Trout Creek Dam Breach Inundation Report

February 18, 2014

Prepared for: Paul Moltz
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SEO DamID:110233

Applegate Group, Inc.
Water Resource Advisors for the West

AG Project No. : 13-116

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INTRODUCTION

This report presents the results of a breach inundation mapping analysis performed for the Trout Creek Dam, State of Colorado DAMID 110233. The report summarizes the three main tasks pertinent to the analysis: 1) breach modeling, 2) flood routing, and 3) flood inundation mapping.

Trout Creek Dam, is located south of Buena Vista, Colorado. The dam is located on Trout Creek, tributary to the Arkansas River, and is generally situated in Section 26, Township 14 North, Range 78 West. This dam, classified as High Hazard by the Dam Safety Branch of the Colorado Division of Water Resources (CDWR), is owned and operated by Paul Moltz.

Applegate Group, Inc. (Applegate) was retained by Mr. Moltz to complete this work. The following Applegate personnel contributed to the analysis and completion of this report:

Lindsay George, P.E.	Project Manager
Carrie Herbolsheimer, PE	Water Resource Engineer

Our professional services for preparing this breach inundation mapping report were performed in accordance with generally accepted engineering practices and the standard of care used in performing these types of analyses; no other warranty, express or implied, is made.

BREACH MODELING

The first task of this analysis was to develop a flood hydrograph resulting from a "sunny-day" breach of the dam assuming the reservoir was at normal capacity prior to the breach. As such, no inflow into Trout Creek Dam at the time of the breach was assumed.

According to guidance published under the CDWR's *Guidelines for Hazard Classification* (CDWR, Nov 2010), the Trout Creek Dam is considered a Large dam. Pursuant to the CDWR's *Guidelines for Dam Breach Analysis* (CDWR, Feb 2010), for Large Dams with a medium storage intensity, the dam breach parameters should be based on either the empirical breach relationships developed by David C. Froehlich (Froehlich, 1987) or the MacDonald & Langridge Monopolis with Washington State failure time (MLM). Because a sunny day breach was modeled, an overtopping breach is not considered likely, so only the piping failure mode was considered.

The Froehlich and MLM calculations require certain parameters of the dam be specified. These parameters, and the values selected for this analysis, are as follows:

Parameter	Value	Source
Maximum Water Depth (H_w)	70.7 ft	Dam height per spillway (7950) and outlet (7879.3) elevations
Reservoir Volume (V_w)	671.7 ac-ft	Storage at spillway height (7950) per stage-storage table
Reservoir Surface Area (A_s)	26.5 ac	Maximum surface area per Stage/Storage curve
Height of Breach (H_b)	72.7 ft	Dam Crest (7952) and outlet (7879.3)
Crest Width of Dam (C)	15 ft	From as-constructed drawings
Slope of Upstream Dam Face (Z_u)	vertical	From as-constructed drawings
Slope of Downstream Dam Face (Z_d)	0.7	From as-constructed drawings

The resulting breach parameters for the empirical relationships can be found in **Appendix A**. The predicted peak breach discharge based on the Froelich Method is 89,500 cfs, with a breach formation time of 0.23 hours. The MLM Method predicts a peak breach discharge of 24,223 cfs with a breach formation time of 0.64 hours.

Because the dam is constructed of roller compacted concrete, neither the Froelich Method nor the MLM method is necessarily applicable. Therefore a literature review was performed, which resulted in only one paper related to modeling an RCC dam breach in the International Journal of Civil Engineering and Technology (Alghazali, April 2013). The paper recommends a breach development time of 0.2 hours (12 minutes) for RCC dams. They also recommend a breach width of 30% to 50% of the dam length. The failure in this case study is an overtopping type of failure due to overstressing.

