***CWCB Water Project Loan Feasibility Study***

# Lookout Mountain Water District
# Infrastructure Improvements

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FEASIBILITY STUDY APPROVAL.
Pursuant to Colorado Revised Statutes 37-60-121 &122, and in accordance with policies adopted by the Board, the CWCB staff has determined this Feasibility Study meets all applicable requirements for approval.

Signed 11/2/2020 Date

**September 16, 2020**

# Table of Contents


1. Background ..... 4
   1.1. Purpose ..... 4
   1.2. Study Area Description ..... 5
   1.3. Previous Studies ..... 8
2. Project Sponsor ..... 9
   2.1. Sources of Revenue ..... 10
   2.2. Future Priorities for LMWD ..... 11
   2.3. LMWD Personnel ..... 12
3. Water Rights ..... 13
   3.1. Water Availability ..... 13
      3.1.1. Water Rights ..... 13
   3.2. Water Supply Demands ..... 14
      3.2.1. Annual Demand for Water ..... 14
      3.2.2. Water Supply Adequacy ..... 14
      3.2.3. District's Operations and Other Information ..... 16
4. Project Description - Analysis of Alternatives & Selected Alternative ..... 18
   4.1. Analysis of Alternatives ..... 18
      4.1.1. Alternatives for Lower Beaver Brook Dam ..... 19
      4.1.2. Alternatives for Increased Water Management Efficiency ..... 19
   4.2. Selected Alternative ..... 20
   4.3. Cost Estimate ..... 21
   4.4. Implementation Schedule ..... 21
   4.5. Impacts ..... 21
   4.6. Institutional Feasibility ..... 21
5. Financial Feasibility Analysis ..... 22
   5.1. Loan Amount ..... 22
   5.2. Financing Sources ..... 22
   5.3. Revenue and Expenditure Projections ..... 23
   5.4. Loan Repayment Sources ..... 26
   5.5. Financial Impacts ..... 27
   5.6. TABOR (Taxpayer's Bill of Rights) Issues ..... 28
   5.7. Collateral ..... 28
   5.8. Sponsor Creditworthiness ..... 28

6. Conclusions and Recommendation ..... 29
Appendix A: TABOR Ballot and Certified Results ..... A-1
Appendix B: LBB Alternatives Study (W.W. Wheeler and Associates) ..... B-1
Appendix C: LBB Dam Reconstruction Proposal (GEI Consultants, Inc.) ..... C-1
Appendix D: Water Operations Alternatives Study (Momentum CE Inc.) ..... D-1
Appendix E: Environmental Study ..... E-1
Appendix F: LMWD Board Motion to apply for CWCB loan. ..... F-1
Appendix G: Audited Annual Reports for 2019, 2018 and 2017 ..... G-1
Appendix H: Spread of Annual reports ..... H-1
Appendix I: Schedule of Revenues and Expenses ..... I-1
Appendix J: Cost Estimate Breakdown ..... J-1

# 1. Background

## 1.1. Purpose

Lookout Mountain Water District ("LMWD" or "District"), located within Clear Creek and Jefferson Counties, is a small Title 32 water district created in 1988 from the City of Golden's former water system infrastructure and water rights between the Beaver Brook Basin and Lookout Mountain. LMWD is a unique and complex public water system composed of approximately 12 miles of main pipeline and three reservoirs, including Upper Beaver Brook Reservoir (UBB; 397 AF capacity), Lower Beaver Brook Reservoir (LBB; 31 AF capacity), and Lookout Mountain Reservoir (LMR; 101 AF capacity). The District serves a population of about 1,600 residing in the mountain communities of unincorporated areas of Evergreen and Golden, Colorado.

LMWD is applying to the Colorado Water Conservation Board to finance a multi-faceted project within the Water Project Loan Program. The purpose for this loan request is to bring assets in the Beaver Brook drainage up to a safety and operational level acceptable to state and federal regulators and to improve LMWD's water management and operational efficiency. Several components are needed to achieve this goal:

1. Replacement of the LBB dam for safety and risk mitigation requirements. This is the highest cost element of the project.

2. Installation of a new pump and tank system for feeding the Treatment Plant from Lower Beaver Brook (LBB) reservoir. This will allow the fluctuation of water levels in this reservoir and provide additional operational flexibility.

3. Reconstruction of the Upper Beaver Brook (UBB) outlet works, which will include replacing the nearly 100-year-old gate and relining the outlet pipe.

4. Installation of a a Supervisory Control and Data Acquisition (SCADA) system to automate the measurement of water flows at various points in the system and control this newly installed UBB outlet gate.

The replacement of Lower Beaver Brook Dam is needed to maintain the storage at Lower Beaver Brook Reservoir, to continue to supply raw water for treatment to potable use, and meet dam safety requirements for the facility. To meet the project objectives of providing a dam with a spillway capacity that meets the requirements of the Colorado Division of Water Resources – Dam Safety (SEO), GEI Consultants, Inc. (GEI) is designing a new Roller Compacted Concrete (RCC) dam structure and appurtenant facilities to replace the existing Lower Beaver Brook Dam.

The District rehabilitated Upper Beaver Brook Dam in the 1990s and purchased additional water rights to better serve its existing and future customer base with reliable water. The spillway was raised at Upper Beaver Brook in 2016 to provide additional storage and was funded with a loan from the CWCB.

The new dam at Lower Beaver Brook will be designed to meet the flood routing requirements of the SEO. The design process will include the review of the project design with LMWD and the SEO at key design stages to ensure the project meets LMWD's goals and SEO design requirements. GEI will work directly with the special committee of the LMWD Board or at the entire LMWD Board's direction. The design of the Lower Beaver Brook Dam Replacement Project includes geotechnical field investigations and laboratory testing, environmental permitting, engineering design and analyses, final design report, plans and technical specifications, opinion of probable construction costs (OPCC), and construction support services.

In addition, a recently performed study by Momentum CE Inc. (Attachment D) found that there were excess water storage releases from the District's reservoirs in the past and that water supply gains will be realized through increased operational efficiency. The proposed project will design and install a SCADA system to automate Upper Beaver Brook Reservoir's release gate operation based upon realtime measured flow data and additional user inputs (e.g. current water right priority call date, forecasted water treatment plant demands, etc.). It is also critical that the District improves the 96-year old outlet infrastructure in order to fully utilize this new SCADA system. Finally, a pumping system will be installed to better utilize Lower Beaver Brook Reservoir's storage.

## 1.2. Study Area Description

The District serves a population of about 1,600 residing in the mountain communities of unincorporated areas of Evergreen and Golden, Colorado. Two of LMWD's reservoirs and one treatment facility are in Clear Creek County, Colorado. The LMWD customers reside or operate in the unincorporated areas of Evergreen and Golden, primarily in the area known as Lookout Mountain in Jefferson County, Colorado (zip codes 80401 and 80439). The LMWD operates as a system, comprised of tap owners and property owners included in the District's boundaries, the elected Board of Directors, and the contractors and consultants who provide operation and management.

LMWD has two high altitude reservoirs on Beaver Brook: Upper Beaver Brook Reservoir (also known as the John Roscoe Reservoir at Upper Beaver Brook) and Lower Beaver Brook Reservoir. Lower Beaver Brook Dam is located approximately 7.2 miles northwest of Evergreen, Colorado in Clear Creek County, Northeast Quarter, Section 14, Township 4 South, Range 72 West of the 6th Principal Meridian. The dam is located on Beaver Brook, a tributary to Clear Creek and the South Platte River upstream of Golden, Colorado. Coordinates of the dam are approximately 39.705952$^{o}$N, 105.41136$^{o}$W. The reservoir parcel and embankment dam are owned by LMWD. Lower Beaver Brook Reservoir serves as the forebay for LMWD's water treatment plant, without which, LMWD could not provide water to its users. The site location is shown in Figure 1.

Lower Beaver Brook Dam is a small, high-hazard, concrete-face rockfill dam originally constructed in 1903. Several dam safety deficiencies have been identified at Lower Beaver Brook Dam during the annual Colorado Division of Water Resources (DWR) Dam Safety Engineer inspections.

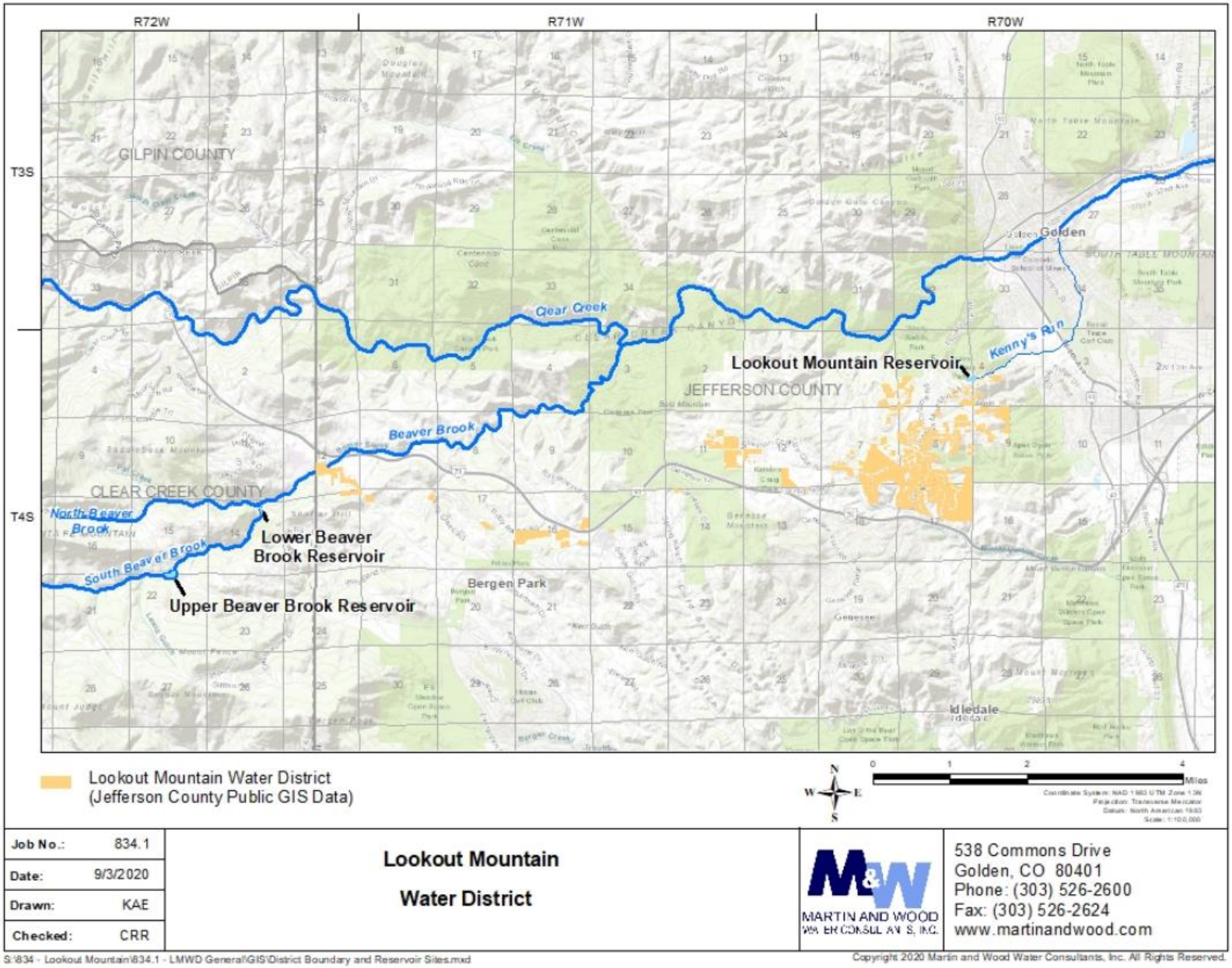


*Figure 1: Map showing counties, towns or cities, topography, major streams, project facilities, and lands served*

The identified dam safety issues include:

1) The spillway is far too undersized to pass the required Inflow Design Flood of 4,755 cubic feet per second (cfs). The existing spillway is capable of passing approximately 300 cfs before engineers project embankment overtopping would occur, which is less than the 2-year flood.
2) The dam is experiencing a significant amount of uncontrolled embankment and/or foundation seepage.
3) There are concerns associated with the stability of the dam embankment.
4) There are concerns associated with the age (and potential condition) of some of the outlet works components. See Appendix B for more information.

These dam safety issues could be related to the fact that there were different design standards and requirements that were in place at the time of construction 117 years ago, as well as the general age of the dam. A dam failure, which is possible as a result of the identified dam safety deficiencies, is expected to have the following adverse impacts:

1) Loss of human life, as indicated by its high-hazard potential dam classification.
2) Loss of water for the LMWD Water Consumers for an extended period of time. The Water Consumers include residences, governmental sites (including a high school and about 10 business or church sites), and a critical communications infrastructure site.
3) Damage to downstream residences, businesses, access roads, the LMWD's Water Treatment Facility, and other critical infrastructure that is necessary to provide potable water to the LMWD Water Consumers.
4) The loss of Lower Beaver Brook Reservoir, which provides valuable storage water for water supply and drought protection

Construction of the new concrete dam will mitigate the dam safety deficiencies identified at the existing Lower Beaver Brook Dam thereby reducing the risk of failure. The new concrete dam will be constructed to modern design standards, in conformance with the State of Colorado Division of Water Resources Dam Safety Branch Rules and Regulations for Dam Safety and Dam Construction, thus mitigating the dam safety deficiencies identified at the existing Lower Beaver Brook Dam.

The proposed reconstruction will provide a more reliable dam than what currently exists for the Lookout Mountain Water District's operations, will maximize water storage for drought protection, and will reduce the risk associated with flooding (and its impacts) resulting from a failure of the existing Lower Beaver Brook Dam. The following hazards remain after the dam is completed:

1) The new dam will remain a high hazard-potential structure, meaning that loss of human life is possible as a result of a dam failure. Note that the hazard classification is unrelated to the condition of the structure, only based on the consequences associated with a failure.

2) The new dam will be designed for flood events up to the inflow design flood (IDF) of 4,755 cubic feet per second (cfs), which is in excess of the 1000-year flood. Floods in

excess of the IDF may pose a risk to the dam structure.

3) The existing flood risk associated with downstream areas will remain after the dam is completed. However, the construction of the new concrete dam (with consistency in the normal reservoir pool, service spillway size, and emergency spillway elevation remaining consistent with the existing dam elevation) is not expected to result in increased flood discharges beyond what would currently be expected with the existing dam.

4) Even though Lower Beaver Brook Reservoir provides valuable storage water for drought protection to the Lookout Mountain Water District, the risk associated with an extended or multi-year drought that exceeds the storage capacity remains.

### 1.3. Previous Studies

GEI completed a hydrology and Incremental Damage Analysis study in March 2015 for Lower Beaver Brook Dam and revised the study in December 2016 in response to SEO comments. As a result of these studies, GEI developed a hydrologic model for Lower Beaver Brook Dam in accordance with the Rules and Regulations for Dam Safety and Dam Construction and Hydrologic Basin Response Parameter Estimation Guidelines. GEI updated the 2016 model in 2020 with the precipitation values from the Colorado-New Mexico Regional Extreme Precipitation Study (REPS) and developed a Loss of Life (LOL) analysis associated with a hydrologic failure of Lower Beaver Brook. GEI concluded in favor of a high hydrologic rating for Lower Beaver Brook Dam in the LOL analysis.

A technical memorandum (TM) summarizing the updated hydrologic and hydraulic analyses performed for the construction of the new Lower Beaver Brook Dam was completed by GEI Consultants in August 2020. The TM is currently under review by the State Engineers Office; excerpts from the TM can be found in Appendix C. The TM summarizes the methods and parameters used in the updated hydrology study, hydraulic routing results of the Inflow Design Flood (IDF), and hydraulic design considerations at the new Lower Beaver Brook Dam.

In addition, Momentum CE Inc. completed a technical evaluation of firm water supply and economic revenue improvement strategies in April 2020 (Appendix D). This work performed a prefeasibility-level analysis of five water supply development alternatives. Water supply improvements were measured based upon their ability to cost-effectively supply water storage to the District in times of drought.

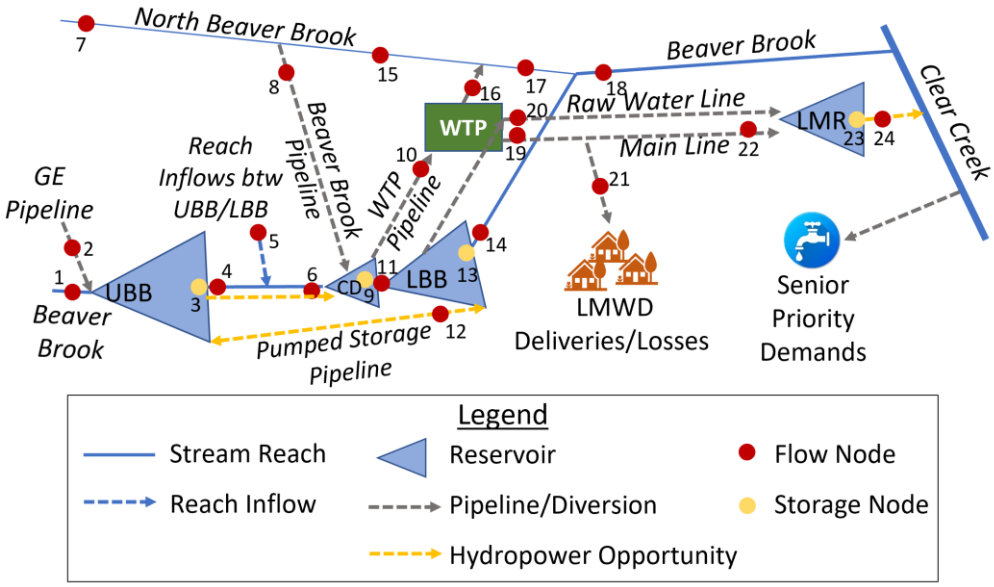


*Figure 2: Schematic of the computational model in the Momentum CE Inc. study*

## 2. Project Sponsor

Lookout Mountain Water District is a Colorado Special District, a division of the government of the State of Colorado formed pursuant to the Special District Act, Title 32, Colorado Revised Statutes, by decree of the District Court in Jefferson County, Colorado, in Civil Action 88CV0265, March 1988.

LMWD was created in 1988 from the City of Golden's former water system infrastructure between the Beaver Brook Basin and Lookout Mountain. LMWD is a unique and complex public water system composed of approximately 12 miles of main pipeline and three reservoirs, including Upper Beaver Brook Reservoir (397 AF capacity), Lower Beaver Brook Reservoir (31 AF capacity), and Lookout Mountain Reservoir (101 AF capacity). In addition, there are seasonal instream flow requirements on Beaver Brook below Lower Beaver Brook Reservoir.

Since the District was formed in 1988, its focus was on creating a water system that would meet EPA requirements and provide a reliable supply of safe drinking water to its customers. LMWD first financed and built the current treatment plant using the initial mil levy approved by district voters. Eventually a 1 million-gallon tank was constructed to help regulate supply and pressure. Additional water rights were acquired and a pricing structure to encourage conservation was implemented. District voters approved an increase to the mil levy when LMWD started its first project to improve UBB dam. With help and financing through the revenue bonds and the CWCB, Upper Beaver Brook dam and reservoir were improved in two phases, the second of which constructed a weir spillway in 2016 to increase reservoir capacity.

Due to the nature of how the taps were first issued on Lookout Mountain, approximately 21 laterals exist which are not owned by LMWD. These laterals total approximately 9 miles in length. Seven of the laterals are treated as large service lines for commercial or Government

users.

About 80% of all households receive water that goes through a private lateral and 14 of the laterals serve primarily residential households. These private laterals are all essentially owned by the homeowners on the particular lateral through an entity like an HOA, Water company or sometime as tenants in common. The private laterals are of various ages and condition, but some are over 50-60 years old. Water leaks on the private laterals can threaten the entire District, so finding ways to accomplish these needed improvements and unifying the District are being worked on. Ultimately the burden will fall on the current lateral owners.

Newer laterals and the LMWD main line have fire hydrants and provide domestic water and water for fire suppression to a communications infrastructure site serving Jefferson County Sheriff's Department and other agencies providing emergency response (this communications facility and tower(s) are considered "critical communications" infrastructure). Other important governmental sites served, as well as hydrants for fire suppression are operated by Evergreen Fire Protection District, Clear Creek School District RE-1, Denver Mountain Parks (City and County of Denver), Jefferson County, and Jefferson County Open Space, Foothills Fire Protection District and Highland Rescue Team Ambulance District.

Information about the District is available to the public on-line via the World Wide Web:

http://www.lookoutmountainwaterdistrict.org/

The District's Policies, Rules and Regulations, annual reports (water quality, financial, budgetary, transparency notices) election results, monthly Board meeting minutes, and many other records can be accessed without cost.

### 2.1. Sources of Revenue

The District generates revenue from two sources; water sales and fees through its Enterprise Fund and property tax receipts from its mil levy collected by Jefferson County which flow into its General Fund. LMWD's customers reside or operate in the unincorporated areas of Evergreen and Golden, primarily in the area known as Lookout Mountain in Jefferson County (zip codes 80401 and 80439), Colorado.

LMWD is authorized to set water usage rates and fees to be paid by the tap holders/customers, is empowered to disconnect water deliveries to customers that fail to make payments, as well as to assess property liens for unpaid charges. LMWD is also authorized by statute and by the electorate to levy property taxes against property within its boundaries. The LMWD by-laws are included in Appendix J.

The District has 563 authorized taps, of which approximately 502 are active and 61 are inactive. Active tap service is comprised of 95.4% -- residential, 2.8% -- tax-exempt or government, and 1.8% -- commercial. Of the 61 inactive taps, 34 are presently assigned to property and 27 are unassigned, all of which the District has a future obligation to serve, once these taps are activated. Current active taps include:

a) 479 households
b) 14 governmental sites including a high school
c) 9 business or church sites

The average bill across the whole system through the first 7 months of 2020 was $116.23. Details and projections on these revenues are in the Financial Section of this document and the Schedule of Revenues and Expenses in Appendix I.

## 2.2. Future Priorities for LMWD

Overall, the District forecasts exceptionally low growth in the number of active taps. Expectations are that a small number of current tap holders will opt for going to a well rather than pay the costs of upgrading a lateral line. This would occur in some situations where the lateral line length is quite long and very few taps are using it. This shrinkage would be offset by inactive taps becoming active and new development in areas already in close proximity to LMWD lines or lateral lines.

LMWD has been generally more concerned about water shortages and has encouraged its water consumers to conserve and not waste water. Water consumption has fallen to a point where it raises the question, "Could we support more active taps?". After water rates were restructured in 2015, water treated in the treatment plant has fallen to around 112 AF per year. Billed water per year is running around 70 AF per year. This is discussed in detail in the Water Rights and Financial sections.

The District's 12-mile main line is the next priority once this project is complete. Approximately 9 miles of this pipe are from 50 to 75 years old. LMWD would most likely repair this in segments, trying to reline or replace the highest problem areas first. It is anticipated that greater revenues or additional mil levy will be required to fully solve this issue. This is also discussed in the Financial section.

In addition, LMWD would like to continue to improve its water rights portfolio. Purchasing additional water rights would have to make economic sense, but persistent drought conditions, changing environmental factors, desire for a more diverse water supply, or continued competition for water may make this a necessity in the future.

## 2.3. LMWD Personnel

The LMWD Board of Directors oversees all affairs of the District and is elected to serve by the residents of the District. Below is a list of LMWD Personnel:

**Board of Directors and Officers**
Barbara Nevins, President
Dean Snyder, Vice President
Kyle Schroeder, Treasurer
Steve Swain, Director
Robert Heine, Director
Nickie Holder, Secretary

**Attorney**
Dylan Woods
Toussaint & Coaty, P.C.
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Evergreen CO 80439

**Operations and Maintenance**
O R C Water Professionals
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Suite 116A
Wheat Ridge, CO 80033

**Engineering and Technical Support**
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Will Raatz, PE
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Arvada, CO 80007

Cristy Radabaugh, PE
Martin and Wood Water Consultants, Inc.
538 Commons Drive
Golden, CO 80401

Brent Cody, PhD, PE
Momentum CE Inc.
941 Coho Run
Fort Collins, CO 80524

# 3. Water Rights

## 3.1. Water Availability

### 3.1.1. Water Rights

Lookout Mountain Water District's water rights portfolio includes storage rights, direct flow rights, changed irrigation rights, and exchanges. Summary information on the District's water rights is provided below in Table 1.

*Table 1: Summary of Lookout Mountain Water District Water Rights*

| Name | Amount | Status | Priority Date | Case Number | Adjudication Date |
|---|---|---|---|---|---|
| **Beaver Brook Water Rights** | | | | | |
| Lookout Mountain Reservoir | 18.92 AF | absolute | 12/31/1903 | CA41340 | 10/9/1914 |
| | 82.17 AF | absolute | 10/10/1914 | CA60052 | 5/13/1936 |
| Lower Beaver Brook Reservoir | 24.16 AF | absolute | 12/31/1903 | CA41340 | 10/9/1914 |
| | 6.64 AF | absolute | 7/29/1917 | CA60052 | 5/13/1936 |
| Upper Beaver Brook Reservoir | 257.21 AF | absolute | 8/27/1924 | CA60052 | 5/13/1936 |
| | 102.0 AF + 38 AF | conditional | 12/29/2011 | 11CW287 | 12/9/2013 |
| | 38.0 AF + 5.8 AF | conditional | 12/31/2013 | 13CW3179 | 1/27/2015 |
| Golden Pipeline | 3.5 cfs | absolute | 12/31/1903 | CA41340 | 10/9/1914 |
| Beaver Brook Pipeline | 3.13 cfs | absolute | 10/1/1917 | CA60052 | 5/13/1936 |
| **Farmers High Line Water Rights** | | | | | |
| Farmers High Line Canal | 0.0055 cfs | absolute | 5/16/1860 | Changed prorata interest of 6 FHL shares in Case No. 94CW291 | 10/4/1884 |
| | 0.018 cfs | absolute | 5/31/1860 | | 10/4/1884 |
| | 0.2188 cfs | absolute | 7/1/1860 | | 10/4/1884 |
| | 0.0088 cfs | absolute | 5/28/1863 | | 10/4/1884 |
| | 0.0151 cfs | absolute | 6/20/1863 | | 10/4/1884 |
| | 0.0159 cfs | absolute | 4/23/1865 | | 10/4/1884 |
| | 0.0018 cfs | absolute | 5/24/1870 | | 10/4/1884 |
| | 0.8465 cfs | absolute | 4/1/1872 | | 10/4/1884 |
| | 1.0498 cfs | absolute | 4/1/1886 | | 10/4/1884 |
| | 1.846 cfs | absolute | 4/23/1895 | | 10/4/1884 |
| **Decreed Exchanges** | | | | | |
| Farmers Highline Exchange | 4.0 cfs (max) | absolute and cond. | 12/31/1987 | 87CW303, 94CW291 | 10/1/1992 |
| Lookout Mt. Res. Exchange | 2.00 cfs (max) | absolute and cond. | 12/31/1987 | 87CW303, 94CW291 | 10/1/1992 |

Note: The District continues to work with legal counsel and consultants to evaluate its water portfolio and the rights received from the City of Golden prior to formation of the District.

The District owns and operates three reservoirs: two reservoirs on Beaver Brook (a tributary to Clear Creek) known as Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir and

a reservoir near the top of Lookout Mountain known as Lookout Mountain Reservoir (see Figure 3 for a simplified schematic of the water system). The water right priority dates associated with these reservoirs range from 1903 to 2013. The District also has direct flow water rights from Beaver Brook and North Beaver Brook with priorities from 1903 and 1917 (Table 1).

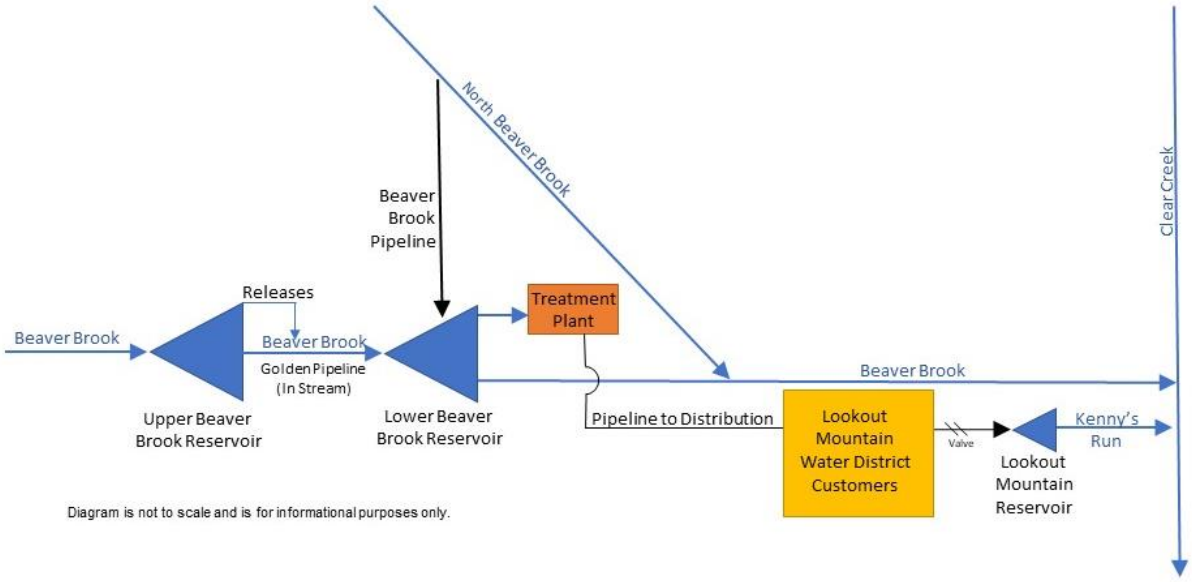


*Figure 3: Lookout Mountain Water District: Simplified Straight-line Diagram*

In addition to storage and direct flow rights, the Districts owns six shares of the Farmers High Line Canal which diverts water from Clear Creek in Golden, Colorado with priorities ranging from 1860 through 1895. The District currently exchanges this water up Clear Creek and Beaver Brook pursuant to the exchange decree in Case No. 87CW303 which allow for exchange rates up to 4.0 cfs.

## 3.2. Water Supply Demands

### 3.2.1. Annual Demand for Water

The projected annual water use for the District was previously determined in the District's planning to be up to 226 ac-ft/year. This is based on an increase over the historical demands attributed to anticipated moderate build-out within the District and expected to be the maximum for the planning horizon of the District.

The actual total use of water in Water Year 2012 (a dry year in the South Platte River Basin) was approximately 180 ac-ft for water treatment and evaporative losses from the reservoirs. The average annual water use over the last 5 years has declined due to changing water rates, customer needs, and other factors. The average annual diversions and evaporation obligations for Water Years 2012 through 2019 were less than 140 ac-ft/year.

### 3.2.2. Water Supply Adequacy

Beaver Brook, which currently supplies water to Upper and Lower Beaver Brook Reservoirs and

the Golden Pipeline water right, has its highest flows in April, May, and June. The peak flows can reach over 6 cfs and the low flows can be below 0.1 cfs. The stream does not have gaging stations but is measured and recorded by the District upstream of Upper Beaver Brook Reservoir and downstream of Lower Beaver Brook Reservoir. A summary of average daily Beaver Brook flows is provided below in Table 2.

*Table 2: Average Daily Streamflow in Beaver Brook (cfs)*

| Water Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2012 | ND | ND | ND | 0.5 | 0.3 | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 0.1 | ND |
| 2013 | ND | ND | ND | 0.2 | 1.7 | 0.4 | 0.2 | 0.2 | 5.3 | 2.1 | 0.8 | 0.1 |
| 2014 | ND | ND | ND | 1 | 4.5 | 3.2 | 1 | 0.8 | 0.5 | 0.5 | 0.6 | 0.5 |
| 2015 | ND | ND | ND | 1.6 | 6 | 6 | 3.8 | 1.2 | 0.6 | 0.7 | 0.2 | 0.6 |
| 2016 | 0.6 | 0.9 | 2 | 3.6 | 5.6 | 5.7 | 1.2 | 0.6 | 0.5 | 0.4 | 0.7 | 0.7 |
| 2017 | 0.7 | 0.7 | 0.7 | 1 | 2 | 1.7 | 0.6 | 0.8 | 0.5 | 1.1 | 0.7 | 0.5 |
| 2018 | 0.5 | 0.5 | 0.5 | 0.7 | 1.2 | 0.4 | 0.2 | 0.1 | 0.1 | 0.2 | 0.3 | 0.2 |
| 2019 | 0.2 | 0.3 | 0.3 | 1 | 1.5 | 1.9 | 1.4 | 0.4 | 0.2 | 0.2 | ND | ND |
| Average | - | - | - | 1.2 | 2.9 | 2.4 | 1.1 | 0.5 | 1 | 0.7 | - | - |

Data based on recorded inflows to Upper Beaver Brook Reservoir. In many of the winter months, the data are not available due to freezing although in some years, the flow was estimated. ND indicates "no data" available.

North Beaver Brook is estimated to be able to provide an average yield of over 200 ac-ft/yr of in-priority water from the Beaver Brook Pipeline water right, based on streamflow and administrative data from April 2012 through August 2019. The annual in-priority yield during this period varied from 0 ac-ft/yr to over 500 ac-ft/yr, and the water right is not considered reliable due to the variability and the 1917 priority date. The stream does not have a gaging station but is measured and recorded by the District near the District's water treatment plant.

There are times each year when the 1903 direct flow right from Beaver Brook is utilized to supply the water treatment plant. This water right has yielded between 8 and 90 ac-ft/yr over the last 5 water years and is used when in-priority in order to allow the District to save its stored water supplies. Generally, the District is working to store as much water as allowed in its Beaver Brook Reservoirs and preserve the water in storage to prevent water supply shortages. The stored water supplies are particularly important during droughts when the storage rights may not come into priority for extended periods and during times when the physical flows in Beaver Brook and North Beaver Brook may be nearly nonexistent.

The Upper and Lower Beaver Brook Reservoirs, when full, provide approximately 3 years of water supply at the average annual water demand and nearly 2 years of water supply at the build-out demand.

Historically, Beaver Brook provided enough water to fill Upper Beaver Brook to 257 ac-ft each year, except for very dry years such as 2002, although some of the water was not stored in priority. The spillway outlet of Upper Beaver Brook Reservoir was modified in 2016-2017 and resulted in additional storage capacity in Upper Beaver Brook Reservoir. Since that winter, Beaver Brook has not yielded enough in-priority water in a single year to fill the enlarged reservoir to its capacity of approximately 400 ac-ft.

In April of 2020, Momentum CE Inc. performed a future projection of LMWD water supply. After calibrating a hydrologic model to observed data from 2017-2019, the model was projected 45 years into the future (2017-2061) by adjusting Beaver Brook's natural flows to mimic the pattern of average annual historic flows at USGS Gage 067195050 Clear Creek at Golden, CO (https://waterdata.usgs.gov/nwis). This study found that, assuming the past 45 years of hydrologic conditions were to repeat themselves, there would be significant shortages in LMWD's water storage supplies.

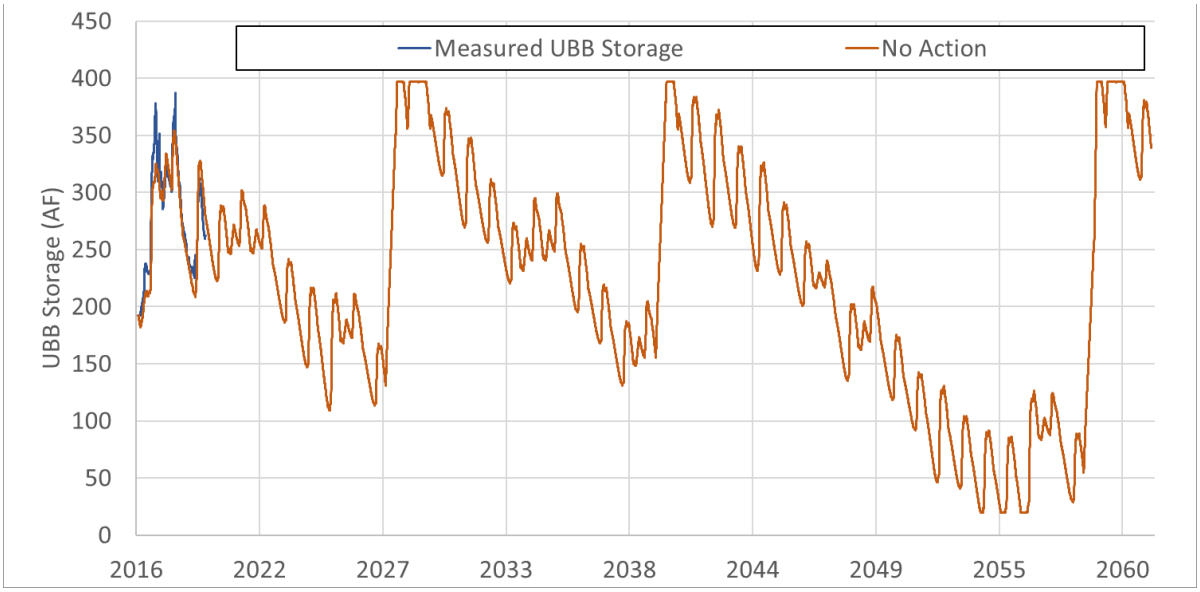


*Figure 4: Modeling results for projected Upper Beaver Brook (UBB) storage.*

### 3.2.3. District's Operations and Other Information

The District typically filled Upper and Lower Brook Reservoirs during the winter and in early spring historically when there was less formal administration of the water rights priority system during the non-irrigation season. As the winter approached and freezing began at Upper Beaver Brook Reservoir (approximate elevation of 8,400 feet), the outlet was closed and all inflows to the on-channel reservoir were stored until much of surrounding snow melted and ice cover had reduced. During the winter, the District would rely on its year-round direct flow rights and supplies stored in Lower Beaver Brook Reservoir to meet the demand for water. Lower Beaver Brook Reservoir was then refilled, as needed, during the spring runoff.

In both 2012 and 2013, the District stored water out of priority in the winter and early spring and incurred replacement obligations to downstream water users of approximately 30 ac-ft and 93 ac-ft, respectively (

Table 3). Since 2014, the District has only diverted or stored water in priority and then used water from storage to meet the demand when its water rights were out of priority. The water levels in Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir are currently managed to prevent storing water out of priority.

*Table 3: Summary of Annual Augmentation Requirements*

| Water Year | Augmentation Requirement (acre-feet) | Notes |
|---|---|---|
| 2012 | 30.27 | Amount based on difference between calculated storage amount and actual storage amount in Upper Beaver Brook Reservoir on October 31, 2012 |
| 2013 | 92.8 | Augmentation water purchased from Golden |
| 2014 | 0 | No augmentation required due to the exceptionally good hydrologic conditions and the filling of a number of downstream reservoirs beginning September 2013 and continuing into the spring and summer of 2014. |

The new operational practices include the need to operate the Upper Beaver Brook outlet year-round in order to prevent storing water when the District's storage rights are not in priority and require more adjustments to the outlet as the reservoir does not begin each irrigation season full and spilling. Because of this, the District is working to increase operational efficiency, find ways to remotely operate the outlets, evaluate water losses within the treatment plant and distribution system to maintain higher water levels, and maximize the beneficial use of the existing water rights and structures.

The proposed project includes modifications to Upper and Lower Beaver Brook Reservoirs which will provide for operational and data improvements including:

1) Improved measurement of reservoir inflows and outflows,

2) Electronic data recording and off-site access to the reservoir water levels for better management of the water resource, particularly during periods with significant diurnal fluctuations and frequently changing water rights administrative conditions,

3) Replacement and modernization of the outlet works at Lower Beaver Brook Reservoir to allow for more efficient operations and better utilization of the stored water, and

4) Upgrades and actuation of the outlet at Upper Beaver Brook Reservoir to allow for off-site operation of the outlet gate year-round and more efficient utilization of the stored water.

# 4. Project Description - Analysis of Alternatives & Selected Alternative

## 4.1. Analysis of Alternatives

The intent of this Project is to replace the existing Lower Beaver Brook Dam with a new roller compacted concrete dam structure and to implement water-saving operational efficiency improvements.

The existing Lower Beaver Brook dam is a concrete-faced rockfill structure that was constructed in 1903 and has been modified several times since. The dam is currently under a compliance plan with the SEO due to the existing spillway being severely undersized. Lower Beaver Brook Dam primarily serves as raw water storage for delivery to the LMWD water treatment plant just downstream of the dam.

