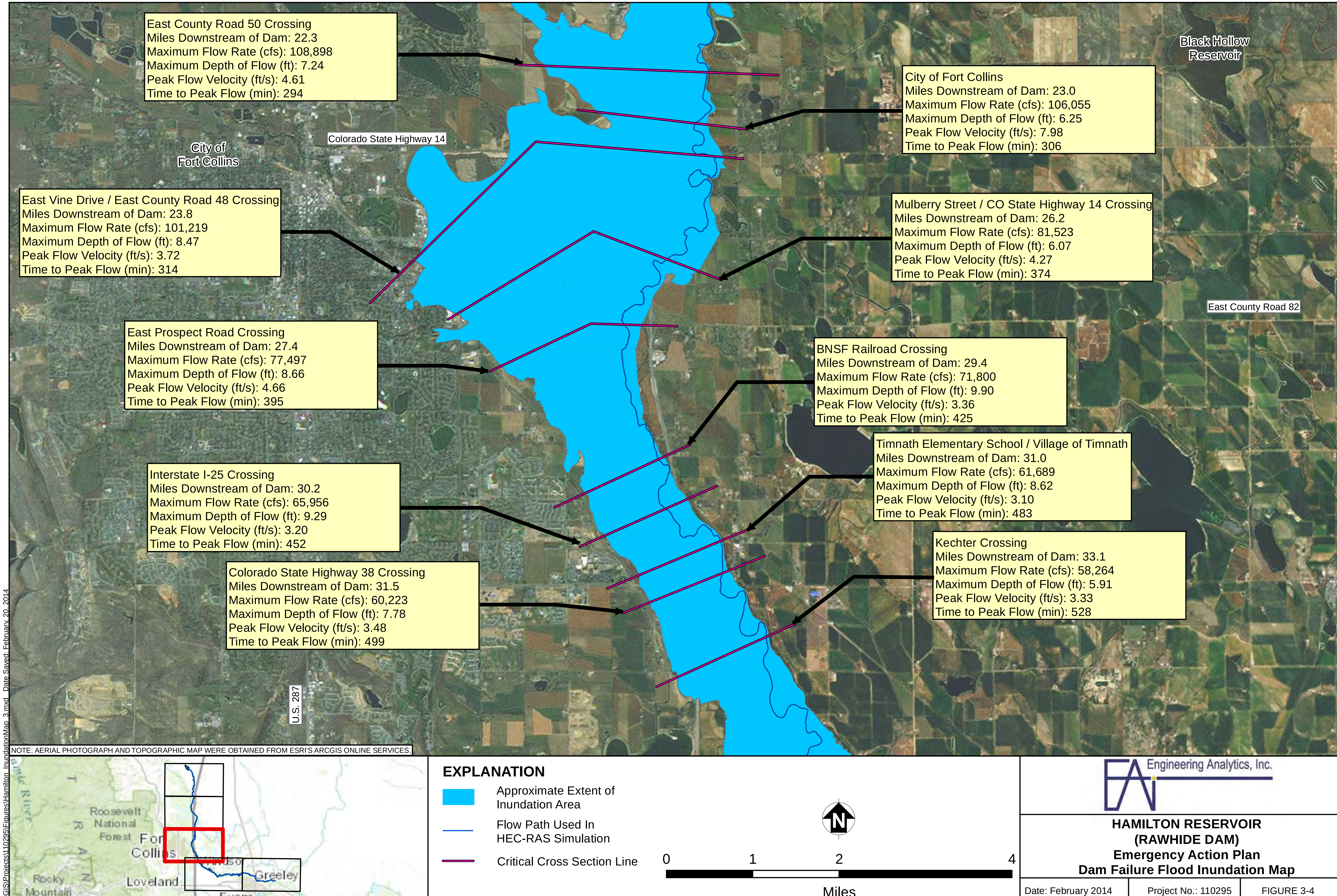
East County Road 50 Crossing
Miles Downstream of Dam: 22.3
Maximum Flow Rate (cfs): 108,898
Maximum Depth of Flow (ft): 7.24
Peak Flow Velocity (ft/s): 4.61
Time to Peak Flow (min): 294
Black Hollow Reservoir
City of Fort Collins
Miles Downstream of Dam: 23.0
Maximum Flow Rate (cfs): 106,055
Maximum Depth of Flow (ft): 6.25
Peak Flow Velocity (ft/s): 7.98
Time to Peak Flow (min): 306
City of Fort Collins
Colorado State Highway 14
East Vine Drive / East County Road 48 Crossing
Miles Downstream of Dam: 23.8
Maximum Flow Rate (cfs): 101,219
Maximum Depth of Flow (ft): 8.47
Peak Flow Velocity (ft/s): 3.72
Time to Peak Flow (min): 314
Mulberry Street / CO State Highway 14 Crossing
Miles Downstream of Dam: 26.2
Maximum Flow Rate (cfs): 81,523
Maximum Depth of Flow (ft): 6.07
Peak Flow Velocity (ft/s): 4.27
Time to Peak Flow (min): 374
East County Road 82
East Prospect Road Crossing
Miles Downstream of Dam: 27.4
Maximum Flow Rate (cfs): 77,497
Maximum Depth of Flow (ft): 8.66
Peak Flow Velocity (ft/s): 4.66
Time to Peak Flow (min): 395
BNSF Railroad Crossing
Miles Downstream of Dam: 29.4
Maximum Flow Rate (cfs): 71,800
Maximum Depth of Flow (ft): 9.90
Peak Flow Velocity (ft/s): 3.36
Time to Peak Flow (min): 425
Timnath Elementary School / Village of Timnath
Miles Downstream of Dam: 31.0
Maximum Flow Rate (cfs): 61,689
Maximum Depth of Flow (ft): 8.62
Peak Flow Velocity (ft/s): 3.10
Time to Peak Flow (min): 483
Interstate I-25 Crossing
Miles Downstream of Dam: 30.2
Maximum Flow Rate (cfs): 65,956
Maximum Depth of Flow (ft): 9.29
Peak Flow Velocity (ft/s): 3.20
Time to Peak Flow (min): 452
Kechter Crossing
Miles Downstream of Dam: 33.1
Maximum Flow Rate (cfs): 58,264
Maximum Depth of Flow (ft): 5.91
Peak Flow Velocity (ft/s): 3.33
Time to Peak Flow (min): 528
Colorado State Highway 38 Crossing
Miles Downstream of Dam: 31.5
Maximum Flow Rate (cfs): 60,223
Maximum Depth of Flow (ft): 7.78
Peak Flow Velocity (ft/s): 3.48
Time to Peak Flow (min): 499
U.S. 287
NOTE: AERIAL PHOTOGRAPH AND TOPOGRAPHIC MAP WERE OBTAINED FROM ESRI'S ARCGIS ONLINE SERVICES.
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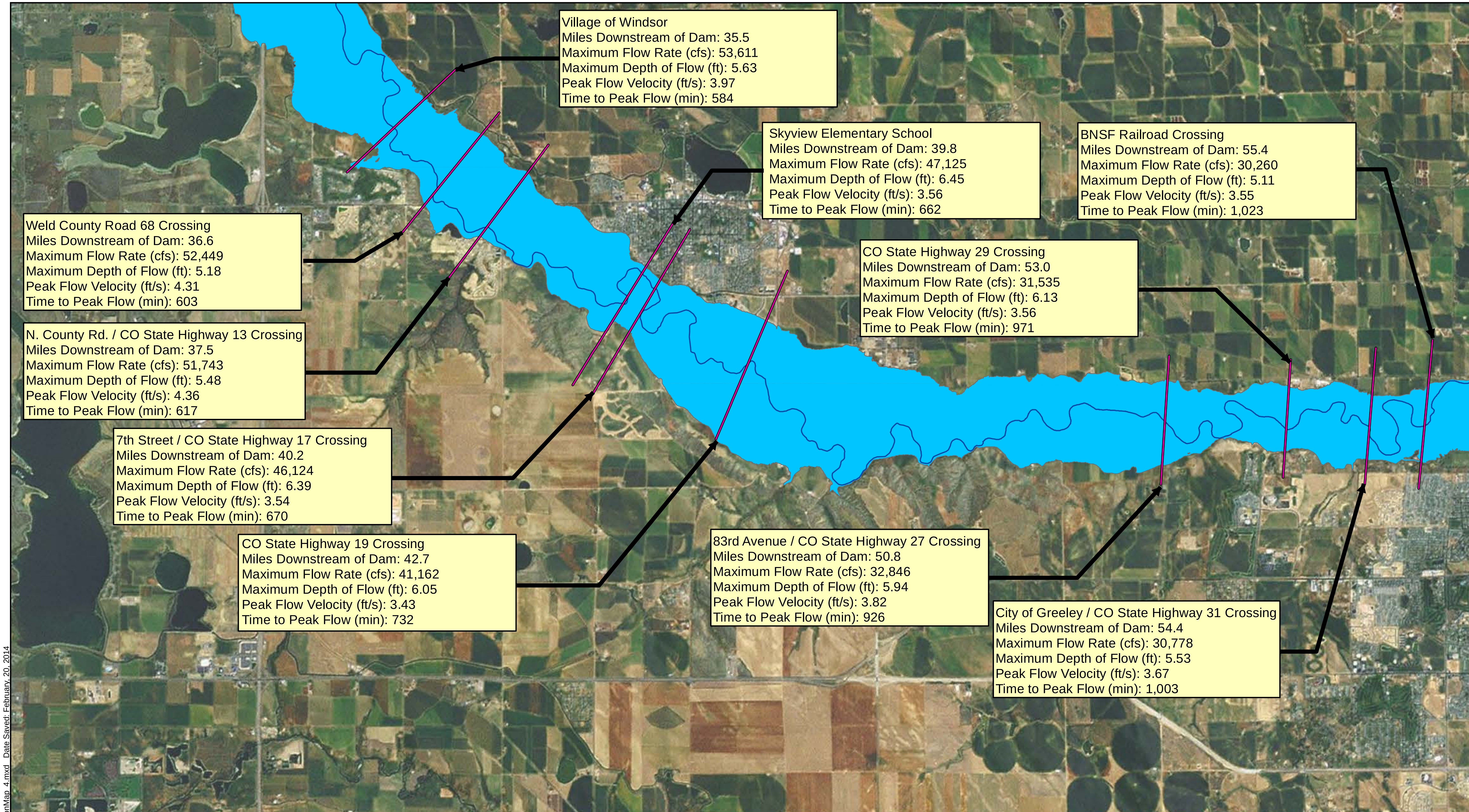
Roosevelt National Forest
Loveland
Greeley
Evans
EXPLANATION
Approximate Extent of Inundation Area
Flow Path Used In HEC-RAS Simulation
Critical Cross Section Line
N
0
1
2
4
Miles
Engineering Analytics, Inc.
HAMILTON RESERVOIR
(RAWHIDE DAM)
Emergency Action Plan
Dam Failure Flood Inundation Map
Date: February 2014
Project No.: 110295
FIGURE 3-4