The breach hydrograph was developed by performing a dam breach analysis using HEC-HMS v3.5. The above parameters were utilized for the dam breach model. The recommended breach development time of 0.2 hours from the Alghazali study was utilized as the most conservative estimate of the three sources. Because the dam width is relatively narrow given the height, it was assumed that the entire dam would be removed in event of a breach. Piping and overtopping failures were considered, the peak outflow was higher for piping failure than for overtopping, so the piping mode was used. The analysis simulated the reservoir as a storage area with a defined stage-storage relationship provided by the as-constructed drawings, included in **Appendix B**. The peak breach discharge predicted by the HEC-HMS model was approximately 70,800 cfs. The dam breach discharge hydrograph can be found in **Appendix C**.

FLOOD ROUTING

The second task of this analysis was to route the dam breach discharge hydrograph downstream until the flow was contained within the downstream channel. The downstream reach included the Arkansas River to just downstream of Nathrop. The modeled reach is approximately seven and a half miles in length.

The Trout Creek Dam is situated at the mouth of the canyon, and the breach outflows would travel as sheet flow from the base of the canyon across agricultural land and into the Arkansas River. A model of the reach was generated in FLO-2D. Base elevations were obtained from the Colorado Geological Survey (CGS) in the form of LiDAR data. The LiDAR elevation data has a horizontal resolution of approximately 3 meters.

Manning's n-values for the reach were based on *Roughness Characteristics of Natural Channels*, USGS. Water Supply Paper 1849, Barnes, 1967. The channel overbanks were assigned a Manning's N value ranging from 0.035 to 0.08 in order to reflect crop land and vegetation observed from 2011 NAIP aerial photos.

The inflow for the model was set as the dam breach discharge hydrograph at the base of the Trout Creek Dam. No base flow was considered in the model. The downstream control for the model defaults to normal depth at the outlet cells using the projected slope from the adjacent upstream cells. The hydraulic calculations were performed in FLO-2D Build No. 13.07.05 using average time step intervals of 1-4 second computation intervals.

Upon routing the dam breach flood downstream, it was determined that the peak discharge attenuates from approximately 70,000 cfs at the dam to approximately 3,245 cfs at the downstream limit of the reach. This flow is less than the predicted 100 year flood in this reach of the Arkansas River at Buena Vista, upstream of the dam site 3,930 cfs (FEMA 1987). The FLO-2D model shows that all flow is contained within the Arkansas River channel about a mile upstream of Nathrop, about four miles upstream of the model limits.

FLOOD INUNDATION MAPPING

The third and final task of this analysis was to map the resulting breach flood inundation extents.

Critical locations were identified using 2011 imagery obtained from the National Agriculture Imagery Program (NAIP). A structure was identified as being critical if it was located within the flood extent or overtopped by the flood wave. A total of 30 critical structures were identified (See Figure 1 for details on each structure analyzed). The resulting inundation map can be found in **Figure 1**.

In general, all of the structures identified between the dam site and the point where flow is channelized into the Arkansas River are within a "high hazard zone" where the depth exceeds 2-ft and/or the product of depth times velocity exceeds 7.

REFERENCES

1. Colorado Division of Water Resources (CDWR, Nov 2010), *Guidelines for Hazard Classification*, Denver, CO, November 15, 2010.
2. Colorado Division of Water Resources (CDWR, Feb 2010), *Guidelines for Dam Breach Analysis*, Denver, CO, February 10, 2010.
3. Barnes, H. Harry (Harry, 1967), *Roughness Characteristics of Natural Channels*, Washington D.C., 1967.
4. Alghazali, NajmObaidSalim and Dilshad A.H. Alhadrawi (Alghazali, April 2013) *Mathematical Model of RCC Dam Break Bastora RCC Dam as a Case Study*, International Journal of Civil Engineering and Technology Volume 4, Issue 2, March-April 2013.
5. Federal Emergency Management Agency (FEMA, 1987), *Flood Insurance Study, Town of Buena Vista, Colorado Chaffee County,* Washington D.C., March 30, 1982.