LMWD has identified several deficiencies at Lower Beaver Brook Dam, including inadequate spillway sizing, a deteriorated concrete facing, a steep upstream slope, and seepage through cracks in the concrete facing or dam foundation. The new RCC structure will address these deficiencies by providing overtopping protection during a flood, modified geometry, and through the use of modern construction materials and methods. The proposed reservoir will maintain nearly the current storage capacity.

In addition to the replacement of Lower Beaver Brook dam, several water-saving operational efficiency measurements were evaluated as described in Section 4.1.2 and Appendix D.

### 4.1.1. Alternatives for Lower Beaver Brook Dam

W.W. Wheeler, Inc. completed an alternatives evaluation study in 2017 for replacing the Lower Beaver Brook Dam in which alternatives were evaluated and priced. The LBB Alternatives Study by W.W. Wheeler is included in Appendix B. Six alternatives (A1-A6) as well as a no action alternative (A0) were considered:

1) Alternative A0: no-action alternative. A three-foot storage restriction would be put on the reservoir, which would prohibit LMWD from effectively using the reservoir to feed the Water Treatment Plant.

2) Alternatives A1-A3 consisted of spillway size increases but did not address other dam safety deficiencies. As a result, these were ruled out.

3) Alternative A4 included rehabilitating the existing dam with an RCC overtopping protection. This alternative would allow the spillway size to be increased but would not improve seepage conditions related to the existing structure. GEI estimated that A4 would cost approximately $300K to $600K less than alternative A5 but included additional risk because of the unknown condition of the concrete facing. Additionally, due to the proximity of the Xcel gas line, this alternative could not be constructed without relocating the gas line at an estimated cost of $400K to $1M. The low incremental cost difference between the two alternatives and added risk made this alternative the less favorable option.

4) Alternative A5 included replacing the existing dam with a new RCC gravity structure.

5) Alternative A6 included dam removal and construction of a water storage tank to feed the Water Treatment Plant. This alternative was ruled out because it would forfeit the water storage rights for Lower Beaver Brook. As a small water district, with only one other storage option at Upper Beaver Brook, this was not an acceptable alternative to the LMWD.

### 4.1.2. Alternatives for Increased Water Management Efficiency

Momentum CE Inc. completed a study in 2020 to provide LMWD with a firm understanding of the long-term benefits and costs associated with identified potential water supply improvement strategies. The Momentum CE Inc. study is included in Appendix D.

Herein, five water supply improvement alternatives (B1-B5), as well as a no action alternative (B0), are considered:

1) Alternative B0: The no-action alternative. No water supply improvements would be made to LMWD's raw water supply system

2) Alternative B1: Implement Supervisory Control and Data Acquisition (SCADA) to optimize reservoir operations

3) Alternative B2: Install a tank system that will allow LMWD's water treatment plant to utilize water in the lower half of Lower Beaver Brook Reservoir

4) Alternative B3: Rehabilitate the Golden Emergency Pipeline

5) Alternative B4: Rehabilitate the Beaver Brook Pipeline

6) Alternative B5: Install a raw water pipeline to maximize the use of Lookout Mountain Reservoir

### 4.2. Selected Alternative

Alternative A5 was selected as the preferred option for Lower Beaver Brook Dam because it provided a long-term solution to storage at Lower Beaver Brook while protecting the downstream population from a dam failure scenario. Alternative A5 involves construction of a replacement RCC dam section to increase the spillway capacity to meet State requirements and increase the designed life expectancy relative to the rehabilitation alternatives. The replacement of the existing dam structure also allows for foundation improvements to reduce overall storage loss due to leakage and realign the outlet works to eliminate the downstream creek crossing. The proposed dam alignment was shifted upstream to limit impacts to the existing Xcel pipeline on the left dam abutment. This modification does result in a slight reduction in the reservoir capacity but will significantly limit additional costs associated with moving and replacing the pipeline. An additional loss of storage capacity may occur due to sediment buildup. The 30% dam replacement design drawings for the selected alternative can be found in Appendix C.

The completion of both Alternatives B1 and B2 was selected as the preferred option for improving LMWD's water supply. Alternative B1 consists of the installation of Supervisory Control and Data Acquisition (SCADA) equipment at key points throughout the LMWD system to minimize non-beneficial releases from Upper Beaver Brook Reservoir. This would involve water flow measuring stations throughout the system that would send realtime flow data to a computational program that would calculate the optimum release from Upper Beaver Brook Reservoir. The program would then send this calculated target outflow to actuators installed to control Upper Beaver Brook Reservoir's outlet gates. The outflow gates would then automatically adjust until measured outflow below Upper Beaver Brook Reservoir was within tolerance of the calculated target outflow rate. Alternative B1 is estimated to provide approximately 20 AF per year of reduced storage releases from Upper Beaver Brook Reservoir. This will result in cumulative water storage buildup (i.e. saved water can be carried

over to the future years), thereby providing increased resiliency to water shortage from climate change and drought.

Alternative B2 consists of the installation of a 20,000-gallon capacity storage tank on the left abutment of the dam with a pumping system with the capacity to fill the tank at a rate of 200 to 300 gpm. This tank system will allow the water treatment plant to utilize water in the lower half of the reservoir. Currently, the water treatment plant cannot utilize water within Lower Beaver Brook below approximately 8 feet under the spillway crest due to hydraulic constraints associated with treatment plant intake and operations. This pumping system will provide the LMWD with access to approximately 10 acre-feet of storage that the District could previously not utilize regularly.

### 4.3. Cost Estimate

The estimated cost of the project is broken out in the following table. Table 3 provides estimated costs for the construction of Lower Beaver Brook Dam Improvements.

| **Estimated Costs of projects:** | |
|---|---|
| Outlet works UBB, Gate, SCADA | $750,000 |
| New Tank/Pump WTP feed system | $200,000 |
| Lower Beaver Brook dam (includes 20% contingency) | $7,348,000 |
| *Total* | *$8,298,000* |

### 4.4. Implementation Schedule

Final design of the project modification is expected to be completed in the Fall of 2020. Construction is anticipated to begin in the Spring of 2021 and be completed within one construction season. Construction will require the complete draining of the reservoir and temporary diversion pumping and piping to the water treatment plant.

### 4.5. Impacts

The Project will have no significant social impacts, since it will support the continued operation of the existing reservoir, dam and spillway. The Project will have minor physical impacts, during and after construction. The existing reservoir, dam and spillway are located in an area that is not readily visible from existing structures or roadways due to the topography, forest coverage, potential for water coverage of the majority of the concrete weir, and infrequency of human contact in the area.

### 4.6. Institutional Feasibility

Funding of flood mitigation projects by FEMA triggers the requirements of the National Environmental Policy Act (NEPA; 42 U.S. Code [U.S.C.] §§ 4321–4327), which includes an evaluation by federal agencies of the potential environmental impacts of a Proposed Action and a consideration of those impacts during the decision-making process. Therefore, FEMA has completed an Environmental Assessment (EA) in accordance with the Council on Environmental Quality (CEQ) regulations implementing NEPA (Title 40 Code of Federal

Regulations [CFR] Parts 1500–1508) and FEMA's NEPA procedures (directive). Following completion of the EA, FEMA issued a Finding of No Significant Impact (FONSI) and a Record of Environmental Consideration (REC). The final step in the environmental permitting process is acquisition of a Clean Water Act Section 404 permit from the U.S. Army Corps of Engineers (USACE), Omaha District. Impacts to aquatic resources are expected to be permitted under a Nationwide Permit 3 for currently serviceable structures. The permit application will be submitted to the USACE upon reaching 60% design; final acquisition is expected within 60-90 days from time of submission.

Entities that are, or may be, involved in the design, construction, and financing of the project include:

- Lookout Mountain Water District – Financing and project management
- GEI Consultants, Inc. – Design and construction management
- Colorado Water Conservation Board (CWCB) – Financing and financial assistance
- Federal Emergency Management Agency (FEMA) – Financial assistance
- ORC Water Professionals – Water management and operations
- Burns & McDonnell – Rate and reserve study/financial plan
- Martin and Wood Water Consultants, Inc. – Water rights consultation
- Momentum CE Inc. – Resource planning and management consultation

LMWD will be the lead for the financing, design and construction of the project and will be the entity entering into contracts and agreements with the various entities for the services provided by each.

# 5. Financial Feasibility Analysis

## 5.1. Loan Amount

| | |
|---|---|
| Requested Loan Amount: | Up to $3,500,000 |
| Requested term: | 30 years |
| Rate requested: | 2.25% or as low as possible for risk, term and loan size |

Debt Service could run about $162,000 fully drawn at 2.25%
Required reserve would bring this up to $178,000 each year.

## 5.2. Financing Sources

| **Funding Sources:** | |
|---|---|
| FEMA grant on LBB dam replacement | $4,437,500 |
| Potential WSRF grant SCADA, gates, outlet works | $150,000 |
| Variable portion from LMWD reserves | $210,500 |
| Requested CWCB long term loan | $3,500,000 |
| *Total* | *$8,298,000* |

About $4,000,000 of the FEMA grant has been awarded. LMWD has been verbally notified on the remaining portion and accepted but has not yet received the award notification.

WSRF grant application has been submitted, MRT basin funds of $50,000 were approved at the basin level. The CWCB decision on the basin recommendation and additional $100,000 from the statewide funds will occur in September.

Variable portion from LMWD reserves represents current cash reserves that would be used to fund a portion of costs. LMWD's obligation may go to $250,000 depending on final project costs.

Lastly, the CWCB long term loan should end up being a maximum of $3,500,000 if project costs can be kept in line with estimates. When final costs are known LMWD will attempt to balance its cash contribution, liquidity reserves and loan amount/debt service level to create the best situation for the district's finances.

### 5.3. Revenue and Expenditure Projections

A rate study was performed by Burns & McDonnell for the Upper Beaver Brook Spillway project in September of 2015. This rate study was performed to support placing the financing for the project within the Enterprise Fund and making payments based on cash flow from the District's water sales.

*Table 4: Proposed 2020 Water Rates from Burns & McDonnell Rate Study vs. Actual Water Rates*

| | Proposed 2020 Rates | | Actual LMWD 2020 rates | |
|---|---|---|---|---|
| Usage (1,000 gallons) | Taxable Properties | Tax Exempt Properties | Taxable Properties | Tax Exempt Properties |
| 0-3 | $40.45 | $134.84 | $43.00 | $143.00 |
| 4 | $20.23 | $40.45 | $21.45 | $42.90 |
| 5 | $26.97 | $53.94 | $28.60 | $57.20 |
| 6 | $33.71 | $67.42 | $35.75 | $71.50 |
| 7 | $40.45 | $80.90 | $43.00 | $86.00 |
| 8 | $47.19 | $94.39 | $50.00 | $89.00 |
| 9 | $53.94 | $94.39 | $57.20 | $89.00 |
| 10 | $60.68 | $94.39 | $64.35 | $89.00 |
| 11 | $67.42 | $94.39 | $71.50 | $89.00 |
| 12 | $74.16 | $94.39 | $78.65 | $89.00 |
| 13 | $80.90 | $94.39 | $85.80 | $89.00 |
| 14 | $87.64 | $94.39 | $89.00 | $89.00 |
| 15 | $94.39 | $94.39 | $89.00 | $89.00 |
| 16 | $94.39 | $94.39 | $89.00 | $89.00 |
| 17 | $94.39 | $94.39 | $89.00 | $89.00 |
| 18 | $94.39 | $94.39 | $89.00 | $89.00 |
| 19 | $94.39 | $94.39 | $89.00 | $89.00 |
| 20 | $94.39 | $94.39 | $89.00 | $89.00 |
| 21 | $94.39 | $94.39 | $89.00 | $89.00 |
| 22 | $94.39 | $94.39 | $89.00 | $89.00 |

As can be seen from this chart, actual water rates are about 6% higher from base levels to the fixed price per 1,000 gallons than the proposed rates from Burns & McDonnell. Going forward, the goal on pricing will be to average a 3% increase in revenues and continue to encourage conservation of water. If the growth of operating costs can be held below 3% annually, some water pricing flexibility should exist.

When LMWD implemented increased rates in 2015, water consumption began to drop. The District has gone from treating approximately 200 acre-feet of water per year to about 100 acre-feet.

*Table 5: Projected Water Sales Revenues from Burns & McDonnell Rate Study vs. Actual Water Sales*

| | Projected Water Sales Fees & Revenues | Actual Water Sales Revenue | Actual Net other Water Revenue | | Actual vs. Projected | Actual Water Billed AF |
|---|---|---|---|---|---|---|
| 2016 | 535,900 | 506,001 | 29,371 | per audit | -528 | 71.35 |
| 2017 | 588,400 | 552,742 | 42,956 | per audit | 7,298 | 69.53 |
| 2018 | 646,000 | 606,945 | 46,483 | per audit | 17,126 | 69.91 |
| 2019 | 652,100 | 633,736 | 70,969 | per audit | 52,241 | 66.51 |
| YTD 2020 | 412,548 | 393,279 | 24,737 | internal 7/31 | 5,468 | 41.90 |

***YTD 2020 - 62% of year for projected*

*Grants and Subdistrict A revenue were removed from Projected and Actual numbers*

Though the amount of water being billed has fallen, water sales revenue has met or exceeded the projections. In 2019 the revenue per $1,000 gallons was $29.31, leaving the District somewhat reliant on higher use residential and commercial/ tax exempt taps to offset the better conserving residential taps. The mean residential water bill is about $60 a month for consumption of 4 to 5 thousand gallons. The average water bill across all users the first 7 months of 2020 was $116. Debt service requirements have also been maintained per the CWCB loan agreement for existing loans to the Enterprise Fund.

LMWD forecasts little growth in the number of taps or consumption. To be conservative, the number of taps in the projections used for this Loan Feasibility Study were held steady.

Please see spreadsheet: Schedule of Revenue and Expenditures.xlsx (Appendix I). This spreadsheet shows Project Costs, Financing variables for loan, variable growth rates for revenues and expenses and details for existing long-term debt.

This spreadsheet demonstrates the District's projected cash flow and ability to make debt service payments from these normalized revenues and expenses. It tracks Fund reserves and by altering the growth rates of revenues and expenses on both the property tax funded General Fund and water sales driven Enterprise Fund we are led to the following conclusions:

<u>Enterprise Fund (Water Sales driven)</u>

a) Operating expenses for the water sales operations must be kept in check. If these expenses grow at a 3% annual rate, Revenues must keep pace with at least a 3% growth rate.

b) Keeping this balance in the operations side will allow a significant 33% improvement in cash flow after debt service in 2023. This is due to the payoff of CWCB loan C153598 which matures in 2022 and increasing cash flow from consistent, smaller water rate increases projected at 3% per year.

c) These projections do not include the normal cycle of higher repair costs which occur in some years. These are often due to the main transmission line breaks. These breaks have created additional expenses of $40K to $80K in some years. However, we would consider the amounts in the "Inc/Dec Reserves" as available for potential capital expense spending. This demonstrates the District will have the ability to continue infrastructure improvements while still increasing Enterprise Fund reserves.

d) The additional reserves provided for in these projections would eventually be used towards projects or debt service to support the upgrade or replacement of aging infrastructure, primarily main water lines after the current project is complete. Acquiring additional water rights would also be a use of such funds. Potentially some of the excess reserves would be first transferred to the General Fund.

e) Depreciation and Amortization costs are accounted for internally as Enterprise Fund expenses. This is really an overall cost to LMWD. Traditional cash flow measurements give a quick measure of how cash and liquidity should be generated in the Enterprise Fund.

General Fund (Property Tax driven)

a) Administrative expenses for the District must be kept in balance. The challenge here can be unexpected costs around water rights, legal fees, and administrative changes. These expenses are projected to grow 3% per year and basically keep pace with increases in the Property Taxes. Since the property tax receipts cannot be raised easily, the District will have to be diligent to balance revenues and expenses.

b) The District has put a ballot question in place for the November 2020 election asking the voters to approve a de-Gallagher measure. Outreach will be different with current COVID restrictions but are in process.

c) By keeping the debt service requirements down, the District hopes to continue to build reserves and have the financial flexibility to tackle other aging infrastructure issues. We do not foresee carrying this level of reserve balances. Bringing main pipelines up to standard and pursuing additional water rights would be likely uses for levels of reserves beyond 1 to 2 years of then current revenues.

### 5.4. Loan Repayment Sources

This loan will be an obligation of the LMWD general fund, so the primary source of repayment will be Property tax receipts of the District. The District taxes property within its boundaries at a rate of 17.7 mils. Per the opinion of Bond Counsel, the general fund is allowed to use property tax receipts for these infrastructure improvements. A TABOR election was held on May 5, 2020. The voters approved the District taking on debt for these projects which will be repaid by making annual payments with property tax receipts.

As demonstrated by the cash flow projections, which show a minimum of 1.39 debt service coverage including the initial payment reserve, the General Fund property tax receipts are a

solid source of repayment for the requested loan.

Risks for this repayment source should be limited to Gallagher amendment impacts and mismanagement of administration expenses. The District will have a question on the November 2020 ballot to address the Gallagher issue along with the state. A positive vote cannot be counted on, but hopefully the debt service can be kept low enough that LMWD will have sufficient flexibility to make payments from cash flow.

The reserve balances in the General Fund also provide some flexibility in making certain that debt payments will be made as expected.

### 5.5. Financial Impacts

LMWD recognizes that the Lower Beaver Brook (LBB) dam needs to be replaced for safety reasons. Prior to 2015, the District was planning to deal with the dam by spending around $50K to redo the insufficient spillway. The reality that this high hazard dam needed to be replaced created much financial angst.

Replacing the dam will create a much safer corridor along the Beaver Brook basin. Storage in the reservoir will not materially change. In order to gain operational and water management improvements, the financing includes a SCADA system, UBB outlet works improvements, and the tank and pump to feed the water treatment plant.

Due to the small size of the District, taking on the full costs of the LBB dam replacement and related operational improvements would have created a burden that would have been nearly impossible to handle. This would have fallen very harshly on the customers and property owners within the District. Thanks to federal (FEMA, DHS) and state (WSRF, CWCB) support, the District will be able to handle the LBB dam project.

The other future major capital improvement priorities of LMWD include:

a) Replacement or upgrade of main pipeline, about 9 miles of line are still needing work and are 50 to 75 years old. This is possibly $9.5 Million dollars at $200 a foot.
b) Improved water rights
c) Working with privately owned laterals to upgrade to LMWD standards (not at district cost, but also 9 miles of lines).

If the LBB dam was not in need of replacement, these priorities are where money would be spent by the District. These needs are not going away, so after this project is complete, LMWD will evaluate how to attack these problem areas.

As stated in other areas of this study, this loan will be repaid from existing property tax receipts. While property taxes will not increase to repay this debt, we anticipate additional revenue will have to be generated to deal with LMWD's other Capital Improvement priorities.

To keep other aspects of the District's finances in order, water sales and fee revenue will try to be managed to a 3% increase per year. This will most likely be done with small targeted rate and fee increases. Management of operational expenses will try to limit increases to no

more than 3 to 4% per year.

Nonoperational revenues from tax receipts should be consistent, but the District is pursuing a ballot measure to negate the impact of Gallagher. Administrative costs need to be kept in line and should not exceed the growth rate of property tax receipts.

Total long-term debt at the end of 2020 should be $2.88 million including the current portion. All of this debt will be within the Enterprise Fund. If the General Fund draws fully on this requested loan, total long-term debt will reach about $6.3 million. This compares with a projected Net Position of at the end of 2020 of about $4.9 million. Depending on how these new assets are capitalized, once the project is complete, total long-term debt should not represent more than 38 to 40% of total asset funding. This mainly reflects the fact this project is projected to cost about $8.3 million and will only increase debt about $3.5 million.

### 5.6. TABOR (Taxpayer's Bill of Rights) Issues

On May 5, 2020, LMWD included a TABOR question on the election ballot to approve this potential debt offering being repaid with property tax receipts. The electors approved the ballot question 92% to 8%. Please see the election certification in Appendix A.

Bond Counsel worked with LMWD to ensure that the ballot language allowed the District to include the LBB dam construction, SCADA system, Outlet works upgrades at UBB dam, and the pump and storage tank for LBB reservoir's feed to the Water Treatment Plant.

The ballot measure passed provided an approval to issue debt up to $3.75 million to be repaid by the existing levy of 17.7 mils. The ballot measure did not approve any additional taxes beyond what was already in place.

### 5.7. Collateral

The primary collateral for this project will be the pledge of a portion of property tax receipts collected by Jefferson County for the District's 17.7 mil levy.

### 5.8. Sponsor Creditworthiness

The District is requesting a 30-year loan from the CWCB with annual payments estimated at $161,698. LMWD has utilized a variety of borrowing over the past 32 years since formation in the form of revenue bonds, general obligation bonds, and lease purchases. LMWD has never been in default and re-financed the general obligation bonds twice to successfully reduce the total cost and maturity date of the bonds.

LMWD has a loan currently with the CWCB that demonstrates a commitment to paying obligations on time and maintaining a good relationship with creditors. The LMWD's existing debt, operating requirements and proposed debt service have been analyzed in connection with this project. As noted above, the financial analysis can be found in the spreadsheet: Schedule of Revenue and Expenditures.xlsx in Appendix I.

# 6. Conclusions and Recommendation

The following provides a summary of study conclusions from this study:

1) The Lookout Mountain Water District has the authority to enter into a contract with the CWCB for the purpose of obtaining a loan to fund this project, using the Enterprise Fund.

2) Rights-of Way easements and permits are adequate for the construction of this project.

3) The project would provide for the continued delivery of drinking water to current tap holders with an increased reliability for future demands.

4) Preliminary studies, financial feasibility study, and project engineering have been completed and/or are currently in progress; they have been funded or will be funded by the District's annual budgets and a grant.

5) The total estimated cost of the project is $8.298 million. This will be funded, in part, by grants of $4,587,500 and a $3.5 million loan from the CWCB. The remaining balance has been or will be funded out of the District's current annual budgets.

6) The project is technically and financially feasible and offers many years of benefits.

LMWD has been helped and guided in this process and supported tremendously with grants from both the Federal government and the State of Colorado. Without that support, this project would not have been viable.

LMWD and its board of directors have put in countless hours in the effort to get this project done right. We believe in the team assembled and we will continue to work with Federal and State governments to see this project completed successfully.

With a known borrower, reasonable Net Position and projected cash flow, adequate tax receipts pledged for repayment, and a TABOR vote already passed overwhelmingly by the District voters, this loan request should be considered a strong credit with limited risk.

# Appendix A: TABOR Ballot and Certified Results

# Appendix B: LBB Alternatives Study (W.W. Wheeler and Associates)

# Appendix C: LBB Dam Reconstruction Proposal (GEI Consultants, Inc.)

# Appendix D: Water Operations Alternatives Study (Momentum CE Inc.)

# Appendix E: Environmental Study

# Appendix F: LMWD Board Motion to apply for CWCB loan.

# Appendix G: Audited Annual Reports for 2019, 2018 and 2017

# Appendix H: Spread of Annual reports

# Appendix I: Schedule of Revenues and Expenses

# Appendix J: Cost Estimate Breakdown

Lookout Mountain Water District
10200 West 44th Avenue
Suite 130
Wheatridge, CO 80033
303-526-2025
www.lookoutmountainwaterdistrict.org

September 16, 2020

Colorado Water Conservation Board
Finance Section
1313 Sherman St., Ste #718
Denver, CO 80203

Attn: Matt Stearns

RE: Loan Application to the Colorado Water Conservation Board's Water Project Loan Program

On behalf of the Lookout Mountain Water District (LMWD), I am submitting the attached Loan Approval Application, Loan Feasibility Study and associated Appendices. This package will be submitted electronically and in hard copy. The loan would be to finance the replacement of the Lower Beaver Brook Dam (LBB) for safety and risk mitigation requirements, installation of a new pump and tank system for feeding the Treatment Plant from the LBB reservoir, reconstruction of the Upper Beaver Brook outlet works, which includes replacing a nearly 100 year old gate and potentially relining the equally old outlet pipe, and installing a Supervisory Control and Data Acquisition (SCADA) system at UBB to automate the measurement of water flows at various points in the system and control the newly installed gate.

This submission is associated with LMWD's grant application received by the Colorado Water Conservation Board (CWCB) for the Upper Beaver Brook outlet works and SCADA system.

This requested loan from CWCB is critical to LMWD's ability to undertake the required dam replacement and other much needed upgrades. We greatly appreciate this loan opportunity and the past support of the CWCB

Thank you so much for your consideration. Please don't hesitate to contact me if there are any questions.

Sincerely,

Barbara Nevins
President
Lookout Mountain Water District

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

# Water Project Loan Program

*Projects financed by the Water Project Loan Program must align with the goals identified in Colorado's Water Plan and its measurable objectives.*

## Application Type

☐ Prequalification *(Attach 3 years of financial statements)* ☑ Loan Approval *(Attach Loan Feasibility Study)*

## Agency/Company Information

Company / Borrower Name: Lookout Mountain Water District

Authorized Agent &Title: Barbara Nevins, Board President

Address: 10200 West 44th Avenue, Wheat Ridge, CO 800

Phone: ( 303 ) 526-2025 | Email: Administrator: nmholderbiz@gmail.com

Organization Type: ☐ Ditch Co, ☑ District, ☐ Municipality ☐ other:_____ | Incorporated? ☐ YES ☑ NO

County: Jefferson | Number of Shares/Taps: 553

Water District: Lookout Mountain Water District | Avg. Water Diverted/Yr 185 acre-feet

Number of Shareholders/Customers Served: 502 | Current Assessment per Share $_____ (Ditch Co)

Federal ID Number: 84-1090570 | Average monthly water bill $ 116.23 (Municipality)

## Contact Information

Project Representative: Kyle Schroeder, Treasurer

Phone: ( 303 ) 548-7375 | Email: kschroeder@team-ate.com

Engineer: Chad Masching - GEI Consultants, Inc

Phone: ( 303 ) 264-1088 | Email: cmasching@geiconsultants.com

Attorney: Dylan Woods - Toussaint & Coaty

Phone: ( 303 ) 674-0800 | Email: dwoods@tnclaw.com

## Project Information

Project Name: Replacement of Lower Beaver Brook dam, Outlet works for Upper Beaver Brook dam

Brief Description of Project: (Attach separate sheets if needed)

See attached sheet

Other costs, construction management.

Project Start Date(s) Design: Fall 2019 Construction: Spring 2021

General Location: (Attach Map of Area)

## Project Costs - Round to the nearest thousand

Estimated Engineering Costs: $350,000 | Estimated Construction Costs: $7,650,000

Other Costs (Describe Above): $300,000 | Estimated Total Project Costs: $8,300,000

Requested Loan Amount: $ 3,500,000 | Requested Loan Term(10, 20, or 30 years): 30 Years

## Signature

Barb B N ~ / President LMWD 9/15/20

Signature / Title Date

Return to: Finance Section Attn: Matt Stearns
1313 Sherman St #718
Denver, CO 80203
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The purpose for LMWD's loan request to the Colorado Water Conservation Board is to finance this project within the Water Project Loan Program. This project is to bring assets in the Beaver Brook drainage up to a safety and operational level acceptable to state and federal regulators and to improve LMWD's water management and operational efficiency. Several components are needed in order to achieve this goal:

1. Replacement of the LBB dam for safety and risk mitigation requirements. This is the highest cost element of the project.

2. Installation of a new pump and tank system for feeding the Treatment Plant from Lower Beaver Brook (LBB) reservoir. This is aimed at allowing the fluctuation of water levels in this reservoir and providing some operational flexibility.

3. Reconstruction of the Upper Beaver Brook (UBB) outlet works, which will include replacing the nearly 100-year-old gate and relining the outlet pipe.

4. Install a Supervisory Control and Data Acquisition (SCADA) system to automate the measurement of water flows at various points in the system and control the newly installed gate.

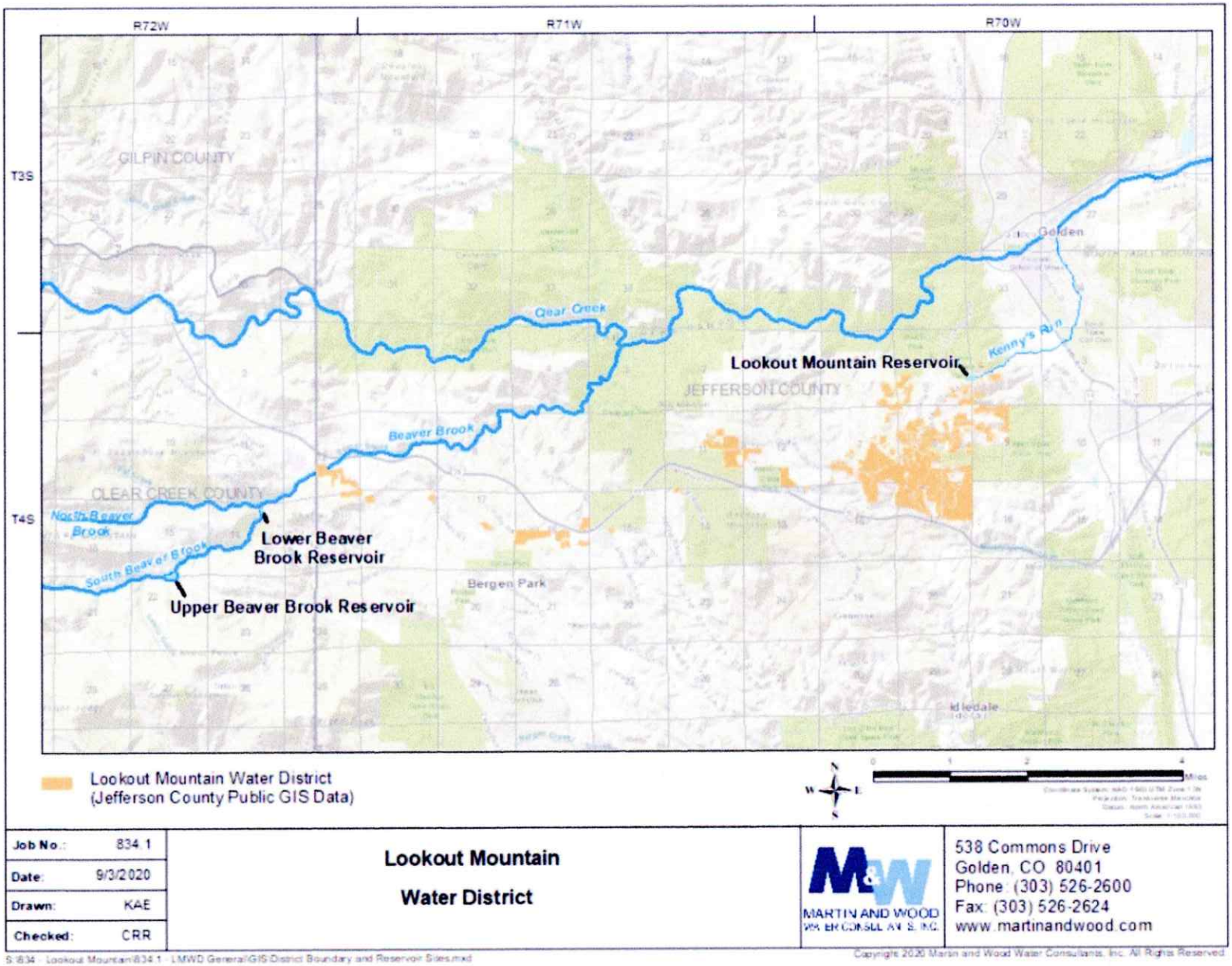


*Figure 1: Map showing counties, towns or cities, topography, major streams, project facilities, and lands served*

# LOWER BEAVER BROOK DAM

# ALTERNATIVES ANALYSIS REPORT FOR DAM SAFETY MITIGATION

Prepared for the

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***October 2, 2017***

# EXECUTIVE SUMMARY

Lower Beaver Brook Dam was originally constructed in 1903 and is located in Clear Creek County, Colorado. It is classified as a small-sized, high-hazard potential dam, with the potential of loss of human life as a result of the failure of the dam. The goal of the Lower Beaver Brook Dam Alternatives Analysis Report was to evaluate the identified dam safety issues at Lower Beaver Brook Dam and develop the most practical reasonable solution to address the identified dam safety issues. The dam is owned by the Lookout Mountain Water District (LMWD) that supplies potable water to approximately 480 residential taps and several other facilities, including a high school, in Jefferson and Clear Creek Counties.

Several dam safety issues have been identified at Lower Beaver Brook Dam, including a significantly undersized spillway for routing the inflow design flood (IDF). The spillway is capable of passing approximately 300 cubic feet per second (cfs) before embankment overtopping is expected to occur, which is less than the 2-year flood (GEI, 2016). Other dam safety issues include uncontrolled embankment and/or foundation seepage; concerns associated with the stability of the embankment; and concerns associated with the age and operability of the outlet works components.

W. W. Wheeler and Associates, Inc. evaluated six alternatives to mitigate the dam safety issues at Lower Beaver Brook Dam, which are briefly summarized in Table No. ES-1. Alternative Nos. 1, 2, and 3 were from a previous study by GEI Consultants, Inc. (GEI, 2015). After considering each alternative's ability to adequately address the dam safety issues; their construction and long-term stability; their ability to maintain the LMWD's water storage, water level, and water rights for operation; their ability to maintain existing routine flow conditions for the downstream floodplain; and their expected future maintenance work; Alternative No. 5, a new concrete dam, was considered to be the preferred alternative. Alternative No. 4, Dam Rehabilitation with RCC Overtopping Protection, is considered a secondary alternative.

**Table ES-1 – Summary of Alternatives and Selection**

| Alternative No. & General Description | Evaluation |
|---|---|
| 1 – Lower normal pool with a 100-foot-wide spillway | Eliminated from consideration based on concerns with flow; rock slope excavation and stability concerns; the lower normal pool not being favorable for operations of the water treatment facility; and the additional discharges that would be released from the dam during routine flow conditions that could impact the downstream floodplain. |
| 2 - Lower normal pool with a 60-foot-wide spillway and a 3-foot-high parapet wall dam raise | |
| 3 - Lower normal pool with a 45-foot-wide spillway and a 5-foot-high MSE wall dam raise | |
| 4 - Dam Rehabilitation with RCC Overtopping Protection | This alternative was not selected because of expected maintenance issues associated with a portion of the 114-year-old embankment remaining. |
| 5 - New Concrete Dam | **This is the preferred alternative.** This alternative eliminates the identified dam safety deficiencies and provides the best long-term solution. |
| 6 - Dam (and reservoir) Removal | Eliminated from consideration due to the value of the reservoir storage. |

# LOWER BEAVER BROOK DAM
# ALTERNATIVES ANALYSIS REPORT

## TABLE OF CONTENTS


**EXECUTIVE SUMMARY** ..... **I**
**TABLE OF CONTENTS** ..... **II**
**1.0 INTRODUCTION** ..... **1**
1.1 OBJECTIVE ..... 1
1.2 AUTHORIZATION ..... 1
1.3 SCOPE OF WORK ..... 1
1.4 PLANNING PROCESS ..... 2
1.5 LOOKOUT MOUNTAIN WATER DISTRICT OVERVIEW ..... 3
**2.0 BACKGROUND** ..... **4**
2.1 LOWER BEAVER BROOK DAM DESCRIPTION ..... 4
2.2 IDENTIFIED DAM SAFETY ISSUES ..... 5
2.3 INFLOW DESIGN FLOOD (IDF) ..... 6
**3.0 ALTERNATIVE DEVELOPMENT** ..... **7**
3.1 ALTERNATIVE DEVELOPMENT PROCESS ..... 7
3.2 DESIGN CRITERIA AND ASSUMPTIONS ..... 8
**4.0 CONCEPTUAL ALTERNATIVE PLANS** ..... **10**
4.1 CONCEPTUAL ALTERNATIVE PLAN DESIGN DESCRIPTIONS ..... 10
4.1.1 ALTERNATIVE NOS. 1 - 3 – SPILLWAY SIZE ALTERNATIVES 10
4.1.2 ALTERNATIVE NO. 4 – DAM REHABILITATION WITH RCC OVERTOPPING PROTECTION ..... 11
4.1.3 ALTERNATIVE NO. 5 – NEW CONCRETE DAM ..... 13
4.1.4 ALTERNATIVE NO. 6 – DAM REMOVAL – WATER STORAGE TANK ..... 14
4.2 ALTERNATIVES EVALUATION AND BENEFIT ANALYSIS ..... 14
4.3 ALTERNATIVE COSTS ..... 16
4.4 BENEFIT-COST COMPARISON ..... 17
4.5 SUMMARY OF CONCEPTUAL ALTERNATIVE PLANS ..... 18
**5.0 RECOMMENDED PLAN** ..... **20**
5.1 BASIS FOR SELECTION ..... 20
**6.0 REFERENCES** ..... **21**

**List of Tables** **Page**


Table ES-1 Summary of Alternatives & Selection ..... i
Table 4.1 Conceptual Alternative Plans ..... 10
Table 4.2 Typical Rockfill Embankment Slopes ..... 12
Table 4.3 Summary of Preliminary Benefits and Impacts of each Alternative ... 15
Table 4.4 Summary of Alternatives - Opinions of Probable Costs ..... 17
Table 4.5 Advantage vs. Disadvantage Summary Comparison Alternative Nos. 4 and 5 ..... 18
Table 4.6 Alternative Plan Summary ..... 19


**List of Figures**


Figure 1 Location Map


**List of Appendices**


Appendix A – Engineer's Inspection Reports by the Colorado Division of Water Resources Dam Safety Engineer

Appendix B – Previous Studies Performed by GEI Consultants

Appendix B-1 – Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report (GEI, 2016)

Appendix B-2 – Technical Memorandum – Lower Beaver Brook IDF Modifications – Conceptual Design Alternatives (GEI, 2015-1) *Includes documentation for Alternative Nos. 1, 2, and 3*

Appendix C – Conceptual Design Drawings for Alternative No. 4 – Dam Rehabilitation with RCC Overtopping

Appendix D – Conceptual Design Drawings for Alternative No. 5 – New Concrete Dam

Appendix E – Feasibility-Level Cost Opinions for Alternative Nos. 4 and 5

Appendix F – Preliminary Construction Schedule for Alternative Nos. 4 and 5


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# 1.0 INTRODUCTION

## 1.1 Objective

The objective of the Lower Beaver Brook Dam Alternatives Analysis Report was to evaluate the identified dam safety issues at Lower Beaver Brook Dam and develop the most practical reasonable solution to address the dam safety issues. This Lower Beaver Brook Dam Alternatives Analysis Report is a comprehensive report, including previous work completed in 2015 by GEI Consultants, Inc. (GEI, 2015) as well the documentation of the development of additional conceptual alternative plans for mitigation of the identified dam safety deficiencies at Lower Beaver Brook Dam. This report provides the Lookout Mountain Water District (LMWD), the owner of Lower Beaver Brook Dam, with a recommended plan for mitigating the identified dam safety deficiencies at Lower Beaver Brook Dam.

## 1.2 Authorization

The work documented in this report was prepared by W. W. Wheeler and Associates, Inc. (Wheeler) in accordance with an agreement authorized by the Lookout Mountain Water District on January 9, 2017.

## 1.3 Scope of Work

Wheeler performed the following work as part of the Lower Beaver Brook Dam Alternatives Analysis Report.

1. Previous studies were reviewed and evaluated, including previously developed alternatives for mitigating the spillway issues at Lower Beaver Brook Dam by GEI, 2015.
2. Wheeler performed a dam inspection and reviewed information from previous dam safety inspections performed by the Colorado Division of Water Resources (DWR).
3. Additional conceptual alternative plans were developed to address the spillway and other dam safety deficiencies at Lower Beaver Brook Dam.
4. Feasibility-level designs and opinions of probable costs were developed for each additional alternative plan.
5. Alternatives were evaluated based on their ability to adequately address the dam safety issues; their construction and long-term stability; their ability to maintain the LMWD's water storage, water level, and water rights for operation; their expected future maintenance work; and their comparative costs.
6. Wheeler met with the LMWD Board of Directors and Treatment Technology, who operates the water treatment facility, to discuss the alternatives and their associated benefits and costs.

7. The Lower Beaver Brook Dam Alternatives Analysis Report was developed summarizing the conceptual alternative plans and the recommended plan for mitigation of the dam safety deficiencies at Lower Beaver Brook Dam.