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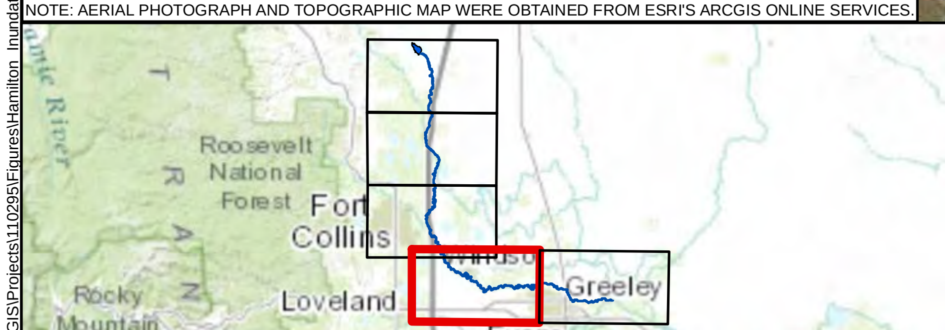

EXPLANATION

- Approximate Extent of Inundation Area
- Flow Path Used In HEC-RAS Simulation
- Critical Cross Section Line

N

0 1 2 4

Miles

Engineering Analytics, Inc.

HAMILTON RESERVOIR
(RAWHIDE DAM)
Emergency Action Plan
Dam Failure Flood Inundation Map

Date: February 2014	Project No.: 110295	FIGURE 3-5

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TABLES

Table 1-1 Hamilton Reservoir Dam Characteristics

Elevation Top Dam Embankment	5,680 feet
Elevation Toe Dam Embankment	5,590 feet
Elevation Invert Principal Outlet Pipe	5,590 feet
Emergency Spillway Elevation	5,670.5 feet
Slope of Upstream Dam Face	3H:1V
Slope of Downstream Dam Face	3H:1V
Width of Dam Crest	40 feet
Length of Dam Crest	7,200 feet

Table 3-1 Geometric Parameters

Emergency Spillway Elevation	5,670.5 feet
Outlet Elevation	5,590 feet
Jurisdictional Dam Height	80.5 feet
Area at Spillway Elevation	458.5 acres
Volume at Spillway Elevation	16,308 acre-feet
Hazard Classification	High
Size	Large

Table 3-2 Hamilton Reservoir Elevation-Storage Relationship

Elevation (feet)	Total Volume (acre-feet)	Description
5,590	0.0	Bottom of Reservoir
5,596	4.6	
5,600	23.9	
5,604	80.1	
5,608	194.2	
5,612	388.2	
5,616	684.0	
5,620	1089.0	
5,624	1600.7	
5,628	2226.7	
5,632	2973.9	
5,636	3842.6	
5,640	4825.0	
5,644	5919.0	
5,648	7133.8	
5,652	8462.8	
5,656	9904.7	
5,660	11470.7	
5,664	13169.1	
5,668	15,190.0	
5,669	15,645.0	
5,670	16,090.0	
5,670.5	16,308.0	Emergency Spillway

Table 3-3 Froehlich (2008) Results

ESTIMATION OF DAM BREACH PARAMETERS
USING THE FROEHLICH 2008 METHOD

PROJECT: Rawhide Dam, DamID 710107

BREACH INPUT PARAMETERS:

Select Failure Mode From Drop-Down Menu:	PIPING	
Height of water over base elevation of breach (H_w) =	80.5	Feet
Volume of water in the reservoir at the time of failure (V_w) =	16,308.0	Acre-Feet
Reservoir Surface Area at Hw (A_s) =	510.0	Acres
Height of breach (H_b) =	90.0	Feet
Failure Mode Factor (K_o) =	1	
Breach Side-Slope Ratio (Z_b) =	0.7	Z(H):1(V)
Dam Size Class:	Large	Assumes Full Reservoir At Time of Breach.

CALCULATED BREACH CHARACTERISTICS:

Average Breach Width (B_{avg}) =	219.8	Feet
Bottom Width of Breach (B_b) =	156.8	Feet
Breach Formation Time (T_f) =	0.92	Hours
Storage Intensity (SI) =	202.6	Acre Feet/Foot
Predicted Peak Flow (Q_p) =	322398	Cubic Feet per Second

RESULTS CHECK:

Average Breach Width Divided by Height of Breach (B_{avg}/H_b) =	2.44	If (B_{avg}/H_b) > 0.6, Full Breach Devlopment is Anticipated
Erosion Rate (ER), Calculated as (B_{avg}/T_f) =	239.9	
Erosion Rate Divided by Height of Water Over Base of Breach (ER/H_w) =	3.0	If 1.6 < (ER/H_w) < 21, Erosion Rate is Assumed Reasonable

Table 3-4 Input for HEC-RAS Dam Breach

Breach Parameters	
Initial Water Elevation	5,670.5 ft
Top Elevation	5,680 ft
Bottom Elevation	5,590 ft
Piping Hole Width	156.8 ft
Piping Elevation	5,590 ft
Piping Coefficient	0.5 ft
Development time	0.92 hr

Table 3-5 HEC-RAS Output

Critical Cross-Section	River Station	Downstream Distance (miles)	Peak Flow (ft^3/s)	Peak Flow Velocity (ft/s)	Maximum Water Surface Elevation (ft amsl)	Maximum Depth of Flow (ft)	Time to Peak Flow (min)
A	356896	0.6	225,309	8.37	5,610.51	31.79	76
B	356070	0.7	223,306	10.21	5,607.80	34.08	76
C	311187	9.2	178,260	13.61	5,341.19	8.85	141
D	303217	10.7	167,561	5.54	5,305.13	10.74	154
E	297249	11.9	166,552	14.08	5,254.33	7.44	160
F	291080	13.0	163,456	6.11	5,214.64	13.69	168
G	290811	13.1	163,136	6.53	5,212.81	13.29	169
H	286641	13.9	159,495	6.42	5,198.99	12.02	175
I	285699	14.1	157,265	5.84	5,195.22	11.87	179
J	284068	14.4	154,846	5.61	5,187.21	11.77	185
K	280329	14.9	150,673	6.37	5,166.33	9.85	196
L	278153	15.5	148,740	6.31	5,155.97	9.11	200
M	271527	16.7	140,111	6.06	5,124.95	7.52	218
N	264006	18.2	129,280	7.10	5,091.45	11.32	239
O	256128	19.7	118,434	6.36	5,058.47	11.13	258
P	251172	20.6	113,588	6.33	5,039.45	12.42	272
Q	242426	22.3	108,898	4.61	4,997.99	7.24	294
R	238573	23.0	106,055	7.98	4,979.18	6.25	306
S	234530	23.8	101219	3.72	4,934.20	8.47	314
T	221550	26.2	81,523	4.27	4,912.83	6.07	374
U	215327	27.4	77,497	4.66	4,895.13	8.66	395
V	204607	29.4	71,800	3.36	4,870.04	9.90	425
W	200609	30.2	65,956	3.20	4,835.85	9.29	452
X	196241	31.0	61,689	3.10	4,855.61	8.62	483

Table 3-5 HEC-RAS Output (continued)

Y	193724	31.5	60,223	3.48	4,850.81	7.78	499
Z	185291	33.1	58,264	3.33	4,828.03	5.91	528
AA	172328	35.5	53,611	3.97	4,814.05	5.63	584
BB	166741	36.6	52,449	4.31	4,804.67	5.18	603
CC	162184	37.5	51,743	4.36	4,796.49	5.48	617
DD	149735	39.8	47,125	3.56	4,776.69	6.45	662
EE	147553	40.2	46,124	3.54	4,774.47	6.39	670
FF	134558	42.7	41,162	3.43	4,761.30	6.05	732
GG	91891	50.8	32,846	3.82	4,714.60	5.94	926
HH	80360	53.0	31,535	3.56	4,702.15	6.13	971
II	72477	54.4	30,778	3.67	4,693.02	5.53	1003
JJ	67254	55.4	30,260	3.55	4,686.60	5.11	1023
KK	56686	57.4	29,101	3.12	4,673.06	4.24	1071
LL	50262	58.7	28,637	3.11	4,663.65	4.15	1100
MM	42572	60.1	27,927	2.61	4,652.26	3.99	1137
NN	35620	61.4	27,156	3.11	4,642.18	4.44	1176
OO	27702	62.9	26,627	3.18	4,630.42	4.67	1211
PP	4407	67.3	23,054	3.52	4,598.33	4.94	1363