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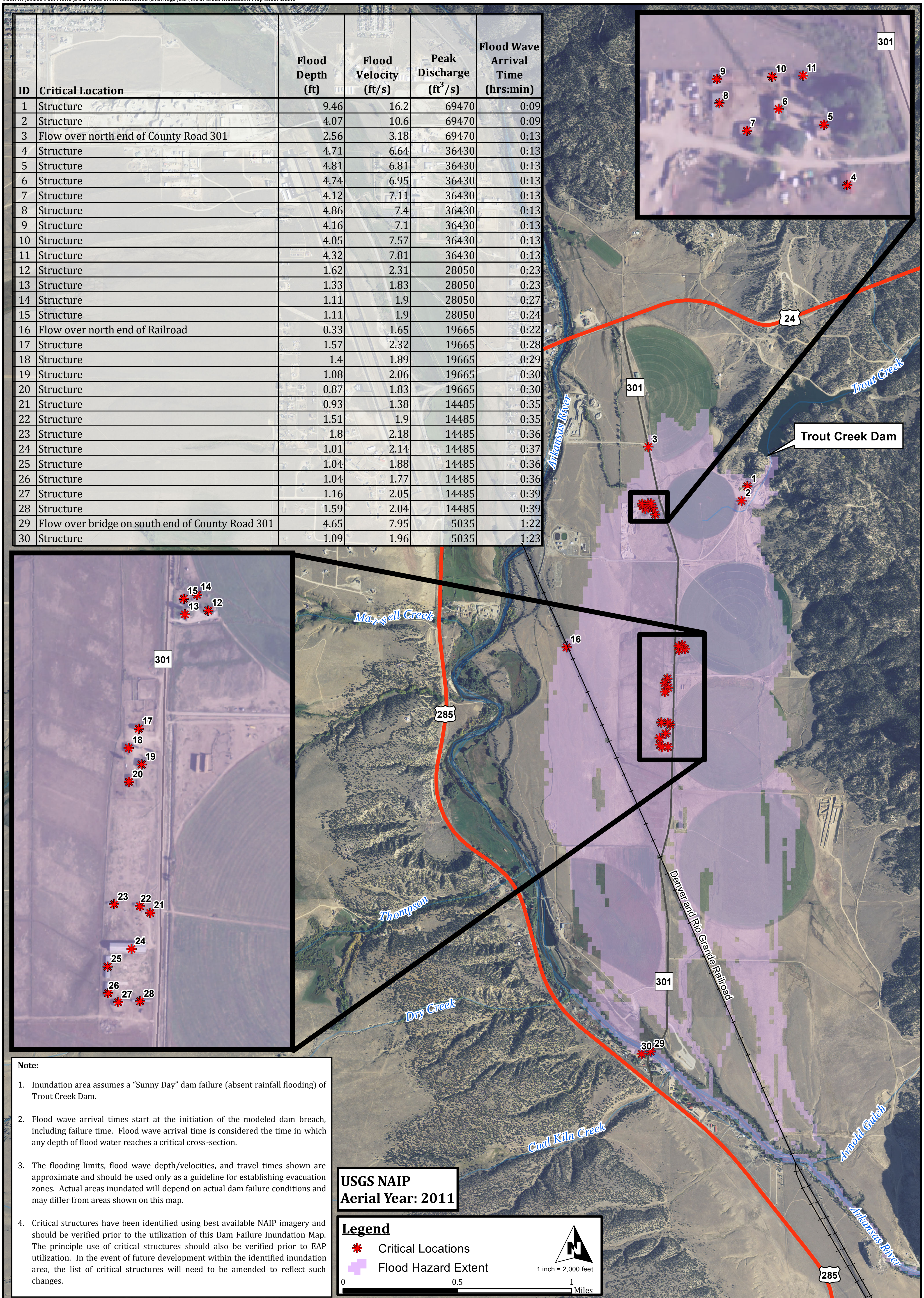
ID	Critical Location	Flood Depth (ft)	Flood Velocity (ft/s)	Peak Discharge (ft^3/s)	Flood Wave Arrival Time (hrs:min)
1	Structure	9.46	16.2	69470	0:09
2	Structure	4.07	10.6	69470	0:09
3	Flow over north end of County Road 301	2.56	3.18	69470	0:13
4	Structure	4.71	6.64	36430	0:13
5	Structure	4.81	6.81	36430	0:13
6	Structure	4.74	6.95	36430	0:13
7	Structure	4.12	7.11	36430	0:13
8	Structure	4.86	7.4	36430	0:13
9	Structure	4.16	7.1	36430	0:13
10	Structure	4.05	7.57	36430	0:13
11	Structure	4.32	7.81	36430	0:13
12	Structure	1.62	2.31	28050	0:23
13	Structure	1.33	1.83	28050	0:23
14	Structure	1.11	1.9	28050	0:27
15	Structure	1.11	1.9	28050	0:24
16	Flow over north end of Railroad	0.33	1.65	19665	0:22
17	Structure	1.57	2.32	19665	0:28
18	Structure	1.4	1.89	19665	0:29
19	Structure	1.08	2.06	19665	0:30
20	Structure	0.87	1.83	19665	0:30
21	Structure	0.93	1.38	14485	0:35
22	Structure	1.51	1.9	14485	0:35
23	Structure	1.8	2.18	14485	0:36
24	Structure	1.01	2.14	14485	0:37
25	Structure	1.04	1.88	14485	0:36
26	Structure	1.04	1.77	14485	0:36
27	Structure	1.16	2.05	14485	0:39
28	Structure	1.59	2.04	14485	0:39
29	Flow over bridge on south end of County Road 301	4.65	7.95	5035	1:22
30	Structure	1.09	1.96	5035	1:23