## 1.4 Planning Process

The LMWD was formed in 1988 as a special district that owns and operates facilities to support the water service to approximately 480 residential taps and several other facilities, including a high school, in Jefferson County and Clear Creek County, Colorado. The LMWD owns and operates three reservoirs (dams) to support the water system.

The Colorado Division of Water Resources (DWR) Dam Safety Branch implemented a Dam Safety Compliance Plan for Lower Beaver Brook Dam on February 9, 2016 based on the spillway inadequacy and deficiencies associated with the outlet works. In accordance with the Compliance Plan, LMWD finalized the Incremental Damage Assessment (IDA) to size the Lower Beaver Brook Dam spillway and completed an inundation map for Lower Beaver Brook Dam in 2016 and 2017. The Compliance Plan recommends that an interim design be prepared for the Lower Beaver Brook spillway by November 1, 2017. The LMWD has met with the Colorado DWR and have expressed their interest in focusing on securing funding for the design and construction of a comprehensive Lower Beaver Brook Dam rehabilitation project as opposed to a costly, interim fix. The LMWD and Colorado DWR are in agreement on modifying the Dam Safety Compliance Plan and the LMWD plans to propose modifications to the compliance plan to suggest various temporary solutions to provide additional residual flood storage in the drainage basin above Lower Beaver Brook Dam.

The LMWD has been proactive in working towards addressing the Colorado DWR's concerns on the spillway size. In 2015, prior to the issuance of the Dam Safety Compliance Plan, the LMWD contracted with GEI to develop conceptual level alternatives for mitigating the spillway size deficiency. The preferred alternative, based on the conceptual design alternatives developed by GEI, was a conceptual design to modify the existing dam with Roller Compacted Concrete (RCC) overtopping protection for the dam crest and downstream slope.

The LMWD has been proactive in researching funding options for the design and construction for the Lower Beaver Brook Dam rehabilitation. The LMWD elected to retain W. W. Wheeler and Associates, Inc. (Wheeler) to perform an independent review of the GEI conceptual alternatives and associated costs for spillway repairs; evaluate if other alternatives should be considered; and ultimately to develop a feasibility-level design to address the identified dam safety issues. Wheeler's work is summarized in this report.

## 1.5 Lookout Mountain Water District Overview

The Lookout Mountain Water District is a special district as governed by Title 32 of the Colorado Revised Statutes (C.R.S.). Two of the LMWD reservoirs (and associated dams, including Lower Beaver Brook Dam) and one water treatment facility are in Clear Creek County, Colorado. The LMWD water consumers reside or operate in the unincorporated areas of Evergreen and Golden, primarily in the area known as Lookout Mountain in Jefferson County (zip codes 80401 and 80439), Colorado. The LMWD operates as a system comprised of tap owners and property owners included in the LMWD's boundaries; the elected Board of Directors; and the contractors and consultants who provide operation and management.

LMWD assets include land, dams and reservoirs, water rights, a treatment facility, and components of the distribution system, such as the main pipeline and meters. Approximately 480 households, 14 governmental sites including a high school and about 10 business or church sites are served by LMWD taps and fire hydrants; some additional tap owners do not currently have active service but will be connected in future years. The LMWD provides water for domestic uses and fire suppression to a critical communications infrastructure site serving Jefferson County and the adjacent counties. Governmental sites are operated by Evergreen Fire Protection District, Clear Creek School District RE-1, Denver Mountain Parks, Jefferson County and Jefferson County Open Space, Foothills Fire Protection District and Highland Rescue Ambulance District. Together the described served households, tap owners, and sites (also known as customers) will be referred to as "Water Consumers".

# 2.0 BACKGROUND

## 2.1 Lower Beaver Brook Dam Description

Lower Beaver Brook Dam is located in Clear Creek County Colorado approximately 7.1 miles northwest of Evergreen, Colorado. See the location on Figure No. 1. Lower Beaver Brook Dam is owned by the LMWD and is operated by Treatment Technology. The Upper Beaver Brook Dam is located upstream of the Lower Beaver Brook Dam.

Lower Beaver Brook Dam is a small, high-hazard, concrete-face rockfill dam with a reinforced concrete slab installed on the upstream slope. The dam was originally constructed in 1903 and was modified in 1936 by reinforcing the upstream concrete face and flattening the downstream slope (Gardner, 1936). Lower Beaver Brook Dam has a crest length of 224 feet and a crest width of 12 feet at Elevation 7840.0[1]. The dam height, as measured from the dam crest to the downstream invert of the outlet works is about 39 feet. The upstream slope is approximately 0.7H:1V (Horizontal to Vertical) and the downstream slope is about 1.25H:1V. Lower Beaver Brook Dam impounds approximately 27.9 acre-feet of water at the normal operating level (spillway crest) elevation of 7837.7 feet (GEI, 2016).

The spillway is an uncontrolled rectangular channel with a width of approximately 29 feet located on the right abutment. The spillway has an upstream concrete control sill that is approximately 2 feet long at Elevation 7837.7 feet. The spillway discharge channel is an open channel founded on exposed bedrock with several near-vertical drops and a concrete-constructed drop structure. The spillway capacity is approximately 313 cubic feet per second (cfs) (GEI, 2016).

The outlet works consists of two 14-inch-diameter steel pipes extending through a rock tunnel. The rock tunnel is constructed through the foundation bedrock beneath the right half of the dam. A concrete bulkhead is installed on the upstream end of the rock tunnel. The 14-inch-diameter pipe on the right was lined with a 12-inch-diameter HDPE pipe in 1988. This pipe provides water to the water treatment facility and is operated in a constant pressurized condition. The 14-inch-diameter pipe on the left routes discharges to the downstream channel; the downstream discharge elevation of this pipe is approximately 7801.0 feet. Both pipes have gate valves installed immediately downstream of the bulkhead at the upstream end of the rock tunnel. It is our understanding that the gate valve on the right (for the pipe that extends to the water treatment facility) has not been operated in years and the left gate valve is operated occasionally for releases. A 4-inch-diameter PVC bypass pipe is installed extending from the springline of the right 14-inch-diameter pipe, routing discharges into the crown of the left 14-inch-diameter pipe that ultimately discharges into the downstream channel. This bypass system is used to release discharges of a lesser amount from the reservoir.

[1] Elevations in this report are based on the National Geodetic Vertical Datum of 1929 (NGVD 29) to be consistent with the original construction drawings.

## 2.2 Identified Dam Safety Issues

Several dam safety deficiencies have been identified at Lower Beaver Brook Dam. A majority of these deficiencies were initially identified by the Colorado DWR during the Dam Safety Engineer Inspections and were confirmed by Wheeler during a January 2017 site visit. The 2015 and 2016 Colorado DWR Engineer's Inspection Reports are included in Appendix A. The identified issues include the following:

1. **The spillway is undersized to pass the Inflow Design Flood (IDF) and is deteriorated.** The existing spillway has a normal freeboard of approximately 2.3 feet (from the dam crest to the spillway crest) and is capable of passing approximately 300 cfs before embankment overtopping is expected to occur, which is less than the 2-year flood (GEI, 2016). The IDF for Lower Beaver Brook Dam has a peak inflow of 4,755 cfs (GEI, 2016). The existing spillway can only pass approximately 6% of the IDF prior to embankment overtopping occurring.

   The upstream concrete control sill for the spillway has severe concrete deterioration. This deterioration was documented in a 1993 inspection and repairs have not been made.

2. **The dam is experiencing a significant amount of uncontrolled embankment and/or foundation seepage.** Dam safety inspections have estimated seepage downstream of the embankment of 40 to 100 gallons per minute (gpm), which emanates along the toe of the dam. The source of seepage is unknown; potential sources of seepage may include the deteriorated upstream concrete facing (likely at the construction joints that have been noted to be deteriorated since 1993), through the foundation since foundation grouting was not performed with construction, or from the concrete facing/foundation contact. The 2016 Colorado DWR dam safety inspection recommended that the LMWD consider performing a dive inspection of the upstream facing and dye testing to locate the source of the seepage.

3. **There are concerns associated with the stability of the dam embankment.** The upstream slope is approximately 0.7H:1V and the downstream slope is about 1.25H:1V. A typical rockfill dam has slopes of 1.3H:1V and a downstream slope of 1.5H:1V. Documentation of an embankment stability analysis is not available for review.

4. **There are concerns associated with the age (and potential condition) of some of the outlet works components.** The gate valve to the 14-inch-diameter steel pipe that extends to the water treatment facility has not been operated in years and its operability is unknown. The 14-inch-diameter steel pipe and gate valve for the outlet works is unlined and is at least 80 years old.

## 2.3 Inflow Design Flood (IDF)

The Colorado DWR Rules and Regulations (DWR, 2007) requires that the spillway be designed to route the storm generated by a percentage of the Probable Maximum Precipitation (PMP) developed using Hydrometeorological Report No. 55 (HMR-55) for a small size, high hazard-potential dam, or a lesser flood supported by an Incremental Damage Assessment (IDA). An IDA was performed for the dam and the IDF is 27.5% of the PMP which results in a peak inflow of 4,755 cfs (GEI, 2016). The analyses supporting the IDF is included in Appendix B-1.

The Lower Beaver Brook Dam has a total contributing drainage basin of 7.45 square miles with 6.5 square miles contributing water to Upper Beaver Brook Dam, through the spillway, then to Lower Beaver Brook Dam and an uncontrolled 0.95 square mile drainage basin routing flows directly to Lower Beaver Brook Dam. The Upper Beaver Brook Dam spillway is 3 cycle labyrinth weir structure that is capable of passing approximately 22,500 cfs with the water at the dam crest (10.75 feet of head over the spillway). The labyrinth weir spillway is capable of passing the IDF for Lower Beaver Brook Dam (~4,755 cfs) with approximately 2 feet of head over the labyrinth weir spillway crest.

# 3.0 ALTERNATIVE DEVELOPMENT

## 3.1 Alternative Development Process

The LMWD retained GEI to develop conceptual design alternatives to mitigate the spillway size deficiencies in 2015. GEI developed conceptual designs and costs for four alternatives: three alternatives including a combination of widening the spillway into the right abutment and raising the dam crest, and one alternative of modifying the existing dam so it could be safely overtopped during the IDF. The conceptual designs and costs for the alternatives developed by GEI did not include costs or designs for mitigating the other dam safety issues identified at Lower Beaver Brook Dam.

The LMWD retained W. W. Wheeler and Associates, Inc. (Wheeler) to perform an engineering review of the conceptual design alternatives developed by GEI in 2015 and to assess if any additional conceptual alternatives should be evaluated that may be more effective. As part of this evaluation, Wheeler determined that further refinement to GEI's alternative for overtopping protection so it could be safely overtopped during the IDF were necessary to address the other dam safety concerns and that a new concrete dam should be developed as a conceptual design alternative.

As a result, two additional conceptual design alternatives (Alternative Nos. 4 and 5) were evaluated by Wheeler to mitigate the identified dam safety deficiencies for Lower Beaver Brook Dam documented in Section 2.2. Wheeler's evaluations included performing preliminary hydraulic analyses, preparing conceptual-level design drawings, and estimating the construction costs.

Based on the alternative development process, six alternatives were identified and are generally described below.

1. **Alternative No. 1 – 100-foot-wide spillway** – Alternative No. 1 consists of lowering the existing spillway elevation (and normal high water line) by approximately 4.5 feet and extending the spillway approximately 71 feet into the right abutment to have a total spillway length of 100 feet. This alternative was developed by GEI in 2015 and only addresses the spillway deficiencies.

2. **Alternative No. 2 – 60-foot-wide spillway with a 3-foot-high parapet wall** – Alternative No. 2 consists of lowering the existing spillway elevation (and normal high water line) by approximately 4.5 feet, extending the spillway approximately 31 feet into the right abutment to have a total spillway length of 60 feet, and the installation of a 3-foot-high parapet wall on the dam crest. This alternative was developed by GEI in 2015 and only addresses the spillway deficiencies.

3. **Alternative No. 3 – 45-foot-wide spillway with a 5-foot-high Mechanically Stabilized Earth (MSE) wall –** Alternative No. 3 consists of lowering the existing spillway elevation (and normal high water line) by approximately 4.5 feet,

extending the spillway approximately 16 feet into the right abutment to have a total spillway length of 45 feet, and the installation of a 5-foot-high MSE wall on the dam crest. This alternative was developed by GEI in 2015 and only addresses the spillway deficiencies.

4. **Alternative No. 4 – Dam Rehabilitation with Roller Compacted Concrete (RCC) Overtopping Protection** – Alternative No. 4 consists of modifying the existing dam to be safely overtopped routing the IDF. This includes RCC constructed on top of the existing dam crest with a stair-stepped RCC downstream facing. The original concept of this alternative was evaluated by GEI in 2015; however, the concept drawings did not have adequate details and only addressed the spillway deficiencies. This conceptual design was further developed by Wheeler to account for additional details and the other dam safety deficiencies including flattening the embankment slopes for stability; a new upstream concrete facing on the modified upstream slope and foundation grout curtain to address the seepage concerns; an upgraded spillway; and a new outlet pipe and upstream gate valves.

5. **Alternative No. 5 – New Concrete Dam** – Alternative No. 5 consists of constructing a new concrete dam downstream of the existing dam, and removing the existing dam. The new dam eliminates all of the identified dam safety concerns.

6. **Alternative No. 6 – Dam Removal** – Alternative No. 6 consists of removing the existing dam. In order for the LMWD to continue providing water services to the water consumers, a storage tank would need to be constructed upstream and modifications made to route the raw water into the water treatment facility. This conceptual alternative was identified; however, a conceptual design and cost was not developed.

## 3.2 Design Criteria and Assumptions

The design criteria and assumptions to mitigate the dam safety deficiencies at Lower Beaver Brook Dam for Wheeler's feasibility designs of the additional alternatives are as follows:

1. In general, the designs should comply with the dam-safety requirements of the Colorado Dam Safety Branch, Division of Water Resources (DWR, 2007).

2. The new spillway or modified spillway should safety pass the IDF (see Section 2.3) with one foot of minimum freeboard.

3. The modified embankment should meet the stability requirements of both the upstream slope and downstream slope under various loading conditions. Compliance of this requirement will require flattening of the upstream and

downstream slopes of the embankment in the rehabilitation alternative (Alternative No. 4).

4. The normal pool elevation of 7837.7 should be maintained for spillway designs for Alternative Nos. 4 and 5, as requested by LMWD to maintain the current storage in the reservoir and to maintain current operations of the water treatment facility.

5. The modified outlet works should meet the reservoir drawdown requirements per the Colorado Dam Safety Branch, Division of Water Resources (DWR, 2007).

6. The construction work will be performed “in the dry”.

For Alternative Nos. 4 and 5, reservoir routing of the IDF was performed to size the spillways and to estimate the maximum reservoir water surface. Wheeler did not perform stability analyses and seepage analyses for the modified embankment and new concrete dam. Wheeler’s designs were based on published empirical data, judgment, and experience. Wheeler’s understanding of the geology and foundation conditions is based on existing design and construction documents that were provided by the LMWD, and observations made during our site visits of the exposed soil and rock materials.

The new concrete replacement dam will be located immediately downstream of the existing embankment. The new dam footprint will not encroach on the existing water treatment facility on the downstream left abutment.

# 4.0 CONCEPTUAL ALTERNATIVE PLANS

The conceptual alternative plans are presented and evaluated in this section, including the three spillway alternatives proposed by GEI. The additional conceptual alternatives developed by Wheeler were designed based on the design criteria and assumptions presented in Section 3.2. Brief descriptions of the conceptual alternative plans are provided in Table No. 4.1.

**Table 4.1 - Conceptual Alternative Plans**

| Alternative | Description |
|---|---|
| 1 | Lower normal pool with a 100-foot-wide spillway |
| 2 | Lower normal pool with a 60-foot-wide spillway and a 3-foot-high parapet wall dam raise |
| 3 | Lower normal pool with a 45-foot-wide spillway and a 5-foot-high MSE wall dam raise |
| 4 | Dam Rehabilitation with RCC Overtopping Protection |
| 5 | New Concrete Dam |
| 6 | Dam Removal |

## 4.1 Conceptual Alternative Plan Design Descriptions

A brief description of the alternative designs and assumptions used to evaluate the alternatives are described below.

### *4.1.1 Alternative Nos. 1 - 3 – Spillway Size Alternatives*

Alternative Nos. 1 through 3 were developed by GEI in 2015. The complete documentation of these alternatives is provided in Appendix B-2. A brief description of these alternatives is provided below. These alternatives only address the dam deficiencies related to the capacity of the spillway for routing the IDF and did not mitigate the other dam safety issues listed in Section 2.2.

Alternative No. 1 lowers the spillway crest and normal high water line by approximately 4.5 feet to Elevation 7833.25 and extends the spillway into the right abutment by approximately 71 feet for a total spillway width of 100 feet. Widening the spillway by 71 feet results in approximately 22,600 CY of rock excavation and excavation depths exceeding 80 feet.

Alternative No. 2 lowers the spillway crest and normal high water line by approximately 4.5 feet to Elevation 7833.25 and extends the spillway into the right abutment by approximately 31 feet for a total spillway width of 60 feet. Widening the spillway by 31 feet results in approximately 8,700 CY of rock excavation and excavation depths exceeding 55 feet. Alternative No. 2 includes a 3-foot high parapet wall constructed on the dam crest to raise the dam crest to Elevation 7843.

Alternative No. 3 lowers the spillway crest and normal high water line by approximately 4.5 feet to Elevation 7833.25 and extends the spillway into the right abutment by approximately 16 feet for a total spillway width of 45 feet. Widening the spillway by 16 feet results in approximately 5,700 CY of rock excavation and excavation depths exceeding 40 feet. Alternative No. 3 includes a 5-foot high mechanically stabilized earth (MSE) wall constructed on the dam crest to raise the dam crest to Elevation 7845.

### *4.1.2 Alternative No. 4 – Dam Rehabilitation with RCC Overtopping Protection*

For Alternative No. 4, the existing embankment dam will be rehabilitated to mitigate the identified dam safety deficiencies, namely, the inadequate spillway capacity, potential inadequate slope stability, uncontrolled seepage, and structural deterioration of the service spillway and outlet works. The main feature of this alternative is to armor the dam crest, downstream face, downstream toe, and both abutments with roller compacted concrete (RCC) to protect the dam from erosion during floods in excess of the capacity of the spillway resulted in dam overtopping up to the IDF. This overtopping protection scheme essentially converts the entire dam into an emergency spillway. The conceptual dam plan view, maximum dam section, and details for construction of Alternative No. 4 are provided in Appendix C.

Alternative No. 4 includes flattening of the upstream and downstream slopes to mitigate the potential slope stability issues. The upstream and downstream slope for the conceptual design are based on typical slopes of rockfill dams since a stability analysis has not been performed. Table 4.2 contains typical rockfill embankment slopes of 25 dams. For the upstream slope, the existing upstream earthfill berm will be excavated, and then the existing deteriorated concrete facing will be demolished and removed. The upstream slope will then be rebuilt to an overall slope of 1.5H:1V (horizontal: vertical) with new compacted rockfill. The new concrete facing is a reinforced concrete slab with a thickness of 12 inches and keyed into the bedrock with a footing known as “plinth”. A transition material will be installed between the concrete facing and the rockfill embankment. The foundation will be pressure-grouted through drill holes into the plinth. The new concrete facing and the foundation grouting are intended to mitigate the uncontrolled seepage observed at the toe and abutments of the existing dam.

**Table 4.2 – Typical Rockfill Embankment Slopes**

| Dam Name | Location | Height (feet) | Embankment Slope | | Foundation Rock |
|---|---|---|---|---|---|
| | | | Upstream | Downstream | |
| Cogoti | Chile | 280 | 1.4H:1V | 1.5H:1V | Andersite |
| New Exchequer | California | 490 | 1.4H:1V | 1.4H:1V | Meta-Andersite |
| Fades | France | 218 | 1.3H:1V | 1.3H:1V | Granite |
| Kangaroo Creek | Australia | 200 | 1.3H:1V | 1.4H:1V | Schist |
| Alto Anchicayer | Columbia | 460 | 1.4H:1V | 1.4H:1V | Schist |
| Golillas | Columbia | 410 | 1.6H:1V | 1.6H:1V | Shale/sandstone |
| Outardes | Canada | 180 | 1.4H:1V | 1.4H:1V | Gneiss |
| Foz do Areira | Brazil | 510 | 1.4H:1V | 1.4H:1V | Basalt |
| Mangrove Creek | Australia | 250 | 1.5H:1V | 1.6H:1V | Sandstone/siltsonte |
| Shiroro | Nigeria | 400 | 1.3H:1V | 1.3H:1V | Granite |
| Fortuna | Panana | 190 | 1.3H:1V | 1.4H:1V | Andersite |
| Salvajina | Columbia | 485 | 1.5H:1V | 1.4H:1V | Sandstone/siltsonte |
| Boondooma | Australia | 210 | 1.3H:1V | 1.3H:1V | Granite |
| Khao | Thailand | 426 | 1.4H:1V | 1.4H:1V | Shale/siltstone/ Sandstone |
| Terror Lake | Alaska | 193 | 1.5H:1V | 1.4H:1V | Graywacke |
| Kotmale | Sri Lanke | 300 | 1.4H:1V | 1.45H:1V | Gneiss |
| Balsam Meadow | California | 126 | 1.3H:1V | 1.3H:1V | Granite |
| Deer Creek | Wyoming | 280 | 1.3H:1V | 1.3H:1V | Gneiss |
| Xingo | Brazil | 460 | 1.4H:1V | 1.3H:1V | Schist |
| Segredo | Brazil | 476 | 1.3H:1V | 1.4H:1V | Basalt |
| Machadinho | Brazil | 417 | 1.3H:1V | 1.3H:1V | Basalt |
| Ita | Brazil | 400 | 1.3H:1V | 1.3H:1V | Basalt |
| Macagua | Venezuela | 66 | 1.3H:1V | 1.3H:1V | Granite |
| Cirata | Indonesia | 400 | 1.5H:1V | 1.5H:1V | Mudstone |
| Terminal | Colorado | 78 | 1.7H:1V | 1.8H:1V | Gneiss |

The plan view of the RCC embankment overtopping protection and the maximum section of the downstream slope and toe are shown in Appendix C. Four feet of RCC is used to armor the dam crest, which maintains the same elevation of 7840. Two RCC training berms, one at each end of the dam, are used to train the overtopping flows toward the middle of the embankment and prevent erosion of the abutments. The training berms have a crest elevation 7845, providing more than one foot of minimum freeboard during the IDF. The downstream slope of the embankment will be flattened to 1.5H:1V, and will be armored with 10 feet (measured horizontally) of RCC constructed in a stair-step fashion. The RCC on the downstream slope will be keyed into the bedrock abutment. A 20-foot-wide RCC stilling basin at the toe of the dam provides the energy dissipation.

The service spillway will remain in the same location. The deteriorated reinforced concrete sill will be demolished and removed, and a new 23-foot-wide reinforced concrete sill will be constructed, with the same crest elevation of 7837.7. Therefore, there is no change in the normal pool elevation for this alternative. Flow through the service spillway will be discharged through the same downstream channel in rock, and then terminated in the new RCC stilling basin.

Modifications of the existing outlet works consist of replacing the two original gate valves with new gate valves (12-inch for the water-supply line, and 14-inch for the outlet pipe), extending the inlet pipes under the flattened upstream slope, and replacing the existing 14-inch-diameter outlet pipe with new 14-inch-diameter steel outlet pipe.

Construction of Alternative No. 4 will require draining the reservoir, and maintaining the reservoir in a drained condition with a temporary upstream cofferdam installed for protection from flows during construction. The existing outlet works can be used for stream diversion and controlling the reservoir levels during construction. A temporary diversion upstream of the dam will be needed to provide continued water supply to the water treatment facility. Wheeler assumed that an on-site borrow area near the dam will be available for the materials for the new rockfill, riprap, and RCC aggregates in the cost analysis. RCC was assumed to be batched on site. A preliminary construction schedule was developed and included in Appendix F. With the construction of the left training berm (looking downstream), there will be no vehicle access to the new dam crest.

### *4.1.3 Alternative No. 5 – New Concrete Dam*

For Alternative No. 5, the existing embankment dam will be removed, and a new concrete gravity dam will be constructed immediately downstream of the existing dam. Even though geology and subsurface data is currently unavailable for this dam, it is Wheeler's opinion that the gneiss bedrock that is exposed in the right abutment of the dam is suitable as a foundation for a relatively small concrete gravity dam. The new gravity dam can be designed and constructed either with conventional mass concrete, or with roller compacted concrete (RCC). For this study, the new dam was assumed to be constructed with RCC, but a conventional concrete gravity is equally applicable for this site. The conceptual dam plan view, maximum dam section, and details for construction of Alternative No. 5 are provided in Appendix D.

The new concrete dam has a non-overflow crest at elevation 7845 at each end, with a central emergency spillway in the middle. The emergency spillway is 125 feet wide with a crest elevation of 7840. The existing service spillway on the right abutment will be rehabilitated to maintain the same normal pool elevation of 7837.7. The RCC cross section is designed conservatively based on Wheeler's experience with dam

construction and judgment, and no stability analysis was performed to size the dam. The RCC section has a vertical upstream face, a 20-foot-wide crest, and vertical chimney section from the crest to elevation 7815, and a 0.8H:1V (horizontal: vertical) downstream face from elevation 7815 to the toe of the dam. The upstream face, dam crest, and the downstream face are protected from freeze-thaw damages with a grout-enriched RCC. A 20-foot-wide RCC stilling basin is provided at the downstream toe to dissipate energy from the emergency spillway flow.

The outlet works of the new dam consists of two slide gates mounted on the upstream face of the dam, with an 18-inch-diameter steel outlet pipe in the dam. The two slide gates will provide a multi-level withdrawal from the reservoir. The release from the outlet pipe is bifurcated at the downstream toe: one pipe providing water supply to the treatment plan, and one pipe for reservoir drawdown. The reservoir drawdown pipe enters into the same RCC stilling basin that is used for the spillway.

Construction of the new dam will require draining of the reservoir. The existing rockfill embankment can be excavated in stages for three reasons: (a) the rockfill materials removed from the top portion of the dam can be processed as a source of the RCC aggregate; (b) the remaining embankment can function as a cofferdam for flood protection; (c) the lowered embankment provides a suitable flat area for the RCC batch plant. After the new dam is constructed, the existing embankment can be partially breached or completely removed. It is anticipated that the existing embankment will supply adequate materials for the new RCC dam, and no on-site borrow area was assumed to be required. A preliminary construction schedule was developed and included in Appendix F.

#### *4.1.4 Alternative No. 6 – Dam Removal – Water Storage Tank*

This alternative was not fully developed at the request of the LMWD. However, the general concept includes an upstream diversion structure on Beaver Brook that diverts water into a pipeline that is routed to a water storage tank. A pipeline would be connected from the water storage tank to the water treatment facility.

## 4.2 Alternatives Evaluation and Benefit Analysis

The alternatives were qualitatively evaluated based on the effectiveness of the alternatives and the impacts associated with implementing the conceptual level designs. The benefits and impacts are summarized in Table 4.3.

**Table 4.3 - Summary of Preliminary Benefits and Impacts of each Alternative**

| Benefits & Impacts | Alternative | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| ***Highlighted - Result is considered not favorable.*** | | | | | | |
| Addresses the spillway capacity dam safety issue | Yes | Yes | Yes | Yes | Yes | Yes |
| Maintains the existing reservoir storage pool | No | No | No | Yes | Yes | No |
| Additional discharges expected in the downstream floodplain during routine flow conditions | Yes | Yes | Yes | No | No | Yes |
| Addresses the non-spillway related dam safety issues | No | No | No | Yes | Yes | Yes |
| Likely require rock blasting of the right hillside | Yes | Yes | Yes | No | No | No |
| Significant impacts to right hillside | Yes | Yes | Yes | No | No | No |
| Requires decreasing the normal pool elevation | Yes, decreases by 4.5 feet | Yes, decreases by 4.5 feet | Yes, decreases by 4.5 feet | No | No | Yes, eliminates pool |

Alternative Nos. 1 – 3 were evaluated in terms of the LMWD's requirements, technical feasibility, constructability, and other risks and unknowns, and have the following comments:

1. Lowering the normal operating pools by 4.5 feet assumed in all three alternatives is contrary to the operational requirements of LMWD, who prefers to maintain the same normal pool;

2. The hydraulics of the enlarged spillway will require further evaluation and analysis for hydraulic stability. There is a significant convergence of the enlarged spillway discharge channel. The converged channel also includes a 45-degree bend to the left (looking downstream) along a very steep chute, eventually terminating in a small plunge pool stilling basin. The flow convergence and the bend in the chute under high flow velocities may result in flow instability and erosion of the right side of the embankment.

3. The excavation for the spillway is in a hard rock in the right abutment, which will require blasting. The effects of blasting vibration may have adverse effects on the existing embankment and outlet works, and would need to be further evaluated. In addition, there appears to be a residential structure on top of the right abutment, and how the excavation will affect this structure has not been addressed.

4. The temporary and permanent rock slope stability of the massive and steep (0.5H:1V) spillway cuts (in the range of 45 to 80 feet high, will require detailed analysis and evaluation.

5. Widening the service spillway will result in higher discharges being released from the dam at lower storage levels. This could impact the downstream floodplain during routine flow conditions.

In Wheeler's opinion, the spillway designs in Alternative Nos. 1 to 3 contain significant risk and uncertainties which may affect the feasibility of further development. As a result, these alternatives were eliminated from consideration are not discussed further in the report. GEI developed costs related to Alternative Nos. 1, 2, and 3; however, these costs did not include the additional costs associated with addressing the dam safety deficiencies other than the spillway capacity deficiency. As a result, the costs for Alternative Nos. 1, 2, and 3 would be higher if all the dam safety issues were addressed, thus these costs are not directly comparable to the costs for Alternative Nos. 4 and 5. Additional information on these alternatives are included in Appendix B-2.

The Alternative No. 6, dam removal, conceptual design was not further developed. The LMWD considers the storage in Lower Beaver Brook Reservoir and the associated water rights as a very important component of their water rights portfolio. The water storage also serves a very important role in drought protection. As a result, the LMWD cannot accept Alternative No. 6 as a viable alternative. Other potential impacts that were considered not favorable for this alternative include the loss of reservoir aesthetics and floodplain aesthetics, potential wetland impacts, and potential habitat impacts.

## 4.3 Alternative Costs

Wheeler developed feasibility-level opinions of probable costs for Alternative Nos. 4 and 5. Direct construction costs include items directly related to the dam construction. The indirect costs include a budget for non-construction items that are required to develop the project such as engineering and permitting. A summary of the opinion of probable direct construction and indirect project development costs are provided in Table No. 4.4 presented in 2020 dollars, which is the planned construction year. Additional details of Wheeler's feasibility-level opinion of probable project costs for Alternatives 4 and 5 are provided in Appendix E.

The costs associated with this level of cost are within an expected accuracy range (USSD, 2012). The range of expected project costs is included in Table 4.4.

**Table 4.4 - Summary of Alternatives - Opinions of Probable Costs [A]**

| Alternative No. | Description | Direct Construction Costs | Indirect Construction Costs | Total Project Costs [B] |
|---|---|---|---|---|
| 4 | Dam Rehabilitation with RCC Overtopping Protection | $3,245,000 | $788,000 | $4,033,000 ($3.6M - $4.8M) |
| 5 | New Concrete Dam [C] | $4,262,000 | $1,055,000 | $5,317,000 ($4.8M - $6.4M) |

[A] Costs presented are in 2020 dollars, which is the planned construction year.
[B] Range of expected costs based on a Class 4 cost estimate for a Feasibility level design (USSD, 2012).
[C] For these costs, the new concrete dam was assumed to be constructed with RCC.

## 4.4 Benefit-Cost Comparison

Alternative Nos. 4 and 5 include the mitigation of the identified dam safety concerns, namely including the inadequate spillway, slope stability concerns, seepage concerns, and outlet works upgrades. Both alternatives also maintain the existing normal high water line and reservoir storage for the water treatment facility operations and storage for drought protection. As a result, both of these alternatives are considered equal in their ability to maintain the reservoir aesthetics and preserve the habitat and wetlands associated with the reservoir.

The benefits associated with Alternative No. 5, a new concrete dam, are primarily the benefits in having a new structure which will likely result in less future maintenance expenses and time, the dam is expected to last longer, and the construction of the entire dam will be well-documented.

A summary of the advantages and disadvantages associated with the Alternative Nos. 4 and 5 are summarized below.

**Table 4.5 - Advantage vs. Disadvantage Summary Comparison for Alternative Nos. 4 and 5**

| Evaluation Factor | Alternative No. 4 Dam Rehabilitation with RCC Overtopping Protection | Alternative No. 5 New Concrete Dam |
|---|---|---|
| ***Highlighted - Result is considered favorable.*** | | |
| **Cost** | Expected Opinion of Probable Cost is $1.3M less (~30-percent) | Expected Opinion of Probable Cost is $1.3M more (~30-percent) |
| **Construction Period** | Construction period expected to be approximately 8 months. | Construction period expected to be approximately 8.5 months. |
| **New Construction vs. Rehabilitation** | A portion of the 114-year-old dam still exists. The exact material composition and design standards used are (and will likely always be) unknown for the existing portion of the embankment. | Complete modern design. Construction will be documented in accordance with the Colorado DWR Dam Safety Rules. |
| **Design Life** | The life span is expected to be less than the new dam considering some of the 114-year-old embankment and features will still exist. | Expected to have a longer life span since the entire dam and appurtenant features will be new. |
| **Maintenance** | More frequent and costly maintenance items are expected considering parts of the dam are in excess of 114-year-old. | Less frequent maintenance items are expected to arise considering the entire dam and appurtenant features will be new. |

## 4.5 Summary of Conceptual Alternative Plans

The alternatives that were evaluated present a range of different approaches to address the dam safety deficiencies for Lower Beaver Brook Dam. Table No. 4.6, Alternative Plan Summary, presents a brief description of the basis for the selection of Alternative No. 5.

**Table 4.6 – Alternative Plan Summary**

| Alternative Description | Summary of Selection/Elimination Reasoning |
|---|---|
| 1 – Lower normal pool with a 100-foot-wide spillway | Eliminated from consideration based on concerns with flow; rock slope excavation and stability concerns; the additional discharges that would be released from the dam during routine flow conditions that could impact the downstream floodplain; and the lower normal pool not being favorable for operations of the water treatment facility. |
| 2 - Lower normal pool with a 60-foot-wide spillway with a 3-foot-high parapet wall dam raise | |
| 3 - Lower normal pool with a 45-foot-wide spillway with a 5-foot-high MSE wall dam raise | |
| 4 - Dam Rehabilitation with RCC Overtopping Protection | This alternative mitigates the identified dam safety issues and maintains the current reservoir storage and normal high water line, which should maintain the existing LMWD water treatment facility operations, storage, habitat, and wetlands associated with the reservoir. This alternative was approximately 30-percent cheaper than Alternative No. 5; however, a portion of the embankment will be in excess of 114 years old. This is considered a secondary alternative. |
| 5 - New Concrete Dam | **This is the preferred alternative.** This alternative mitigates the identified dam safety issues and maintains the current reservoir storage and normal high water line, which should maintain the existing LMWD water treatment facility operations, storage, habitat, and wetlands associated with the reservoir. This alternative was approximately 30-percent more expensive than Alternative No. 5; however, the LMWD considered the benefits associated with the expected increased life span and decreased annual maintenance was favorable since the dam will be new. A conventional concrete gravity dam as opposed to an RCC dam can be considered in final design as for a potential reduction in construction costs for this alternative. |
| 6 - Dam (and reservoir) Removal | Eliminated from consideration due to the value of the water rights and reservoir storage. Other potential impacts that were considered not favorable for this alternative include the loss of reservoir aesthetics and floodplain aesthetics, potential wetland impacts, and potential habitat impacts. |

# 5.0 RECOMMENDED PLAN

Six alternatives were evaluated in this alternatives analysis report. After considering each alternative's ability to adequately address the dam safety issues; their constructability and long-term stability; their ability to maintain the LMWD's water storage, water level, and water rights for operation; and their expected future maintenance work; Alternative No. 5, a new concrete dam, is considered to be the preferred alternative. Alternative No. 4, Dam Rehabilitation with RCC Overtopping Protection, is considered a secondary alternative.

## 5.1 Basis for Selection

The primary objective defined at the outset of the study was to mitigate the dam safety concerns identified at Lower Beaver Brook Dam. Alternative No. 5, the new concrete dam, was selected for several reasons including:

1. It mitigates the identified dam safety issues,

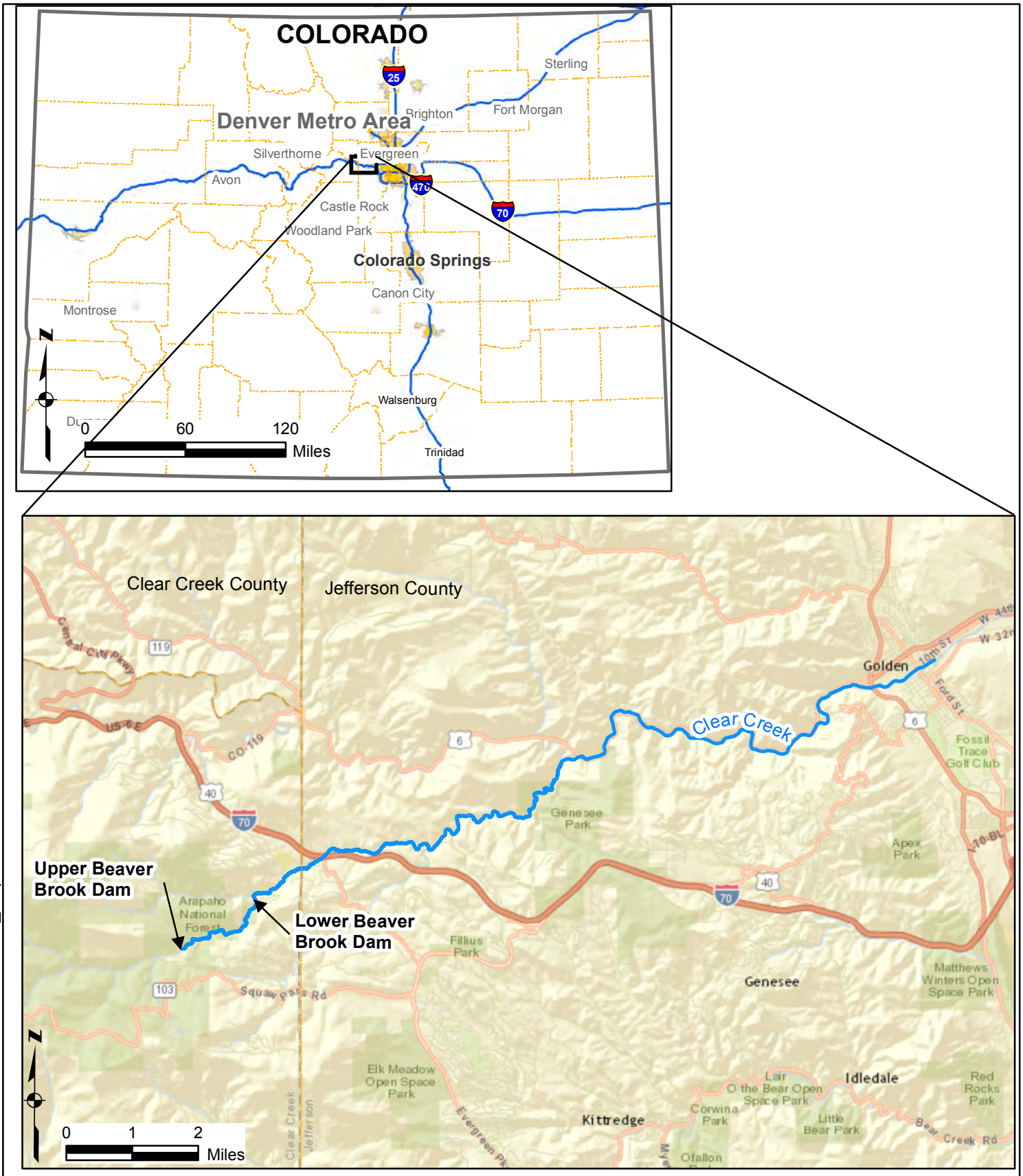
2. It maintains the existing reservoir storage and normal high water line which will maintain the LMWD's reserves for drought protection and the current water treatment facility operations,

3. It maintains the reservoir at the current level for habitat and wetland benefits,

4. It provides the LMWD with the benefits of having a new dam, which is expected to result in less annual maintenance and a longer future life span for operations.