Table 3-6 Critical Cross-Sections

Critical Cross-Section	River Station	Downstream Distance (miles)	Cross-Section Description
A	356896	0.6	East County Road 82 / Buckeye Road
B	356070	0.7	Residences Near Reservoir
C	311187	9.2	Interstate (I-25) / East County Road 70
D	303217	10.7	East County Road 68
E	297249	11.9	East County Road 66
F	291080	13.0	City of Wellington
G	290811	13.1	East County Road 64
H	286641	13.9	Eyestone Elementary School and Wellington Junior High School
I	285699	14.1	Interstate (I-25)
J	284068	14.4	Cleveland Avenue / East County Road 62
K	280329	14.9	Rice Elementary School
L	278153	15.5	East County Road 60
M	271527	16.7	East County Road 58
N	264006	18.2	East County Road 56
O	256128	19.7	East County Road 54
P	251172	20.6	Interstate (I-25) / East County Road 52
Q	242426	22.3	Mountain Vista Drive / East County Road 50
R	238573	23.0	City of Fort Collins
S	234530	23.8	East Vine Drive / County Road 48
T	221550	26.2	East Mulberry Street / Colorado State Highway 14
U	215327	27.4	East Prospect Road
V	204607	29.4	BNSF Railroad Tracks
W	200609	30.2	Interstate (I-25)
X	196241	31.0	Timnath Elementary School / Village of Timnath
Y	193724	31.5	East Harmony Road / Colorado State Highway 38

Table 3-6 Critical Cross-Sections (continued)

Z	185291	33.1	Kechter Road
AA	172328	35.5	Village of Windsor / East County Road 32
BB	166741	36.6	Weld County Road 68
CC	162184	37.5	North County Road / Colorado State Highway 13
DD	149735	39.8	Skyview Elementary School
EE	147553	40.2	7th Street / Colorado State Highway 17
FF	134558	42.7	Colorado State Highway 19
GG	91891	50.8	83rd Avenue / Colorado State Highway 27
HH	80360	53.0	Colorado State Highway 29
II	72477	54.4	City of Greeley / Colorado State Highway 31
JJ	67254	55.4	BNSF Railroad Tracks
KK	56686	57.4	North 35th Avenue
LL	50262	58.7	Platte Valley Youth Services Center / North 25th Avenue
MM	42572	60.1	U.S. 85
NN	35620	61.4	BNSF Railroad Tracks
OO	27702	62.9	Weld County Road 43
PP	4407	67.3	Confluence With South Platte River

APPENDIX A
REFERENCES

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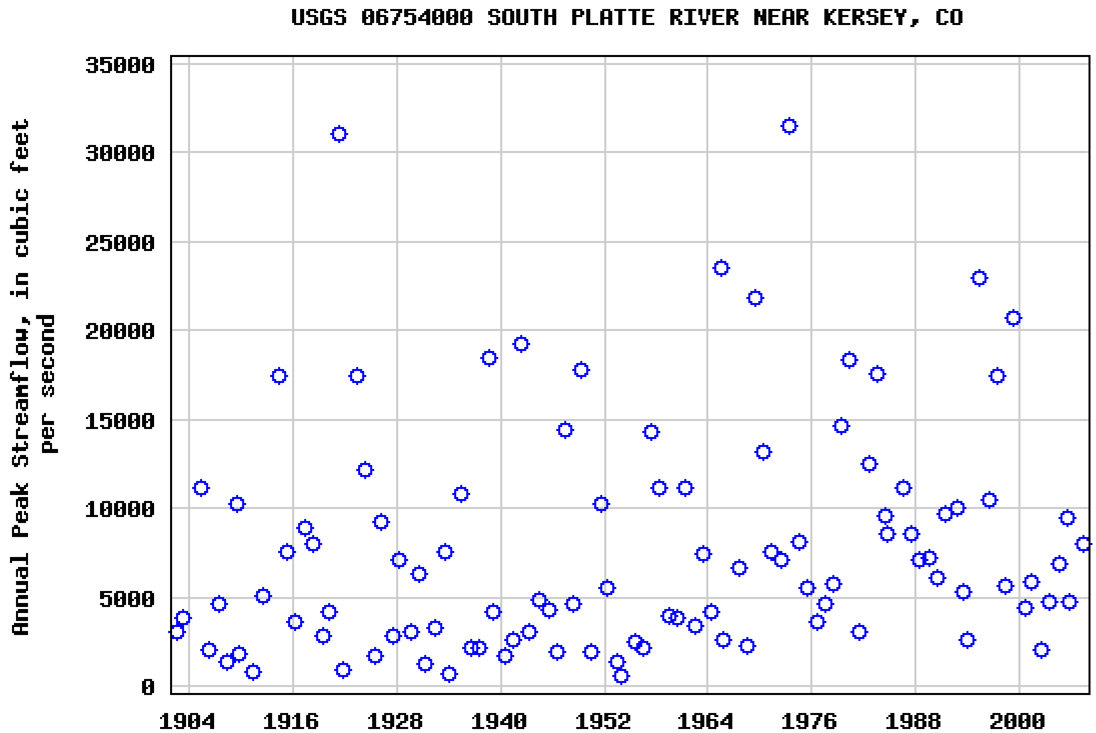
APPENDIX B
HEC-RAS ANALYSIS

APPENDIX B.1
PEAK STREAMFLOW – SOUTH PLATTE RIVER
USGS STREAM GAGE #06754000
SOUTH PLATTE RIVER NEAR KERSEY, CO



USGS 06754000 SOUTH PLATTE RIVER NEAR KERSEY, CO
Annual Peak Streamflow, in cubic feet per second
35000
30000
25000
20000
15000
10000
5000
0
1904
1916
1928
1940
1952
1964
1976
1988
2000