Note:

1. Inundation area assumes a "Sunny Day" dam failure (absent rainfall flooding) of Trout Creek Dam.
2. Flood wave arrival times start at the initiation of the modeled dam breach, including failure time. Flood wave arrival time is considered the time in which any depth of flood water reaches a critical cross-section.
3. The flooding limits, flood wave depth/velocities, and travel times shown are approximate and should be used only as a guideline for establishing evacuation zones. Actual areas inundated will depend on actual dam failure conditions and may differ from areas shown on this map.
4. Critical structures have been identified using best available NAIP imagery and should be verified prior to the utilization of this Dam Failure Inundation Map. The principle use of critical structures should also be verified prior to EAP utilization. In the event of future development within the identified inundation area, the list of critical structures will need to be amended to reflect such changes.

Figure: 1 Of: 2

Date: 04 Feb 2014
Job #: 13-116
Drawn By: NCY

No.	Rev. Date	Revision Description

TROUT CREEK DAM, DAMID: 110233

Emergency Action Plan
Dam Failure Flood Inundation Map

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ID	Critical Location	Flood Depth (ft)	Flood Velocity (ft/s)	Peak Discharge (ft3/s)	Flood Wave Arrival Time (hrs:min)
29	Flow over bridge on south end of County Road 301	4.65	7.95	5035	1:22