## 6.0 REFERENCES


1. Colorado Division of Water Resources (DWR, 1993), Engineer's Inspection Report by Gregory G. Hammer, P.E., Dam Safety Engineer, July 14, 1993.
2. Colorado Division of Water Resources (DWR, 2007), Rules and Regulations for Dam Safety and Dam Construction, January 1, 2007.
3. Colorado Division of Water Resources (DWR, 2015), Outlet Video Inspection Review by Ryan Schoolmeesters, P.E., Dam Safety Engineer, June 9, 2015.
4. Colorado Division of Water Resources (DWR, 2015), Engineer's Inspection Report by Ryan Schoolmeesters, P.E., Dam Safety Engineer, May 6, 2015.
5. Colorado Division of Water Resources (DWR, 2016), Engineer's Inspection Report by Ryan Schoolmeesters, Dam Safety Engineer, July 13, 2016.
6. Colorado Division of Water Resources (DWR, 2016), Dam Safety Compliance Plan for Lower Beaver Brook Dam DAMID 070102, letter dated February 9, 2016.
7. FEMA, (FEMA, 2013), Light Detection and Ranging (LiDAR), Resolution 0.7 meter, Vendor: Photoscience, Inc., available through Colorado GeoData Cache, Acquisition Date: 10/16/2013.
8. Gardner, M.W., City Engineer (Gardner, 1935) Repairs for Golden Reservoir and Dam No. 1 being Lower Beaver Brook Dam including Bypass Tunnel and Concrete Face and Loose Rock Backfill for Dam, October 1935.
9. GEI Consultants, Inc. (GEI, 2015-1), *Technical Memorandum Lower Beaver Brook IDF Modifications – Conceptual Design Alternatives,* November 2015.
10. GEI Consultants, Inc. (GEI, 2015-2), *Upper Beaver Brook Dam Spillway Improvements Project Design Report,* October 2015.
11. GEI Consultants (GEI, 2016) *Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report*, Revised December 2016.
12. RS Means (RS Means, 2017), Heavy Construction Data, 31st Annual Ed., 2017.
13. United States Society on Dam (USSD, 2012), Guidelines for Construction Cost Estimating for Dam Engineers and Owners, May 2012.

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JULY 2017

W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers

**Lower Beaver Brook Dam Alternative Analysis Report Location Map**

Job. #: 1867.01

**FIGURE 1**

# APPENDIX A

## ENGINEER'S INSPECTION REPORTS

## COLORADO DIVISION OF WATER RESOURCES DAM SAFETY ENGINEER

# ENGINEER'S INSPECTION REPORT

INSPECTOR: RDS

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: | LOWER BEAVER BROOK | | T: 040S | R: 0720W | S: 14 | COUNTY: | CLEAR CREEK | DATE OF INSPECTION: | 7/13/2016 |
| DAM ID: | 070102 | YRCompl: 1903 | DAM HEIGHT(FT): | 35.0 | | SPILLWAY WIDTH(FT): | 29.0 | PREVIOUS INSPECTION: | |
| CLASS: | High hazard | | DAM LENGTH(FT): | 224.0 | | SPILLWAY CAPACITY(CFS): | 95.0 | NORMAL STORAGE (AF): | 30.0 |
| DIV: | 1 | WD: 7 | CRESTWIDTH(FT): | 12.0 | | FREEBOARD (FT): | 1.1 | SURFACE AREA(AC): | 2.0 |
| EAP: | 5/5/2014 | | CRESTELEV(FT): | 7840.0 | | DRAINAGE AREA (AC.): | 5120.0 | OUTLET INSPECTED: | 9/26/2014 |

**CURRENT RESTRICTION:** -- NONE --

| | | | |
|---|---|---|---|
| OWNER: | LOOKOUT MOUNTAIN WATER DISTRICT | OWNER REP.: | CHRISTINA SHEA |
| ADDRESS: | 1202 BERGEN PARKWAY | CONTACT NAME: | TREATMENT TECHNOLOGY |
| | EVERGREEN CO 80439 | CONTACT PHONE: | (303) 670-3936X |

INSPECTION PARTY : Jeremy Wheeler; Ryan Schoolmeesters

REPRESENTING : Treatment Technology; Colorado Dam Safety

FIELD CONDITIONS OBSERVED

WATER LEVEL: BELOW DAM CREST 1.1 FT. Above Spillway 0.1 FT. GAGE ROD READING 3.1

GROUND MOISTURE CONDITION: [x] 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

[x] (8) CONCRETE FACING - HOLES, CRACKS, DISPLACED, UNDERMINED [ ] (9) OTHER

**PAST RECOMMENDED ACTIONS:**

**1. Repairs to the upstream slope will eventually need to be performed. (2014)**

**CONDITIONS OBSERVED:**

**The upstream slope generally appears to be in good condition. There are three areas that display spall damage at the normal high water line, and three vertical cracks that don't appear to be intentional construction joints due to a lack of expansion material or water stop. Two of the cracks extend to depths beyond view, while the third appears to terminate about 5 to 6 feet below the crest. These conditions are not new and have been observed in the past inspections.**

**Cracks at:**
**- 50' from left abutment**
**- 50' from spillway**
**-40' from spillway**

**Spalls at:**
**- 60' from left abutment**
**-90' from left abutment**
**-120' from left abutment**

**A small diameter pipe was observed at the NHWL at the left abutment, which Jeremy identified as the original diversion inflow pipe from North Beaver Brook. The pipe was cut when the WTP was built and therefore is no longer in service. Jeremy also mentioned that there was no spilling from the outfall near the WTP when the reservoir was at its peak in 2013.**

**The openings & deterioration of the upstream concrete facing have not historically been closely monitored other than qualitative assessments. What's more, the LMWD maintains a near full reservoir level as a necessity for water delivery to the District treatment plant on the left abutment, thereby preventing observation of the majority of the upstream face during routine dam safety inspections. The presence of relatively large seepage flows at the downstream toe suggests that a portion of the upstream facing may be compromised, presumably at one of the seven construction joints. To evaluate this possibility, the District may want to consider a dive inspection of the construction joints including joint measurements and dye testing for seepage. Identification of high seepage areas would help determine and prioritize upstream facing repairs. The dive inspection could simultaneously evaluate the degree of sedimentation in the bottom of the reservoir.**

**CURRENT RECOMMENDED ACTIONS:**

**1. See item #1 and discussion above. It is noted that Colorado Dam Safety does not consider this item a high priority at this time.**

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

**PAST RECOMMENDED ACTIONS:**
**1. Modifications to the dam crest should be completed as part of a future larger rehabilitation project. The objective would be to regrade the crest to a uniform elevation and cross slope for even drainage. (2014)**

**CONDITIONS OBSERVED:**
**No changed conditions observed. There is a known low area near the left abutment, which is where the reservoir elevation is monitored. Also of note is that the elevation stamped on the movement monument at the spillway is about 10 feet lower than shown in the record drawings, which raises questions about the accuracy of the drawings and volume of reservoir.**

**The sandbag freeboard dike along the crest remains and appears to provide about the same level of freeboard as originally, however vandalism has resulted in damage to the bags and visqueen.**

**CURRENT RECOMMENDED ACTIONS:**
**1. See item #1 above.**

CONDITIONS OBSERVED: ☐ 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

**PAST RECOMMENDED ACTIONS:**
**None.**

**CONDITIONS OBSERVED:**
**No changed conditions observed.**

**The downstream slope is rather steep (nearly 1H:1V per C-0292 record drawings). The described rockfill nature of the embankment material has been physically adequate to support this slope since the last modification project in 1933; however it is unclear whether this slope meets the slope stability requirements under the recently revised IDF conditions. Subsurface investigations and geotechnical lab testing is anticipated to be necessary to support slope stability analyses required for the pending freeboard modification project.**

**CURRENT RECOMMENDED ACTIONS:**
**None at this time.**

CONDITIONS OBSERVED: ☐ 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

**PAST RECOMMENDED ACTIONS:**
**1. Modification of the existing seepage measurement device or installation of a new seepage measurement system should be a high priority on a list of maintenance tasks for the District. (2013)**

**CONDITIONS OBSERVED:**
**A minor seep was noted immediately adjacent to the outflow measurement flume. The flow rate is about 0.5 gpm and is not captured in the flow measurement flume, but does not appear to be a dam safety issue.other than that, the seepage conditions appear about the same as in the past. Majority of the flows surface at the left toe of the dam, but some contribution from the outlet tunnel was also observed. Jeremy stated that the flows are generally around 30-40 gpm, though there is no reliable method of measurement when the spillway is active. Past records suggest that there's an internal clay tile drain within about 10 feet of the toe, but the pipe is not visible and therefore cannot be conformed. Theme is also no detail for this drain, so filter compatibility cannot be checked.**

**CURRENT RECOMMENDED ACTIONS:**
**1. See item #1 above.**

**The poor rating is based on a lack of seepage quality and measurement ability.**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☒ Poor

# OUTLET

PROBLEMS NOTED: ☐(40) NONE ☐(41) NO OUTLET FOUND ☐(42) POOR OPERATING ACCESS ☐(43) INOPERABLE

☐(44) UPSTREAM OR DOWNSTREAM STRUCTURE DETERIORATED (45) OUTLET OPERATED DURING INSPECTION ☐YES ☑NO

INTERIOR INSPECTED ☑(120) NO ☐(121)YES ☐(46) CONDUIT DETERIORATED OR COLLAPSED ☐(47) JOINTS DISPLACED ☐(48) VALVE LEAKAGE

☐(49) OTHER

**PAST RECOMMENDED ACTIONS:**
**1. The pipe supports in the outlet tunnel should be replaced or reinforced as soon as possible to prevent accidental and sudden collapse of the pipe supports and damage to the pipe, which could result in sudden loss of the entire reservoir contents. (2014)**
**2. The right pipe is overdue for an interior inspection. This will be complicated by the lack of access to the pipe interior. The District should begin developing plans for providing camera access to the pipeline interior. (2014)**
**3. The emergency drawdown capacity of the small diameter PVC pipe should be evaluated to determine adequacy with Rule 5.9.6.2.1.**
**4. Better tunnel access provisions should be established such that the District staff are comfortable accessing the outlet controls at the upstream end of the tunnel.**

**CONDITIONS OBSERVED:**
**the outlet appears to be in the same condition as observed in the past.**

**- The right pipe was lined with HDPE through the outlet tunnel concurrent with the WTP construction project.**
**- The District has reportedly reinstated operation of the left pipeline that serves as a direct stream discharge, therefore item #3 above may be disregarded.**
**- The District have made notable progress towards improving tunnel accessibility, including addition of lighting and ventilation. Placement of pea gravel or other material to provide a firm foundation in the upstream half of the tunnel is a remaining item to be addressed.**

**CURRENT RECOMMENDED ACTIONS:**
**1. See item #1 above. (2014)**
**2. See item #2 above. It should be noted that the State Dam Safety Office does not consider this a high priority in light of other District priorities at this time. (2014)**
**3. Continue to improve outlet tunnel accessibility by adding pea gravel or other material along the floor of the tunnel, particularly along the upstream half of the tunnel. (2014)**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

# SPILLWAY

PROBLEMS NOTED: ☐(50) NONE ☐(51) NO EMERGENCY SPILLWAY FOUND ☐(52) EROSION WITH BACKCUTTING ☐(53) CRACK - WITH DISPLACEMENT

☐(54) APPEARS TO BE STRUCTURALLY INADEQUATE ☐(55) APPEARS TOO SMALL ☐ (56) INADEQUATE FREEBOARD ☐ (57) FLOW OBSTRUCTED

☐(58) CONCRETE DETERIORATED / UNDERMINED ☑(59) OTHER hydrologically inadequate

**PAST RECOMMENDED ACTIONS:**
**1. Continue to make progress towards rehabilitating the spillway to meet the requirements identified in the Dam Safety Rules for the long term. (2014)**

**CONDITIONS OBSERVED:**
**No changes since the last inspection.**

**The District has entered into a compliance plan with the State Engineer's Office that includes completion of an incremental damage assessment (IDA) by the end of this year and construction of a modified spillway to address freeboard inadequacy by May 2020. The District appears to be on track to meet these requirements.**

**CURRENT RECOMMENDED ACTIONS:**
**1. See item #1 above. (2014)**

**The acceptable rating is based on the District's continued efforts toward bringing the spillway into compliance with the State Dam Safety rules.**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

# MONITORING

EXISTING INSTRUMENTATION FOUND ☐ (110) NONE ☑ (111) GAGE ROD ☐ (112) PIEZOMETERS ☐ (113) SEEPAGE WEIRS / FLUMES
☑ (114) SURVEY MONUMENTS ☐ (115) OTHER

MONITORING OF INSTRUMENTATION ☐ (116) NO ☑ (117) YES PERIODIC INSPECTIONS BY: ☑ (118) OWNER ☐ (119) ENGINEER

**PAST RECOMMENDED ACTIONS:**
**None.**

**CONDITIONS OBSERVED:**
**There are no functioning seepage monitoring instrumentation at this dam despite the rather heavy seepage at the downstream toe, therefore there is no data to review during routine dam safety inspections. A flow measurement device is present below the spillway discharge channel, however the persistent spillway flows prevents accurate measurement of seepage flows with this device. Recommendations to improve seepage monitoring is discussed in the Seepage section of this report.**

**CURRENT RECOMMENDED ACTIONS:**
**None.**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

# MAINTENANCE AND REPAIRS

PROBLEMS NOTED: ☐ (60 NONE ☐ (61) ACCESS ROAD NEEDS MAINTENANCE ☐ (62) CATTLE DAMAGE
☐ (63) BRUSH ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE ☐ (64) TREES ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE
☐ (65) RODENT ACTIVITY ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE ☐ (66) DETERIORATED CONCRETE - FACING, OUTLET, SPILLWAY
☐ (67) GATE AND OPERATING MECHANISM NEED MAINTENANCE ☐ (68) OTHER

**PAST RECOMMENDED ACTIONS:**
**None.**

**CONDITIONS OBSERVED:**
**The District has been very responsive and proactive with maintenance efforts in recent years, which is greatly appreciated. A small shrub is present just below the dam crest on the downstream slope that should be removed. The grass along the toe should also be trimmed.**

**CURRENT RECOMMENDED ACTIONS:**
**1. Remove shrub on downstream slope and from grass along toe area. (2016)**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

*Go to next page for Overall Conditions and Items Requiring Actions*

## OVERALL CONDITIONS

**The down appears to be in acceptable condition with exception of the spillway deficiency. The District's progress toward compliance with this issue is noted and appreciated.**

**The emergency action plan was updated in 2014 and appears to contain current contact information for State representatives. The inundation mapping is rather outdated and poorly defined. The District has expressed an interest in developing updated mapping and in taking advantage of the State inundation mapping grant to do so. A scope of work and grant application were provided to the District in advance of this inspection.**

**The extent of dam safety concerns at this dam are sufficient to warrant a storage restriction. A partial storage restriction would provide little benefit to address the safety concerns associated with either the outlet or spillway. A zero storage restriction could be warranted, however it is recognized that the District would be completely unable to provide water to its constituents depending on the restricted level, which would only push the problems downstream to a different population. Additionally, the low level outlet is unlikely to have sufficient capacity to keep up with normal reservoir inflows. Therefore, a conditionally satisfactory rating will be assigned on the basis that the District continues to make demonstrable progress towards addressing the dam safety concerns.**

Based on this Safety Inspection and recent file review, the overall condition is determined to be:

☐ (71) SATISFACTORY ☑ (72) CONDITIONALLY SATISFACTORY ☐ (73) UNSATISFACTORY

## ITEMS REQUIRING ACTION BY OWNER TO IMPROVE THE SAFETY OF THE DAM

The State Engineer, by providing this dam safety inspection report, does not assume responsibility for any unsafe condition of the subject dam. The sole responsibility for the safety of this dam rests with the reservoir owner or operator, who should take every step necessary to prevent damages caused by leakage or overflow of waters from the reservoir or floods resulting from a failure of the dam.

MAINTENANCE - MINOR REPAIR - MONITORING

- ☐ (80) PROVIDE ADDITIONAL RIPRAP:
- ☐ (81) LUBRICATE AND OPERATE OUTLET GATES THROUGH FULL CYCLE:
- ☑ (82) CLEAR TREES AND/OR BRUSH FROM: **as stated in the MAINTENANCE section of this report.**
- ☐ (83) INITIATE RODENT CONTROL PROGRAM AND PROPERLY BACKFILL EXISTING HOLES:
- ☐ (84) GRADE CREST TO A UNIFORM ELEVATION WITH DRAINAGE TO THE UPSTREAM SLOPE:
- ☐ (85) PROVIDE SURFACE DRAINAGE FOR:
- ☐ (86) MONITOR:
- ☐ (87) DEVELOP AND SUBMIT AN EMERGENCY ACTION PLAN:
- ☑ (88) OTHER **as stated in the OUTLET section of this report**
- ☑ (89) OTHER **develop updated inundation mapping as discussed in the OVERALL section of this report**

ENGINEERING - EMPLOY AN ENGINEER EXPERIENCED IN DESIGN AND CONSTRUCTION OF DAMS TO: (Plans and Specifications must be approved by State Engineer prior to construction.)

- ☑ (90) PREPARE PLANS AND SPECIFICATIONS FOR REHABILITATION OF THE DAM: **As discussed in the CREST, SEEPAGE and SPILLWAY sections of this report**
- ☐ (91) PREPARE AS -BUILT DRAWINGS OF:
- ☐ (92) PERFORM A GEOTECHNICAL INVESTIGATION TO EVALUATE THE STABILITY OF THE DAM:
- ☐ (93) PERFORM A HYDROLOGIC STUDY TO DETERMINE REQUIRED SPILLWAY SIZE:
- ☐ (94) PREPARE PLANS AND SPECIFICATIONS FOR AN ADEQUATE SPILLWAY:
- ☐ (95) SET UP A MONITORING SYSTEM INCLUDING WORK SHEETS, REDUCED DATA AND GRAPHED RESULTS:
- ☐ (96) PERFORM AN INTERNAL INSPECTION OF THE OUTLET:
- ☑ (97) OTHER: **As described in the UPSTREAM SLOPE section of this report**
- ☐ (98) OTHER:
- ☐ (99) OTHER:

## SAFE STORAGE LEVEL: RECOMMENDED AS A RESULT OF THIS INSPECTION

- ☐ (101) FULL STORAGE
- ☑ (102) CONDITIONAL FULL STORAGE
- ☐ (103) RECOMMENDED RESTRICTION → { _____ FT. BELOW DAM CREST / _____ FT. BELOW SPILLWAY CREST / _____ FT. GAGE HEIGHT
- ☐ (104) CONTINUE EXISTING RESTRICTION → { ☐ NO STORAGE-MAINTAIN OUTLET FULLY OPEN

REASON FOR RESTRICTION

ACTIONS REQUIRED FOR CONDITIONAL FULL STORAGE OR CONTINUED STORAGE AT THE RESTRICTED LEVEL:

**Action Item (90)**

Engineer's Signature _____ INSPECTED BY

Owner's Signature _____ OWNER/OWNER'S REPRESENTATIVE DATE: ___/___/___

## GUIDELINES FOR DETERMINING CONDITIONS

### CONDITIONS OBSERVED - APPLIES TO UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, OUTLET, SPILLWA

GOOD
In general, this part of the structure has a near new appearance, and conditions observed in this area do not appear to threaten the safety of the dam.

ACCEPTABLE
Although general cross-section is maintained, surfaces may be irregular, eroded, rutted, spalled, or otherwise not in new condition. Conditions in this area do not currently appear to threaten the safety of the dam.

POOR
Conditions observed in this area appear to threaten the safety of the dam.

### CONDITIONS OBSERVED - APPLIES TO SEEPAGE

GOOD
No evidence of uncontrolled seepage. No unexplained increase in flows from designed drains. All seepage is clear. Seepage conditions do not appear to threaten the safety of the dam.

ACCEPTABLE
Some seepage exists at areas other than the drain outfalls, or other designed drains. No unexplained increase in seepage. All seepage is clear. Seepage conditions observed do not currently appear to threaten the safety of the dam.

POOR
Seepage conditions observed appear to threaten the safety of the dam. Examples:
1) Designed drain or seepage flows have increased without increase in reservoir level.
2) Drain or seepage flows contain sediment, i.e., muddy water or particles in jar samples.
3) Widespread seepage, concentrated seepage, or ponding appears to threaten the safety of the dam.

### CONDITIONS OBSERVED - APPLIES TO MONITORING

GOOD
Monitoring includes movement surveys and leakage measurements for all dams, and piezometer readings for Class I dams. Instrumentation is in reliable, working condition. A plan for monitoring the instrumentation and analyzing results by the owner's engineer is in effect. Periodic inspections by owner's engineer.

ACCEPTABLE
Monitoring includes movement surveys and leakage measurements for Class I 11 dams; leakage measurements for Class III dams. Instrumentation is in serviceable condition. A plan for monitoring instrumentation is in effect by owner. Periodic inspections by owner or representative. OR, NO MONITORING REQUIRED.

POOR
All instrumentation and monitoring described under "ACCEPTABLE" here for each class of dam, are not provided, or required periodic readings are not being made, or unexplained changes in readings are not reacted to by the owner.

### CONDITIONS OBSERVED - APPLIES TO MAINTENANCE AND REPAIR

GOOD
Dam appears to receive effective on-going maintenance and repair, and only a few minor items may need to be addressed.

ACCEPTABLE
Dam appears to receive maintenance, but some maintenance items need to be addressed. No major repairs are requirecl

POOR
Dam does not appear to receive adequate maintenance. One or more items needing maintenance or repair has begun to threaten the safety of the dam.

### OVERALL CONDITIONS

SATISFACTORY
The safety inspection indicates no conditions that appear to threaten the safety of the dam, and the dam is expected to perform satisfactorily under all design loading conditions. Most of the required monitoring is being performed.

CONDITIONALLY SATISFACTORY
The safety inspection indicates symptoms of structural distress (seepage, evidence of minor displacements, etc.), which, if conditions worsen, could lead to the failure of the dam. Essential monitoring, inspection, and maintenance must be performed as a requirement for continued full storage in the reservoir.

UNSATISFACTORY
The safety inspection indicates definite signs of structural distress (excessive seepage, cracks, slides, sinkholes, severe deterioration, etc.), which could lead to the failure of the dam if the reservoir is used to full capacity. The dam is judged unsafe for full storage of water.

### SAFE STORAGE LEVEL

FULL STORAGE
Dam may be used to full capacity with no conditions attached.

CONDITIONAL FULL STORAGE
Dam may be used to full storage if certain monitoring, maintenance, or operational conditions are met.

RESTRICTION
Dam may not be used to full capacity, but must be operated at some reduced level in the interest of public safety.

### HAZARD CLASSIFICATION OF DAMS

CLASS High hazard
Loss of human life is expected in the event of failure of the dam, while the reservoir is at the high water line.

CLASS Significant hazard
Significant damage to improved property is expected in the event of failure of the dam while the reservoir is at the high water line, but no loss of human life is expected.

CLASS Low hazard
Loss of human life is not expected, and damage to improved property is expected to be small, in the event of failure of the dam while the reservoir is at high water fine.

Class NPH hazard - No loss of life or damage to improved property, or loss of downstream resource is expected in the event of failure of the dam while the reservoir is at the high water line.

**Photo 1: Aerial view of Lower Beaver Brook Dam**

**Photo 2: Intentional construction joint with exposed copper waterstop (left); spall damage along NHWL (center); example vertical crack (right)**

**Photo 3: Sandbag dike along upstream shoulder and reservoir staff gage**

**Photo 4: Typical view of dam crest (left); typical movement monument (center and right)**

**Photo 5: Downstream slope and seepage collection pool (left); downstream slope from right abutment facing west (right)**

**Photo 6: Flow measurement flume**

**Photo 7: New seep area adjacent to the flume attributed to either flows from spillway or losses from treated water main**

**Photo 8: Outlet valves at upstream end of tunnel (left); small diameter drain tap from service line to drain line (right)**

**Photo 9: Exposed bedrock in upstream half of outlet tunnel – right wall (left) and ceiling (right)**

**Photo 10: Spillway sill (left); historic patch on downstream left end of spillway sill (right)**

**Photo 11: Spillway discharge channel with pile of debris removed from spillway channel last year**

# ENGINEER'S INSPECTION REPORT

INSPECTOR: RDS

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: | LOWER BEAVER BROOK | T: 040S | R: 0720W | S: 14 | COUNTY: | CLEAR CREEK | | DATE OF INSPECTION: | 5/6/2015 |
| DAM ID: | 070102 | YRCompl: 1903 | | DAM HEIGHT(FT): | 39.0 | SPILLWAY WIDTH(FT): | 29.0 | PREVIOUS INSPECTION: | 6/2/2014 |
| CLASS: | High hazard | | | DAM LENGTH(FT): | 224.0 | SPILLWAY CAPACITY(CFS): | 95.0 | NORMAL STORAGE (AF): | 30.0 |
| DIV: | 1 | WD: 7 | | CRESTWIDTH(FT): | 12.0 | FREEBOARD (FT): | 1.1 | SURFACE AREA(AC): | 2.0 |
| EAP: | 5/5/2014 | | | CRESTELEV(FT): | 7840.0 | DRAINAGE AREA (AC.): | 5120.0 | OUTLET INSPECTED: | 6/2/2014 |

**CURRENT RESTRICTION:** -- NONE --

| | | | |
|---|---|---|---|
| OWNER: | LOOKOUT MOUNTAIN WATER DISTRICT | OWNER REP.: | CHRISTINA SHEA |
| ADDRESS: | 24958 GENESEE TRAIL, PMB 514 | CONTACT NAME: | TREATMENT TECHNOLOGY |
| | GOLDEN CO 80401-5742 | CONTACT PHONE: | (303) 670-3936X |

INSPECTION PARTY: Jeremy, Terry; Ryan Schoolmeesters

REPRESENTING: Treatment Technology; CO Dam Safety

**FIELD CONDITIONS OBSERVED**

WATER LEVEL: BELOW DAM CREST 0.6 FT. Above Spillway 0.5 FT. GAGE ROD READING inundated

GROUND MOISTURE CONDITION: ☐ DRY ☑ WET ☐ SNOWCOVER OTHER clear, calm, recent rains

**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) DEPRESSION OR BULGES ☐ (7) SLIDES

☑ (8) CONCRETE FACING - HOLES CRACKS, DISPLACED, UNDERMINED ☑ (9) OTHER deterioration and damage to joint seals & filler

**CONDITIONS OBSERVED: The upstream slope appears to be in the same condition as was observed in past inspections; though the high, murky water prevented inspection of the slope below the reservoir water level.**

**Based on past inspections, full-depth cracks and spalling has been observed at multiple locations. A missing section of concrete facing was observed at the left abutment, however this is primarily in the freeboard section of the dam and is not anticipated to be a significant dam safety concern.**

**RECOMMENDED ACTIONS: Repairs to the upstream slope will eventually need to be performed.**

CONDITIONS OBSERVED: ☐ Good ☒ 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

**CONDITIONS OBSERVED: The dam crest appears to be in the same condition as was observed in the past. The crest is narrower than preferred, adversely graded, has at least one minor depression and a low area near the left abutment that reduces the spillway freeboard from 2 feet to about 13 inches. The upstream shoulder displays minor alignment deviations; however these are assumed to be remnant from original construction.**

**RECOMMENDED ACTIONS: Modifications to the dam crest should be completed as part of a future larger rehabilitation project. The objective would be to regrade the crest to a uniform elevation and cross slope for even drainage.**

CONDITIONS OBSERVED: ☐ 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) DEPRESSION OR BULGES ☐ (27) SLIDE ☐ (28) SOFT AREAS ☐ (29) OTHER

**CONDITIONS OBSERVED: No noticable changes from the last inspection were observed.**

**From recent past inspections: "The downstream slope has an irregular convex appearance, presumed to be remnant from original construction. The rockfill appears well-placed and interlocked. A bulge approximately 10-feet upslope of the downstream toe has historically been a point of consternation, however review of the C-292 record drawings (1936) suggests that the bulge is a relic of the past construction project. This lower slope appears oversteepened as a result of the bulge, however a stability analysis has not been performed to substantiate instability at this point."**

**RECOMMENDED ACTIONS: A slope flattening project may be necessary in the future if the dam stability is found to be inadequate; however no modifications are necessary at this time.**

CONDITIONS OBSERVED: ☐ 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 ☐ (37) FLOW INCREASED / MUDDY ☐ (38) DRAIN DRY / OBSTRUCTED

☐ (39) OTHER

**CONDITIONS OBSERVED: Seepage along the toe near the maximum section appears to be moderately worse than observed in the past; however a lack of effective flow measurement device prevents quantifiable verification. Total seepage flows appear to be in the 50-100gpm range, and are most significant at the bottom left side of the valley, directly over the presumed 10 inch drain pipe location, though the drain pipe is completely buried (if it exists) and cannot be observed. Seepage is also present at the base of the outlet tunnel access port and within the "cave" at the right downstream groin to varying degrees up to several gpm each.**

**RECOMMENDED ACTIONS: Refer to recommendations in the 2014 inspection report.**

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☒ Poor

## OUTLET

PROBLEMS NOTED ☐ (40) NONE ☐ (41) NO OUTLET FOUND ☑ (42) POOR OPERATING ACCESS ☐ (43) INOPERABLE

☐ (44) UPSTREAM OR DOWNSTREAM STRUCTURE DETERIORATED (45) OUTLET OPERATED DURING INSPECTION ☑ YES ☐ NO

INTERIOR INSPECTED ☑ (120) NO ☐ (121)YES ☑ (46) CONDUIT DETERIORATED OR COLLAPSED ☐ (47) JOINTS DISPLACED ☐ (48) VALVE LEAKAGE

☐ (49) OTHER

**CONDITIONS OBSERVED: The outlet tunnel was not accessed or observed on this day. The outlet was discharging directly to the stream at the maximum capacity on this day due to concerns about the high water levels. Treatment Technology reps reported no changes to the outlet system since the last inspection.**

**An internal inspection of the outlet works was performed in 2014 and a copy was submitted to this office for review. The video shows the interior of 110 feet of the 14 inch steel pipe, which appears to be in acceptable condition. The points of initiation and termination are somewhat unclear and the outlet modifications with the small diameter PVC pipes were not inspected; however the efforts to perform and provide this inspection is appreciated. The interior inspection of the outlet pipe is acceptable; therefore another interior inspection will be due again in 2024.**

**RECOMMENDED ACTIONS: Refer to recommendations in the 2014 inspection report.**

CONDITIONS OBSERVED: ☐ Good ☐ Acceptable ☒ Poor

## SPILLWAY

PROBLEMS NOTED ☐ (50) NONE ☐ (51) NO EMERGENCY SPILLWAY FOUND ☐ (52) EROSION WITH BACKCUTTING ☐ (53) CRACK - WITH DISPLACEMENT

☐ (54) APPEARS TO BE STRUCTURALLY INADEQUATE ☑ (55) APPEARS TOO SMALL ☑ (56) INADEQUATE FREEBOARD ☐ (57) FLOW OBSTRUCTED

☑ (58) CONCRETE DETERIORATED / UNDERMINED ☐ (59) OTHER

**CONDITIONS OBSERVED: The spillway is in the same condition as was observed in past inspections. A sandbag dike was constructed along the dam crest around the same time as this inspection in response to elevated reservoir water levels encroaching to within 7 inches of the dam crest. As a result, the total freeboard provided by the spillway and sandbag dike is approximately 28 inches, up from about 13 inches. Additional freeboard will be necessary to fully address the spillway capacity inadequacy.**

**The spillway is known to be undersized according to the Dam Safety Rules and Regulations (Jan. 2007), and an incremental damage assessment (IDA) has recently been performed to address this deficiency. The IDA is presently under review by this office, and the owner has stated plans to construct permanent modifications to the spillway once the IDA and a design for modifications are approved, and when funding becomes available. Since this may not happen for years to come, additional freeboard may be achievable in the short term by removing the 3- to 4-foot high concrete spillway sill.**

**RECOMMENDED ACTIONS: Continue to make progress towards rehabilitating the spillway to meet the requirements identified in the Dam Safety Rules for the long term. Controlled removal of the concrete spillway sill would greatly improve the safety of the dam in the near term until permanent modifications can be completed.**

**The rating has been increased to "Acceptable" based on the progress made towards addressing known spillway deficiencies.**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

## MONITORING

EXISTING INSTRUMENTATION FOUND ☐ (110) NONE ☑ (111) GAGE ROD ☐ (112) PIEZOMETERS ☑ (113) SEEPAGE WEIRS / FLUMES

☑ (114) SURVEY MONUMENTS ☐ (115) OTHER

MONITORING OF INSTRUMENTATION ☐ (116) NO ☑ (117) YES PERIODIC INSPECTIONS BY: ☑ (118) OWNER ☐ (119) ENGINEER

**CONDITIONS OBSERVED: The water treatment plant is located at the downstream left abutment and is staffed full time. WTP staff visually monitor the dam and reservoir on a daily basis. Seepage monitoring is discussed in the SEEPAGE section of this report.**

**RECOMMENDED ACTIONS: None.**

CONDITIONS OBSERVED: ☐ Good ☒ Acceptable ☐ Poor

# MAINTENANCE AND REPAIRS

PROBLEMS NOTED ☑ (60 NONE ☐ (61) ACCESS ROAD NEEDS MAINTENANCE ☐ (62) LIVESTOCK DAMAGE
☐ (63) BRUSH ON UPSTREAM SLOPE, CREST DOWNSTREAM SLOPE, TOE ☐ (64) TREES ON UPSTREAM SLOPE, CREST DOWNSTREAM SLOPE, TOE
☐ (65) RODENT ACTIVITY ON UPSTREAM SLOPE, CREST DOWNSTREAM SLOPE, TOE ☐ (66) DETERIORATED CONCRETE - FACING, OUTLET SPILLWAY
☐ (67) GATE AND OPERATING MECHANISM NEED MAINTENANCE ☐ (68) OTHER

**CONDITIONS OBSERVED: Woody shrubs noted on the last inspection report have been removed. Maintenance efforts are appreciated.**

**RECOMMENDED ACTIONS: None.**

CONDITIONS OBSERVED: ☒ Good ☐ Acceptable ☐ Poor

*Go to next page for Overall Conditions and Items Requiring Actions*

## OVERALL CONDITIONS

**The dam appears to be functioning as intended, and significant efforts by the owner and Treatment Technology have been made since the last inspection to bring the dam up to standard. Nevertheless, several significant issues remain that will continue to require attention for some time to come, including the excessive seepage without adequate monitoring, the inadequate spillway capacity, and the potentially insufficient outlet discharge capacity.**

**The emergency action plan appears to be up to date. The recent emergency incident highlighted the need for an updated inundation map, which should be developed as part of the spillway modification project.**

**The extent of dam safety concerns at this dam are sufficient to warrant a storage restriction. A partial storage restriction would provide little benefit to address the safety concerns associated with either the outlet or spillway. A zero storage restriction could be warranted, however it is recognized that the District would be completely unable to provide water to its constituents depending on the restricted level, which would only push the problems downstream to a different population. Additionally, the low level outlet is unlikely to have sufficient capacity to keep up with normal reservoir inflows. Therefore, a conditionally satisfactory rating will be assigned on the basis that the District continues to make demonstrable progress towards addressing the dam safety concerns.**

Based on this Safety Inspection and recent file review, the overall condition is determined to be:

☐ (71) SATISFACTORY ☑ (72) CONDITIONALLY SATISFACTORY ☐ (73) UNSATISFACTORY

## ITEMS REQUIRING ACTION BY OWNER TO IMPROVE THE SAFETY OF THE DAM

The State Engineer, by providing this dam safety inspection report, does not assume responsibility for any unsafe condition of the subject dam. The sole responsibility for the safety of this dam rests with the reservoir owner or operator, who should take every step necessary to prevent damages caused by leakage or overflow of waters from the reservoir or floods resulting from a failure of the dam.

MAINTENANCE - MINOR REPAIR - MONITORING

- ☐ (80) PROVIDE ADDITIONAL RIPRAP:
- ☐ (81) LUBRICATE AND OPERATE OUTLET GATES THROUGH FULL CYCLE
- ☐ (82) CLEAR TREES AND/OR BRUSH FROM:
- ☐ (83) INITIATE RODENT CONTROL PROGRAM AND PROPERLY BACKFILL EXISTING HOLES:
- ☐ (84) GRADE CREST TO A UNIFORM ELEVATION WITH DRAINAGE TO THE UPSTREAM SLOPE:
- ☐ (85) PROVIDE SURFACE DRAINAGE FOR:
- ☑ (86) MONITOR: **as described in the SEEPAGE section of this report**
- ☐ (87) DEVELOP AND SUBMIT AN EMERGENCY ACTION PLAN:
- ☑ (88) OTHER **as described in the OUTLET section of this and the 2014 inspection reports**
- ☐ (89) OTHER

ENGINEERING - EMPLOY AN ENGINEER EXPERIENCED IN DESIGN AND CONSTRUCTION OF DAMS TO: (Plans and Specifications must be approved by State Engineer prior to construction.

- ☑ (90) PREPARE PLANS AND SPECIFICATIONS FOR REHABILITATION OF THE DAM: **as described in the OUTLET and SPILLWAY sections of this report**
- ☐ (91) PREPARE AS -BUILT DRAWINGS OF:
- ☐ (92) PERFORM A GEOTECHNICAL INVESTIGATION TO EVALUATE THE STABILITY OF THE DAM:
- ☐ (93) PERFORM A HYDROLOGIC STUDY TO DETERMINE REQUIRED SPILLWAY SIZE:
- ☐ (94) PREPARE PLANS AND SPECIFICATIONS FOR AN ADEQUATE SPILLWAY:
- ☐ (95) SET UP A MONITORING SYSTEM INCLUDING WORK SHEETS, REDUCED DATA AND GRAPHED RESULTS:
- ☐ (96) PERFORM AN INTERNAL INSPECTION OF THE OUTLET:
- ☑ (97) OTHER: **as described in the UPSTREAM SLOPE, CREST and DOWNSTREAM SLOPE sections of this report**
- ☑ (98) OTHER: **inundation map as described in the OVERALL section of this report**
- ☐ (99) OTHER:

## SAFE STORAGE LEVEL: RECOMMENDED AS A RESULT OF THIS INSPECTION

- ☐ (101) FULL STORAGE
- ☑ (102) CONDITIONAL FULL STORAGE
- ☐ (103) RECOMMENDED RESTRICTION →
- ☐ (104) CONTINUE EXISTING RESTRICTION

_____ FT. BELOW DAM CREST
_____ FT. BELOW SPILLWAY CREST
_____ FT. GAGE HEIGHT
☐ ☐ NO STORAGE-MAINTAIN OUTLET FULLY OPEN

REASON FOR RESTRICTION

ACTIONS REQUIRED FOR CONDITIONAL FULL STORAGE ~~OR CONTINUED STORAGE AT THE RESTRICTED LEVEL~~

**Action Item (90)**

Engineer's Signature _____ INSPECTED BY

Owner's Signature _____ OWNER/OWNER'S REPRESENTATIVE DATE: ___/___/___

## GUIDELINES FOR DETERMINING CONDITIONS

### CONDITIONS OBSERVED - APPLIES TO UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, OUTLET, SPILLWAY

GOOD
In general, this part of the structure has a near new appearance, and conditions observed in this area do not appear to threaten the safety of the dam.

ACCEPTABLE
Although general cross-section is maintained, surfaces may be irregular, eroded, rutted, spalled, or otherwise not in new condition. Conditions in this area do not currently appear to threaten the safety of the dam.

POOR
Conditions observed in this area appear to threaten the safety of the dam.

### CONDITIONS OBSERVED - APPLIES TO SEEPAGE

GOOD
No evidence of uncontrolled seepage. No unexplained increase in flows from designed drains. All seepage is clear. Seepage conditions do not appear to threaten the safety of the dam.

ACCEPTABLE
Some seepage exists at areas other than the drain outfalls, or other designed drains. No unexplained increase in seepage. All seepage is clear. Seepage conditions observed do not currently appear to threaten the safety of the dam.

POOR
Seepage conditions observed appear to threaten the safety of the dam. Examples:
1) Designed drain or seepage flows have increased without increase in reservoir level.
2) Drain or seepage flows contain sediment, i.e., muddy water or particles in jar samples.
3) Widespread seepage, concentrated seepage, or ponding appears to threaten the safety of the dam.

### CONDITIONS OBSERVED - APPLIES TO MONITORING

GOOD
Monitoring includes movement surveys and leakage measurements for all dams, and piezometer readings for High hazard dams. Instrumentation is in reliable, working condition. A plan for monitoring the instrumentation and analyzing results by the owner's engineer is in effect. Periodic inspections by owner's engineer.