>

```
Z06754000                         USGS
H06754000        402443104334400008123SW101900039661           4578.02
N06754000        SOUTH PLATTE RIVER NEAR KERSEY, CO
Y06754000
306754000        19020922   300026             4.50
306754000        19030619   385026             5.00
306754000        19050523  1120026             8.50
306754000        19060507   208026             4.60
306754000        19070730   461026
306754000        19080731   135026
306754000        19090706  1020026
306754000        19091016   179026
306754000        19110706    84826
306754000        19120717   512026
306754000        19140604  1750026
306754000        19150427   750026
306754000        19160522   365026
306754000        19170602   895026             7.85
306754000        19180626   799026
306754000        19190802   28206              3.926
306754000        19200505   41906              4.54
306754000        19210607  3100016
306754000        19211213    9376              1.836
306754000        19230611  1750026
306754000        19240607  122006              6.456
306754000        19250616   16606              4.50
306754000        19260423   92106              6.96
306754000        19270730   28606              4.89
306754000        19280605   71206              6.63
306754000        19290808   30506              4.95
306754000        19300816   63606              6.44
306754000        19310531   12006              3.73
306754000        19320730   32506              5.20
306754000        19330912   75006              6.59
306754000        19340219    6876              3.07
306754000        19350531  108006              7.29
306754000        19360805   22006              5.396
306754000        19370628   21406              5.47
306754000        19380904  185006              9.73
306754000        19390312   41606              6.59
306754000        19400704   16706              4.73
306754000        19410610   26406              5.62
306754000        19420425  192006              9.50
306754000        19430603   30906              5.97
306754000        19440518   49006              6.51
306754000        19450810   43106              6.13
306754000        19460720   18906              4.99
306754000        19470624  144006              9.62
306754000        19480602   46206              6.28
306754000        19490615  178006              9.66
306754000        19500618   19606              4.97
306754000        19510805  103006              8.55
306754000        19520609   54706              6.70
306754000        19530621   13706              4.44
306754000        19531106    6106              3.60
306754000        19550808   25106              5.63
306754000        19560528   21906              5.21
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306754000	19570510	143006	10.26
306754000	19580526	112006	8.70
306754000	19590523	40006	6.07
306754000	19600520	38006	5.71
306754000	19610605	112006	8.35