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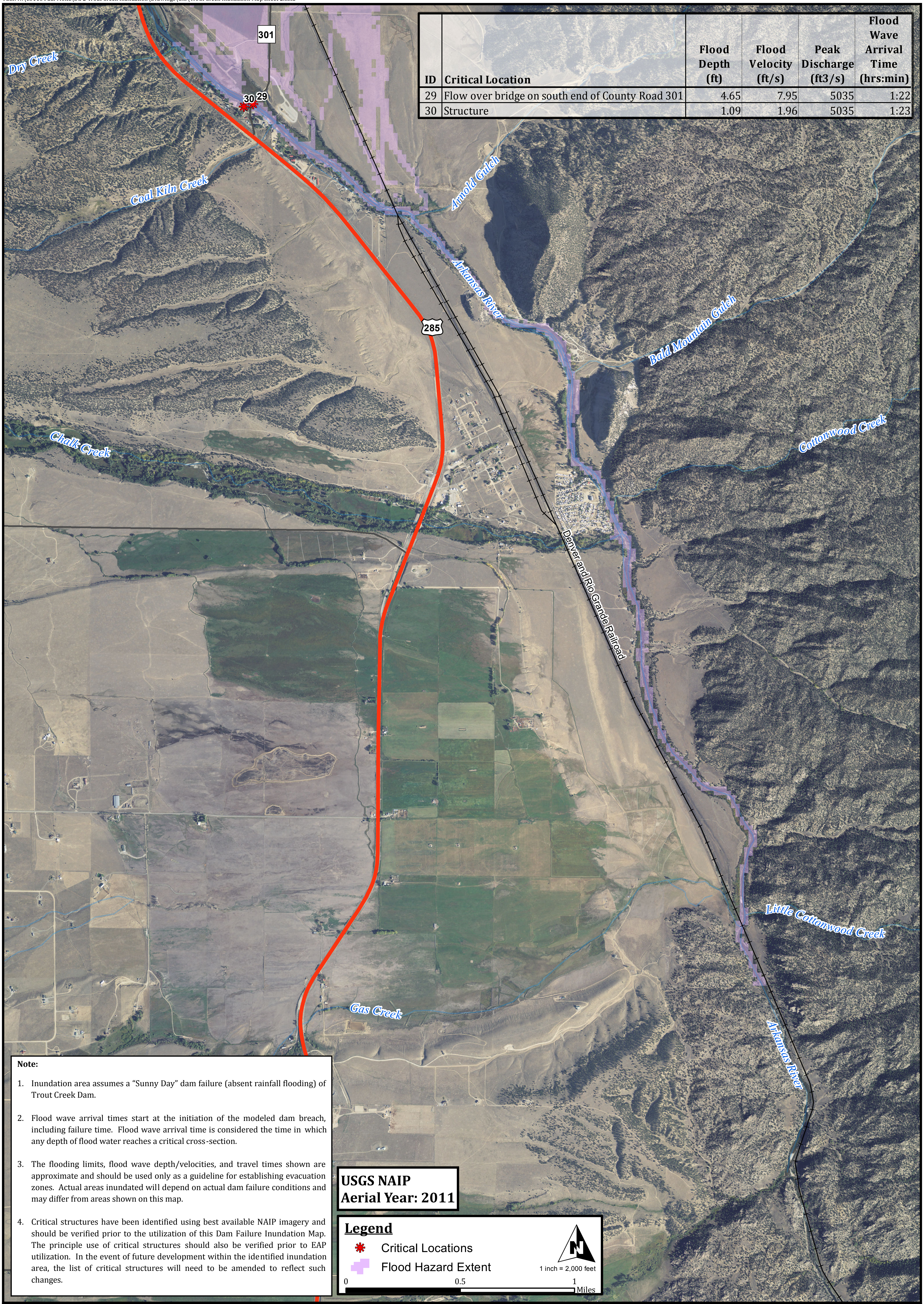

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Figure: 2
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Appendix A

Estimated Dam Breach Parameters

ESTIMATION OF DAM BREACH PARAMETERS
USING THE FROEHLICH 2008 METHOD

PROJECT: Trout Creek Dam

BREACH INPUT PARAMETERS:

Select Failure Mode From Drop-Down Menu:	PIPING	
Height of water over base elevation of breach (H_w) =	70.7	Feet
Volume of water in the reservoir at the time of failure (V_w) =	671.7	Acre-Feet
Reservoir Surface Area at Hw (A_s) =	26.5	Acres
Height of breach (H_b) =	72.7	Feet
Failure Mode Factor (K_o) =	1	
Breach Side-Slope Ratio (Z_b) =	0.4	Z(H):1(V)
Dam Size Class:	Large	Assumes Full Reservoir At Time of Breach.

CALCULATED BREACH CHARACTERISTICS:

Average Breach Width (B_{avg}) =	78.5	Feet
Bottom Width of Breach (B_b) =	49.4	Feet
Breach Formation Time (T_f) =	0.23	Hours
Storage Intensity (SI) =	9.5	Acre Feet/Foot
Predicted Peak Flow (Q_p) =	74972	Cubic Feet per Second

RESULTS CHECK:

Average Breach Width Divided by Height of Breach (B_{avg}/H_b) =	1.08	If (B_{avg}/H_b) > 0.6, Full Breach Devlopment is Anticipated
Erosion Rate (ER), Calculated as (B_{avg}/T_f) =	341.2	
Erosion Rate Divided by Height of Water Over Base of Breach (ER/H_w) =	4.8	If 1.6 < (ER/H_w) < 21, Erosion Rate is Assumed Reasonable