ACCEPTABLE
Monitoring includes movement surveys and leakage measurements for High and Significant hazard dams; leakage measurements for Low hazard dams. Instrumentation is in serviceable condition. A plan for monitoring instrumentation is in effect by owner. Periodic inspections by owner or representative. OR, NO MONITORING REQUIRED.

POOR
All instrumentation and monitoring described under "ACCEPTABLE" here for each class of dam, are not provided, or required periodic readings are not being made, or unexplained changes in readings are not reacted to by the owner.

### CONDITIONS OBSERVED - APPLIES TO MAINTENANCE AND REPAIR

GOOD
Dam appears to receive effective on-going maintenance and repair, and only a few minor items may need to be addressed.

ACCEPTABLE
Dam appears to receive maintenance, but some maintenance items need to be addressed. No major repairs are requirecl

POOR
Dam does not appear to receive adequate maintenance. One or more items needing maintenance or repair has begun to threaten the safety of the dam.

### OVERALL CONDITIONS

SATISFACTORY
The safety inspection indicates no conditions that appear to threaten the safety of the dam, and the dam is expected to perform satisfactorily under all design loading conditions. Most of the required monitoring is being performed.

CONDITIONALLY SATISFACTORY
The safety inspection indicates symptoms of structural distress (seepage, evidence of minor displacements, etc.), which, if conditions worsen, could lead to the failure of the dam. Essential monitoring, inspection, and maintenance must be performed as a requirement for continued full storage in the reservoir.

UNSATISFACTORY
The safety inspection indicates definite signs of structural distress (excessive seepage, cracks, slides, sinkholes, severe deterioration, etc.), which could lead to the failure of the dam if the reservoir is used to full capacity. The dam is judged unsafe for full storage of water.

### SAFE STORAGE LEVEL

FULL STORAGE
Dam may be used to full capacity with no conditions attached.

CONDITIONAL FULL STORAGE
Dam may be used to full storage if certain monitoring, maintenance, or operational conditions are met.

RESTRICTION
Dam may not be used to full capacity, but must be operated at some reduced level in the interest of public safety.

### HAZARD CLASSIFICATION OF DAMS

High hazard
Loss of human life is expected in the event of failure of the dam, while the reservoir is at the high water line.

Significant hazard
Significant damage to improved property is expected in the event of failure of the dam while the reservoir is at the high water line, but no loss of human life is expected.

Low hazard
Loss of human life is not expected, and damage to improved property is expected to be small, in the event of failure of the dam while the reservoir is at high water fine.

NPH hazard - No loss of life or damage to improved property, or loss of downstream resource is expected in the event of failure of the dam while the reservoir is at the high water line.

**Photo 1: Aerial view of Lower Beaver Brook Dam**

**Photo 2: Dam crest and downstream slope (typical)**

**Photo 3: Downstream slope, outlet works tunnel access door and direct discharge pipe; and spillway discharge channel (left); dam crest after sandbag dike construction (right)**

**Photo 4: Seepage at left downstream toe of maximum section near supposed 10-inch VCP drain**

**Photo 5: Seepage exiting outlet works tunnel (left); gage rod at low point near left abutment**

**Photo 6: Spillway control sill (left); spillway discharge channel immediately below sill (right)**

# APPENDIX B

## PREVIOUS STUDIES PERFORMED

## BY GEI CONSULTANTS, INC.

# APPENDIX B-1

## LOWER BEAVER BROOK DAM HYDROLOGY AND INCREMENTAL DAMAGE ANALYSIS REPORT (GEI, 2016)

GEI Consultants

Geotechnical
Environmental
Water Resources
Ecological

# Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report

DAMID: 070102

Submitted to:
**Lookout Mountain Water District**
25958 Genesee Trail Road #514
Golden, CO 80401

Submitted by:
**GEI Consultants, Inc.**
4601 DTC Boulevard, Suite 900
Denver, CO 80237

March 2015
(Revised December 2016)
Project 1410080

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CHAD M. MASCHING
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PROFESSIONAL ENGINEER

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Project Manager

# Table of Contents

**Executive Summary** ..... **ES-1**
ES.1 Background ..... ES-1
ES.2 Hydrology Study Results ..... ES-2
ES.3 Incremental Damage Analysis Results ..... ES-7

**1. Introduction** ..... **1-1**
**1.1** Purpose ..... 1-1
**1.2** Background ..... 1-2
**1.3** Scope of Work ..... 1-2
**1.4** Authorization ..... 1-2
**1.5** Project Personnel ..... 1-2
**1.6** Limitation of Liability ..... 1-3

**2. Site Description** ..... **2-1**
**2.1** General ..... 2-1
**2.2** Historic Dam Names ..... 2-1
**2.3** Lower Beaver Brook Dam and Reservoir ..... 2-1
**2.4** Size and Hazard Classification ..... 2-2

**3. Hydrology** ..... **3-1**
**3.1** Probable Maximum Flood Overview ..... 3-1
**3.2** Basin Delineation ..... 3-1
**3.3** Design Rainfall ..... 3-2
**3.3.1** Probable Maximum Precipitation ..... 3-2
**3.3.2** NOAA Atlas 14, 100-Year Storm ..... 3-4
**3.4** Loss Rates ..... 3-4
**3.4.1** PMF Loss Rates ..... 3-5
**3.4.2** 100-Year and More Frequent Storm Loss Rates ..... 3-7
**3.4.3** Loss Rate Sensitivity Analysis ..... 3-7
**3.5** Unit Hydrograph Methods ..... 3-8
**3.5.1** Unit Hydrograph Sensitivity Analysis ..... 3-9

**4. Hydrologic Modeling Parameters** ..... **4-1**
**4.1** Hydrologic Computer Model ..... 4-1
**4.2** Precipitation ..... 4-1
**4.3** Loss Rates ..... 4-1
**4.4** Time Steps ..... 4-1
**4.5** Baseflow ..... 4-1
**4.6** Reservoir Routing ..... 4-1
**4.7** Channel Routing ..... 4-2
**4.8** Snowmelt ..... 4-2

**4.9** Discussion of PMF Modeling Parameters ..... 4-2

**5. Hydrology Study Results ..... 5-1**
**5.1** PMF Study Results ..... 5-1
**5.2** Frequency Storm Study Results ..... 5-2
**5.3** Sensitivity Analysis ..... 5-6
**5.4** Conclusion ..... 5-8

**6. Incremental Damage Analysis ..... 6-1**
**6.1** Overview ..... 6-1
**6.2** Incremental Damage Analysis Scenarios ..... 6-1
**6.3** Downstream Reach ..... 6-2
**6.3.2** Downstream Stream Crossings ..... 6-2
**6.3.3** Downstream Structures ..... 6-4
**6.4** Hydraulic Model ..... 6-4
**6.5** Breach Parameters ..... 6-5

**7. Incremental Damage Analysis Results ..... 7-1**
**7.1** Base Flood Results ..... 7-1
**7.2** Dam Breach Flood Results ..... 7-2
**7.3** Incremental Impacts ..... 7-2

**8. Conclusions ..... 8-1**

**9. References ..... 9-1**

## List of Figures

Figure 1: Location Map
Figure 2: Lower Beaver Brook Watershed with 2013 NAIP Imagery
Figure 3: Lower Beaver Brook Watershed with USGS Topographic Image
Figure 4: Hydrologic Soil Groups
Figure 5: Lower Beaver Brook Reservoir Elevation–Area–Capacity Curves
Figure 6: Upper Beaver Brook Reservoir Elevation–Area–Capacity Curves
Figure 7: Lower Beaver Brook Spillway Rating Curve
Figure 8: Upper Beaver Brook Proposed Spillway Rating Curve
Figure 9: Upper and Lower Beaver Brook Inflow and Outflow PMF Hydrographs
Figure 10: Upper and Lower Beaver Brook Inflow and Outflow 100-yr Hydrographs
Figure 11: Interstate 70 Interchange Photographs
Figure 12: Interstate 70 Profile
Figure 13: Lower Beaver Brook Base and Breach Flood Hydrographs
Figure 14: Lower Beaver Brook Inundation Limits (1 of 6)
Figure 15: Lower Beaver Brook Inundation Limits (2 of 6)
Figure 16: Lower Beaver Brook Inundation Limits (3 of 6)
Figure 17: Lower Beaver Brook Inundation Limits (4 of 6)
Figure 18: Lower Beaver Brook Inundation Limits (5 of 6)

Figure 19: Lower Beaver Brook Inundation Limits

## List of Tables

Table ES-1: Results of the HMR 55A General-Storm PMF Model ..... 3
Table ES-2: Results of the HMR 55A Local-Storm PMF Model ..... 4
Table ES-3: Results of NOAA Atlas 10-Year Storm Model ..... 5
Table ES-4: Results of NOAA Atlas 25-Year Storm Model ..... 5
Table ES-5: Results of NOAA Atlas 50-Year Storm Model ..... 6
Table ES-6: Results of NOAA Atlas 100-Year Storm Model ..... 6
Table ES-7: Lower Beaver Brook Dam Inflow Design Flood ..... 8
Table 2-1: Lookout Mountain Water District Dam Names ..... 2-1
Table 2-2: Pertinent Data for Lower Beaver Brook Dam ..... 2-2
Table 3-1: SEO Reduced General-Storm PMP, Total Watershed ..... 3-3
Table 3-2: SEO Reduced Local-Storm PMP, Upper Subbasin ..... 3-3
Table 3-3: SEO Reduced Local-Storm PMP, Lower Subbasin ..... 3-3
Table 3-4: 100-Year Storm Precipitation Data ..... 3-4
Table 3-5: Hydrologic Soil Group Descriptions (NRCS, 1968) ..... 3-6
Table 3-6: Uniform Loss Rates for PMF Modeling ..... 3-6
Table 3-7: Selected Loss Rates for PMF Modeling ..... 3-7
Table 3-8: Green and Ampt Input Parameters for the 100-Year Storm ..... 3-7
Table 3-9: USBR Dimensionless Unit Hydrograph Parameters ..... 3-8
Table 3-10: USBR Dimensionless Kn Value, Unit Duration, Lag Time, and Timestep ..... 3-9
Table 5-1: Results of the HMR 55A General-Storm PMF Model ..... 5-1
Table 5-2: Results of the HMR 55A Local-Storm PMF Model ..... 5-2
Table 5-3: Results of NOAA Atlas 10-Year Storm Model ..... 5-3
Table 5-4: Results of NOAA Atlas 25-Year Storm Model ..... 5-3
Table 5-5: Results of NOAA Atlas 50-Year Storm Model ..... 5-4
Table 5-6: Results of NOAA Atlas 100-Year Storm Model ..... 5-4
Table 5-7: Results of NOAA Atlas 500-Year Storm Model ..... 5-5
Table 5-8: Results of NOAA Atlas 1,000-Year Storm Model ..... 5-5
Table 5-9: Sensitivity Analysis Results of the HMR 55A Local-Storm Model ..... 5-7
Table 6-1: Summary of Bridge and Culvert Crossings ..... 6-3
Table 6-2: Summary of Suggested Breach Parameters Based on Engineering Guidelines ..... 6-5
Table 6-3: Summary of Breach Parameters Used in HEC-HMS Model ..... 6-6
Table 7-1: Results of Lower Beaver Brook Dam Base Flood ..... 7-1
Table 7-2: Summary of IDA Flood Routing Results ..... **Error! Bookmark not defined.**
Table 8-1: Lower Beaver Brook Dam Inflow Design Flood ..... 8-1

## List of Appendices

Appendix A: Hydrology Information
A.1 – Watershed, Reservoir, and Dam Documents
A.2 – 100-year Event Calculations
A.3 – General-Storm Event Calculations
A.4 – Local-Storm Event Calculations

Appendix B: HEC-HMS Input and Output Summary

Appendix C: Proposed Spillway Information

Appendix D: Dam Breach Inputs and HEC-RAS Summary

Appendix E: Electronic Files

Appendix F SEO Comment Response Memorandum

## List of Acronyms and Abbreviations

| | |
|---|---|
| AF | acre-feet |
| cfs | cubic feet per second |
| DEM | digital elevation model |
| Eds. | editors |
| El. | elevation |
| EPAT | Extreme Precipitation Analysis Tool |
| ESP | Extreme Storm Precipitation |
| FERC | Federal Energy Regulatory Commission |
| ft | feet |
| GEI | GEI Consultants, Inc. |
| HEC-HMS | Hydrologic Engineering Center's - Hydrologic Modeling System |
| HMR 55A | Hydrometeorological Report No. 55A |
| HSG | Hydrologic Soil Groups |
| H:V | Horizontal to Vertical |
| IA | initial abstractions |
| IDA | Incremental Damage Analysis |
| IDF | Inflow Design Flood |
| II | initial infiltration |
| LMWD | Lookout Mountain Water District |
| $mi^2$ | square miles |
| NAIP | National Agricultural Imagery Program |
| NOAA | National Oceanic and Atmospheric Administration |
| NRCS | Natural Resources Conservation Service |
| NWS | National Weather Service |
| OT | overtopping |
| PMF | Probable Maximum Flood |
| PMP | Probable Maximum Precipitation |
| SEO | Colorado Office of the State Engineer |
| SSESP | site-specific Extreme Storm Precipitation |
| SSHMA | site-specific Hydrometeorological Analysis |
| USACE | U.S. Army Corps of Engineers |
| USBR | United States Bureau of Reclamation |
| USGS | United States Geological Survey |
| vol/vol | volume per volume |
| WSE | water surface elevation |
| XS | cross section |

# Executive Summary

## ES.1 Background

This report presents and compares the Inflow Design Flood (IDF) estimates for Lower Beaver Brook Dam/Reservoir based on the results of an Incremental Damage Assessment (IDA). The IDF estimates were developed using the Probable Maximum Precipitation (PMP) estimates from the Hydrometeorological Report No. 55A (HMR 55A) methods. The report summarizes hydrometeorological analyses, precipitation estimates, parameter development and selection, inflow hydrographs, and results of the IDA.

Lower Beaver Brook Dam is located approximately 7.1 miles northwest of Evergreen, Colorado in Clear County in the NE ¼ of Section 14, Township 4 South, Range 72 West of the 6th Principal Meridian. The dam is located on Beaver Brook, a tributary to Clear Creek and the South Platte River, upstream of Golden, Colorado. The dam is classified as a High Hazard dam by the Colorado Office of the State Engineer (SEO) because loss of life is anticipated in the event that there is a failure of the dam. Lower Beaver Brook Dam is classified as a "Small Dam" because the embankment height is between 20 and 50 feet. A project location map is shown in Figure 1.

Lookout Mountain Water District (LMWD) has two high altitude reservoirs on Beaver Brook; Upper Beaver Brook Dam/Reservoir and Lower Beaver Brook Dam/Reservoir. Upper Beaver Brook Reservoir is LMWD's primary raw water storage facility while Lower Beaver Brook Reservoir serves as a forebay to the LMWD water treatment plant. Upper Beaver Brook Dam/Reservoir is described in *Upper Beaver Brook Dam No. 3A Spillway Improvements Project Hydrology Report* (GEI, 2014).

An enlargement of Upper Beaver Brook Dam/Reservoir is currently under design. The proposed design is documented in GEI, 2014 and proposed conditions were used for the Lower Beaver Brook hydrologic analyses. The proposed conditions at Upper Beaver Brook Dam result in a larger peak outflow to Upper Beaver Brook, and thus a larger peak inflow to Lower Beaver Brook. This results in a larger design flood and a larger spillway at Lower Beaver Brook Dam. Therefore, the proposed conditions at Upper Beaver Brook produce conservative results compared to the existing conditions.

Lower Beaver Brook Dam is an earth/rockfill dam with structural height of 39 feet and impounds approximately 30 acre-feet (AF) at the normal pool elevation (El.) 7,837.7. The original Lower Beaver Brook Dam was originally constructed around 1903 and was modified to the current configuration in 1935. The dam crest is at El. 7,840.0 and is about 224 feet long and has an average crest width of 12 feet. The upstream slope is approximately 0.7H:1V (Horizontal to Vertical) and the downstream slope is about 1.25H:1V.

The spillway is located at the right side of the dam crest. The spillway is an ungated overflow channel with a crest width of approximately 29 feet at El. 7,837.7 with a maximum capacity of 313 cubic feet per second (cfs). The concrete control sill is approximately 2 feet long with near vertical side slopes. The discharge channel between the spillway sill and the dam toe consists of short, steep sections of channel between vertical drops. There is a concrete drop structure approximately halfway between the spillway and dam toe. The drop structure consists of a 1 foot-wide concrete sill between vertical sidewalls. The sill is approximately 8 feet wide with about a 3 foot vertical drop immediately downstream.

The existing outlet works consists of two 14-inch steel pipes through a rock tunnel. The outlet works is controlled by two 24-inch diameter gates, operated from the dam crest. The approximately downstream invert is El. 7,801. According to design drawings, the outlet pipe is about 122 feet long with and is sloped at 0.02 feet/feet. The calculated upstream invert is El. 7,803.44. The outlet works discharges to the spillway discharge channel near the toe of the dam. Instrumentation consists of a Parshall flume located at the end of the spillway discharge channel near the dam toe for spillway release measurements, survey monuments, and an inoperable seepage weir.

Lower Beaver Brook Reservoir has a gross watershed area of 7.45 square miles ($mi^2$), which is shown in Figure 2. The watershed was modeled using two subbasins, referred to as the Upper Subbasin and the Lower Subbasin. The Upper Subbasin includes Upper Beaver Brook Dam/Reservoir and the associated drainage area to that reservoir (6.50 $mi^2$). The Lower Subbasin incorporates the drainage area below Upper Beaver Brook that contributes to Lower Beaver Brook (0.95 $mi^2$).

## ES.2 Hydrology Study Results

GEI Consultants, Inc. (GEI) developed estimates of general-storm PMP and the local-storm PMP for the Lower Beaver Brook watershed at the dam site. Precipitation estimates were converted to inflow estimates using standard flood runoff modeling practices. Modeling results for the general-storm Probable Maximum Flood (PMF) and the local-storm PMF are summarized in Tables ES-1 and ES-2, respectively. Based on the modeling results, the HMR 55A local-storm produces the PMF inflow to the reservoir.

**Table ES-1: Results of the HMR 55A General-Storm PMF Model**

| Parameter or Modeling Result | General-Storm PMF for the Upper Subbasin and Upper Beaver Brook Dam/Reservoir | General-Storm PMF for the Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
|---|---|---|
| Subbasin Average 72-hr PMP Depth (inches) | 32.80 | 32.80 |
| Subbasin Average Uniform Loss Rate (inches/hour) | 0.106 | 0.083 |
| Hydrologic Soil Groups (HSG)-Adjusted Excess Rainfall (inches) | 26.33 | 27.33 |
| SEO Allowed Reduction | 0.80 | 0.80 |
| SEO Reduced Average 72-hr PMP Depth (inches) | 21.05 | 21.92 |
| Antecedent Moisture Condition | Normal | Normal |
| Subbasin Average Initial Infiltration Losses (inches) | 0.50 | 0.50 |
| Subbasin Average Initial Abstraction Losses (inches) | 0.40 | 0.40 |
| Subbasin Average Total Direct Runoff (inches) | 20.05 | 20.93 |
| Subbasin Average 72-hr Losses (inches) | 12.75 | 11.87 |
| Subbasin Average PMP Runoff Percent (%) | 61.1 | 63.8 |
| Maximum Reservoir Elevation (feet) | 8,414.15 | 7,846.57 |
| Freeboard (feet) | 5.85<br>(Dam Crest El. 8,420.0) | -6.57<br>(Dam Crest El. 7,840.0) |
| Inflow Volume (AF) | 6,952 | 8,008 |
| Peak Inflow (cfs) | 10,743 | 12,186 |
| Peak Outflow (cfs) | 10,640 | 12,185 |

**Table ES-2: Results of the HMR 55A Local-Storm PMF Model**

| Parameter or Modeling Result | Local-Storm PMF for the Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Local-Storm PMF for the Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
|---|---|---|
| Subbasin Average 6-hr PMP Depth (inches) | 9.86 | 10.25 |
| Subbasin Average Uniform Loss Rate (inches/hour) | 0.106 | 0.083 |
| HSG-Adjusted Excess Rainfall (inches) | 9.22 | 9.75 |
| SEO Allowed Reduction | 0.90 | 0.90 |
| SEO Reduced Average 6-hr PMP Depth (inches) | 8.29 | 8.78 |
| Antecedent Moisture Condition | Normal | Normal |
| Subbasin Average Initial Infiltration Losses (inches) | 0.50 | 0.50 |
| Subbasin Average Initial Abstraction Losses (inches) | 0.40 | 0.40 |
| Subbasin Average Total Direct Runoff (inches) | 7.39 | 7.88 |
| Subbasin Average 6-hr Losses (inches) | 2.47 | 2.37 |
| Subbasin Average PMP Runoff Percent (%) | 74.9 | 76.9 |
| Maximum Reservoir Elevation (feet) | 8,418.64<br>Dam Crest El. 8,420.0 | 7,850.06<br>Dam Crest El. 7,840.0 |
| Freeboard (feet) | 1.36 | -10.06 |
| Inflow Volume (AF) | 2,563 | 2,961 |
| Peak Inflow (cfs) | 21,741 | 22,485 |
| Peak Outflow (cfs) | 20,203 | 22,477 |

GEI also developed estimates of the 2-, 5-, 10-, 25-, 50- and 100-year storms for the Lower Beaver Brook Dam watershed. The results for these more frequent storms are based on using the Green and Ampt loss rate method rather than the initial and uniform loss rate method used for IDF modeling. Modeling results for the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 10-, 25-, 50-, and 100-year storms are summarized in Table ES-3 to ES-6.

**Table ES-3: Results of NOAA Atlas 10-Year Storm Model**

| Parameter or Modeling Result | 10-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 10-Year Storm Depth (inches) | 2.62 | 2.62 |
| Subbasin Average 10-Year Storm Runoff (inches) | 0.63 | 0.74 |
| Subbasin Average 24-hr 10-Year Losses (inches) | 1.99 | 1.88 |
| Subbasin Average 10-Year Storm Runoff Percent (%) | 24.0 | 28.2 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,409.81 | 7840.87 |
| Freeboard (feet) | 10.19<br>Dam Crest El. 8,420.0 | -0.87<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 219 | 256 |
| Peak Inflow (cfs) | 901 | 984 |
| Peak Outflow (cfs) | 885 | 982 |

**Table ES-4: Results of NOAA Atlas 25-Year Storm Model**

| Parameter or Modeling Result | 25-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 25-Year Storm Depth (inches) | 3.28 | 3.28 |
| Subbasin Average 25-Year Storm Runoff (inches) | 0.86 | 0.97 |
| Subbasin Average 24-hr 25-Year Losses (inches) | 2.42 | 2.32 |
| Subbasin Average 25-Year Storm Runoff Percent (%) | 26.2 | 29.6 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,409.93 | 7,841.18 |
| Freeboard (feet) | 10.07<br>Dam Crest El. 8,420.0 | -1.18<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 297 | 346 |
| Peak Inflow (cfs) | 1,211 | 1,326 |
| Peak Outflow (cfs) | 1,194 | 1,324 |

**Table ES-5: Results of NOAA Atlas 50-Year Storm Model**

| Parameter or Modeling Result | 50-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 50-Year Storm Depth (inches) | 3.85 | 3.85 |
| Subbasin Average 50-Year Storm Runoff (inches) | 1.04 | 1.15 |
| Subbasin Average 24-hr 50-Year Losses (inches) | 2.81 | 2.70 |
| Subbasin Average 50-Year Storm Runoff Percent (%) | 27.0 | 29.9 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.02 | 7,841.40 |
| Freeboard (feet) | 9.92<br>Dam Crest El. 8,420.0 | -1.40<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 361 | 419 |
| Peak Inflow (cfs) | 1,454 | 1,603 |
| Peak Outflow (cfs) | 1,445 | 1,602 |

**Table ES-6: Results of NOAA Atlas 100-Year Storm Model**

| Parameter or Modeling Result | 100-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 100-Year Storm Depth (inches) | 4.47 | 4.47 |
| Subbasin Average 100-Year Storm Runoff (inches) | 1.22 | 1.34 |
| Subbasin Average 24-hr 100-Year Losses (inches) | 3.24 | 3.13 |
| Subbasin Average 100-Year Storm Runoff Percent (%) | 27.3 | 30.0 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.14 | 7,841.61 |
| Freeboard (feet) | 9.86<br>Dam Crest El. 8,420.0 | -1.61<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 424 | 492 |
| Peak Inflow (cfs) | 1,719 | 1,882 |
| Peak Outflow (cfs) | 1,697 | 1,880 |

## ES.3 Incremental Damage Analysis Results

Due to the very small reservoir size and relatively large magnitude of the local-storm PMF, GEI performed an IDA to estimate the IDF for Lower Beaver Brook Dam. As part of the IDA, GEI developed estimates of the base flood, dam breach parameters, breach flood and downstream incremental impacts. GEI estimated the base flood to be equivalent to a storm with a peak inflow rate of 4,755 cfs, with a dam failure event triggering when the base flood reaches maximum overtopping of the dam crest. The hypothetical failure of the Lower Beaver Brook Dam due to dam crest overtopping from the base flood resulted in a breach flood with a peak breach discharge of about 8,175 cfs.

Two field surveys were conducted to identify critical structures and crossings in the downstream reach. The first, conducted by GEI in October 2014, identified the substantial river crossings and recording culvert/bridge dimensions. The locations and dimensions of the river crossings were used in the hydraulic model developed by GEI to estimate the flood wave. During this site visit, it was determined that a topographic survey identifying critical structures along the reach was necessary. LMWD mailed notifications of the survey to all property owners with property adjacent to Beaver Brook and CCS Consultants, Inc. (CCS) mobilized in December 2014. CCS surveyed 30 cross sections to determine the relative elevation of critical structures and the channel bed. The survey extended between Lower Beaver Brook Dam and the crossing of Interstate 70 (I-70), approximately 1.3 miles downstream of the dam. The survey provided the critical first floor elevations of the buildings surrounding the study area. The two field surveys identified 10 culverts, 2 bridges, and 42 residences/structures that might be near enough to the stream to be impacted by the flood wave.

The culvert crossing of I-70 creates significant attenuation of the flood wave. The difference in the base and breach flood water surfaces has decreased to below 2 feet downstream of the culvert. Generally, the difference in water surface elevations is less than 1 foot downstream of I-70 but varies between 0.4 feet and 1.3 feet. For approximately 400 feet upstream of the US-40 bridge the difference in water surface elevations spikes to above 2 feet. However, the nearest structure upstream of the bridge is above 1,600 feet away and would be unaffected by the short increase. Immediately after the bridge, the incremental rise decreases to less than 0.77 feet. The routing of the Lower Beaver Brook Dam Breach Flood was terminated approximately 3 miles downstream of the Lower Beaver Brook Dam.

Routing the base flood and the breach flood downstream showed that the breach flood does not produce incremental damages at the identified structures; therefore there are no incremental impacts in the zone between the base flood and the breach flood. Based on these results, the existing Lower Beaver Brook Dam meets the SEO IDA criteria to allow an IDF equal to the base flood. Therefore, the IDF for the existing Lower Beaver Brook Dam may be the flood produced by 27.5 percent of the HMR 55 PMP. A summary of the IDF (HMR 55A PMP) parameters is summarized in Table ES-7.

**Table ES-7: Lower Beaver Brook Dam Inflow Design Flood**

| Parameter | Base Flood Modeling Results |
|---|---|
| HMR-55 Local-Storm Average 6-hr PMP Depth, No SEO Reductions | 9.91 inches |
| Base Flood Percent of HMR-55 Local-Storm 6-hr PMP | 27.5% |
| Base Flood Basin Average 6-hr PMP Depth | 2.55 inches |
| Base Flood Basin Average PMP Runoff | 1.66 inches |
| Base Flood Basin Average 72-hr Losses | 0.89 inches |
| Base Flood Basin Average PMP Runoff Percent | 65.1% |
| Maximum Reservoir Elevation | 7,843.3 feet |
| Residual Freeboard | -3.3 feet |
| Inflow Volume | 657 acre-feet |
| Peak Inflow | 4,755 cfs |

Lower Beaver Brook Dam is not capable of passing the IDF in its current form. Lower Beaver Brook Dam is capable of passing about 300 cfs without dam overtopping (less than the estimated NOAA Atlas No. 2 24-hour 2-year flood event). The flood event that results in 1-foot of dam overtopping is the 0.15PMF and is about 1,135 cfs (approximately equivalent to a 15-20 year return period).

# 1. Introduction

## 1.1 Purpose

This report summarizes the Incremental Damage Analysis (IDA) used to evaluate the Inflow Design Flood (IDF) estimates for Lower Beaver Brook Dam (DAMID 070102) in Clear Creek County, Colorado. The analysis was performed by GEI Consultants, Inc. (GEI), under contract to the Lookout Mountain Water District (LMWD), as a subtask of the Dam Safety Compliance Plan issued by the Colorado State Engineer's Office (SEO) in June 2014. The analysis was performed in accordance with the Colorado State Engineer's Office *Rules and Regulations for Dam Safety and Construction* (SEO, 2007) and *Guidelines for Dam Breach Analysis* (SEO, 2010).

The IDA was performed using U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center – Hydrologic Modelling System (HEC-HMS) and U.S. Army Corps of Engineers Hydrologic Engineering Center – River Analysis System (HEC-RAS) computer programs, versions 3.5 and 4.1.0, respectively. The HEC-RAS cross-sections were developed in GIS using the HEC-GeoRAS software developed by the USACE. The spillway geometry for the dam was based on design drawings dated 1935 and SEO inspection records from June, 2014. The downstream topography was developed using 7.5-minute U.S. Geological Survey (USGS) Digital Elevation Models (DEMs).

The breach and base flood flows were routed below the existing Lower Beaver Brook Dam through the Beaver Brook for a total distance of approximately 3 miles. The study reach is generally considered to be moderately developed with the LMWD water treatment plant and the Homestead Hideaway Subdivision located immediately downstream of the dam. Generally, there are a limited number of residences, county roads, and outbuildings near Beaver Brook/Clear Creek. The major road crossings include a culvert crossing of Interstate 70 and a bridge crossing of CO Highway 40.

The IDF estimate is based on Probable Maximum Precipitation (PMP) developed using the Hydrometeorological Report No. 55A (HMR 55A) methods. The report summarizes hydrometeorological analyses, precipitation estimates, parameter development and selection, inflow hydrographs, and results of routing the IDF through the current configuration of the reservoir, dam, and spillway. Refinements of the spillway configuration may occur as final design progresses. The hydrology study was performed in accordance with Colorado State Engineering Office (SEO) *Rules and Regulations for Dam Safety and Construction* (referred to herein as SEO Regulations) (SEO, 2007) and *Hydrologic Basin Response Parameters Estimation Guidelines* (referred to herein as SEO Guidelines) (SEO, 2008).

## 1.2 Background

The LMWD has two high altitude reservoirs on Beaver Brook, Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir. Upper Beaver Brook Reservoir is LMWD's primary raw water storage facility while Lower Beaver Brook Reservoir serves as a forebay to the LMWD water treatment plant.

The dam is classified as a High Hazard dam by the Colorado Office of the State Engineer (SEO) because loss of life is anticipated in the event that there is a failure of the dam. Lower Beaver Brook Dam is classified as a "Small Dam" because the embankment height is between 20 and 50 feet.

An enlargement of Upper Beaver Brook Dam/Reservoir is currently under design. The proposed design is documented in GEI, 2014 and proposed conditions were used for the Lower Beaver Brook hydrologic analyses. The proposed conditions at Upper Beaver Brook produce conservative results compared to the existing conditions. Therefore, it is acceptable for modifications at Lower Beaver Brook to occur prior to the Upper Beaver Brook enlargement.

## 1.3 Scope of Work

GEI was retained by LMWD to perform a hydrology and IDA study to determine the IDF at Lower Beaver Brook Dam. A summary of the scope of work performed by GEI for this study is presented below:

- Developed hydrologic runoff parameters for input to the simulation model;
- Developed reservoir routing parameters;
- Develop an estimate for the PMF and more frequent storm events;
- Perform an IDA to estimate the IDF for Lower Beaver Brook Dam; and
- Prepare a Hydrology and Incremental Damage Analysis Report documenting the IDF estimate and hydrologic inputs.

## 1.4 Authorization

GEI performed the services described in this report under the terms and conditions of the agreement between GEI and LMWD dated August 21, 2014.

## 1.5 Project Personnel

The following GEI personnel were primarily responsible for performing the hydrology and hydraulics analyses and for preparing this report:

Project Manager: Chad Masching, P.E.

| | |
|---|---|
| Water Resource Engineer: | Kerri Price, P.E. |
| Project Reviewer: | Nick Miller, P.E., P.H. |

## 1.6 Limitation of Liability

Our professional services for preparing this Hydrology and Incremental Damage Analysis Report were performed in accordance with generally accepted engineering practices; no other warranty, express or implied, is made.

# 2. Site Description

## 2.1 General

Lower Beaver Brook Dam is located approximately 7.1 miles northwest of Evergreen, Colorado in Clear County in the NE ¼ of Section 14, Township 4 South, Range 72 West of the 6th Principal Meridian. The dam is located on Beaver Brook, a tributary to Clear Creek and the South Platte River, upstream of Golden, Colorado. A project location map is shown in Figure 1.

## 2.2 Historic Dam Names

Upper Beaver Brook Dam, along with Lower Beaver Brook Dam and Lookout Mountain Dam, was officially renamed in 1993 by the Division of Water Resources with consent of the LMWD Board. The historic names of the dams are found in Table 2-1. The documentation of the official name change of these dams is contained in Appendix A.1.

**Table 2-1: Lookout Mountain Water District Dam Names**

| Colorado DNR DAMID | Official Name | Historic Name |
|---|---|---|
| 070102 | Lower Beaver Brook Dam | Beaver Brook #2 |
| 070103 | Upper Beaver Brook Dam | Beaver Brook #3A |
| 070104 | Lookout Mountain Dam | Beaver Brook #3 |

## 2.3 Lower Beaver Brook Dam and Reservoir

Lower Beaver Brook Dam is an earth/rockfill dam with structural height of 39 feet and impounds approximately 30 acre-feet (AF) at the normal pool elevation (El.) 7,837.7. The original Lower Beaver Brook Dam was originally constructed around 1903 and was modified to the current configuration in 1935. The dam crest is at El. 7,840.0 and is about 224 feet long and has an average crest width of 12 feet. The upstream slope is approximately 0.7H:1V (Horizontal to Vertical) and the downstream slope is about 1.25H:1V.

The spillway is located at the right side of the dam crest. The spillway is an ungated overflow channel with a crest width of approximately 29 feet at El. 7,837.7 with a maximum capacity of 313 cubic feet per second (cfs). The concrete control sill is approximately 2 feet long with near vertical side slopes. The discharge channel between the spillway sill and the dam toe consists of short, steep sections of channel between vertical drops. There is a concrete drop structure approximately halfway between the spillway and dam toe. The drop structure consists of a 1 foot-wide concrete sill between vertical sidewalls. The sill is approximately 8 feet wide with about a 3 foot vertical drop immediately downstream. A Parshall flume is located at the end of the spillway discharge channel near the dam toe for flow measurement.

The existing outlet works consists of two 14-inch steel pipes through a rock tunnel. The outlet works is controlled by two 24-inch diameter gates, operated from the dam crest. The approximately downstream invert is El. 7,801. According to design drawings, the outlet pipe is about 122 feet long with and is sloped at 0.02 feet/feet. The calculated upstream invert is El. 7,803.44. The outlet works discharges to the spillway discharge channel near the toe of the dam.

Instrumentation consists of a Parshall flume located at the end of the spillway discharge channel near the dam toe for spillway release measurements, survey monuments, and an inoperable seepage weir.

A summary of selected data for Lower Beaver Brook Dam is presented in Table 2-1.

**Table 2-2: Pertinent Data for Lower Beaver Brook Dam**

| Description | Value |
|---|---|
| Type of Dam | Earth/Rockfill |
| Elevation of Dam Crest (feet) | 7,840.0 |
| Elevation of Normal Pool (feet) | 7,837.7 |
| Dam Height (feet) | 39.0 |
| Dam Length (feet) | 224 |
| Crest Width (feet) | 12 |
| Normal Pool Surface Area (acres) | 2.0 |
| Normal Freeboard (feet) | 2.3 |
| Flood Discharge Freeboard (feet) | ≥1 (required) |

## 2.4 Size and Hazard Classification

Lower Beaver Brook Reservoir has a gross watershed area of 7.45 square miles ($mi^2$), which is shown in Figure 2. The dam is classified as a High Hazard dam by the Colorado Office of the State Engineer (SEO) because loss of life is anticipated in the event that there is a failure of the dam. Lower Beaver Brook Dam is classified as a "Small Dam" because the embankment height is between 20 and 50 feet.

Based on the SEO Regulations (SEO, 2007), the required PMF for a Small, High Hazard dam at or around an elevation of 7,840 feet on the eastern side of the Continental Divide is measured by the greatest of the following:

- The Extreme Storm Precipitation (ESP) as generated by the Extreme Precipitation Analysis Tool (EPAT);
- 0.90 times the PMP as generated by the HMR 55A for a local-storm;
- 0.80 times the PMP as generated by the HMR 55A for a general-storm; and

- The site-specific Extreme Storm Precipitation (SSESP) as determined by a site-specific Hydrometeorological Analysis (SSHMA).

# 3. Hydrology

## 3.1 Probable Maximum Flood Overview

A PMF is produced by extreme rainfall events occurring in conjunction with a conservatively selected set of hydrologic and watershed conditions to produce the largest flood that is reasonably possible. The extreme rainfall event from those noted in Section 3.3, that causes the highest water surface elevation in the reservoir will be "the PMF."

Key components of an IDF include the following:

1. Basin Delineation – modeling boundaries;
2. Design Rainfall – amount of rainfall before losses;
3. Rainfall Loss Rates – amount of excess rainfall available for runoff;
4. Baseflow – amount of additional inflow;
5. Unit Hydrographs – pattern of runoff from 1 inch of precipitation during a unit duration;
6. Channel Routing – storage and discharge through stream channels; and
7. Reservoir Routing – storage in reservoirs and discharge from dams.

Each of these components used to develop the PMF are described in more detail in the following sections.

## 3.2 Basin Delineation

Lower Beaver Brook Reservoir has a gross watershed area of 7.45 square miles ($mi^2$). The watershed was modeled using two subbasins, referred to as the Upper Subbasin and the Lower Subbasin. The Upper Subbasin includes Upper Beaver Brook Dam/Reservoir and the associated drainage area to that reservoir (6.50 $mi^2$). The Lower Subbasin incorporates the drainage area below Upper Beaver Brook that contributes to Lower Beaver Brook (0.95 $mi^2$). The Lower Beaver Brook Dam watershed was delineated based on United States Geological Survey (USGS) 7.5-minute topographic maps. The normal pool water surface area of Lower Beaver Brook created by a 30 AF reservoir is approximately 2 acres, or about 0.04 percent of the total watershed.

The watershed, subbasins, and reservoirs are shown in Figures 2 and 3.

## 3.3 Design Rainfall

GEI developed and evaluated three rainfall events to determine the critical PMF for Lower Beaver Brook Dam. The three rainfall events include the HMR 55A general-storm, HMR 55A local-storm, and the National Oceanic and Atmospheric Administration (NOAA) Atlas 100-year 24-hour storm. The rainfall estimates were developed and reduced in accordance with current SEO Regulations (SEO, 2007). Development of each rainfall event is described in further detail in the following sections and related calculations are shown in Appendix A.

### 3.3.1 *Probable Maximum Precipitation*

HMR 55A defines PMP as "the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage area at a certain time of the year" (American Meteorological Society, 1959 as cited in USBR, 1988). HMR 55A (USBR, 1988) is the governing document that provides the methods and data to develop the PMP for the Upper Beaver Brook Dam drainage basin. The critical PMP is the general-storm PMP (all-season[1] or seasonal) or the local-storm (thunderstorm) PMP, depending on which corresponding PMF produces the maximum reservoir elevation.

GEI followed HMR 55A step-wise procedures to estimate the general-storm PMP. The watershed was delineated on the HMR 55A. A convergence PMP Index Map was developed with isohyetal lines that pertained to the 24-hour, 10-square-mile watersheds. The watershed was then delineated on the HMR 55A elevation and barrier reduction factor map, and on the 6/24-hour ratio map. A similar procedure was performed to estimate the Orographic PMP value. The final PMP for the basin was obtained by adding together the Convergence and Orographic PMP values. GEI developed general-storm PMP based on a single basin due to the relatively small basin area and minor variation in general-storm PMP across the basin.