306754000	19620702	34006	5.63
306754000	19630617	74306	7.11
306754000	19640530	41706	6.07
306754000	19650618	235006	10.75
306754000	19651001	26406	4.93
306754000	19670622	66306	6.75
306754000	19680609	22806	4.80
306754000	19690508	218006	10.70
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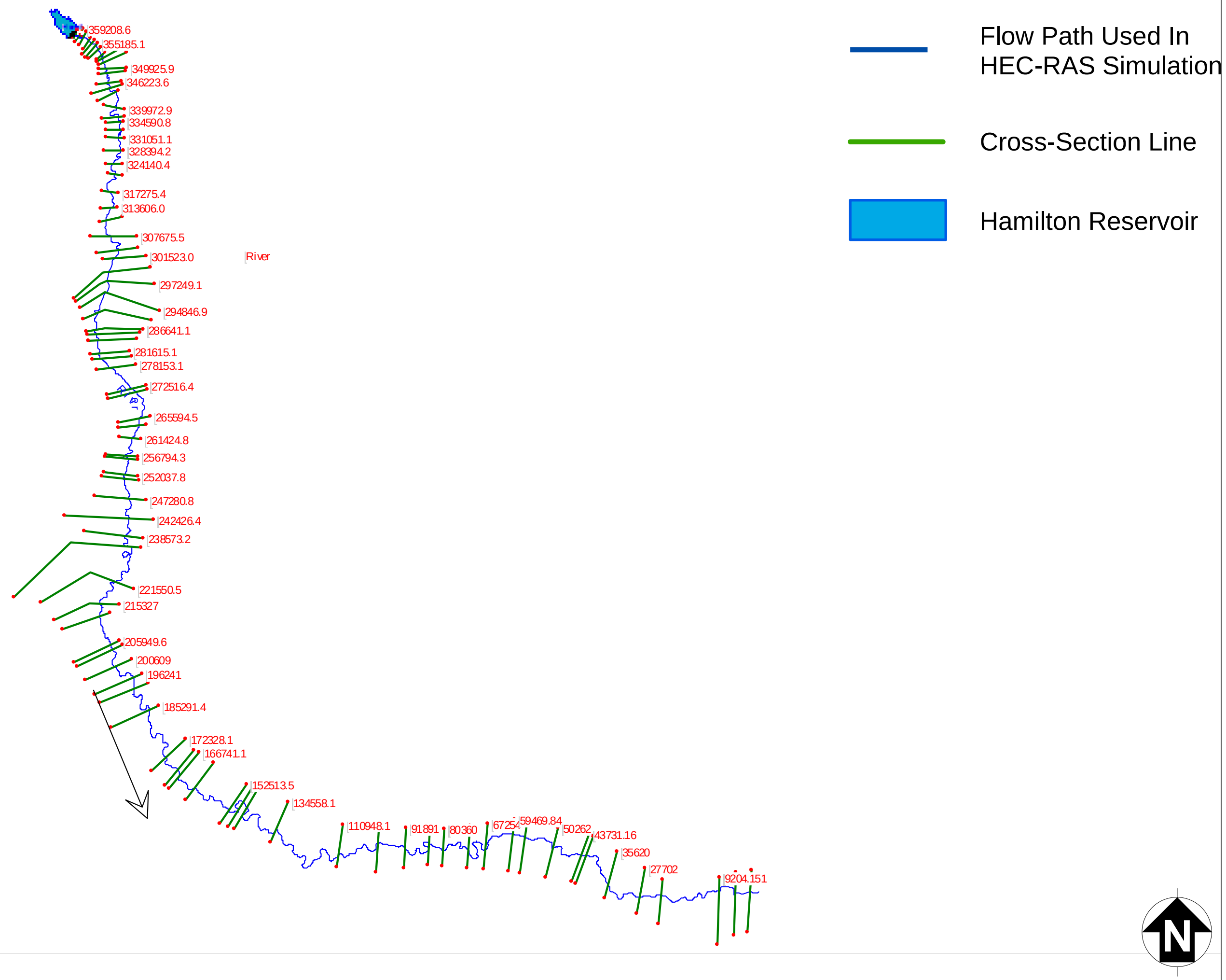
306754000	19931019	26506	5.48
306754000	19950531	229006	11.00
306754000	19960527	105006	8.53
306754000	19970614	175006	10.40
306754000	19980509	56806	7.39
306754000	19990501	207006	11.50
306754000	20000718	43806	6.92
306754000	20010506	58206	8.00
306754000	20020525	20706	5.47
306754000	20030602	46906	7.14
306754000	20040820	68506	8.30
306754000	20050605	95106	9.49
306754000	20051011	47406	7.41
306754000	20070426	80406	8.87

APPENDIX B.2
HEC-RAS MODEL



EXPLANATION

Flow Path Used In HEC-RAS Simulation

Cross-Section Line

Hamilton Reservoir

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Project No. 110295

October 2013

Engineering Analytics, Inc.

HEC-RAS GEOMETRY
FLOW MODEL
HAMILTON RESERVOIR
LARIMER COUNTY, COLORADO

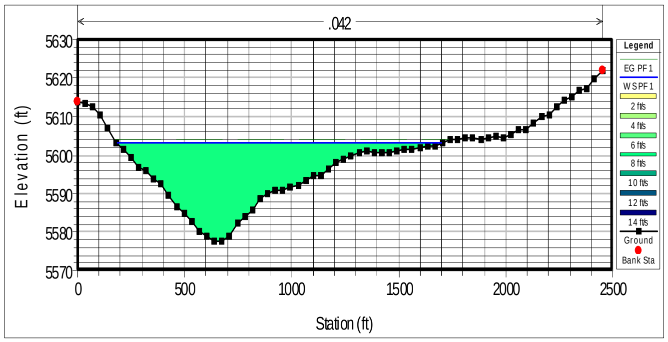
APPENDIX B.3
HEC-RAS RESULTS

HEC-RAS Plan: Sep28 River: Main Reach: Main Profile: PF1

Reach	River Sta	Profile	Q Total (cfs)	W.S. Elev (ft)	Vel Chnl (ft/s)	Max Chl Dpth (ft)	Froude # Chl
River	356896.8	Max WS	225,309	5610.51	8.37	31.79	0.41
River	356070.6	Max WS	223,306	5607.80	10.21	34.08	0.58
River	311187.6	Max WS	178,260	5341.19	13.61	8.85	0.98
River	303217.2	Max WS	167,561	5305.13	5.54	10.74	0.40
River	297249.1	Max WS	166,552	5254.33	14.08	7.44	1.17
River	291080.1	Max WS	163,456	5214.64	6.11	13.69	0.46
River	290811.1	Max WS	163,136	5212.81	6.53	13.29	0.51
River	286641.1	Max WS	159,495	5198.99	6.42	12.02	0.50
River	285699.1	Max WS	157,265	5195.22	5.84	11.87	0.46
River	284068.1	Max WS	154,846	5187.21	5.61	11.77	0.47
River	280329	Max WS	150,673	5166.33	6.37	9.85	0.52
River	278153.1	Max WS	148,740	5155.97	6.31	9.11	0.52
River	271527.1	Max WS	140,111	5124.95	6.06	7.52	0.49
River	264006.1	Max WS	129,280	5091.45	7.10	11.32	0.51
River	256128.1	Max WS	118,434	5058.47	6.36	11.13	0.45
River	251172.1	Max WS	113,588	5039.45	6.33	12.42	0.50
River	242426.4	Max WS	108,898	4997.99	4.61	7.24	0.42
River	238573.2	Max WS	106,055	4979.18	7.98	6.25	0.68
River	234529.8	Max WS	101,219	4934.20	3.72	8.47	0.31
River	221550.5	Max WS	81,523	4912.83	4.27	6.07	0.39
River	215327	Max WS	77,497	4,895.13	4.66	8.66	0.38
River	204607.1	Max WS	71,800	4870.04	3.36	9.90	0.27
River	200609	Max WS	65,956	4835.85	3.20	9.29	0.27
River	196241	Max WS	61,689	4855.61	3.10	8.62	0.27
River	193724.9	Max WS	60,223	4850.81	3.48	7.78	0.32
River	185291.4	Max WS	58,264	4828.03	3.33	5.91	0.34
River	172328	Max WS	53,611	4814.05	3.97	5.63	0.38
River	166741	Max WS	52,449	4804.67	4.31	5.18	0.42
River	162184	Max WS	51,743	4796.49	4.36	5.48	0.41
River	149735	Max WS	47,125	4776.69	3.56	6.45	0.30
River	147553	Max WS	46,124	4774.47	3.54	6.39	0.30
River	134558	Max WS	41,162	4761.30	3.43	6.05	0.30