ESTIMATION OF DAM BREACH PARAMETERS
USING THE MACDONALD & LANGRIDGE-MONOPOLIS OR WASHINGTON STATE METHODS
WITH ALL FAILURE TIMES ESTIMATED BY WASHINGTON STATE METHOD

PROJECT: Upper Black Creek, DAMID: 360127

BREACH INPUT PARAMETERS:

Select Embankment Type From Drop-Down Menu:	EARTHEN (NON-COHESIVE)	
Height of water over base elevation of breach (H_w) =	70.7	Feet
Volume of water stored in reservoir at time of failure (V_w) =	671.7	Acre-Feet
Reservoir Surface Area at H_w (A_s) =	26.5	Acres
Crest width of dam (C) =	15.0	Feet
Height of breach from dam crest to base elevation of breach (H_b) =	72.7	Feet
Slope of upstream dam face (Z_u) =	0.0	Z(H):1(V)
Slope of downstream dam face (Z_d) =	0.7	Z(H):1(V)
Breach side-slope ratio (Z_b) =	0.4	Z(H):1(V)
Piping Orifice Coefficient (C_p) =	0.68	Used To Calculate Peak Discharge Through Piping Hole
Dam Size Class:	Large	Assumes Full Reservoir At Time of Breach

CALCULATED BREACH CHARACTERISTICS:

Breach Formation Factor (BFF) =	47489.19	
Embankment Volume Eroded (V_{er}) =	14962.7	Cubic Yards
Average Dam Width (W_{avg}) =	40.4	Feet (In Direction of Flow)
Average Breach Width (B_{avg}) =	137.4	Feet
Bottom Width of Breach (B_b) =	108.3	Feet
Breach Formation Time (T_f) =	0.64	Hours
Storage Intensity (SI) =	9.5	Acre Feet/Foot
SMPDBK Peak Breach Discharge (Q_p) =	24223	Cubic Feet per Second

RESULTS CHECK:

Average Breach Width Divided by Height of Breach (Bavg/Hb) =	1.89	If (Bavg/Hb) > 0.6, Full Breach Development is Anticipated
Erosion Rate (ER), Calculated as (Bavg/Tf) =	215.7	
Erosion Rate Divided by Height of Water Over Base of Breach (ER/Hw) =	3.1	If 1.6 < (ER/Hw) < 21, Erosion Rate is Assumed Reasonable