The process for estimating the local-storm PMP was similar to that for the general-storm. The index value determined for the local-storm was based on 1-hour PMP for a 1-square-mile basin and then adjusted downward for basin elevations above 5,000 feet. The watershed was then delineated on the 6/1-hour ratio map and the PMP was then reduced based on basin areas above 1-square mile. GEI developed local-storm PMP based on a single basin due to the relatively small basin area and minor variation in local-storm PMP across the basin.

The 72-hour unadjusted general-storm PMP weighted across the watershed is 32.80 inches. In accordance with current SEO Regulations (SEO, 2007), the general-storm PMP values developed based on HMR 55A can be reduced based on the dam hazard classification, size of

[1] The all-season period is the month or months with the largest estimated general-storm PMP depth.

dam, and basin elevation. Lower Beaver Brook Dam is classified as a Large, High Hazard dam, at an elevation above 6,000 feet, located east of the Continental Divide. Based on these classifications the Lower Beaver Brook Dam, the general-storm PMP can be reduced to 80 percent of the HMR 55A PMP. Based on the allowed reduction, the general-storm PMP for 72-hour and shorter durations are shown in Table 3-1.

**Table 3-1: SEO Reduced General-Storm PMP, Total Watershed**

| PMP | PMP Depth (inches) for Indicated Duration (hours) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 0 | 1 | 6 | 12 | 24 | 48 | 72 |
| General-Storm | 0.00 | 5.36 | 11.52 | 15.84 | 20.80 | 23.95 | 26.24 |

The 6-hour unadjusted local-storm PMP weighted across the watershed is 10.08 inches. The local-storm PMP can also be reduced based on the dam hazard classification, size of dam, and basin elevation. Based on the classifications of the Lower Beaver Brook Dam and basin elevation the local-storm PMP can be reduced to 90 percent of the HMR 55A PMP. Based on the allowed reduction, the local-storm PMP for 6-hour and shorter durations for the two subbasins are shown in Table 3-2 and 3-3.

**Table 3-2: SEO Reduced Local-Storm PMP, Upper Subbasin**

| PMP | PMP Depth (inches) for Indicated Duration (hours) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 |
| Local-Storm | 0.00 | 3.82 | 5.15 | 5.77 | 6.21 | 7.28 | 7.81 | 8.22 | 8.58 | 8.87 |

**Table 3-3: SEO Reduced Local-Storm PMP, Lower Subbasin**

| PMP | PMP Depth (inches) for Indicated Duration (hours) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 |
| Local-Storm | 0.00 | 3.97 | 5.35 | 5.99 | 6.45 | 7.57 | 8.12 | 8.55 | 8.92 | 9.22 |

HMR 55A does not recommend a particular temporal distribution for general-storm PMP. For the general-storm PMP, GEI selected to use a center-weighted temporal distribution of the general-storm. The general-storm was simulated as a specified hyetograph with 1-hour incremental rainfall values. A histogram of distributed general-storm rainfall, which has a peak occurring at hour 37, is shown in Appendix A.3.

HMR 55A does specify a temporal distribution for the local-storm PMP that positions the maximum precipitation increment at either the third or fourth hour. GEI selected to use a center-weighted temporal distribution for local-storm PMP with the maximum precipitation increment at the third hour. A histogram of distributed local-storm rainfall is shown in Appendix A.4.

PMP calculations, including temporal distributions of PMP, are provided in Appendix A.

PMF routing results are presented in Section 5. The local-storm PMP was determined to be the governing PMP for Lower Beaver Brook Dam because the local-storm PMP results in a higher reservoir stage.

### 3.3.2 *NOAA Atlas 14, 100-Year Storm*

In addition to estimating the PMP events noted above, GEI also evaluated the 100-year storm event. The rainfall estimates for the 100-year and more frequent storm precipitations were retrieved from the NOAA Precipitation Frequency Data Server (PFDS). The rainfall-depth calculations follow the procedures outlined in *NOAA Atlas 14, Volume 8, Version 2: Colorado* (NWS, 2013). The Lower Beaver Brook watershed centroid was used as the input into the PFDS.

One-hundred-year rainfall values for Upper Beaver Brook Dam are summarized in Table 3-4. The 100-year rainfall calculations from the PFDS are provided in Appendix A.2. GEI used a center-weighted temporal distribution with an intensity position of 50 percent and an intensity duration of 5 minutes.

**Table 3-4: 100-Year Storm Precipitation Data**

| Precipitation (in) for Indicated Durations (hr) and Recurrence Intervals | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Duration (hours)** | 0.083 | 0.25 | 0.50 | 1 | 2 | 3 | 6 | 12 | 24 |
| 100-year | 0.59 | 1.06 | 1.46 | 1.72 | 1.98 | 2.10 | 2.55 | 3.41 | 4.51 |
| 500-year | 0.77 | 1.37 | 1.87 | 2.17 | 2.47 | 2.60 | 3.23 | 4.54 | 6.19 |
| 1,000-year | 0.84 | 1.51 | 2.06 | 2.37 | 2.69 | 2.82 | 3.54 | 5.08 | 7.01 |

## 3.4 Loss Rates

Rainfall runoff volume is essentially the rainfall volume minus initial losses (surface depression storage, interception by vegetation, and initial infiltration capacity of the ground prior to reaching saturation) and ongoing losses due to infiltration.

A common approach to modeling loss rates for storms less frequent than the one percent (100-year) storm is the Initial and Uniform Distributed Loss-Rate Method. This approach is recommended by the SEO for use when modeling very infrequent storms with high amounts of precipitation. Initial loss rates were developed following the procedures described in the SEO Guidelines (SEO, 2008). The uniform loss rates were applied using the Distributed Loss-Rate Method. In this method, rather than using a weighted average loss rate, loss rates within each sub-basin are distributed according to the relative area occupied by distinguishable soil units and applied directly to precipitation prior to modeling.

Physically based uniform loss rates have been estimated for this report and final values are summarized in Section 3.4.1.

Another common approach to modeling loss rates is the Green and Ampt loss rate method. This approach is recommended for use when modeling the one percent and more frequent storms (SEO, 2008). GEI elected to use the Green and Ampt loss rate method for modeling the 100-year storm. The Green and Ampt loss rates method simulates a two-phase process. The first phase is the initial abstractions or surface retention, and the second phase is the infiltration of the rainfall into the soil matrix. Physically-based Green and Ampt loss rates parameters are summarized in Section 3.4.2.

### 3.4.1 *PMF Loss Rates*

The Initial and Uniform rainfall loss rate analysis for Lower Beaver Brook Dam drainage basin was performed in accordance with the SEO Guidelines (SEO, 2008).

It is assumed that the rainfall loss process can be simulated as a two-phase procedure. During the first phase, all rainfall is lost to infiltration and initial abstractions until the accumulated rainfall is equal to the initial losses. After the initial losses are satisfied, a portion of all future rainfall is lost at a uniform infiltration rate. The initial loss is the sum of the initial abstractions (IA) and the initial soil infiltration capacity (II). The initial abstractions account for initial losses due to depression storage, vegetation interception, and evaporation. The initial infiltration accounts for all other losses occurred until the soil is saturated.

IA was determined based on the average basin slope and estimated vegetative cover. Based on 2013 National Agricultural Imagery Program (NAIP) orthophotography, there is currently very little development in the Lower Beaver Brook Dam watershed. The land use in the watershed mainly consists of mountainous forest land and access roads in the watershed generally have gravel surfaces. Based on the limited development in the watershed, the percent vegetative cover was conservatively estimated as 85%. The average slope for the Upper and Lower Subbasins were calculated using ArcGIS and 10 meter digital elevation model (DEM) data, and was determined to be about 9.86% and 18.86%, respectively. The antecedent moisture condition was assumed to be “normal” for the local- and general-storms. Consistent with the SEO Guidelines, the IA loss value was assumed to be 0.4 inches (SEO, 2008, Table 8). Similarly, the II loss value was determined to be 0.5 inches (SEO, 2008, Table 12). The total initial losses are the sum of these components, or 0.90 inches. The spreadsheet calculating the initial losses for the watershed is provided in Appendix A.

The second phase of the Initial and Uniform loss rate methodology occurs after the initial losses are satisfied and infiltration into the soil is assumed to occur at a constant rate. The uniform loss rates were calculated based on Natural Resources Conservation Service (NRCS)

Hydrologic Soil Groups (HSGs) designation of the watershed soils (Table 3-5). The soil survey for the Lower Beaver Brook watershed was acquired from the NRCS' national soil survey database and included data from the Arapaho-Roosevelt National Forest Area and Clear Creek County datasets. The data were imported into GIS to overlay the watershed and the spatial distribution of HSGs was determined. The dominate soil types are HSG Type B and HSG Type D with small percentages of HSG Type A and HSG Type C. The area of Lower and Upper Beaver Brook Reservoirs is considered impermeable area. The distribution of soil types across the watershed is shown in Figure 4.

**Table 3-5: Hydrologic Soil Group Descriptions (NRCS, 1968)**

| Hydrologic Soil Group | Soil Textures | Infiltration & Transmission Rate (in/hr) | Percent of Upper Subbasin | Percent of Lower Subbasin |
|---|---|---|---|---|
| A | Sand, loamy sand, or sandy loam | 0.30 – 0.45 | 9.46 | 0.00 |
| B | Silt loam or loam | 0.15 – 0.30 | 50.00 | 55.30 |
| C | Sandy clay loam | 0.05 – 0.15 | 5.53 | 0.07 |
| D | Clay loam, silty clay loam, sandy clay, silty clay, or clay | 0.00 – 0.05 | 34.77 | 44.58 |
| Impermeable | - | 0.00 | 0.24 | 0.05 |

For this study, minimum infiltration values based on the HSGs were used to estimate the uniform loss rates. The uniform loss rates for the watershed were applied using the Distributed Loss-Rate Method. In this method, rather than using a weighted average loss rate, loss rates within the basin are distributed according to the relative area occupied by distinguishable soil units and applied directly to precipitation prior to modeling. The estimated uniform loss rate value for the Upper and Lower Subbasins is approximately 0.106 inches per hour (in/hr) and 0.083 in/hr, respectively (Table 3-6).

**Table 3-6: Uniform Loss Rates for PMF Modeling**

| Uniform Loss Rate (in/hr) | HSG A | HSG B | HSG C | HSG D | Impermeable Area (%) |
|---|---|---|---|---|---|
| Upper Subbasin | 0.30 | 0.15 | 0.05 | 0.0 | 0.24 |
| Lower Subbasin | 0.30 | 0.15 | 0.05 | 0.0 | 0.05 |

The selected Initial and Uniform loss rates used for PMF modeling are summarized in Table 3-7.

**Table 3-7: Selected Loss Rates for PMF Modeling**

| Basin Name | Initial Abstraction (in) | Initial Infiltration (in) | Initial Loss (in) | Average Weighted Loss Rate (in/hr) |
|---|---|---|---|---|
| Upper Subbasin | 0.30 | 0.40 | 0.70 | 0.106 |
| Lower Subbasin | 0.30 | 0.40 | 0.70 | 0.083 |

### 3.4.2 *100-Year and More Frequent Storm Loss Rates*

GEI used the Green and Ampt loss rate method for modeling of runoff from the 100-year storm. This approach is recommended by the SEO for use when modeling the one percent (100-year) and more frequent storms. The Green and Ampt loss rate method is based on physical basin parameters that correlate to soil properties. The Green and Ampt parameters were estimated using the SEO Guidelines (SEO, 2008).

As stated previously, the initial loss rates are the sum of two components, the surface retention losses or initial abstraction, and the initial infiltration capacity of the soil prior to reaching saturation. It is accepted practice to determine an IA as a function of basin average slope and percent vegetated cover. IA was determined as described in the previous section. For storms more frequent than PMF type storms, such as the 100-year storm, it is common practice to assume that the initial infiltration capacity of the soil has been satisfied by antecedent precipitation and, therefore, the initial water content is equal to the saturated water content for the 100-year storm analysis. Input parameters used for this study are shown in Table 3-8.

**Table 3-8: Green and Ampt Input Parameters for the 100-Year Storm**

| Parameter | Upper Subbasin Value | Lower Subbasin Value |
|---|---|---|
| Initial Water Content (volume per volume; vol/vol) | 0.41 | 0.41 |
| Saturated Water Content (vol/vol) | 0.41 | 0.41 |
| Wetting Front Suction (inches) | 4.0 | 4.5 |
| Saturated Hydraulic Conductivity (inches/hour) | 0.44 | 0.32 |
| Percent Impervious (%) | 0.24 | 0.05 |

### 3.4.3 *Loss Rate Sensitivity Analysis*

GEI investigated the sensitivity of the selected loss rates by comparing the resulting peak reservoir inflow and residual freeboard to adjusted loss rates. The results for the selected loss rates were compared to the results using higher and lower initial and uniform loss rates. The results of this sensitivity analysis are summarized in Table 5-7, in Section 5.

## 3.5 Unit Hydrograph Methods

The unit hydrographs for the Upper and Lower Subbasins were developed using the United States Bureau of Reclamation (USBR) synthetic unit hydrograph method (USBR, 1989), in accordance with the SEO Guidelines (SEO, 2008). Three USBR synthetic unit hydrographs were developed for the each subbasin and include a general-storm unit hydrograph, a local-storm (thunderstorm) unit hydrograph, and a 100-year storm unit hydrograph. Unit hydrographs calculations are provided in Appendix A.

Required physical basin parameters include the basin area, the length of the longest watercourse within the basin, the stream length to a point perpendicular to the basin centroid, the slope along the longest watercourse, and a roughness value, Kn. These physical basin parameters were used to calculate lag time and the required unit duration for each subbasin. Channel length and length to centroid for the watershed were estimated from the downstream end of each subbasin. The parameters are shown on the unit hydrograph calculations spreadsheets in Appendix A, and summarized in Table 3-9.

**Table 3-9: USBR Dimensionless Unit Hydrograph Parameters**

| Basin Name | Area ($mi^2$) | Length of Watercourse (mi) | Length to Centroid (mi) | Basin Slope (ft/mi) |
|---|---|---|---|---|
| Upper Subbasin | 6.50 | 3.79 | 1.647 | 814.5 |
| Lower Subbasin | 0.95 | 1.81 | 1.006 | 504.7 |

The USBR procedure requires an estimation of Kn, which is effectively a composite Manning's "n" value that accounts for run-off delay due to terrain and surface obstructions. The Lower Beaver Brook watershed Kn values were developed in accordance with the SEO Guidelines (SEO, 2008). Kn values vary based on the type of storm and unit hydrograph selection. GEI selected Kn values based on the range of values provided in the SEO Guidelines, from comparable basins in the area, and site visit observations. The selected Kn values, unit duration and timestep used for IDF modeling are summarized in Table 3-10.

**Table 3-10: USBR Dimensionless Kn Value, Unit Duration, Lag Time, and Timestep**

| Storm Type | Kn Value | Unit Hydrograph Type | Unit Duration (min) | | Lag Time (hr) | | Timestep (min) | |
|---|---|---|---|---|---|---|---|---|
| | | | Upper Subbasin | Lower Subbasin | Upper Subbasin | Lower Subbasin | Upper Subbasin | Lower Subbasin |
| 100-Year | 0.20 | Rocky Mountain Thunderstorm | 30 | 15 | 3.15 | 2.27 | 10 | 6 |
| Local Storm (HMR 55A) | 0.070 | Rocky Mountain Thunderstorm | 10 | 5 | 1.10 | 0.79 | 3 | 2 |
| General Storm (HMR 55A) | 0.15 | Rocky Mountain General Storm | 15 | 15 | 2.36 | 1.70 | 10 | 5 |

The selected time steps meet standard criteria for adequately defining the peak of the unit hydrograph.

Lag time for the USBR synthetic unit hydrograph method was calculated as follows:

$$Lag\ Time = 26K_n\left(\frac{L_{ca}L}{S^{0.5}}\right)^{0.33}$$

Where: $Kn$ = measure of basin flow resistance taken from calibrated tables
$Lca$ = distance along the longest watercourse to a point perpendicular to the basin centroid
$L$ = distance along the longest watercourse to the farthest (highest) point in the basin
$S$ = slope along $L$

### 3.5.1 *Unit Hydrograph Sensitivity Analysis*

GEI investigated the sensitivity of the selected unit hydrographs by comparing the resulting peak reservoir inflow and residual freeboard to unit hydrographs with adjusted Kn values. The results of this sensitivity analysis are summarized in Table 5-7, in Section 5.

# 4. Hydrologic Modeling Parameters

## 4.1 Hydrologic Computer Model

The U.S. Army Corps of Engineers (USACE) Hydrologic Engineering Center's - Hydrologic Modeling System (HEC-HMS) Version 4.0 computer model was used to estimate the PMF inflows and outflow hydrographs of Lower Beaver Brook Dam and Reservoir. The parameters used in modeling and model output summaries are included in Appendix B.

## 4.2 Precipitation

Precipitation estimates were based on HMR 55A and NOAA Atlas 14 and are described in Section 3 and Appendix B.

## 4.3 Loss Rates

GEI selected to use the Initial and Uniform Distributed Loss-Rate Method for PMF modeling. Loss rates used for PMF modeling are shown in Table 3-6. GEI selected to use the Green and Ampt Loss-rate Method for the 100-year storm modeling. Loss rates used for 100-year storm are shown in Table 3-7.

## 4.4 Time Steps

A 1-minute time step was selected to model the general-storm PMF, local-storm PMF, and 100-year storm. The selected time steps meet standard criteria for adequately defining the peak of the unit hydrograph and the PMF.

## 4.5 Baseflow

Baseflow for Lower Beaver Brook Dam watershed was not considered to be significant, therefore, baseflow was assumed to be zero.

## 4.6 Reservoir Routing

Level-pool routing was used to route the PMF through Upper and Lower Beaver Brook Reservoirs. Upper and Lower Beaver Brook Reservoirs were assumed to be at the spillway crest (El. 8409.25 and El. 7,840, respectively) at the start of the storm. The elevation-capacity relationships for the two reservoirs are provided in Figures 5 and 6. The rating curves for the existing Lower Beaver Brook spillway and the proposed Upper Beaver Brook spillway are provided in Figures 7 and 8. A description of the proposed spillway at Upper Beaver Brook can be found in Appendix C.

## 4.7 Channel Routing

The Lower Beaver Brook watershed was modeled using two subbasins, referred to as the Upper Subbasin and the Lower Subbasin. The Upper Subbasin includes Upper Beaver Brook Dam/Reservoir and the associated drainage area to that reservoir (6.50 $mi^2$). The Lower Subbasin incorporates the drainage area below Upper Beaver Brook that contributes to Lower Beaver Brook (0.95 $mi^2$). Outflow from Upper Beaver Brook Reservoir is routed through Beaver Brook into Lower Beaver Brook Reservoir. Beaver Brook was modeled having a trapezoidal cross section with bottom width of 4 feet and 2:1 (H:V) side slopes. The reach of Beaver Brook between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir is 9187 feet long and the average slope is 0.064 ft/ft. A Manning's n-value of 0.05 was selected and is based on recommendation from Chow (1959) for a steep mountain stream with bottom material consisting of cobbles to large boulders. The Muskingum-Cunge method was used for routing calculations.

## 4.8 Snowmelt

Snowmelt was not considered for the Lower Beaver Brook Dam PMF because the critical storm is most likely to occur during the summer months when snowpack in the watershed is negligible.

## 4.9 Discussion of PMF Modeling Parameters

The various parameters selected for the Lower Beaver Brook Dam PMF are generally considered conservative and are appropriate for the site-specific conditions. Multiple conservative assumptions compound, therefore the overall PMF analysis is generally more conservative than any single parameter or assumption. This reduces the significance should any one parameter be viewed as not being conservative enough. Therefore, the conditions used in this study are considered to be reasonably conservative.

# 5. Hydrology Study Results

## 5.1 PMF Study Results

GEI Consultants, Inc. (GEI) developed estimates of general-storm PMP and the local-storm PMP for the Lower Beaver Brook watershed at the dam site. Precipitation estimates were converted to inflow estimates using standard flood runoff modeling practices. Modeling results for the general-storm PMF and the local-storm PMF are summarized in Tables 5-1 and 5-2, respectively. Based on the modeling results, the HMR 55A local-storm produces the critical PMF inflow to the reservoir.

**Table 5-1: Results of the HMR 55A General-Storm PMF Model**

| Parameter or Modeling Result | General-Storm PMF for the Upper Subbasin and Upper Beaver Brook Dam/Reservoir | General-Storm PMF for the Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
|---|---|---|
| Subbasin Average 72-hr PMP Depth (inches) | 32.80 | 32.80 |
| Subbasin Average Uniform Loss Rate (inches/hour) | 0.106 | 0.083 |
| Hydrologic Soil Groups (HSG)-Adjusted Excess Rainfall (inches) | 26.33 | 27.33 |
| SEO Allowed Reduction | 0.80 | 0.80 |
| SEO Reduced Average 72-hr PMP Depth (inches) | 21.05 | 21.92 |
| Antecedent Moisture Condition | Normal | Normal |
| Subbasin Average Initial Infiltration Losses (inches) | 0.40 | 0.40 |
| Subbasin Average Initial Abstraction Losses (inches) | 0.30 | 0.30 |
| Subbasin Average Total Direct Runoff (inches) | 20.05 | 20.93 |
| Subbasin Average 72-hr Losses (inches) | 12.75 | 11.87 |
| Subbasin Average PMP Runoff Percent (%) | 61.1 | 63.8 |
| Maximum Reservoir Elevation (feet) | 8,414.15 | 7,846.57 |
| Freeboard (feet) | 5.85 (Dam Crest El. 8,420.0) | -6.57 (Dam Crest El. 7,840.0) |
| Inflow Volume (AF) | 6,952 | 8,008 |
| Peak Inflow (cfs) | 10,743 | 12,186 |
| Peak Outflow (cfs) | 10,640 | 12,185 |

**Table 5-2: Results of the HMR 55A Local-Storm PMF Model**

| Parameter or Modeling Result | Local-Storm PMF for the Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Local-Storm PMF for the Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
|---|---|---|
| Subbasin Average 6-hr PMP Depth (inches) | 9.86 | 10.25 |
| Subbasin Average Uniform Loss Rate (inches/hour) | 0.106 | 0.083 |
| HSG-Adjusted Excess Rainfall (inches) | 9.22 | 9.75 |
| SEO Allowed Reduction | 0.90 | 0.90 |
| SEO Reduced Average 6-hr PMP Depth (inches) | 8.29 | 8.78 |
| Antecedent Moisture Condition | Normal | Normal |
| Subbasin Average Initial Infiltration Losses (inches) | 0.40 | 0.40 |
| Subbasin Average Initial Abstraction Losses (inches) | 0.30 | 0.30 |
| Subbasin Average Total Direct Runoff (inches) | 7.59 | 8.07 |
| Subbasin Average 6-hr Losses (inches) | 0.70 | 0.70 |
| Subbasin Average PMP Runoff Percent (%) | 91.6 | 91.9 |
| Maximum Reservoir Elevation (feet) | 8,418.78<br>Dam Crest El. 8,420.0 | 7,850.13<br>Dam Crest El. 7,840.0 |
| Freeboard (feet) | 1.22 | -10.13 |
| Inflow Volume (AF) | 2,633 | 3,041 |
| Peak Inflow (cfs) | 21,920 | 22,720 |
| Peak Outflow (cfs) | 20,412 | 22,714 |

Based on the results presented in Tables 5-1 to 5-2, the critical PMF for Lower Beaver Brook Dam is the HMR 55A local-storm. The PMF results in a peak inflow of 22,720 cfs, a peak water surface elevation of 7,850.13 feet, and a total peak discharge of 22,714 cfs. The existing spillway is not capable of passing the PMF without overtopping the dam and the depth of overtopping will be approximately 10 feet. The total duration of the discharge through the spillway/over the dam would be approximately 28.0 hours. The existing spillway rating curve is shown in Figure 7 and the PMF hydrographs for Upper and Lower Beaver Brook Dams are provided in Figure 9. A summary of the input and output from the HEC-HMS Model is provided in Appendix B.

## 5.2 Frequency Storm Study Results

GEI also developed estimates of the 2-, 5-, 10-, 25-, 50- and 100-year storms for the Lower Beaver Brook Dam watershed. The results for these more frequent storms are based on using the Green and Ampt loss rate method rather than the initial and uniform loss rate method used for IDF modeling. Modeling results for the National Oceanic and Atmospheric Administration (NOAA) Atlas 14 10-, 25-, 50-, and 100-year storms are summarized in Table 5-3 to 5-8.

**Table 5-3: Results of NOAA Atlas 10-Year Storm Model**

| Parameter or Modeling Result | 10-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 10-Year Storm Depth (inches) | 2.62 | 2.62 |
| Subbasin Average 10-Year Storm Runoff (inches) | 0.63 | 0.74 |
| Subbasin Average 24-hr 10-Year Losses (inches) | 1.99 | 1.88 |
| Subbasin Average 10-Year Storm Runoff Percent (%) | 24.0 | 28.2 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,409.81 | 7840.87 |
| Freeboard (feet) | 10.19<br>Dam Crest El. 8,420.0 | -0.87<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 219 | 256 |
| Peak Inflow (cfs) | 901 | 984 |
| Peak Outflow (cfs) | 885 | 982 |

**Table 5-4: Results of NOAA Atlas 25-Year Storm Model**

| Parameter or Modeling Result | 25-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 25-Year Storm Depth (inches) | 3.28 | 3.28 |
| Subbasin Average 25-Year Storm Runoff (inches) | 0.86 | 0.97 |
| Subbasin Average 24-hr 25-Year Losses (inches) | 2.42 | 2.32 |
| Subbasin Average 25-Year Storm Runoff Percent (%) | 26.2 | 29.6 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,409.93 | 7,841.18 |
| Freeboard (feet) | 10.07<br>Dam Crest El. 8,420.0 | -1.18<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 297 | 346 |
| Peak Inflow (cfs) | 1,211 | 1,326 |
| Peak Outflow (cfs) | 1,194 | 1,324 |

**Table 5-5: Results of NOAA Atlas 50-Year Storm Model**

| Parameter or Modeling Result | 50-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 50-Year Storm Depth (inches) | 3.85 | 3.85 |
| Subbasin Average 50-Year Storm Runoff (inches) | 1.04 | 1.15 |
| Subbasin Average 24-hr 50-Year Losses (inches) | 2.81 | 2.70 |
| Subbasin Average 50-Year Storm Runoff Percent (%) | 27.0 | 29.9 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.02 | 7,841.40 |
| Freeboard (feet) | 19.92<br>Dam Crest El. 8,420.0 | -1.40<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 361 | 419 |
| Peak Inflow (cfs) | 1,454 | 1,603 |
| Peak Outflow (cfs) | 1,445 | 1,602 |

**Table 5-6: Results of NOAA Atlas 100-Year Storm Model**

| Parameter or Modeling Result | 100-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 100-Year Storm Depth (inches) | 4.47 | 4.47 |
| Subbasin Average 100-Year Storm Runoff (inches) | 1.22 | 1.34 |
| Subbasin Average 24-hr 100-Year Losses (inches) | 3.24 | 3.13 |
| Subbasin Average 100-Year Storm Runoff Percent (%) | 27.3 | 30.0 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.14 | 7,841.61 |
| Freeboard (feet) | 19.86<br>Dam Crest El. 8,420.0 | -1.61<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 424 | 492 |
| Peak Inflow (cfs) | 1,719 | 1,882 |
| Peak Outflow (cfs) | 1,697 | 1,880 |

**Table 5-7: Results of NOAA Atlas 500-Year Storm Model**

| Parameter or Modeling Result | 500-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 500-Year Storm Depth (inches) | 6.13 | 6.13 |
| Subbasin Average 500-Year Storm Runoff (inches) | 1.66 | 1.79 |
| Subbasin Average 24-hr 500-Year Losses (inches) | 4.47 | 4.34 |
| Subbasin Average 500-Year Storm Runoff Percent (%) | 27.1 | 29.2 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.32 | 7,842.07 |
| Freeboard (feet) | 9.68<br>Dam Crest El. 8,420.0 | -2.07<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 576 | 666 |
| Peak Inflow (cfs) | 2,327 | 2,551 |
| Peak Outflow (cfs) | 2,304 | 2,549 |

**Table 5-8: Results of NOAA Atlas 1,000-Year Storm Model**

| Parameter or Modeling Result | 1,000-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 1,000-Year Storm Depth (inches) | 6.94 | 6.94 |
| Subbasin Average 1,000-Year Storm Runoff (inches) | 1.85 | 1.99 |
| Subbasin Average 24-hr 1,000-Year Losses (inches) | 5.09 | 4.95 |
| Subbasin Average 1,000-Year Storm Runoff Percent (%) | 26.7 | 28.7 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.41 | 7,842.25 |
| Freeboard (feet) | 9.59<br>Dam Crest El. 8,420.0 | -2.25<br>Dam Crest El. 7,840.0 |
| Inflow Volume (AF) | 643 | 744 |
| Peak Inflow (cfs) | 2,596 | 2,847 |
| Peak Outflow (cfs) | 2,570 | 2,845 |

## 5.3 Sensitivity Analysis

GEI investigated the sensitivity of the selected loss rates and unit hydrographs. The sensitivity of the selected values was evaluated by comparing the resulting peak reservoir inflow and peak water surface elevation to the results of the adjusted values. Results were compared for the critical PMF storm, the HMR 55A local-storm described above. Sensitivity analyses were performed for:

- Time step (varied from 1 minute to 10 minutes);
- HSG loss rates (minimum, average, and maximum infiltration rates);
- Basin average Kn (varied between 0.050 and 0.080); and
- Initial losses (varied between 0.90 inches and 1.10 inches).

The results of the sensitivity analyses are summarized in Table 5-7 and documented in Appendix A.

GEI performed sensitivity analyses of the downstream reach in response to SEO comments. The analyses are documented in a Comment Response Memorandum, included in Appendix F.

**Table 5-9: Sensitivity Analysis Results of the HMR 55A Local-Storm Model**

| Case | Time Step (min) | HSG Loss Rates (in/hr) | Initial Loss (in) | Basin Average Kn | Peak Reservoir Inflow Rate (cfs) | Peak Water Surface Elevation (ft) | Freeboard (ft) |
|---|---|---|---|---|---|---|---|
| Base Case | 1 | Minimum | 0.90 | 0.070 | 22,485 | 7,850.06 | -10.06 |
| Time Step 1 | 2 | Minimum | 0.90 | 0.070 | 22,467 | 7,850.05 | -10.05 |
| Time Step 2 | 5 | Minimum | 0.90 | 0.070 | 22,351 | 7,850.12 | -10.12 |
| Time Step 3 | 10 | Minimum | 0.90 | 0.070 | 21,891 | 7,849.70 | -9.70 |
| HSG Loss 1 | 1 | Average | 0.90 | 0.070 | 22,129 | 7,849.95 | -9.95 |
| HSG Loss 2 | 1 | Maximum | 0.90 | 0.070 | 21,730 | 7,849.82 | -9.82 |
| Kn 1 | 1 | Minimum | 0.90 | 0.050 | 29,322 | 7,852.07 | -12.07 |
| Kn 2 | 1 | Minimum | 0.90 | 0.080 | 20,521 | 7,849.44 | -9.44 |
| Initial Loss 1 | 1 | Minimum | 1.10 | 0.070 | 22,149 | 7,849.95 | -9.95 |

Based on the results of the sensitivity analyses, the PMF model is more sensitive to the unit hydrograph Kn value than the selected loss rates. The PMF model is more sensitive to the unit hydrograph Kn value because the resulting peak water surface elevation is driven by the peak inflow rate rather than inflow volume. This is due to the small reservoir surface area and surcharge storage capacity that produces little attenuation in the peak inflow rate.

Of the five parameters evaluated, the base case uses the most conservative values for time step, HSG infiltration rate, unit hydrograph methodology, and initial losses. The basin average Manning's n selected (Kn of 0.070) reflects the dense evergreen forest that is present throughout the watershed. GEI considers the selected Kn value to be reasonable and appropriate for the watershed conditions and is within the SEO Guidelines recommended range of 0.050 – 0.080 (SEO, 2008, Table 7). Based on the results of the sensitivity analyses, the selected basin response parameters in the base case model are reasonable for PMF estimates.

## 5.4 Conclusion

GEI developed and evaluated multiple rainfall events to determine the critical PMF and other frequency event storms for Lower Beaver Brook Dam based on a High Hazard classification of the dam. All of the storms evaluated were developed in accordance with current SEO Regulations (SEO, 2007) and SEO Guidelines (SEO, 2008). The HMR 55A local-storm was determined to be the critical storm for Lower Beaver Brook Dam and is the PMF. The PMF results in a peak inflow of 22,485 cfs, a peak water surface elevation of 7,850.06 feet, and a total peak discharge of 22,477 cfs. The PMF hydrographs for Lower Beaver Brook Dam are provided in Figure 7.

# 6. Incremental Damage Analysis

## 6.1 Overview

An IDA is basically a comparison between two floods: (1) a Base Flow Flood (base flood) of minimum magnitude that will just cause a breach of the dam (routed assuming no dam in place) and (2) a Dam Breach Flood (breach flood) which occurs due to overtopping, which is routed downstream with the base flood. The IDF will be acceptable where it can be shown that the breach blood would cause no additional loss of life or additional significant property damage within the zone between the two floods. No loss of life or significant damage is expected to occur if the increased depth of flow above the critical flood elevation is 2 feet or less, and/or the product of the flood flow velocity in the incremental zone and the depth of flow at critical locations are less than 7. The magnitude of the base flood may be increased above the minimum magnitude until an acceptable flood is found.

After discussions with the SEO, it was determined that routing the base flood with the dam in place (but with no breach) would be conservative versus routing the base food with no dam in place. Due to the small reservoir size and minimal attenuation, the difference between the base flood with no dam in place and with the dam in place is very small (less than 0.1 percent increase). The results described below assume the conservative scenario with the dam in place.

The breach parameters used in the development of the breach flood were based on the Froehlich (2008) methodology and suggested values in the SEO *Guidelines for Dam Breach Analysis* (SEO, 2010). The breach was simulated as a trapezoid with a bottom width of 18 feet, 1.0H:1V left side slope, 1.0H:1V right side slope, a maximum height of 26 feet, an average breach width of about 39 feet, and a time to failure of 0.15 hours.

## 6.2 Incremental Damage Analysis Scenarios

The minimum base flood scenario at Lower Beaver Brook Dam was selected to be the design storm that produces 1-foot of dam crest overtopping, which was estimated to be the likely flood event with potential for failing the existing dam. The flood event that results in 1-foot of dam overtopping is the 0.15PMF and is approximately equivalent to a 15-20 year return period. The 1-foot overtopping event does not meet SEO criteria that the minimum IDF for a high hazard dam is at least the 100-year flood. Therefore, the 100-year flood event was analyzed as the minimum allowable base flood.

The 100-year base flood has a peak inflow of 1,880 cfs. The hypothetical failure of the Lower Beaver Brook Dam due to the 100-year flood (with failure initiating at a depth of 1.61 feet of overtopping). It was found that incremental damages would occur with the 100-year base flood.

The base flood was increased until no incremental damages occurred. The design storm that produces no incremental damages is equal to 27.5 percent of the general-storm PMP value, and 34.4 percent of the reduced SEO design storm PMP value. The 0.275PMP base flood has a peak flow of about 4,755 cfs and the 0.275PMP break flood is 8,175 cfs.

## 6.3 Downstream Reach

Beaver Brook flows in a northeasterly direction for approximately 3 miles to the confluence with Clear Creek. From the confluence, Clear Creek continues to flow in an easterly direction for approximately 3.5 miles into the Town of Golden. Beaver Brook is steeply sloped with an average slope of approximately 0.046 feet/feet. Beaver Brook flows through a narrow canyon in a small stream channel with generally less than approximately 10 foot top width. The banks of the river are generally steep to very steep. There are no significant lateral inflows to Beaver Brook between Lower Beaver Brook Dam and the Clear Creek Confluence.

The LMWD water treatment plant facilities are located immediately downstream of the dam. In general, there are a number of residential properties located along the banks of Beaver Brook that could potentially be impacted by a failure of Lower Beaver Brook Dam. Figures 14, 15 and 16 show the location of the identified properties along the downstream reach.

#### 6.3.1.1 Field Surveys

Two field surveys were conducted to identify critical structures and crossings. The first, conducted by GEI in October 2014, identified the substantial river crossings and recording culvert/bridge dimensions. GEI determined during this field survey that the number of critical structures along the reach was greater than was previously thought based on aerial photography. It was determined that a topographic survey identifying critical structures along the reach was necessary. LMWD mailed notifications of the survey to all property owners with property adjacent to Beaver Brook and CCS Consultants, Inc. (CCS) mobilized in December 2014. CCS surveyed 30 cross sections to determine the relative elevation of critical structures and the channel bed. The survey extended between Lower Beaver Brook Dam and the crossing of Interstate 70 (I-70), approximately 1.3 miles downstream of the dam. The two field surveys identified 10 culverts, 2 bridges, and 42 residences/structures that might be near enough to the stream to be impacted by the flood wave.

### 6.3.2 *Downstream Stream Crossings*

The reach between the dam and the Beaver Brook crossing of US-40, approximately 3 miles downstream of the dam, was modeled and analyzed for incremental damages. The crossings were surveyed either by GEI staff in October 2014 or CCS Consultants, Inc. in December 2014. There are several county and residential road crossings within this reach. Although a

flood of large magnitude would likely wash out many of these structures, all identified crossings were modeled to provide a conservative estimate of water surface elevations upstream of the crossings. There is a single large embankment/ culvert crossing located under I-70. This culvert crossing creates significant attenuation and is discussed further in Section 6.3.2.1. A summary of the river crossing structures is contained in Table 6-1.

**Table 6-1: Summary of Bridge and Culvert Crossings**

| Structure Type | HEC-RAS Cross Section | Crossing Type | Culvert Size |
|---|---|---|---|
| CMP Arch Culvert | 77000 | Entrance to WTP | 5' x 3.5' |
| CMP Arch Culvert | 76800 | Residential | 5' x 3.5' |
| CMP Circular Culvert | 76330 | Beaver Brook Canyon Road | 33" diameter |
| CMP Circular Culvert | 74900 | Beaver Brook Canyon Road | 48" diameter |
| CMP Circular Culvert | 71250 | Elm Green Lane | 66" diameter |
| CMP Circular Culvert | 70290 | Interstate 70 | 54" diameter |
| Concrete Box Culvert | 68675 | Residential | 12' x 6' |
| Single Span Residential Bridge | 67275 | Residential | N/A |
| CMP Circular Culvert | 67057 | Residential | 48" diameter |
| CMP Circular Culvert | 66950 | Residential | 48" diameter |
| CMP Circular Culvert | 65190 | Soda Creek Road | 48" diameter |
| Single Span Highway Bridge | 62560 | US Highway 40 | N/A |

#### 6.3.2.1 Culvert Crossing of Interstate 70

Beaver Brook flows under I-70 about 1.3 miles downstream of the dam. At this location Beaver Brook flows northeast into 565-feet long culvert with a 54-inch diameter and invert El. 7,493.73. The natural flow path of Beaver Brook is blocked by the embankment of I-70 (oriented east/west) and by the embankment Colorado State Highway 65 (CO-65) bridge crossing of I-70 (oriented north/south). The culvert flows through the vertex where the embankments intersect. The I-70 and CO-65 embankments are approximately 31 feet and 59 feet, respectively, higher than the culvert inlet invert. Water in excess of the culvert capacity backs up behind the I-70 embankment until the embankment overtops. At this point, about El. 7,525, water flows onto I-70.

As shown in Figure 11, US Highway 40 (US-40) roughly parallels westbound I-70. US-40 is located on a bench north of I-70. The off-ramp to Exit 248 allows traffic to merge onto CO-65 or US-40. The Exit 248 embankment creates a barrier in the direction of flow about 12 feet above I-70. Runoff from the north, east, and west flows to a low point on I-70 approximately above the culvert. Under normal conditions, water is drained off the road via the low point on the south side of the I-70 embankment and into the culvert. Because the flood wave flows counter to the typical drainage path, water will back up on I-70 until the Exit 248 embankment overtops. Upon overtopping the Exit 248 embankment, water returns

to Beaver Brook near the culvert outlet. The photographs on Figure 11 depict the embankments and their approximate elevations.