River	91891	Max WS	32,846	4714.60	3.82	5.94	0.32
River	80360	Max WS	31,535	4702.15	3.56	6.13	0.32
River	72477	Max WS	30,778	4693.02	3.67	5.53	0.32
River	67254	Max WS	30,260	4686.60	3.55	5.11	0.32
River	56686	Max WS	29,101	4673.06	3.12	4.24	0.35
River	50262	Max WS	28,637	4663.65	3.11	4.15	0.35
River	42572	Max WS	27,927	4652.26	2.61	3.99	0.32
River	35620	Max WS	27,156	4642.18	3.11	4.44	0.33
River	27702	Max WS	26,627	4630.42	3.18	4.67	0.34
River	4407.605	Max WS	23,054	4598.33	3.52	4.94	0.38

APPENDIX B.4
HEC-RAS CRITICAL CROSS-SECTIONS

Rawhide Dam Breach Plan: Sep13_NewGeo
RS=356896 CROSS-SECTION A



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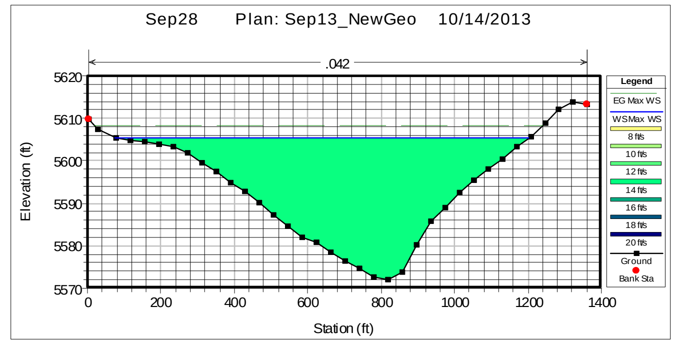

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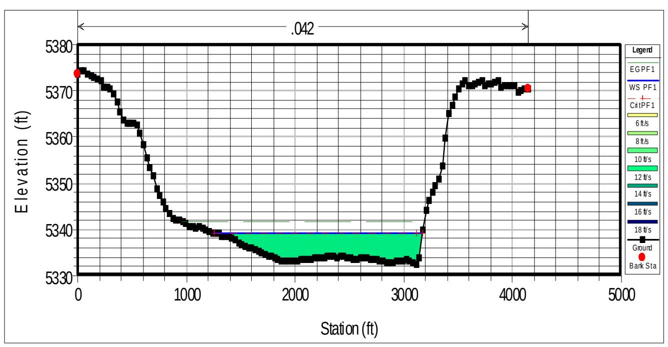

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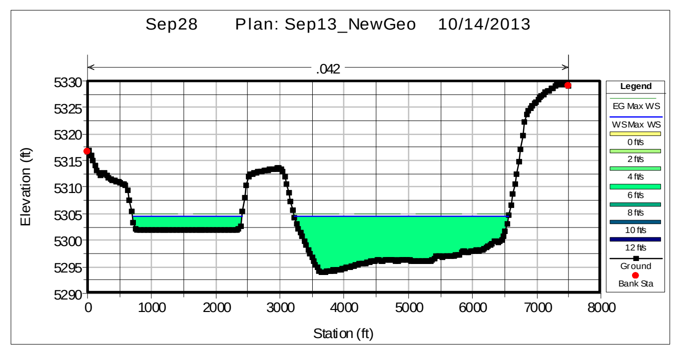

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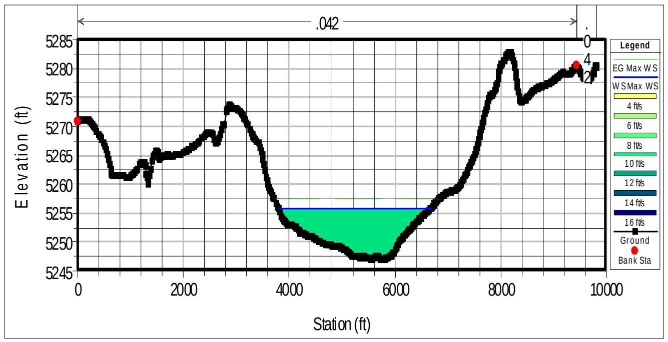

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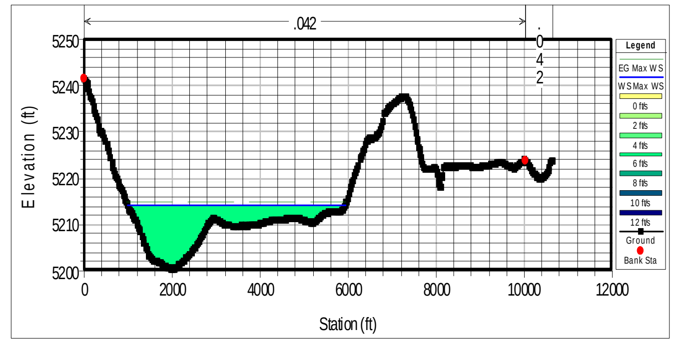

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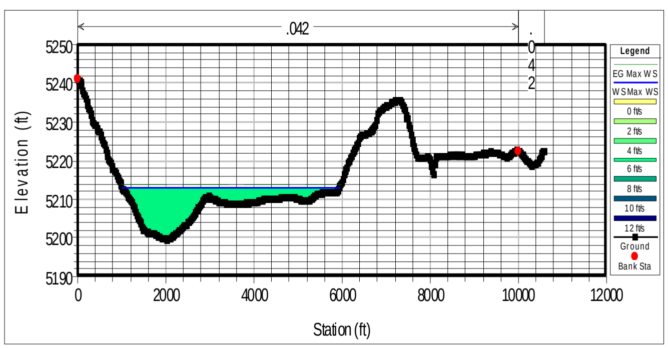

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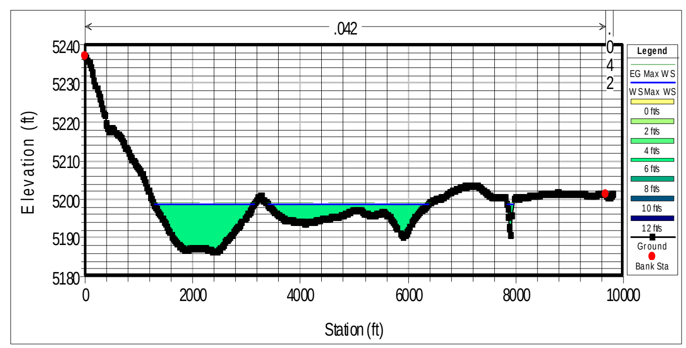
RS=286641 CROSS-SECTION H



Rawhide Dam Breach   Plan: Sep13_NewGeo
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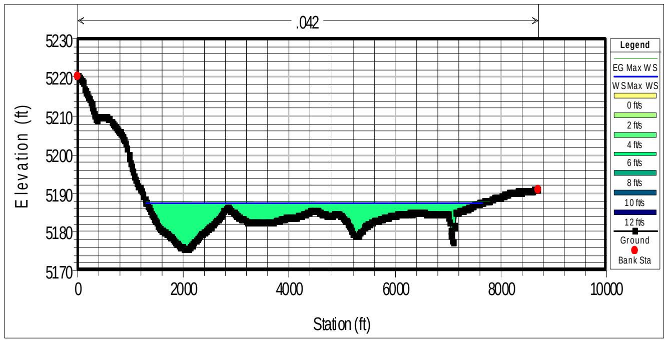

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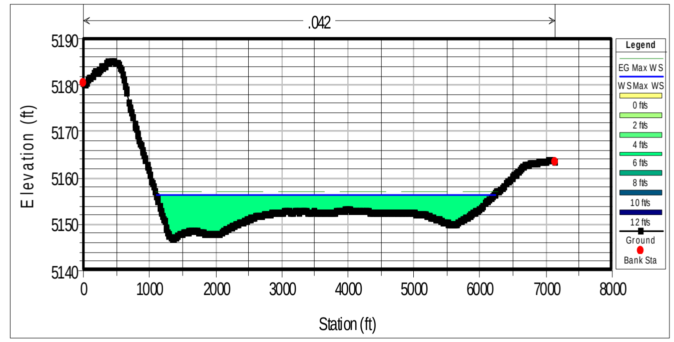

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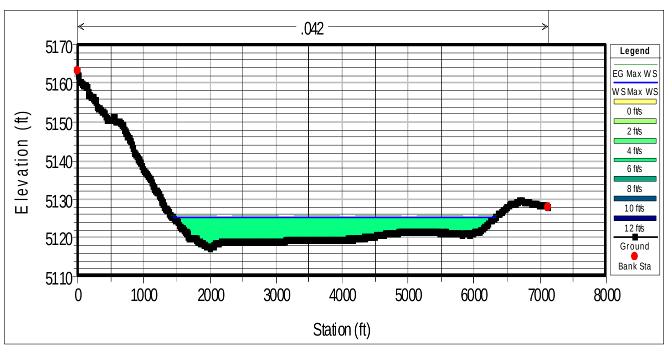

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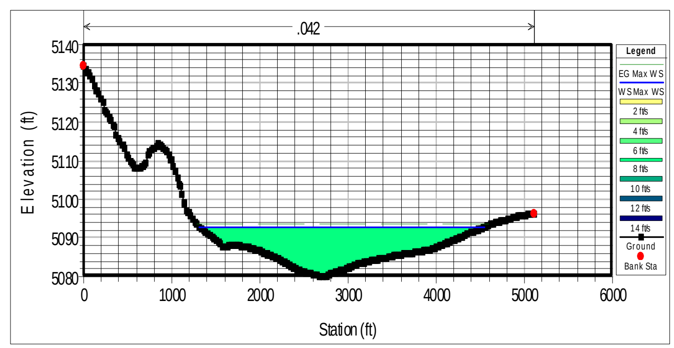

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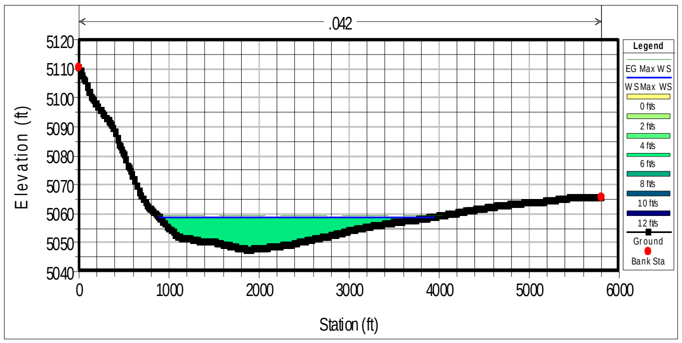

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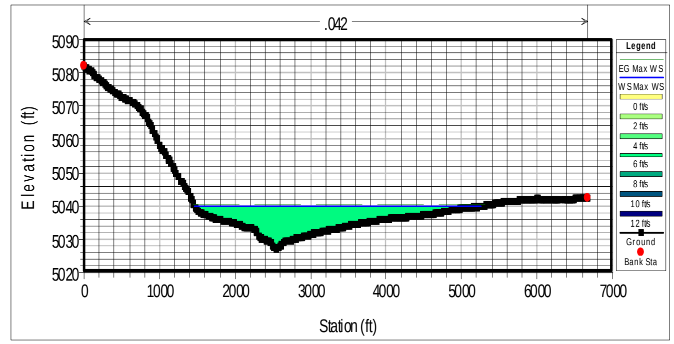

Rawhide Dam Breach   Plan: Sep13_NewGeo
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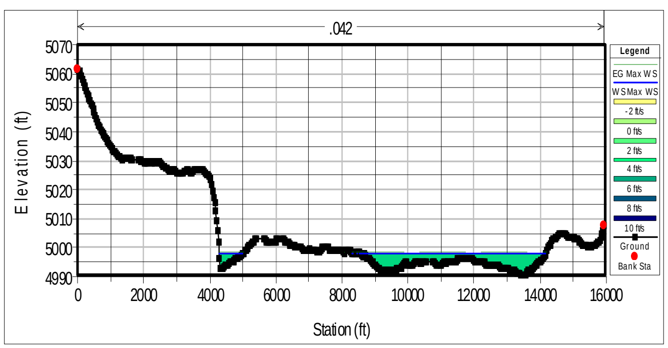
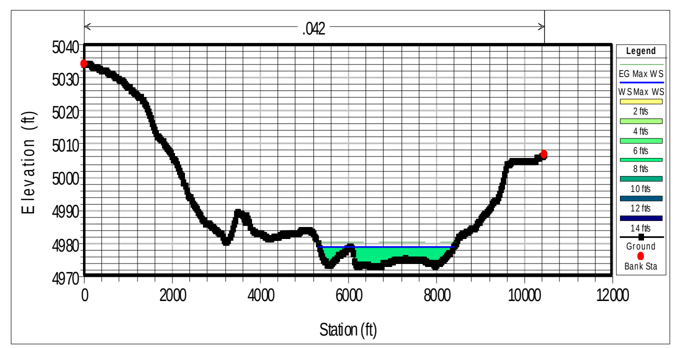
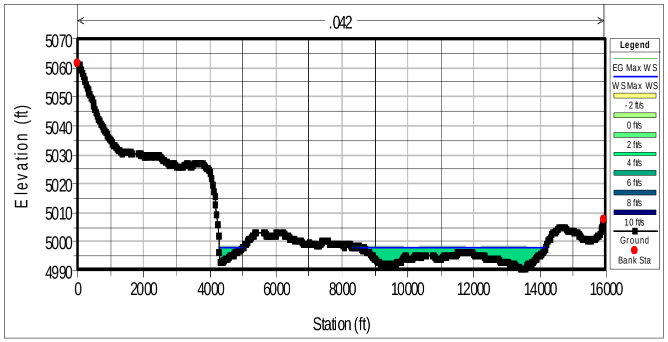


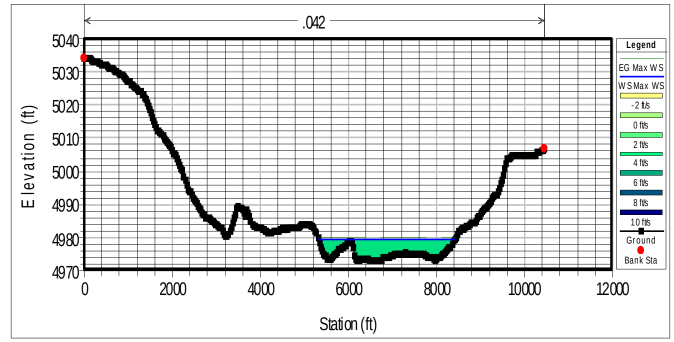
Rawhide Dam Breach   Plan: Sep13_NewGeo
RS=251172 CROSS-SECTION P



Rawhide Dam Breach Plan: Sep13_NewGeo
RS=242426 CROSS-SECTION Q



Rawhide Dam Breach Plan: Sep13_NewGeo
RS=238573 CROSS-SECTION R



Rawhide Dam Breach Plan: Sep13_NewGeo
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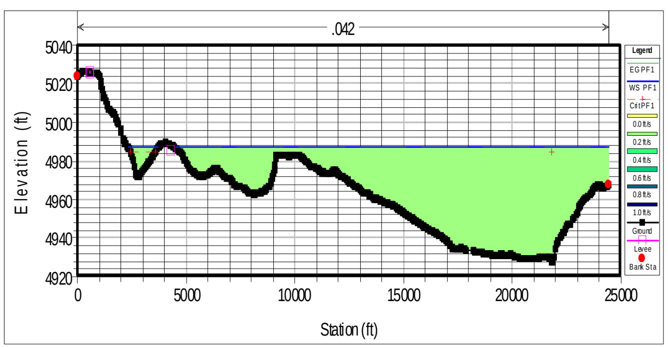

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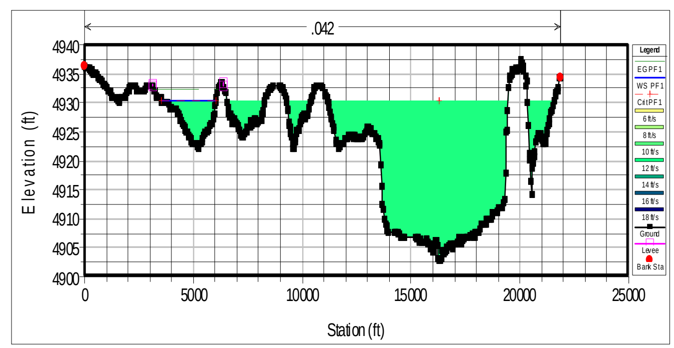

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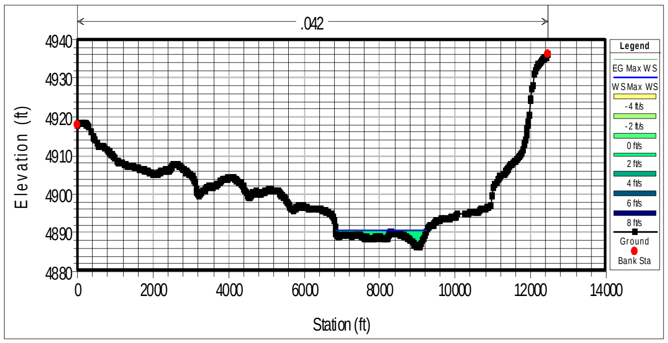
RS=215277 CROSS-SECTION U



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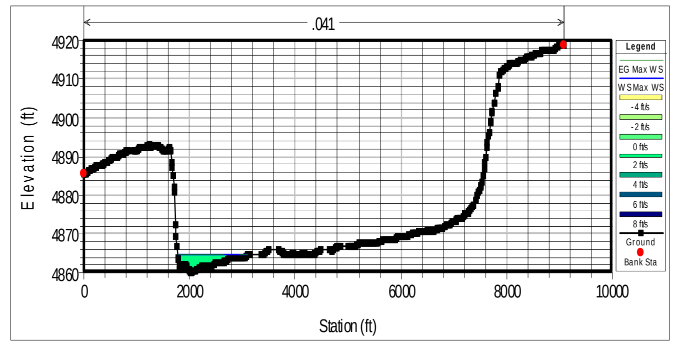
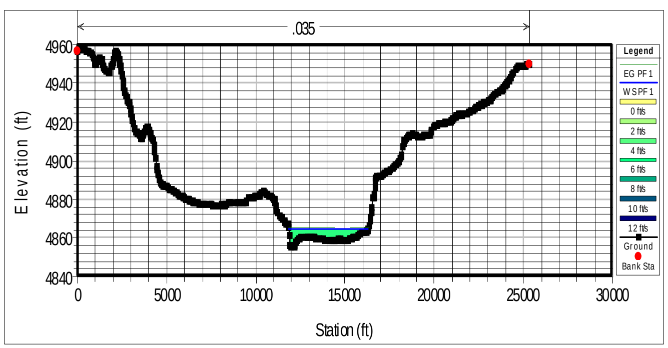
RS=204607 CROSS-SECTION V



Rawhide Dam Breach   Plan: Sep13_NewGeo