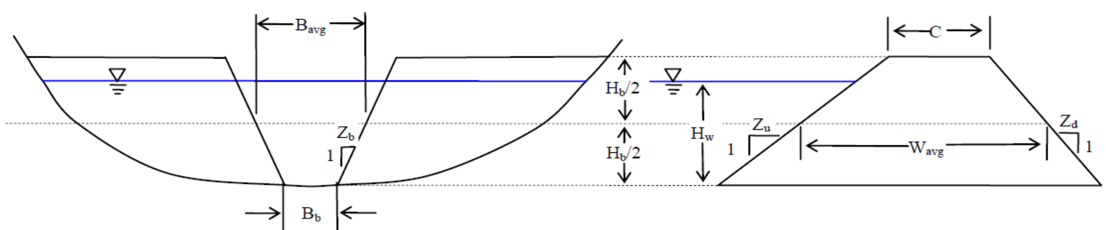


Figure 1- Breach Variable Definition Sketch

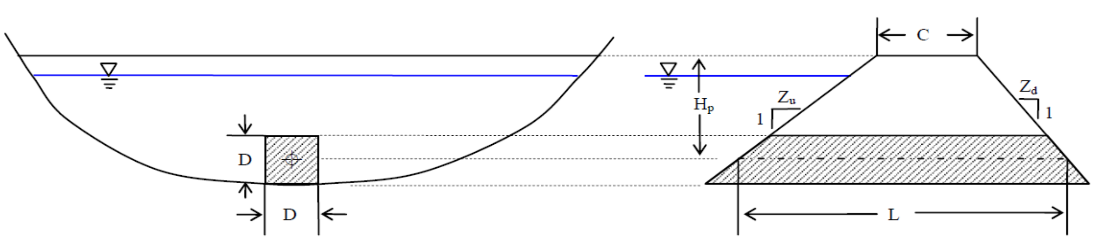


Figure 2 – Piping Hole Variable Definition Sketch

Appendix B

Stage Storage Capacity Table

Trout Creek Dam

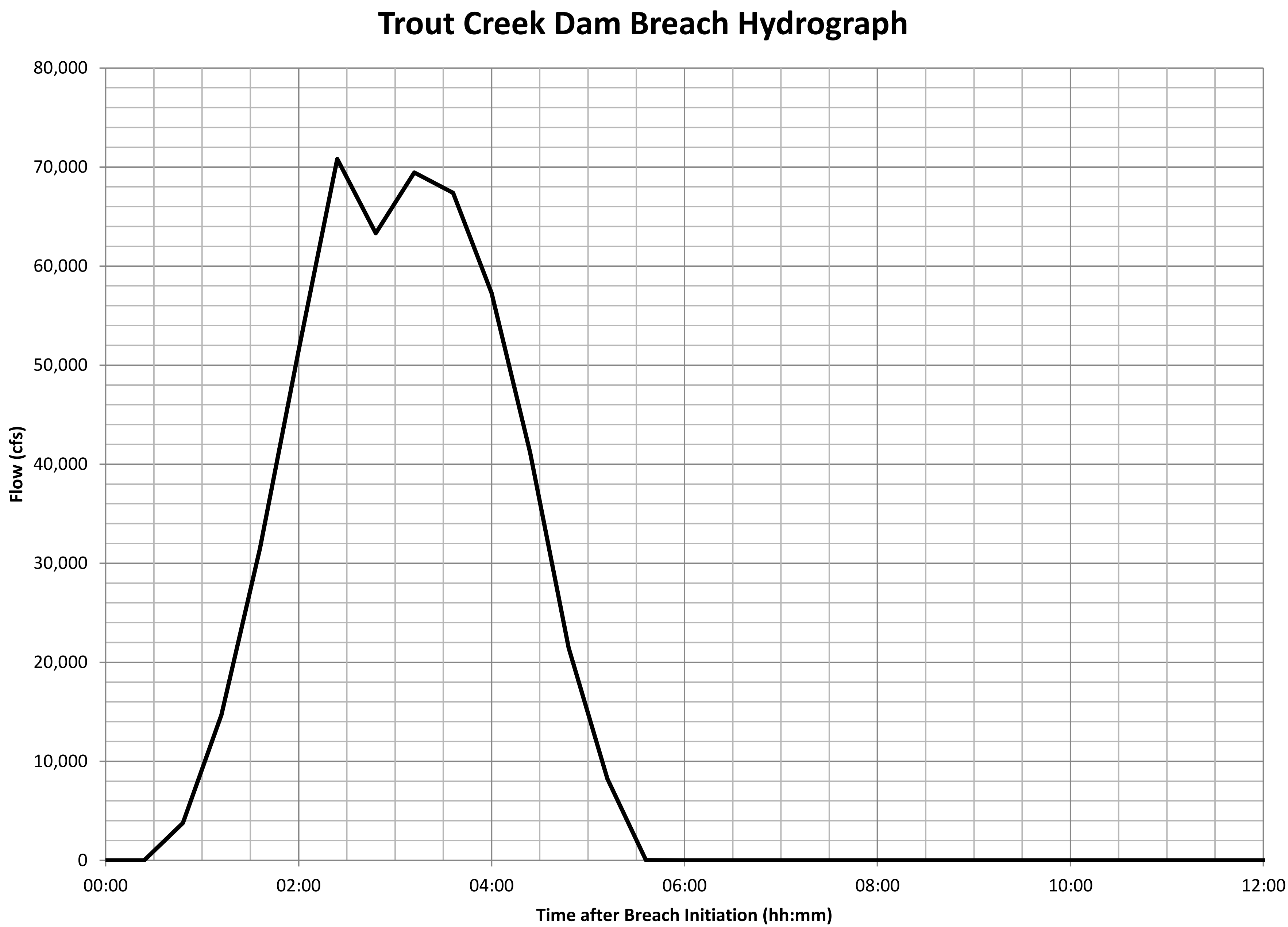
Area Capacity Tables 9-Jul-97

Elevation (ft)	Survey area (ft sq)	Area (acres)	Capacity (a.f.)
7880	0	0.00	0.00
7885	8458	0.19	0.49
7886	11046	0.25	0.74
7887	13634	0.31	1.05
7888	16221	0.37	1.42
7889	18809	0.43	1.86
7890	21397	0.49	2.35
7891	26809	0.62	2.96
7892	32221	0.74	3.70
7893	37633	0.86	4.57
7894	43045	0.99	5.55
7895	48457	1.11	6.67
7896	59179	1.36	8.03
7897	69900	1.60	9.63
7898	80622	1.85	11.48
7899	91344	2.10	13.58
7900	102066	2.34	15.92
7901	114228	2.62	18.54
7902	126391	2.90	21.45
7903	138552	3.18	24.63
7904	150715	3.46	28.09
7905	162878	3.74	31.82
7906	181276	4.16	35.99
7907	199675	4.58	40.57
7908	218073	5.01	45.58
7909	236471	5.43	51.01
7910	254870	5.85	56.86
7911	270819	6.22	63.07
7912	286768	6.58	69.66
7913	302717	6.95	76.61
7914	318666	7.32	83.92
7915	334615	7.68	91.60
7916	353739	8.12	99.72
7917	372862	8.56	108.28
7918	391986	9.00	117.28
7919	411109	9.44	126.72
7920	430233	9.88	136.60
7921	448779	10.30	146.90
7922	467325	10.73	157.63
7923	485871	11.15	168.78
7924	504417	11.58	180.36
7925	522963	12.01	192.37
7926	544751	12.51	204.87
7927	566539	13.01	217.88