The interchange is modeled in HEC-RAS as a single culvert/roadway. The top of the roadway was set to the elevation of the Exit 248 embankment, approximately 43 feet above the culvert invert. Figure 12 shows the model configuration and the approximate geometry of the existing interchange.

Generally, the difference in water surface elevations is less than 1 foot downstream of I-70 and the IDA was terminated at this location. Immediately after the bridge, the incremental rise decreases to less than 0.77 feet.

### 6.3.3 *Downstream Structures*

The two field surveys identified 10 culverts, 2 bridges, and 42 residences/structures upstream of I-70 that might be near enough to the stream to be impacted by the flood wave. Based on the results of the IDA (discussed in Section 7), 16 structures are not inundated by either the base flood or the breach flood and 15 structures are already significantly impacted by the base flood. One structure is minimally inundated by both floods but is not incrementally impacted. Ten residences/structures are located downstream of the I-70 culvert and were not considered in the IDA as the difference in water surface elevations is generally less than 1 foot at these locations.

All 10 culverts/roadways and one residential bridge are overtopped by at least 4 feet by the baseflood and are not incrementally impacted. The US-40 bridge is not impacted by either flood event.

The routing of the Lower Beaver Brook Dam breach flood was terminated approximately 3 miles downstream of the Lower Beaver Brook Dam.

## 6.4 Hydraulic Model

The Incremental Damage Analysis and flood wave routing for Lower Beaver Brook Dam were simulated using the U.S. Army Corps of Engineers Hydraulic Engineering Center – River Analysis System (HEC-RAS) Version 4.1.0.

To simulate the river reach, 84 cross sections were developed for this analysis using HEC-GeoRAS software package and digital 7.5-minute USGS topographic maps. GEI developed 492 interpolated cross sections in HEC-RAS at approximately 30-foot to aid in the computations performed by HEC-RAS.

In response to comments from the SEO, GEI developed a two-dimensional (2D) hydraulic model using Light Detection and Ranging (LiDAR) data available from the Federal Emergency Management Agency (FEMA) through the Colorado GeoData Cache. The

development and results of the model are discussed in the Comment Response Memorandum to the SEO, inlucded in Appendix F.

Manning's "n" values were estimated for the downstream reach based on Chow, 1959. The main channels of the downstream reach were assigned a Manning's n-value of 0.04 based on mountain streams with a channel bottom of gravel, cobble, and a few boulders. Through the initial 0.7 miles downstream of the dam, the river overbanks were assigned n-values of 0.10 based on the medium to dense brush and timber on the river banks that would be reached during flood stages. After the first 0.70 miles, where the canyon below the dam widens, the river overbanks were assigned n-values of 0.06 based on light brush and trees.

A minimal constant inflow or baseflow was simulated in order to assist the HEC-RAS model with initial condition calculations. The selected baseflow was 250 cfs. The selected baseflow is considered negligible relative to the large Base Flow Flood and Dam Breach Flood developed for the IDA.

The upstream control for the hydraulic model was set as an inflow hydrograph. Lateral inflow hydrographs were included as an internal boundary condition to represent the Beaver Brook inflows. The downstream control for the hydraulic model was set as normal depth, using the estimated slope of Beaver Brook at the end of the study reach, which was estimated to be about 0.027 feet/feet.

The hydraulic calculations were performed in HEC-RAS using unsteady flow simulations with a mixed flow regime and 1-minute computation intervals.

## 6.5 Breach Parameters

Breach parameters for LBB Dam were developed based on the SEO *Guidelines for Dam Breach Analysis* (SEO, 2010) suggested breach parameters, the foundation profile, and engineering judgment. Lower Beaver Brook Dam is a rockfill embankment dam as described in Section 2.0. The SEO Guidelines recommend using the Froehlich method for an overtopping failure. The MacDonald Langridge-Monopolis (MLM) method was evaluated for comparison purposes. A summary of the breach parameter evaluations is provided in Table 6-2.

**Table 6-2: Summary of Suggested Breach Parameters Based on Engineering Guidelines**

| Parameter | MLM | Froehlich |
|---|---|---|
| Type of Dam | Rockfill | N/A |
| Height of Dam | 26 ft | 26 ft |
| Average Breach Width | 46.5 | 38.9 ft |
| Avg. Breach Width/Dam Height | 1.8 | 1.5 |
| Side Slopes, Z | 0.22 | 1.0 |
| Bottom Breach Width | 0.1 ft | 12.9 ft |

| Parameter | MLM | Froehlich |
|---|---|---|
| Time to Failure | 0.15 hrs | 0.15 hrs |

Based on review of the suggested breach parameters, the MLM and Froehlich parameters compared reasonably well and the Froehlich parameters were used in the dam break modeling. The initial water surface was set at the spillway crest (El. 7,837.7) and the dam failure was initiated at the peak water surface elevation of the base flood. A summary of the breach parameters used in the HEC-HMS model are provided in Table 6-3.

**Table 6-3: Summary of Breach Parameters Used in HEC-HMS Model**

| Parameter | MLM/WA St. |
|---|---|
| Type of Dam | Rockfill |
| Top Elevation (ft) | 7840.0 |
| Bottom Elevation (ft) | 7808.8 |
| Height of Water over Base Elevation of Breach (ft) | 34.9 |
| Volume of Water in Reservoir at Time of Failure (ac-ft) | 46.4 |
| Reservoir Surface Area at Time of Breach (ac) | 3.5 |
| Height of Breach (ft) | 31.2 |
| Breach Side Slopes (xH:1V) | 0.5 |
| Bottom Width of Breach (ft) | 5.0 |
| Time of Development (hr) | 0.17 |
| Trigger Elevation (ft) | 7843.69 |
| Peak Outflow (cfs) | 8,129.4 |

Reduction of the breach height to 80 percent of the dam height, or 31.2 feet, based on research of washout of rockfill dams (Rozov, 2005). Scoured embankment particles from rockfill dams are deposited just downstream of the dam and prevent the lower 20 percent of the dam height from scouring. Justification and discussion of the breach parameters is documented in a Comment Response Memorandum to the SEO, included in Appendix F.

# 7. Incremental Damage Analysis Results

GEI performed an IDA to estimate the IDF for the existing Lower Beaver Brook Dam. As part of the analysis GEI developed estimates of the base flood, dam breach parameters, breach flood and downstream incremental impacts. Modeling results are based on routing the floods through the current configuration of the reservoir, dam, and spillway. Additionally, the results are based on the existing development downstream of the dam. If future development downstream changes the results presented herein may not be applicable and the SEO could require the dam owner to modify the dam accordingly.

In response to comments from the SEO, GEI developed a 2D model to support a global finding of no incremental damage. The Comment Response Memorandum is included in Appendix F.

## 7.1 Base Flood Results

As indicated above, GEI determined the base flood to be equivalent to a 0.275PMP storm event. A summary of the resulting Base Flow Flood parameters is summarized in Table 7-1. Discussion of the PMP development and results of the PMP/PMF can be found in Sections 3, 4, and 5.

**Table 7-1: Results of Lower Beaver Brook Dam Base Flood**

| Parameter | Base Flood Modeling Results |
|---|---|
| HMR-55 Local-Storm Average 6-hr PMP Depth, No SEO Reductions | 9.91 inches |
| Base Flood Percent of HMR-55 Local-Storm 6-hr PMP | 27.5% |
| Base Flood Basin Average 6-hr PMP Depth | 2.55 inches |
| Base Flood Basin Average PMP Runoff | 1.66 inches |
| Base Flood Basin Average 72-hr Losses | 0.89 inches |
| Base Flood Basin Average PMP Runoff Percent | 65.1% |
| Maximum Reservoir Elevation | 7,843.3 feet |
| Residual Freeboard | -3.3 feet |
| Inflow Volume | 657 acre-feet |
| Peak Inflow | 4,755 cfs |

The estimated base flood is about 3,625 cfs larger than the estimated peak inflow rate of the 1-foot overtopping storm (1,130 cfs) and about 2,875 cfs larger than the 100-year storm (1,880 cfs). The base flood is about 460 acre-feet larger than the inflow volume than the 1-foot overtopping storm (196 acre-feet) and about 165 acre-feet larger than the 100-year storm (492 cfs). The base flood hydrograph is presented in Figure 13.

## 7.2 Dam Breach Flood Results

As previously stated, the storm event that produces a maximum water surface of El. 7,841 (1-foot overtopping) is the 0.15PMF. For this storm, the dam breach is triggered at the peak of the inflow hydrograph. For storms of larger magnitude, like the 0.275PMP base flood, 1-foot of dam overtopping occurs on the rising limb of the inflow hydrograph. For storms larger than the 0.15PMF event, the breach was initiated at the maximum water surface elevation of the base flood.

The breach flood hydrographs were simulated using the HEC-HMS computer model. The hypothetical failure of Lower Beaver Brook Dam due to 3.43 feet of dam crest overtopping triggered by the 0.275PMP base flood event resulted in a peak discharge of about 8,175 cfs. The estimated breach will completely drain the volume of the reservoir, less a small dead pool of about 2.5 acre-feet, for a total of 32.6 acre-feet. The hypothetical failure results for Lower Beaver Brook Dam are presented in Table 7-2 and Figures 14-16. This breach flood was routed downstream with the resulting base flood to estimate the incremental impacts that could potentially occur at the identified critical structures.

## 7.3 Incremental Impacts

GEI used the HEC-RAS Version 4.1.0 computer program to route the flood hydrographs downstream through Beaver Brook for a total of about 3 miles.

The incremental impacts that could potentially occur at the identified structures due to a failure of Lower Beaver Brook Dam were estimated by routing the base flood and breach flood through the downstream reach and comparing the estimated water surface elevations to the estimated critical water surface elevation of the structures downstream. The structures' critical water surface elevations were surveyed to the nearest one-hundredth of a foot. A summary of the IDA flood routing results is shown in Table 7-2.

## 7-2: Summary of IDA Flood Routing Results

| | | | | | Base Flood | | | | | | Breach Flood | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Property or Structure ID (XS #, Bank) | Distance Below Dam | Critical WSE | Min Channel El. | Peak Discharge at Max WSE | Max WSE | Depth in Channel | Water Depth at Structure | Average Overbank Velocity | Depth * Velocity | Peak Discharge at Max WSE | Max WSE | Depth in Channel | Water Depth at Structure | Average Overbank Velocity | Depth * Velocity | Incremental Rise at Structure | Incremental Impacts |
| | | Miles | (ft) | (ft) | (cfs) | (ft) | (ft) | (ft) | (ft/s) | ($ft^2$/s) | (cfs) | (ft) | (ft) | (ft) | (ft/s) | ($ft^2$/s) | (ft) | (Yes/No) |
| 1 | XS 77220.27 (Left) | 0.00 | 7813.40 | 7807.60 | 4752.20 | 7820.13 | 12.53 | 6.73 | 7.48 | 50.34 | 8174.60 | 7822.05 | 14.45 | 8.65 | 7.97 | 68.94 | 1.92 | NO |
| | XS 77132.59 (Left) | 0.01 | 7830.74 | 7799.60 | 4751.53 | 7817.43 | 17.83 | 0.00 | 6.05 | 0.00 | 8008.43 | 7820.14 | 20.54 | 0.00 | 6.23 | 0.00 | 0.00 | NO |
| 3 | XS 77069.6 (Left) | 0.02 | 7821.68 | 7795.13 | 4751.05 | 7811.79 | 16.66 | 0.00 | 9.47 | 0.00 | 8003.17 | 7814.32 | 19.19 | 0.00 | 10.26 | 0.00 | 0.00 | NO |
| 4 | Culvert A | 0.04 | 7801.53 | 7795.13 | 4750.73 | 7808.04 | 12.91 | 6.51 | N/A | N/A | 7996.52 | 7810.26 | 15.13 | 8.73 | N/A | N/A | 2.22 | NO |
| 5 | XS 76944.98A (Left) | 0.05 | 7806.15 | 7791.62 | 4750.73 | 7800.10 | 8.48 | 0.00 | 3.94 | 0.00 | 7996.51 | 7802.36 | 10.74 | 0.00 | 4.12 | 0.00 | 0.00 | NO |
| 6 | XS 76944.98B (Left) | 0.05 | 7802.50 | 7791.62 | 4750.73 | 7800.10 | 8.48 | 0.00 | 3.94 | 0.00 | 7996.51 | 7802.36 | 10.74 | 0.00 | 4.12 | 0.00 | 0.00 | NO |
| 7 | Culvert B | 0.08 | 7792.23 | 7788.26 | 4749.47 | 7798.26 | 10.00 | 6.03 | N/A | N/A | 7944.07 | 7800.54 | 12.28 | 8.31 | N/A | N/A | 2.28 | NO |
| 8 | Culvert C | 0.16 | 7740.97 | 7745.71 | 4748.87 | 7754.77 | 9.06 | 13.80 | N/A | N/A | 7835.84 | 7756.61 | 10.90 | 15.64 | N/A | N/A | 1.84 | NO |
| 9 | XS 76240.0 (Left) | 0.18 | 7745.45 | 7737.64 | 4748.76 | 7747.29 | 9.65 | 1.84 | 4.77 | 8.78 | 7818.49 | 7749.46 | 11.82 | 4.01 | 5.39 | 21.61 | 2.17 | NO |
| 10 | XS 76220.6A (Left) | 0.19 | 7737.12 | 7733.70 | 4748.70 | 7745.74 | 12.04 | 8.62 | 7.10 | 61.20 | 7810.81 | 7748.05 | 14.35 | 10.93 | 7.49 | 81.87 | 2.31 | NO |
| 11 | XS 76220.6B (Right) | 0.19 | 7748.99 | 7733.70 | 4748.70 | 7745.74 | 12.04 | 0.00 | 6.79 | 0.00 | 7810.81 | 7748.05 | 14.35 | 0.00 | 7.09 | 0.00 | 0.00 | NO |
| 12 | XS 76143.17 (Left) | 0.20 | 7733.98 | 7733.00 | 4748.24 | 7744.73 | 11.73 | 10.75 | 2.45 | 26.34 | 7771.64 | 7746.74 | 13.74 | 12.76 | 2.62 | 33.43 | 2.01 | NO |
| 13 | XS 76046.3A (Left) | 0.22 | 7737.80 | 7732.64 | 4747.42 | 7744.33 | 11.69 | 6.53 | 4.65 | 30.36 | 7709.27 | 7746.33 | 13.69 | 8.53 | 4.91 | 41.88 | 2.00 | NO |
| 14 | XS 76046.3B (Right) | 0.22 | 7736.46 | 7732.64 | 4747.42 | 7744.33 | 11.69 | 7.87 | 4.13 | 32.50 | 7709.27 | 7746.33 | 13.69 | 9.87 | 4.39 | 43.33 | 2.00 | NO |
| 15 | XS 76046.3C (Right) | 0.22 | 7738.52 | 7732.64 | 4747.42 | 7744.33 | 11.69 | 5.81 | 4.13 | 24.00 | 7709.27 | 7746.33 | 13.69 | 7.81 | 4.39 | 34.29 | 2.00 | NO |
| 16 | XS 76046.3D (Right) | 0.22 | 7766.77 | 7732.64 | 4747.42 | 7744.33 | 11.69 | 0.00 | 4.13 | 0.00 | 7709.27 | 7746.33 | 13.69 | 0.00 | 4.39 | 0.00 | 0.00 | NO |
| 17 | XS 75917.7A (Left) | 0.24 | 7738.98 | 7731.36 | 4745.71 | 7741.69 | 10.33 | 2.71 | 4.25 | 11.52 | 7624.38 | 7743.56 | 12.20 | 4.58 | 4.55 | 20.84 | 1.87 | NO |
| 18 | XS 75917.7B (Right) | 0.24 | 7738.05 | 7731.36 | 4745.71 | 7741.69 | 10.33 | 3.64 | 5.82 | 21.18 | 7624.38 | 7743.56 | 12.20 | 5.51 | 6.23 | 34.33 | 1.87 | NO |
| 19 | XS 75917.7C (Right) | 0.24 | 7760.41 | 7731.36 | 4745.71 | 7741.69 | 10.33 | 0.00 | 5.82 | 0.00 | 7624.38 | 7743.56 | 12.20 | 0.00 | 6.23 | 0.00 | 0.00 | NO |
| 20 | XS 75757.3A (Right) | 0.27 | 7731.43 | 7724.40 | 4745.58 | 7734.18 | 9.78 | 2.75 | 7.36 | 20.24 | 7512.36 | 7735.72 | 11.32 | 4.29 | 4.78 | 20.51 | 1.54 | NO |
| 21 | XS 75757.3B (Right) | 0.27 | 7738.95 | 7724.40 | 4745.58 | 7734.18 | 9.78 | 0.00 | 7.36 | 0.00 | 7512.36 | 7735.72 | 11.32 | 0.00 | 4.78 | 0.00 | 0.00 | NO |
| 22 | XS 75757.3C (Right) | 0.27 | 7762.28 | 7724.40 | 4745.58 | 7734.18 | 9.78 | 0.00 | 7.36 | 0.00 | 7512.36 | 7735.72 | 11.32 | 0.00 | 4.78 | 0.00 | 0.00 | NO |
| 23 | XS 75662.1 (Right) | 0.29 | 7756.69 | 7716.90 | 4745.45 | 7724.02 | 7.12 | 0.00 | 5.52 | 0.00 | 7473.20 | 7725.39 | 8.49 | 0.00 | 5.64 | 0.00 | 0.00 | NO |
| 24 | XS 75630.3A (Left) | 0.30 | 7724.75 | 7714.40 | 4745.38 | 7721.81 | 7.41 | 0.00 | 9.21 | 0.00 | 7456.26 | 7723.15 | 8.75 | 0.00 | 9.29 | 0.00 | 0.00 | NO |
| 25 | XS 75630.3B (Right) | 0.30 | 7754.97 | 7714.40 | 4745.38 | 7721.81 | 7.41 | 0.00 | 9.25 | 0.00 | 7456.26 | 7723.15 | 8.75 | 0.00 | 9.33 | 0.00 | 0.00 | NO |
| 26 | XS 75538.7 (Left) | 0.31 | 7712.57 | 7708.04 | 4745.17 | 7715.59 | 7.55 | 3.02 | 6.79 | 20.51 | 7408.56 | 7717.08 | 9.04 | 4.51 | 6.90 | 31.12 | 1.49 | NO |
| 27 | XS 75380.8 (Left) | 0.34 | 7706.13 | 7700.47 | 4744.47 | 7709.33 | 8.86 | 3.20 | 4.43 | 14.17 | 7358.30 | 7710.70 | 10.23 | 4.57 | 4.54 | 20.74 | 1.37 | NO |
| 28 | XS 75313.13 (Right) | 0.36 | 7703.99 | 7697.22 | 4743.94 | 7708.85 | 11.63 | 4.86 | 5.84 | 28.38 | 7347.13 | 7710.66 | 13.44 | 6.67 | 5.91 | 39.42 | 1.81 | NO |
| 29 | XS 75158.7 (Right) | 0.39 | 7702.63 | 7692.69 | 4742.13 | 7705.62 | 12.93 | 2.99 | 1.99 | 5.95 | 7308.82 | 7706.65 | 13.96 | 4.02 | 1.99 | 8.00 | 1.03 | NO |
| 30 | Culvert D | 0.44 | 7680.96 | 7701.68 | 4741.43 | 7706.09 | 4.41 | 25.13 | N/A | N/A | 7212.07 | 7707.47 | 5.79 | 26.51 | N/A | N/A | 1.38 | NO |
| 31 | XS 73808.41 (Right) | 0.64 | 7653.04 | 7646.06 | 4735.40 | 7654.37 | 8.31 | 1.33 | 5.93 | 7.89 | 6941.72 | 7655.78 | 9.72 | 2.74 | 5.93 | 16.25 | 1.41 | NO |
| 32 | XS 73020.7 (Left) | 0.79 | 7654.29 | 7607.89 | 4732.47 | 7615.71 | 7.82 | 0.00 | 3.28 | 0.00 | 6818.53 | 7616.73 | 8.84 | 0.00 | 3.27 | 0.00 | 0.00 | NO |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 33 | XS 72282.0A (Left) | 0.93 | 7611.84 | 7572.64 | 4730.04 | 7578.52 | 5.88 | 0.00 | 4.03 | 0.00 | 6714.36 | 7579.19 | 6.55 | 0.00 | 4.02 | 0.00 | 0.00 | NO |
| 34 | XS 72282.0B (Left) | 0.93 | 7612.70 | 7572.64 | 4730.04 | 7578.52 | 5.88 | 0.00 | 4.03 | 0.00 | 6714.36 | 7579.19 | 6.55 | 0.00 | 4.02 | 0.00 | 0.00 | NO |
| 35 | XS 71876.54 (Left) | 1.01 | 7555.30 | 7549.85 | 4728.41 | 7555.36 | 5.51 | 0.06 | 5.25 | 0.31 | 6692.65 | 7556.15 | 6.30 | 0.85 | 5.25 | 4.46 | 0.79 | NO |
| 36 | XS 71395.82 (Left) | 1.10 | 7549.30 | 7539.89 | 4726.63 | 7546.04 | 6.15 | 0.00 | 3.02 | 0.00 | 6609.28 | 7546.49 | 6.60 | 0.00 | 3.02 | 0.00 | 0.00 | NO |
| 37 | Elm Green Lane Culvert | 1.13 | 7543.51 | 7532.50 | 4725.98 | 7546.38 | 13.88 | 2.87 | N/A | N/A | 6604.50 | 7547.10 | 14.60 | 3.59 | N/A | N/A | 0.72 | NO |
| 38 | I-70 Culvert | 1.33 | 7536.75 | 7493.73 | 4647.31 | 7538.65 | 44.92 | 1.90 | N/A | N/A | 6385.63 | 7539.12 | 45.39 | 2.37 | N/A | N/A | 0.47 | NO |
| 39 | Crossing #1 near CO-40 | 1.61 | 7443.03 | 7436.02 | 4634.80 | 7447.19 | 11.17 | 4.16 | N/A | N/A | 6299.46 | 7448.16 | 12.14 | 5.13 | N/A | N/A | 0.97 | NO |
| 40 | Crossing #2 near CO-40 | 1.88 | 7390.75 | 7391.05 | 4614.41 | 7403.29 | 12.24 | 12.54 | N/A | N/A | 6175.69 | 7404.23 | 13.18 | 13.48 | N/A | N/A | 0.94 | NO |
| 43 | Crossing #3 near CO-40 | 1.92 | 7390.75 | 7385.74 | 4611.03 | 7395.32 | 9.58 | 4.57 | N/A | N/A | 6158.93 | 7396.13 | 10.39 | 5.38 | N/A | N/A | 0.81 | NO |
| 44 | Crossing #4 near CO-40 | 1.94 | 7388.01 | 7382.12 | 4608.72 | 7392.29 | 10.17 | 4.28 | N/A | N/A | 6146.96 | 7393.06 | 10.94 | 5.05 | N/A | N/A | 0.77 | NO |
| 46 | Soda Creek Rd Culvert | 2.27 | 7346.76 | 7331.75 | 4539.03 | 7351.54 | 19.79 | 4.78 | N/A | N/A | 5914.56 | 7352.43 | 20.68 | 5.67 | N/A | N/A | 0.89 | NO |
| 49 | CO-40 Bridge | 2.77 | 7270.00 | 7252.00 | 4466.49 | 7267.21 | 15.21 | 0.00 | N/A | N/A | 5602.45 | 7269.43 | 17.43 | 0.00 | N/A | N/A | 0.00 | NO |

Based on the results for the 32 identified structures shown in Table 7-2, there are 16 structures which are not inundated by either the base flood or the breach flood. Thirteen structures are already significantly inundated (water depth greater than 2 feet) by the base flood. Two structures are inundated by less than 2 feet but the depth x velocity criteria (greater than 7 $ft^2/s$) is exceeded by the base flood. One structure is minimally inundated during both the base flood and the breach flood but remains under the SEO criteria for inundation depth and depth x velocity. Therefore, all identified structures are not incrementally damaged by the breach flood.

Due to the relative magnitudes of the base flood and breach flood, the IDA can be used to justify an IDF less than the HMR flood since it was shown no incremental impacts occur between the two floods. Therefore, the IDF for Lower Beaver Brook Dam may be equal to the base flood of 0.275PMP (4,755 cfs). Appendix D contains tabulated results of the IDA and output from the HEC-RAS model. Figures 14, 15, and 16 show the inundation limits and location of structures.

# 8. Conclusions

GEI developed estimates for the all-season general-storm flood and the HMR 55 local-storm for the Lower Beaver Brook Dam watershed. The local-storm magnitude exceeds the all-season general-storm, therefore the PMF is the governing HMR 55 storm. Due to the very small reservoir size and relatively large magnitude of the local-storm PMF, GEI performed an IDA to estimate the IDF for Lower Beaver Brook Dam. As part of the IDA, GEI developed estimates of the base flood, dam breach parameters, breach flood and downstream incremental impacts. GEI estimated the base flood to be equivalent to a storm with a peak inflow rate of 4,755 cfs, with a dam failure event triggering when 1 foot of dam crest overtopping is exceeded. The hypothetical failure of the Lower Beaver Brook Dam due to dam crest overtopping from the base flood resulted in a breach flood with a peak breach discharge of about 8,175 cfs.

Routing the base flood and the breach flood downstream showed that the breach flood does not produce incremental damages at the identified structures; therefore there are no incremental impacts in the zone between the base flood and the breach flood. Based on these results, the existing Lower Beaver Brook Dam meets the SEO IDA criteria to allow an IDF equal to the base flood. Therefore, the IDF for the existing Lower Beaver Brook Dam may be the flood produced by 27.5 percent of the HMR 55 PMP. A summary of the IDF (HMR 55A PMP) parameters is summarized in Table 8-1.

**Table 8-1: Lower Beaver Brook Dam Inflow Design Flood**

| Parameter | Base Flood Modeling Results |
|---|---|
| HMR-55 Local-Storm Average 6-hr PMP Depth, No SEO Reductions | 9.91 inches |
| Base Flood Percent of HMR-55 Local-Storm 6-hr PMP | 27.5% |
| Base Flood Basin Average 6-hr PMP Depth | 2.55 inches |
| Base Flood Basin Average PMP Runoff | 1.66 inches |
| Base Flood Basin Average 72-hr Losses | 0.89 inches |
| Base Flood Basin Average PMP Runoff Percent | 65.1% |
| Maximum Reservoir Elevation | 7,843.3 feet |
| Residual Freeboard | -3.3 feet |
| Inflow Volume | 657 acre-feet |
| Peak Inflow | 4,755 cfs |

Lower Beaver Brook Dam is not capable of passing the IDF in its current form. Lower Beaver Brook Dam is capable of passing about 300 cfs without dam overtopping (less than the estimated NOAA Atlas No. 2 24-hour 2-year flood event). The flood event that results in 1-foot of dam overtopping is the 0.15PMF and is about 1,135 cfs (approximately equivalent to a 15-20 year return period).

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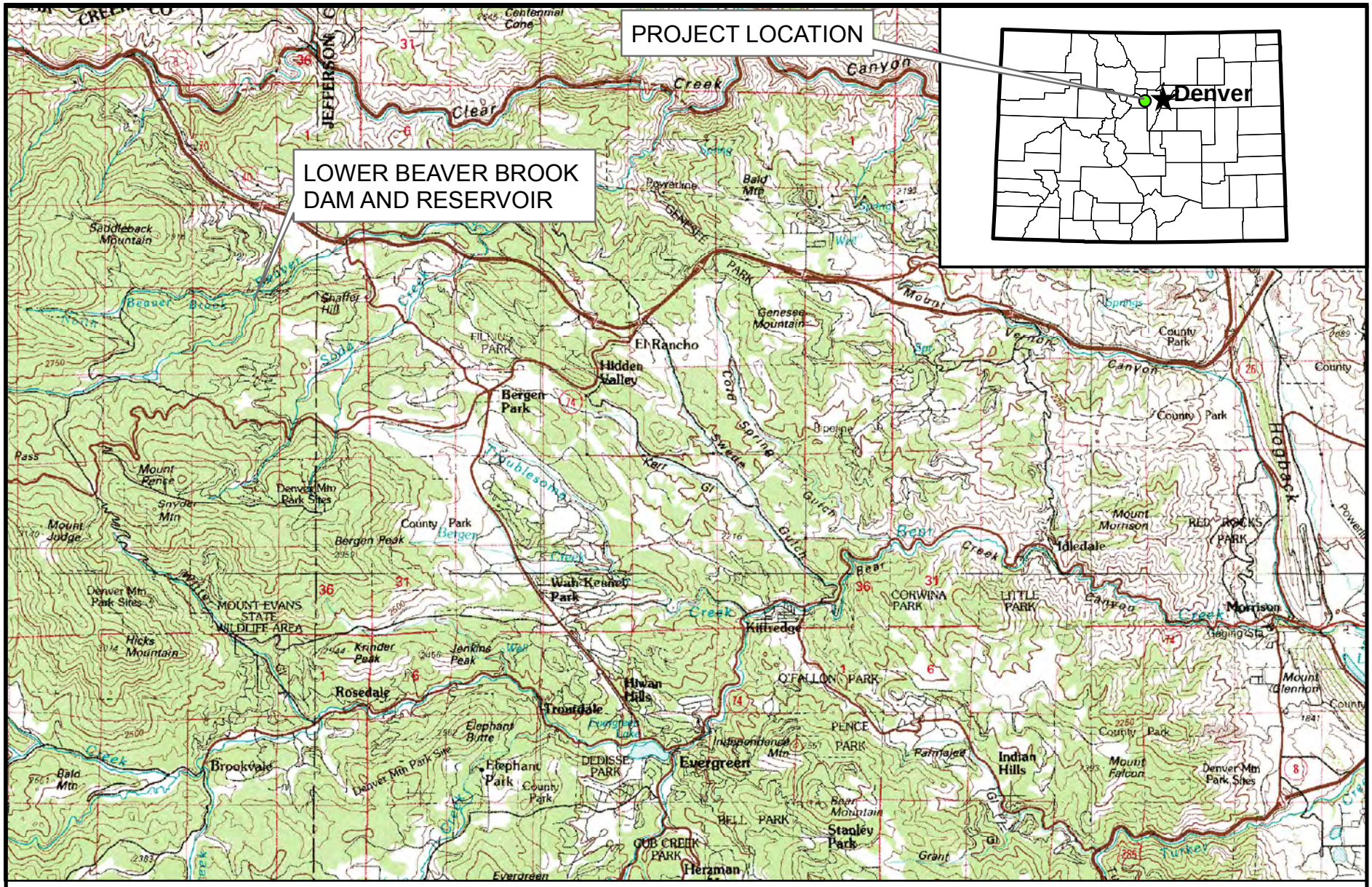
# Figures




Lower Beaver Brook Dam
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Golden, Colorado

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LOCATION MAP

Project 1327820 | February 2015 | Figure 1

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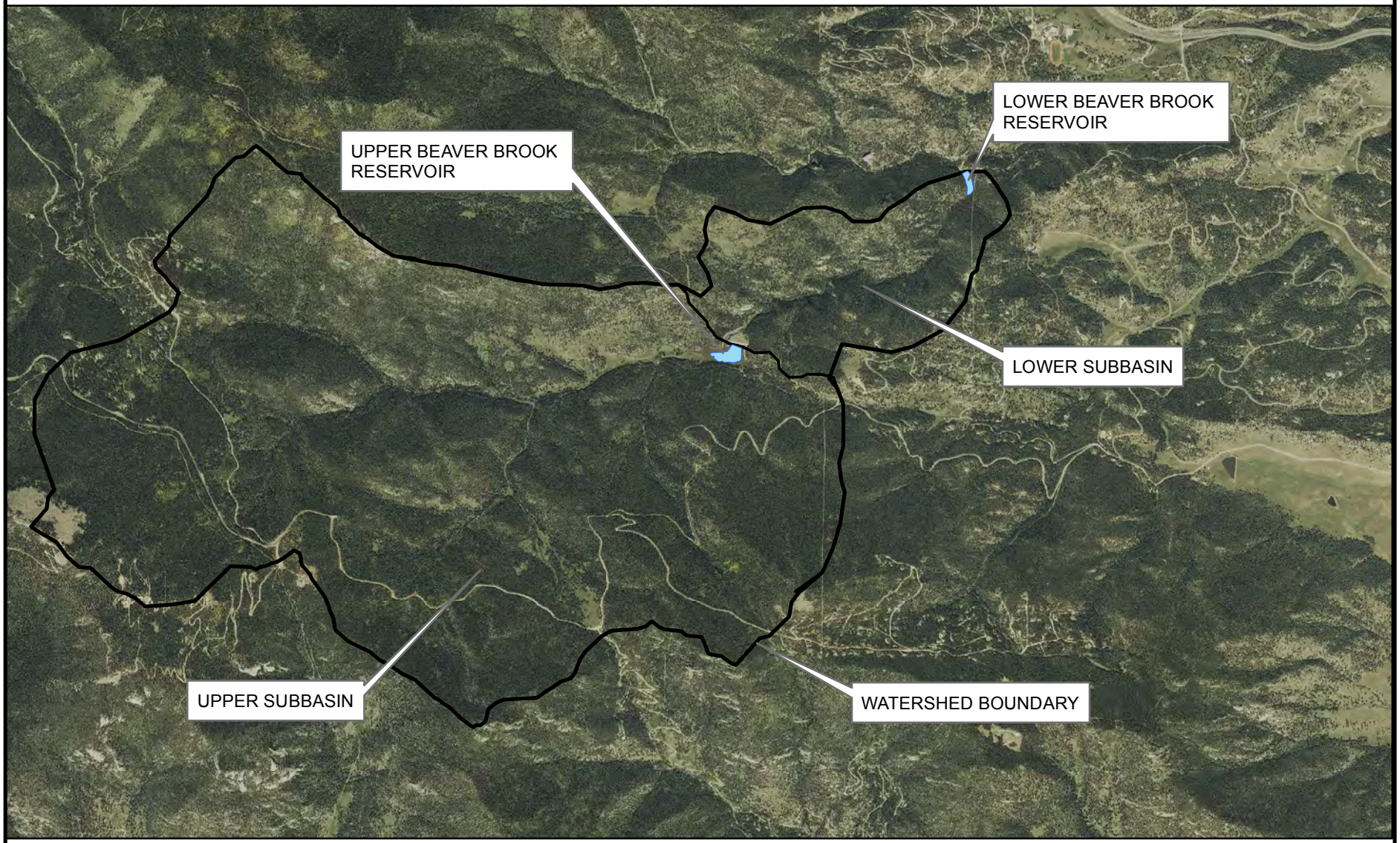


Image: 2013 Clear Creek County NAIP Aerial

0 0.25 0.5 1 1.5 2 Miles

N

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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LOWER BEAVER BROOK WATERSHED AND NAIP AERIAL

Project 1410080 | February 2015 | Figure 2

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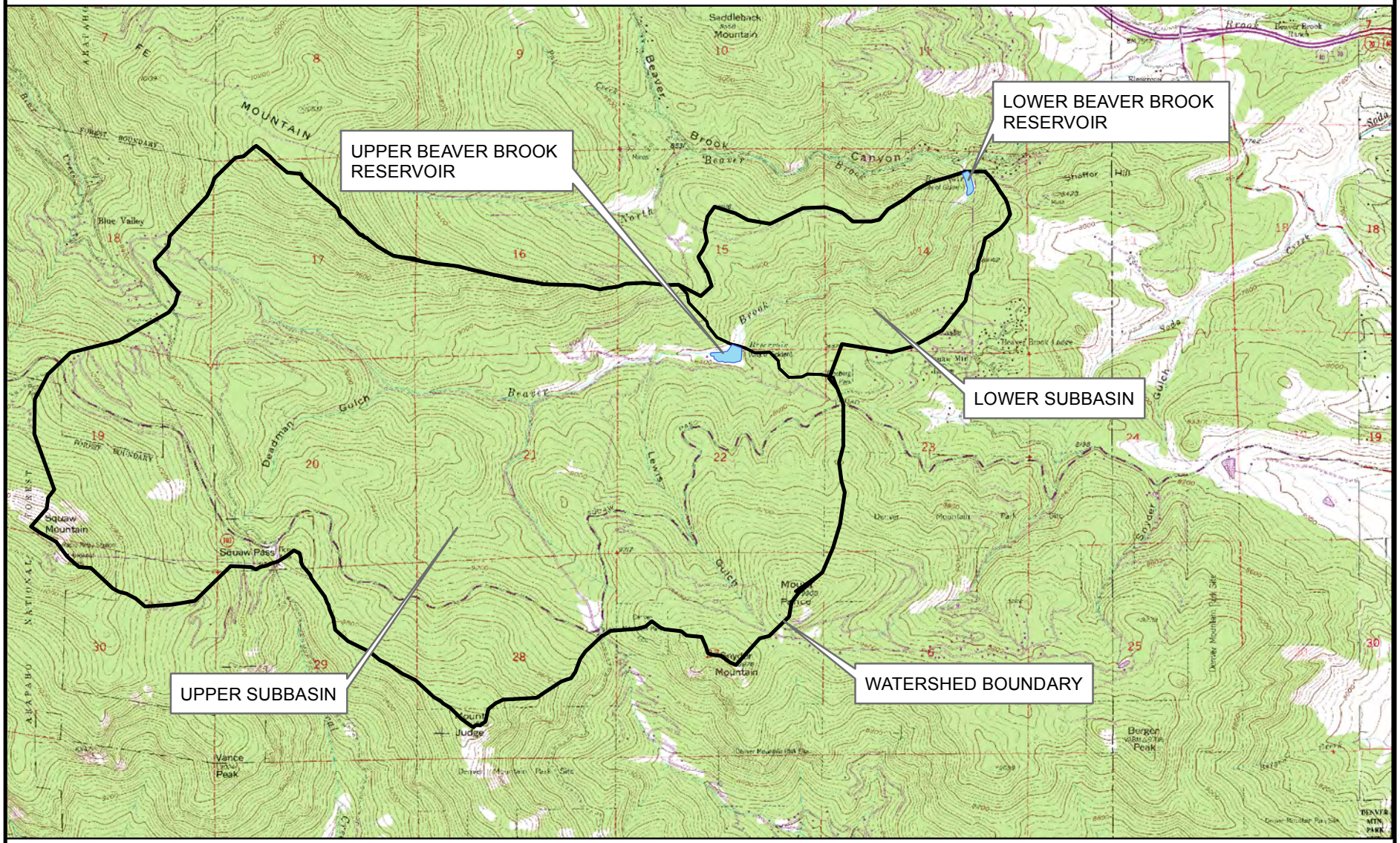


Lower Beaver Brook Dam
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Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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WATERSHED AND USGS 24K TOPOGRAPHY