RS=200639 CROSS-SECTION W



Rawhide Dam Breach   Plan: Sep13_NewGeo
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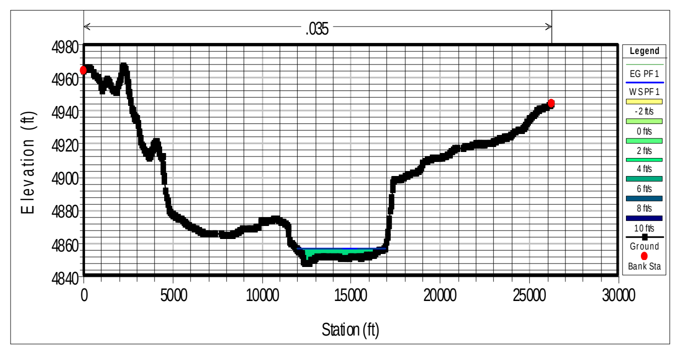

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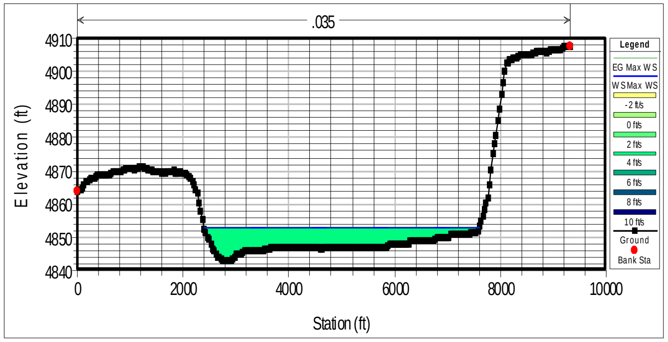
RS=193724 CROSS-SECTION Y



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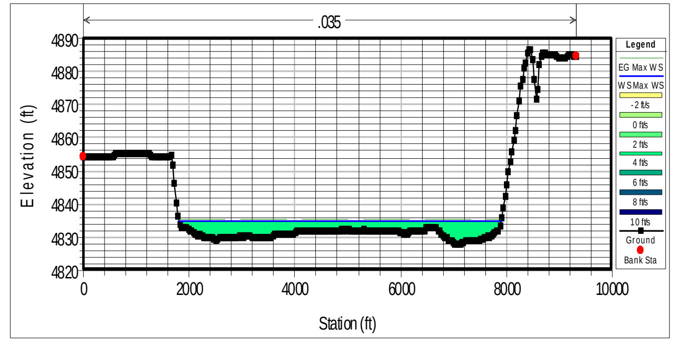
RS=185291 CROSS-SECTION Z



Rawhide Dam Breach   Plan: Sep13_NewGeo
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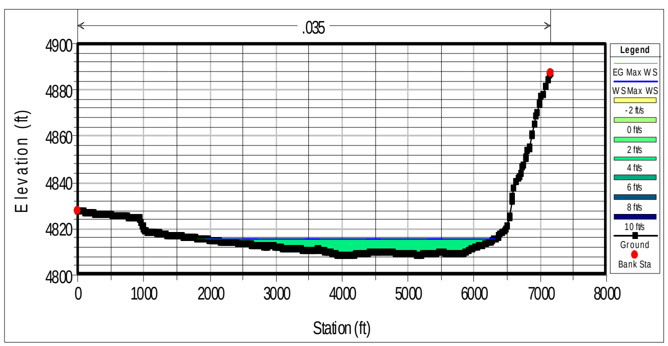

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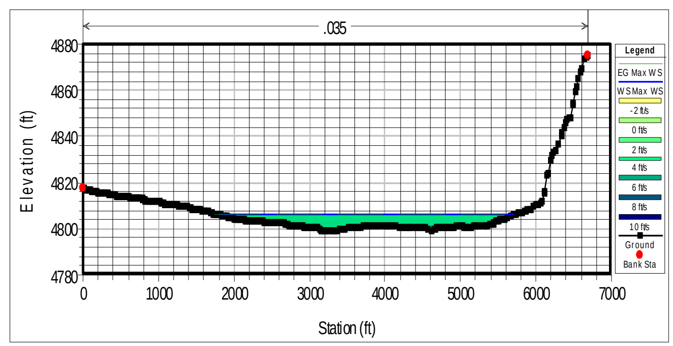

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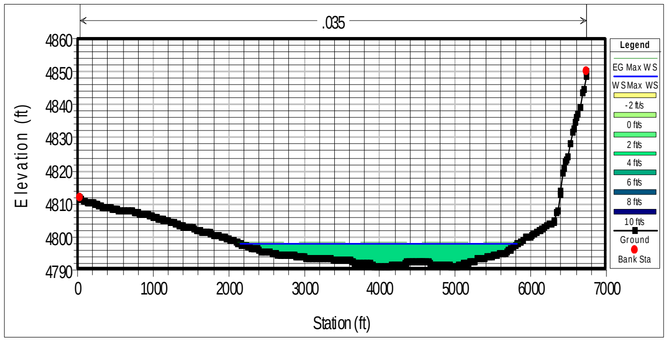
RS=162184 CROSS-SECTION CC



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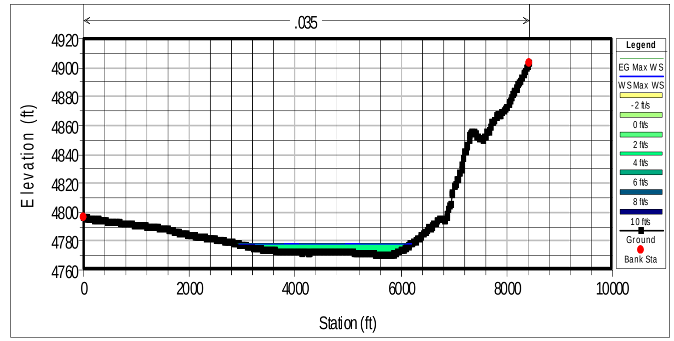

Rawhide Dam Breach   Plan: Sep13_NewGeo
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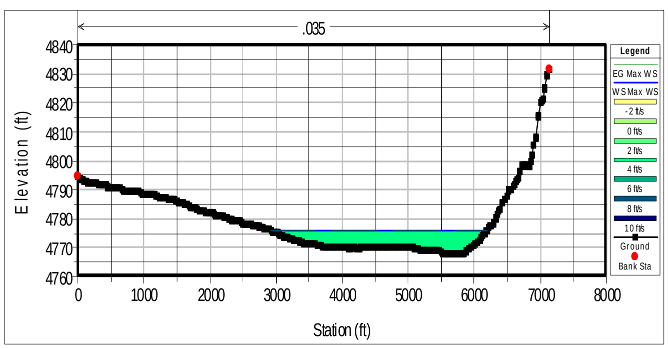

Rawhide Dam Breach   Plan: Sep13_NewGeo
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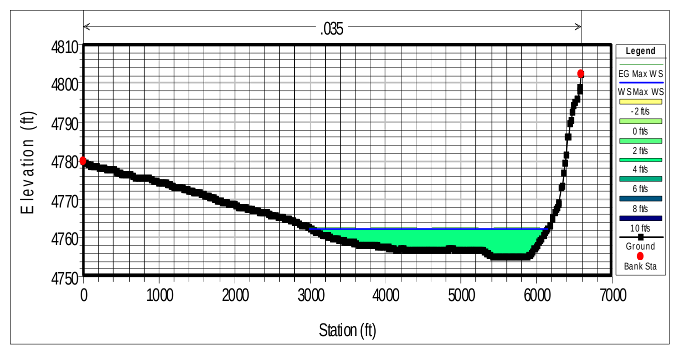

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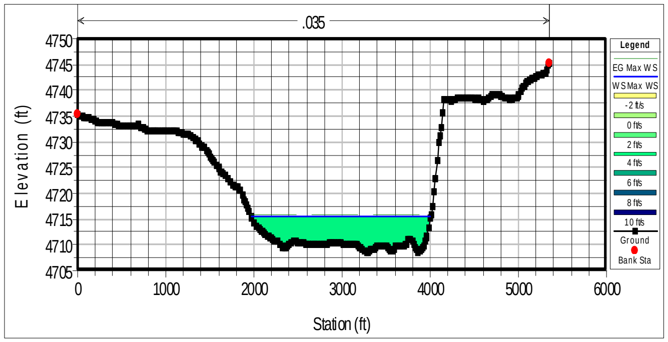

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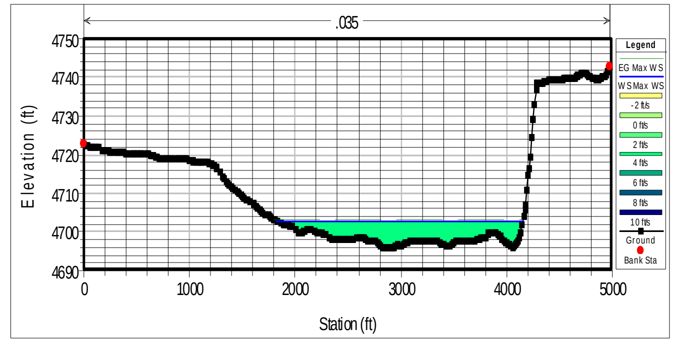

Rawhide Dam Breach   Plan: Sep13_NewGeo
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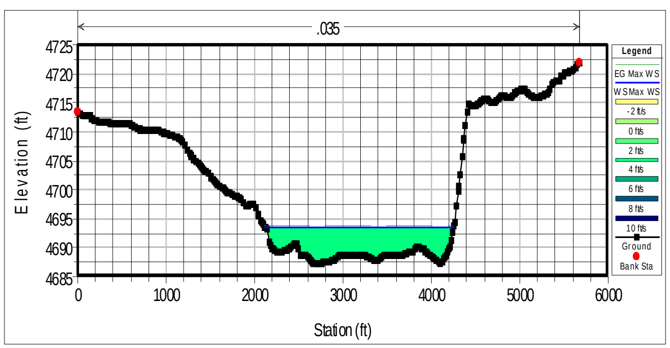

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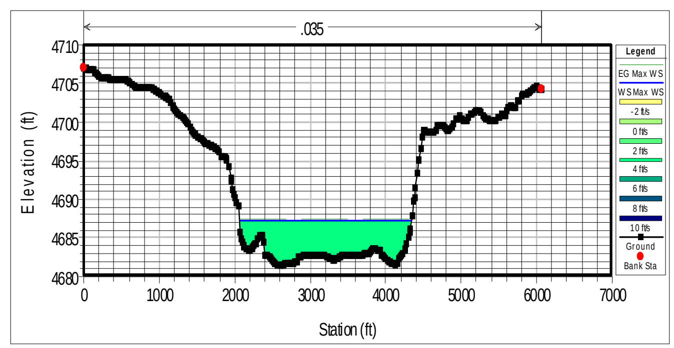
RS=67254 CROSS-SECTION JJ



Rawhide Dam Breach Plan: Sep13_NewGeo
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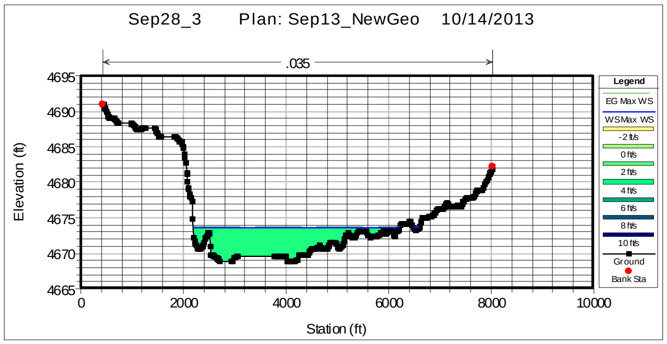

Rawhide Dam Breach Plan: Sep13_NewGeo
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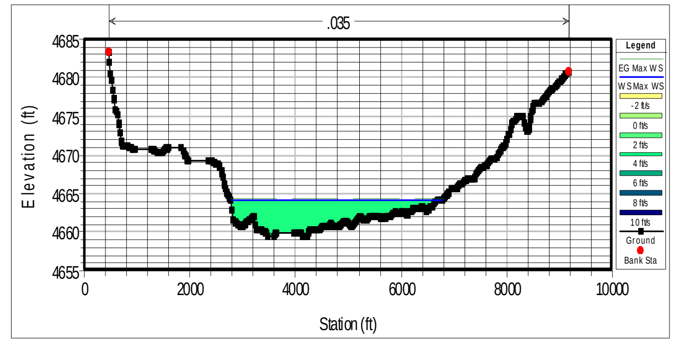

Rawhide Dam Breach Plan: Sep13_NewGeo
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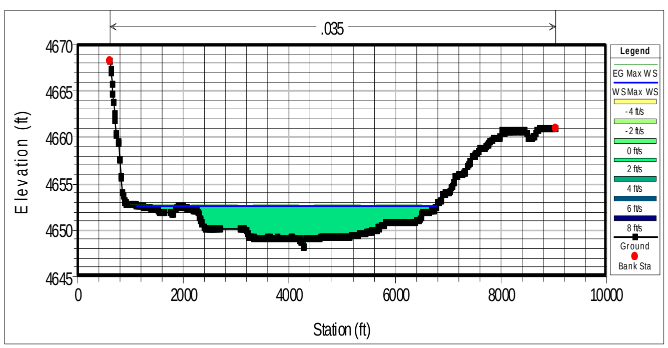
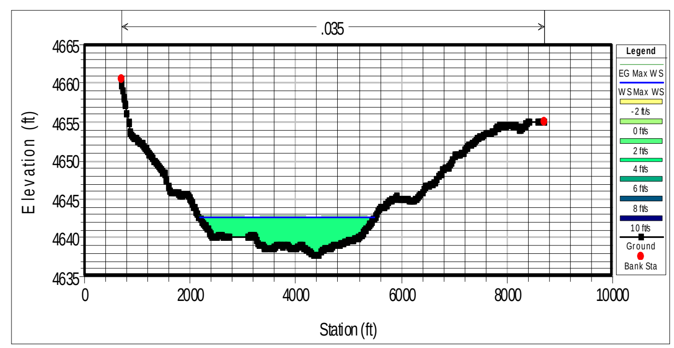
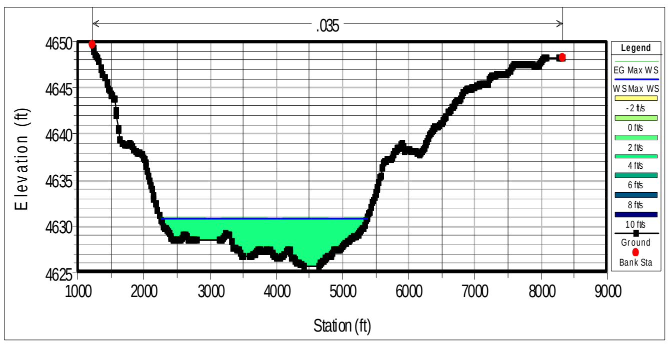


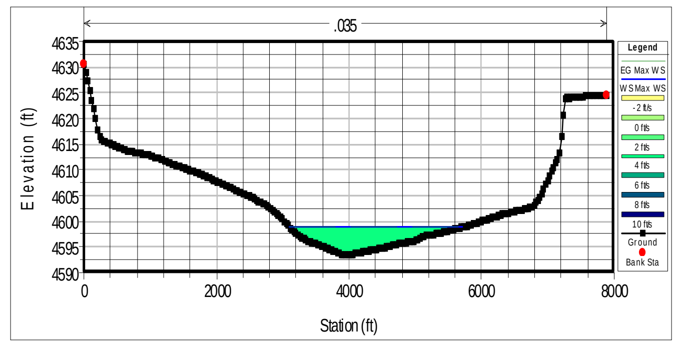
Rawhide Dam Breach Plan: Sep13_NewGeo
RS=35620 CROSS-SECTION NN



Rawhide Dam Breach   Plan: Sep13_NewGeo
RS=27702 CROSS-SECTION OO



Rawhide Dam Breach   Plan: Sep13_NewGeo
RS=4407 CROSS-SECTION PP



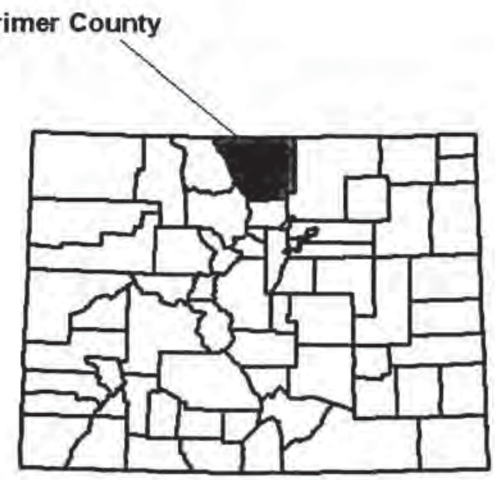
APPENDIX B.5
MANNING’S N

FLOOD INSURANCE STUDY

LARIMER COUNTY, COLORADO

AND INCORPORATED AREAS
VOLUME 1 OF 4

Community Name	Community Number
LARIMER COUNTY	
(UNINCORPORATED AREAS)	080101
BERTHOUD, TOWN OF	080296
ESTES PARK, TOWN OF	080193
FORT COLLINS, CITY OF	080102
JOHNSTOWN, TOWN OF	080250
LOVELAND, TOWN OF	080103
TIMNATH, TOWN OF	080005
WELLINGTON, TOWN OF	080104



REVISED: JUNE 17, 2008

Federal Emergency Management Agency
FLOOD INSURANCE STUDY NUMBER
08069CV001B