7928	588327	13.51	231.39
7929	610115	14.01	245.39
7930	631903	14.51	259.90
7931	655465	15.05	274.95
7932	679029	15.59	290.53
7933	702591	16.13	306.66
7934	726154	16.67	323.33
7935	749717	17.21	340.54
7936	774264	17.77	358.32
7937	798813	18.34	376.66
7938	823360	18.90	395.56
7939	847908	19.47	415.02
7940	872456	20.03	435.05
7941	901832	20.70	455.76
7942	931208	21.38	477.13
7943	960583	22.05	499.19
7944	989959	22.73	521.91
7945	1019335	23.40	545.31
7946	1046564	24.03	569.34
7947	1073792	24.65	593.99
7948	1101021	25.28	619.27
7949	1128249	25.90	645.17
7950	1155478	26.53	671.69 **
7951	1186776	27.24	698.94
7952	1218073	27.96	726.90
7953	1249371	28.68	755.58
7954	1280668	29.40	784.98
7955	1311966	30.12	815.10
7956	1344036	30.85	845.96
7957	1376106	31.59	877.55
7958	1408177	32.33	909.87
7959	1440247	33.06	942.94
7960	1472317	33.80	976.74
7961	1504388	34.54	1011.27
7962	1536458	35.27	1046.55
7963	1568528	36.01	1082.55
7964	1600598	36.74	1119.30
7965	1632669	37.48	1156.78
7966	1664739	38.22	1195.00
7967	1696809	38.95	1233.95
7968	1728880	39.69	1273.64
7969	1760950	40.43	1314.07
7970	1793020	41.16	1355.23

** = Normal Water Level @ Spillway Crest

Appendix C

Dam Breach Hydrograph



Trout Creek Dam Breach Hydrograph
Flow (cfs)
80,000
70,000
60,000
50,000
40,000
30,000
20,000
10,000
0
00:00
02:00
04:00
06:00
08:00
10:00
12:00
Time after Breach Initiation (hh:mm)