Hydraulic analyses for Boxelder Creek and Cooper Slough were conducted by Anderson Consulting Engineers, Inc. (Reference 75). Water surface profiles were developed using HEC-RAS. A combination of field survey data and orthophoto based topographic mapping (prepared at a 2-foot contour interval) was used as the base information for defining cross section geometry and for delineating floodplains. For Boxelder Creek and Cooper Slough, Manning's n-values generally range from 0.035 to 0.060 for the channels and from 0.045 to 0.070 for the overbanks.

Eight study reaches located within the Boxelder Creek/Cooper Slough basins required boundary conditions. During the hydraulic analyses, twelve splitflows were identified within the Boxelder Creek basin, and two splitflows were identified within the Cooper Slough basin. Also, many shallow flooding areas exist adjacent to the floodplains for both basins.

Cross-sectional data for Cache La Poudre River, including overbanks, for the backwater analyses were obtained by field survey. All bridges were surveyed to obtain elevation data and structural geometry. The land-use and hydraulic-roughness data were also obtained by field surveys.

Water-surface elevations for floods of the selected recurrence intervals were computed using the USACE HEC-2 step-backwater program (Reference 22). Starting water-surface elevations for the Cache La Poudre River at the Larimer-Weld County line were obtained from a concurrent study in Weld County (Reference 40).

Channel and overbank hydraulic roughness factors (Manning's "n") used in the hydraulic computations were determined using engineering judgment and were based on field observations of the stream and flood plain areas and the descriptions presented in standard engineering references (Reference 41). The channel "n" value for the Cache La Poudre River was estimated as 0.035 throughout the study reach, and the overbank "n" values ranged from 0.043 to 0.100. The hydraulic analyses for this study were based on unobstructed flow.

During the analysis, several divided-flow and split-flow reaches were identified. The most prominent split flows occur near the upstream end of the study reach, just downstream of Horsetooth Road. For the 2-, 1-, and 0.2-percent annual chance flood events, water splits out over the right overbank and becomes separated from the main flow by the embankment for Interstate Highway 25 (I-25).

The divided-flow path extends southerly along the west side of I-25, before crossing I-25 and returning to the main flow path. There are two locations where water splits away from the divided flow path and returns to the main path.

A third flow path occurs just north of County Road 36E. This path is caused by flow escaping from the I-25 divided-flow path as it returns to the main channel.

At the downstream end of the study reach, another split-flow situation is present. Water splits from the left overbank over the Larimer-Weld County Line Road. This split is affected by backwater conditions, so the weir coefficient for the split has been greatly