Project 1410080 | February 2015 | Figure 3

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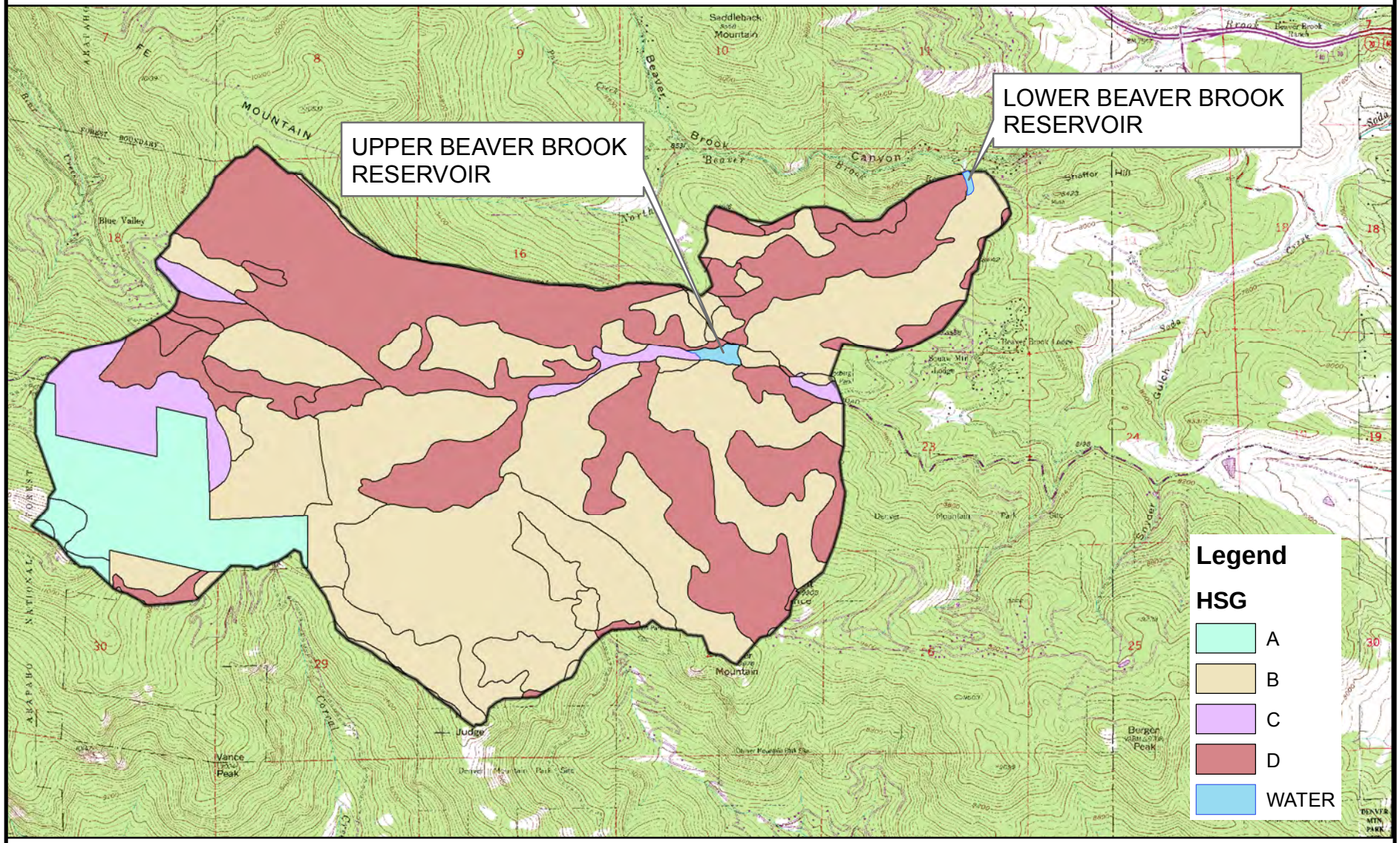


Image: Squaw Pass, CO U.S.G.S. 24k DRG

0 0.25 0.5 1 1.5 2 Miles

N

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Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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SOIL TYPE BY HYDROLOGIC SOIL GROUP

Project 1410080 | February 2015 | Figure 4

V:\Lookout Mountain Water District\Projects\Lower Beaver Brook IDA\GIS\Figures\Soil HSG Map.mxd Sep 2014

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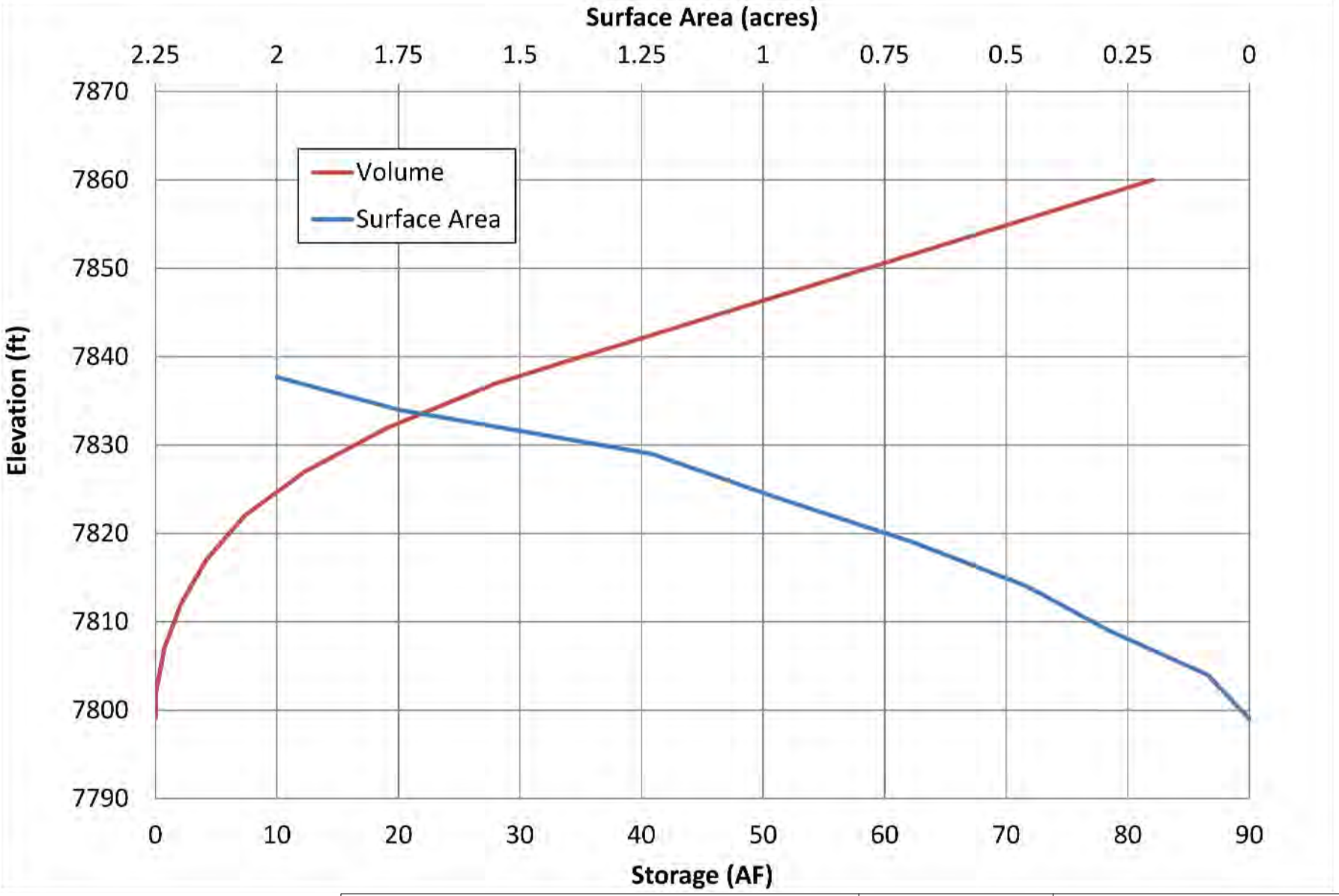
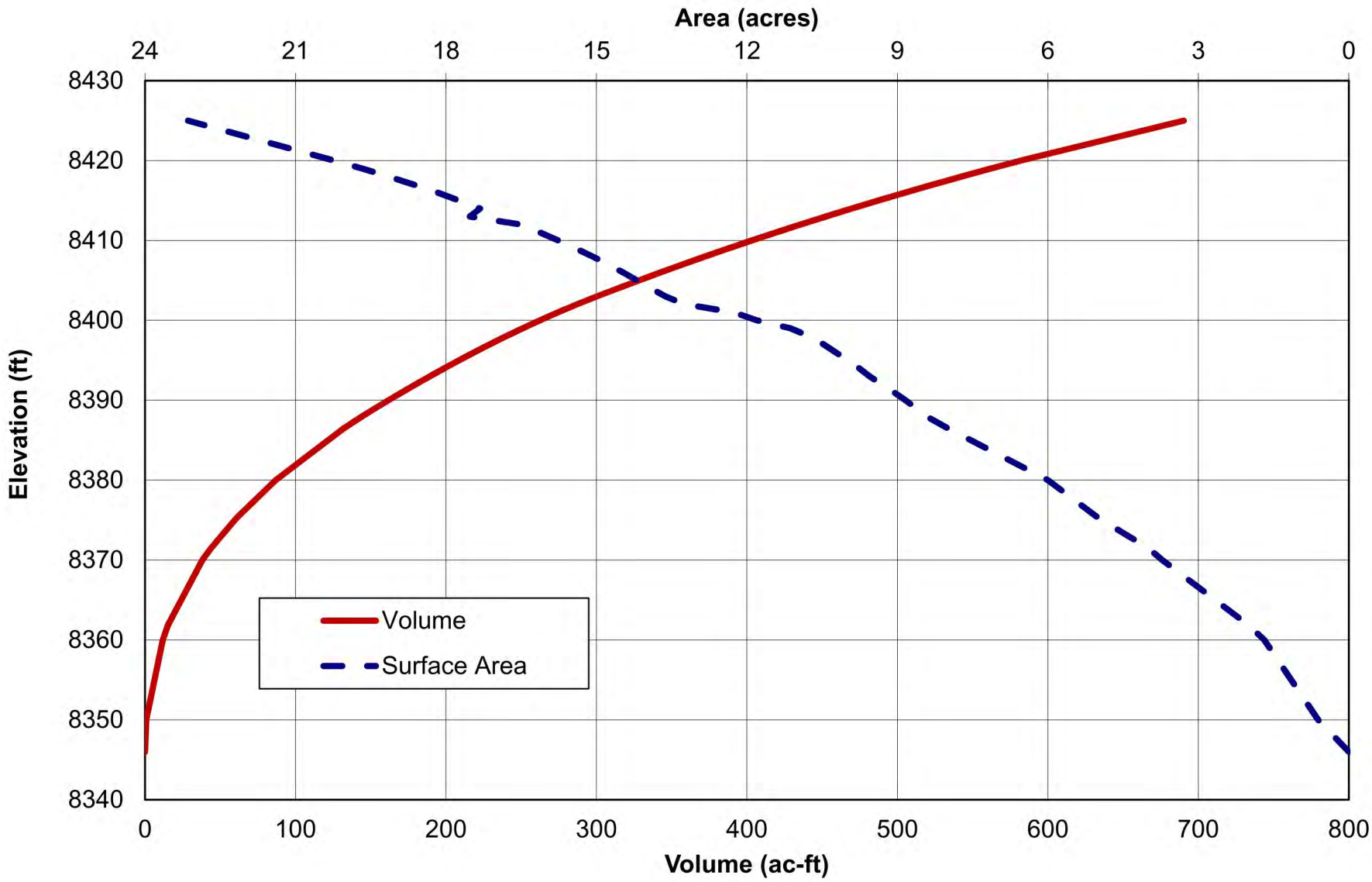



| | | |
|---|---|---|
| Lower Beaver Brook Dam<br>Hydrology and Incremental Damage Analysis Report<br>Clear Creek County, Colorado | GEI Consultants | LOWER BEAVER BROOK<br>ELEVATION-AREA-CAPACITY<br>CURVES |
| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 5 |

V:\Lookout Mountain Water District\Projects\1410080 Lower Beaver Brook IDA\Report\Figures\ Figure 6 - UBB Elev-Area-Capacity.dwg Feb 2015

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| Lower Beaver Brook Dam<br>Hydrology and Incremental Damage Analysis Report<br>Clear Creek County, Colorado | GEI Consultants | UPPER BEAVER BROOK<br>ELEVATION-AREA-CAPACITY<br>CURVES |
| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 6 |

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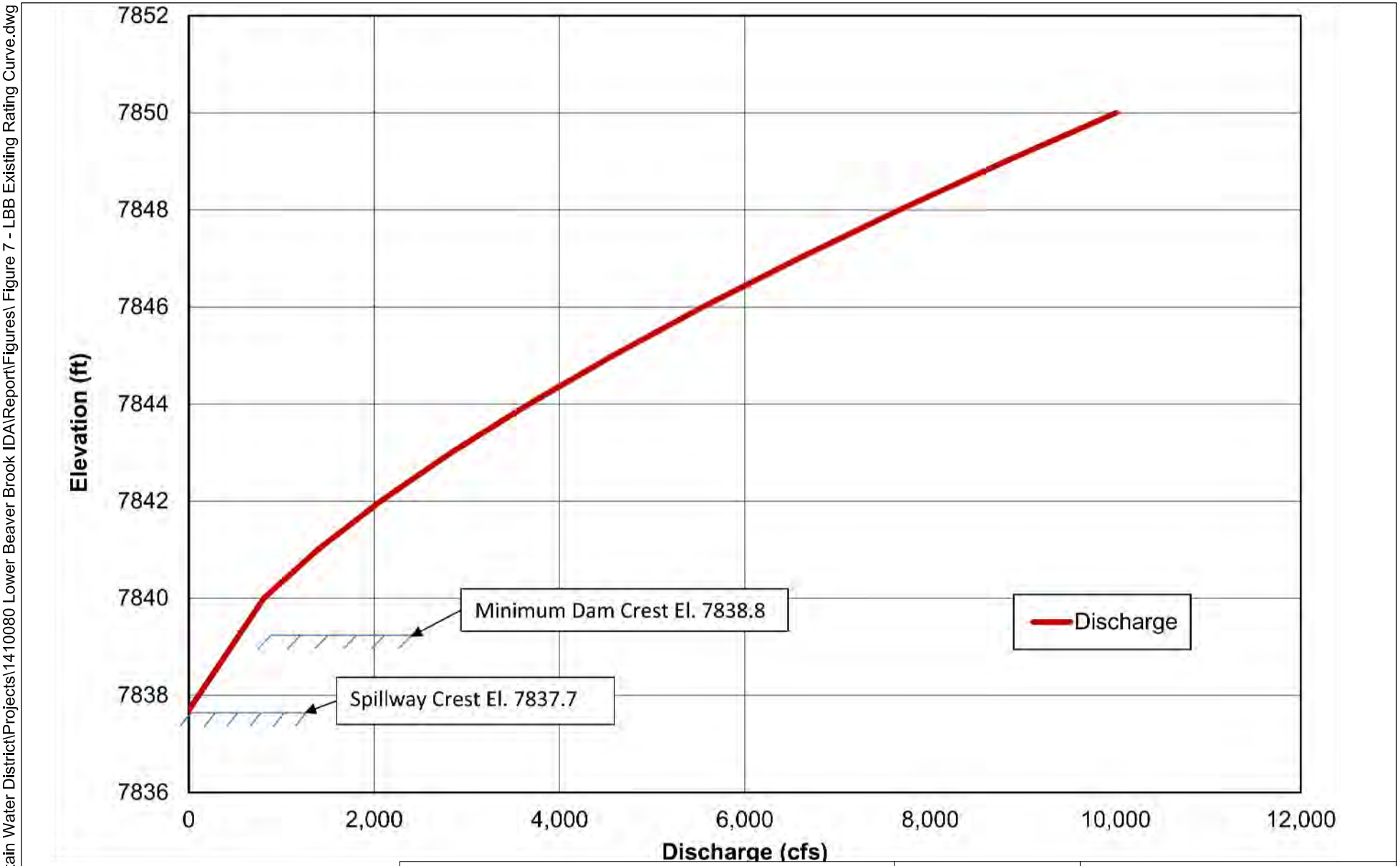


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| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 7 |

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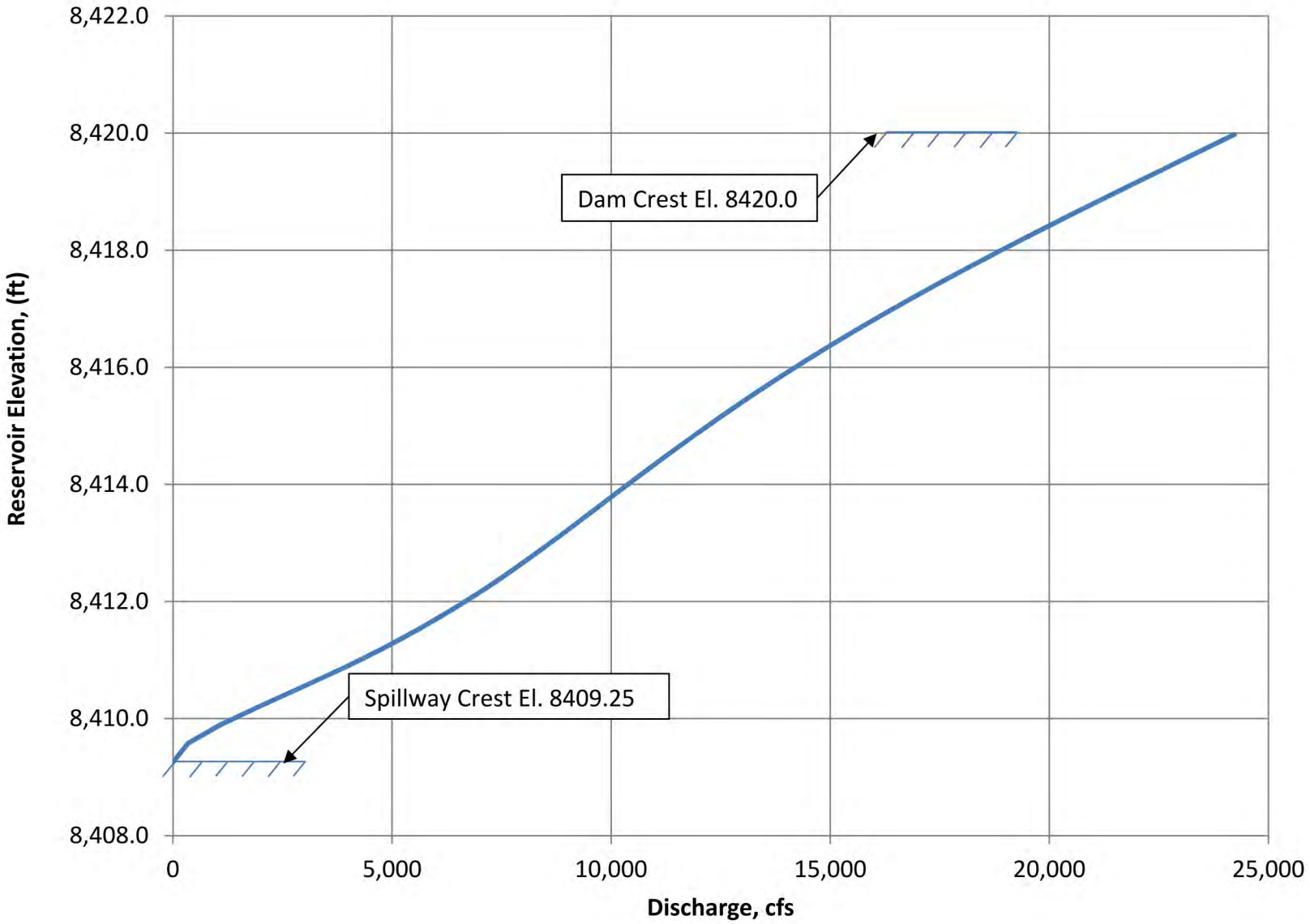


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| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 8 |

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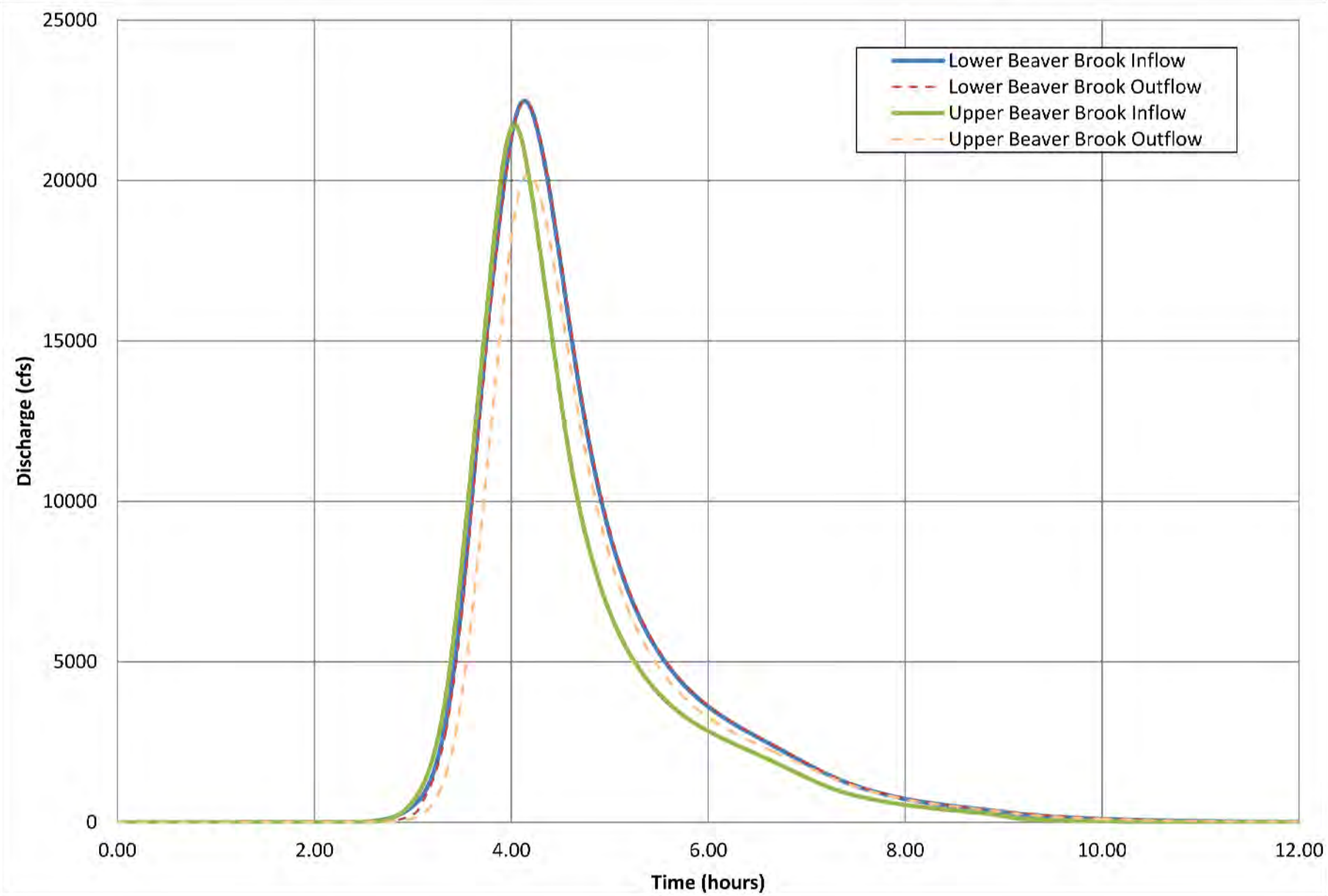


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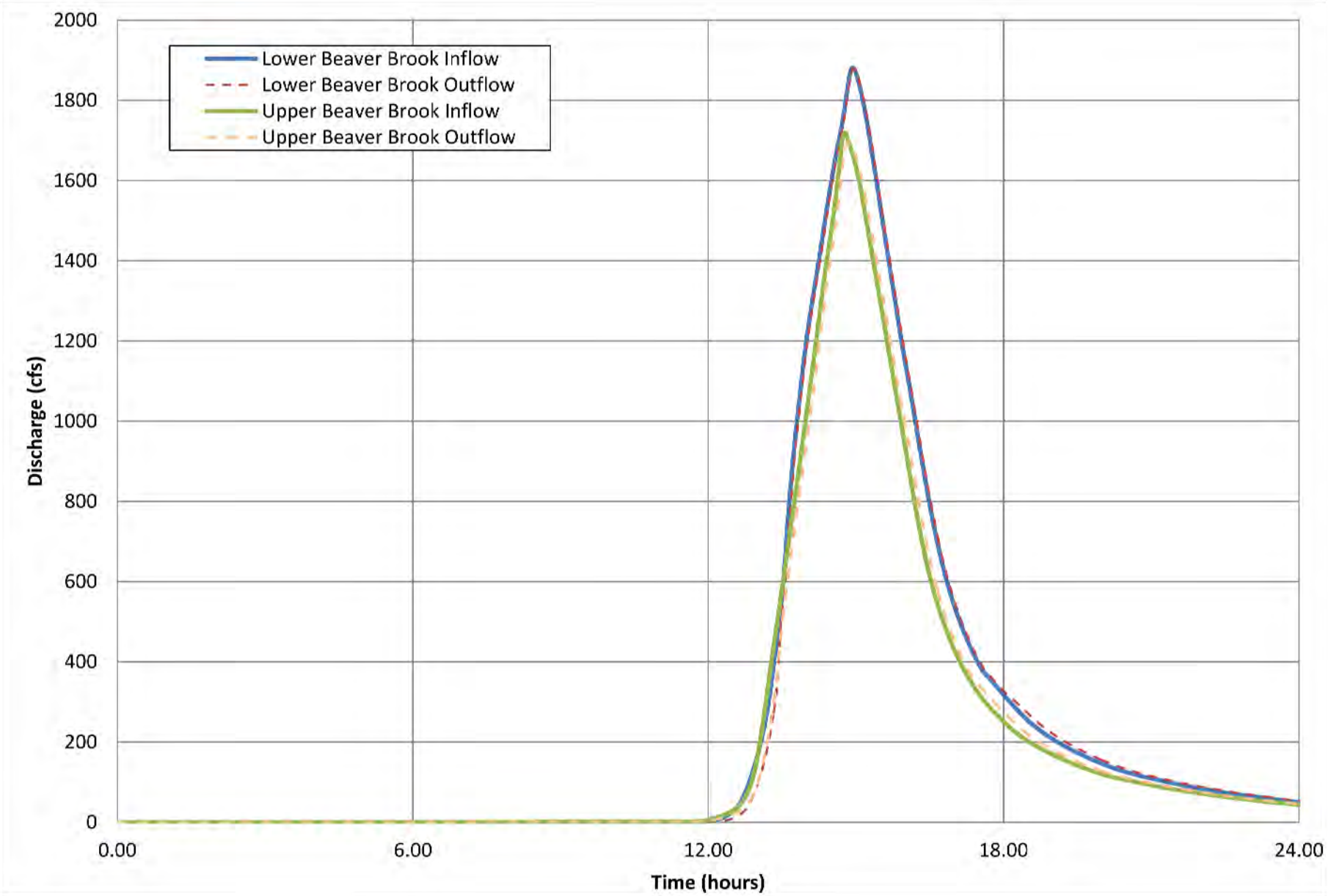
| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 9 |

V:\Lookout Mountain Water District\Projects\1410080 Lower Beaver Brook IDA\Report\Figures\ Figure 10 - 100-yr Hydrographs.dwg Feb 2015

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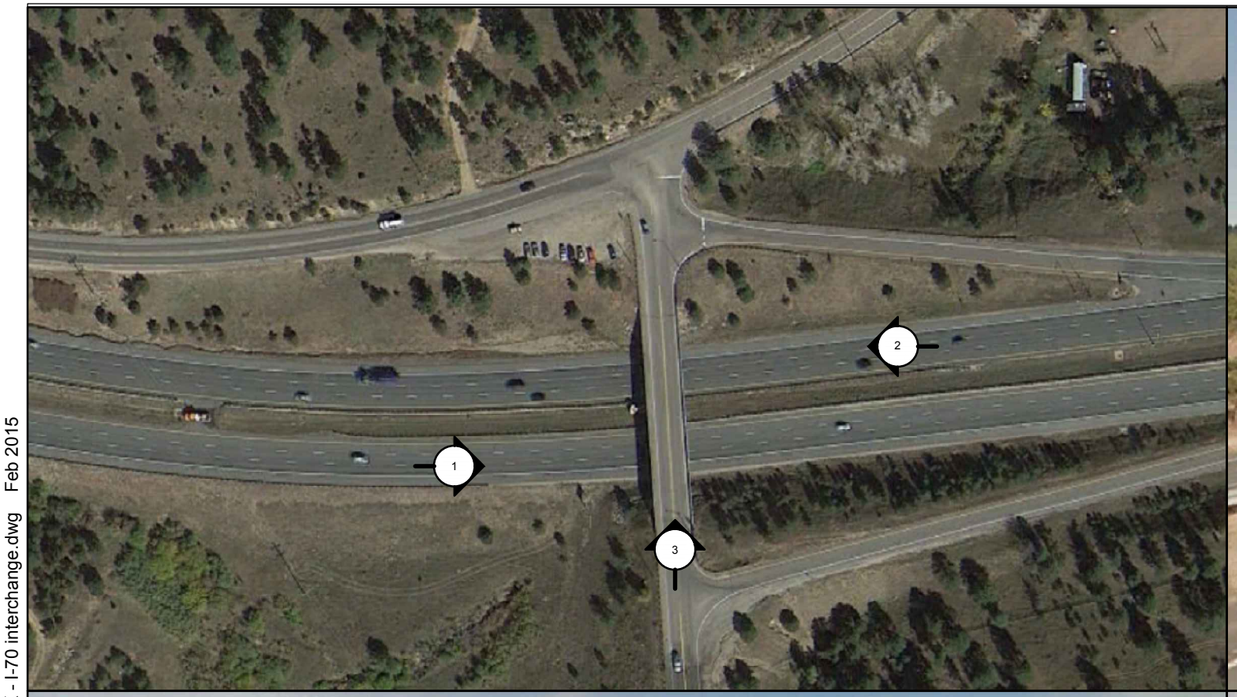

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Golden, Colorado

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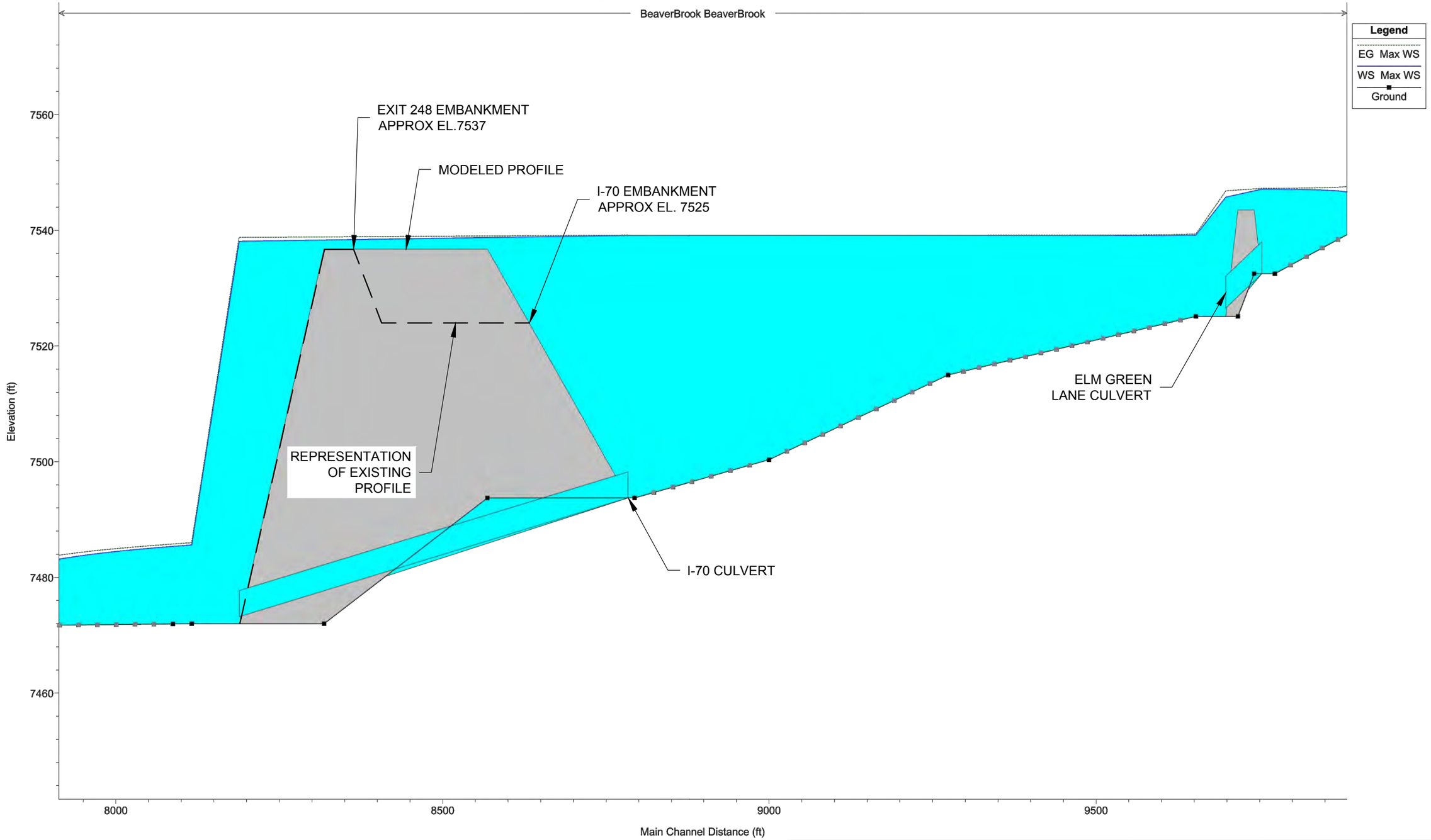
INTERSTATE 70
INTERCHANGE
PHOTOGRAPHS

February 2015 Figure 11

LBB_IDA Plan: 0.275PMP Break 2/5/2015

BeaverBrook BeaverBrook

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| Lower Beaver Brook Dam<br>Hydrology and Incremental Damage Analysis Report<br>Clear Creek County, Colorado | GEI Consultants | INTERSTATE 70<br>MODELED AND EXISTING<br>PROFILES |
| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 12 |

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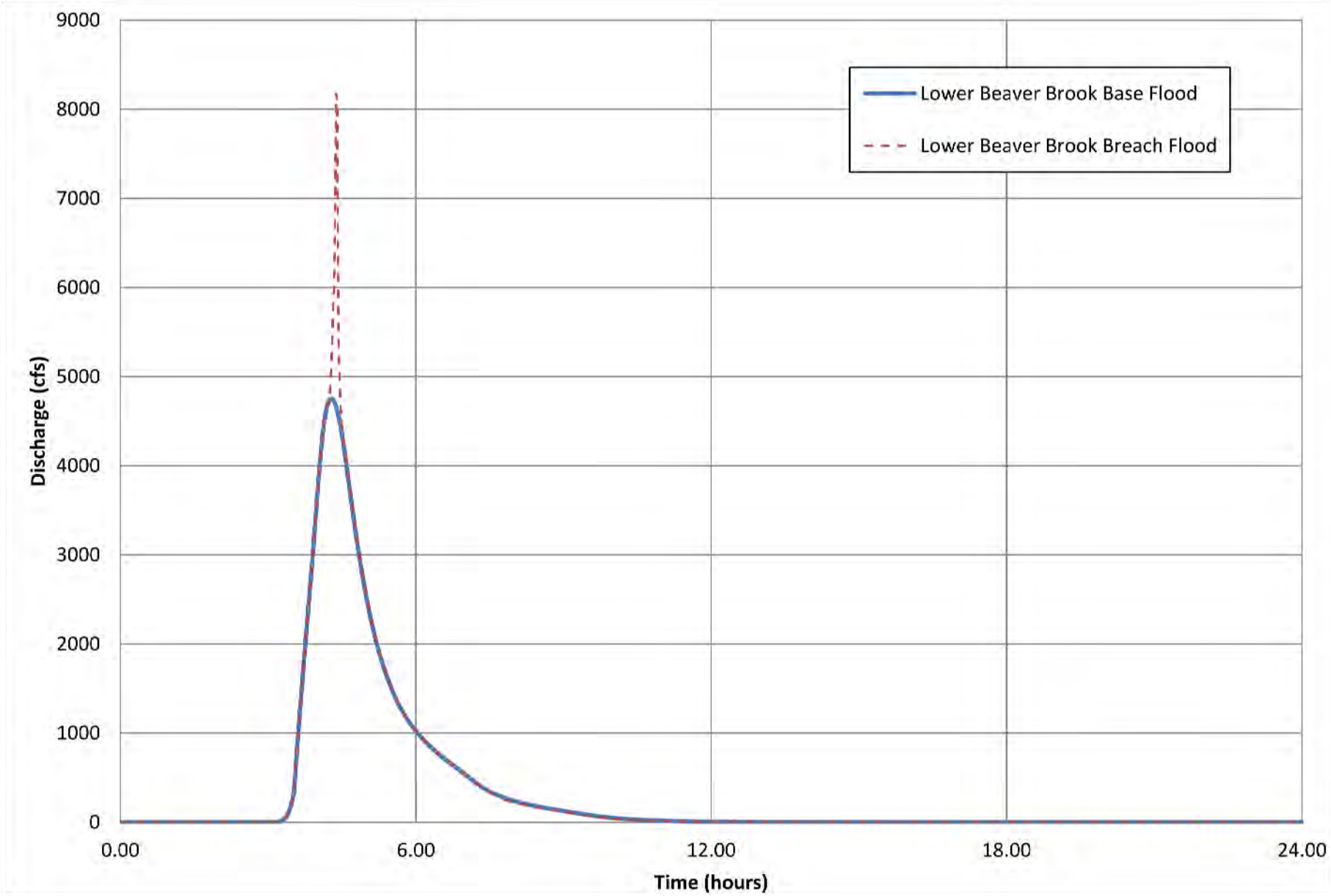


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Clear Creek County, Colorado

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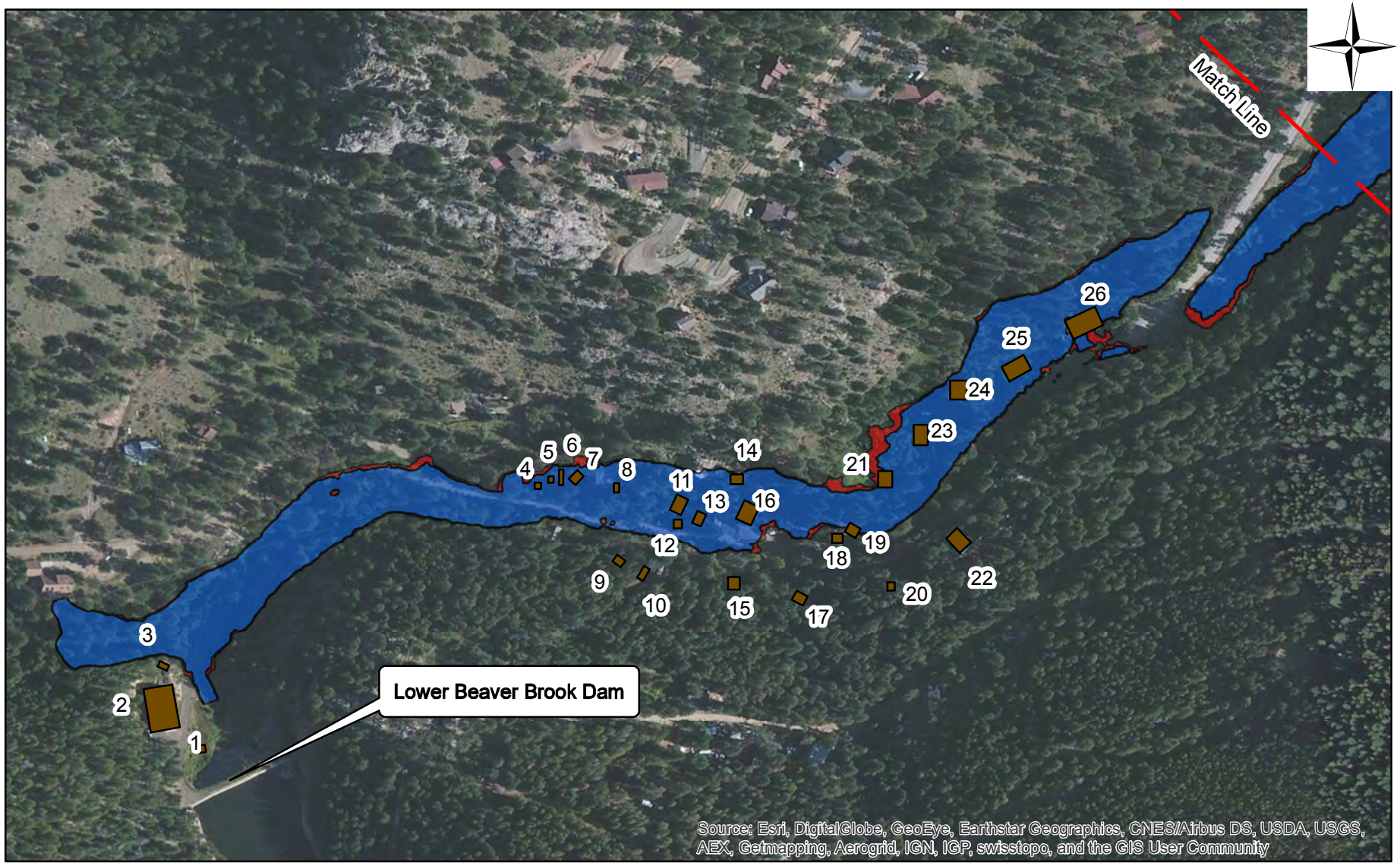
LOWER BEAVER BROOK
BASE FLOOD AND BEACH
FLOOD HYDROGRAPHS

February 2015 Figure 13




**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

0 80 160 320 480 640 Feet

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Clear Creek County, Colorado

Lookout Mountain Water District
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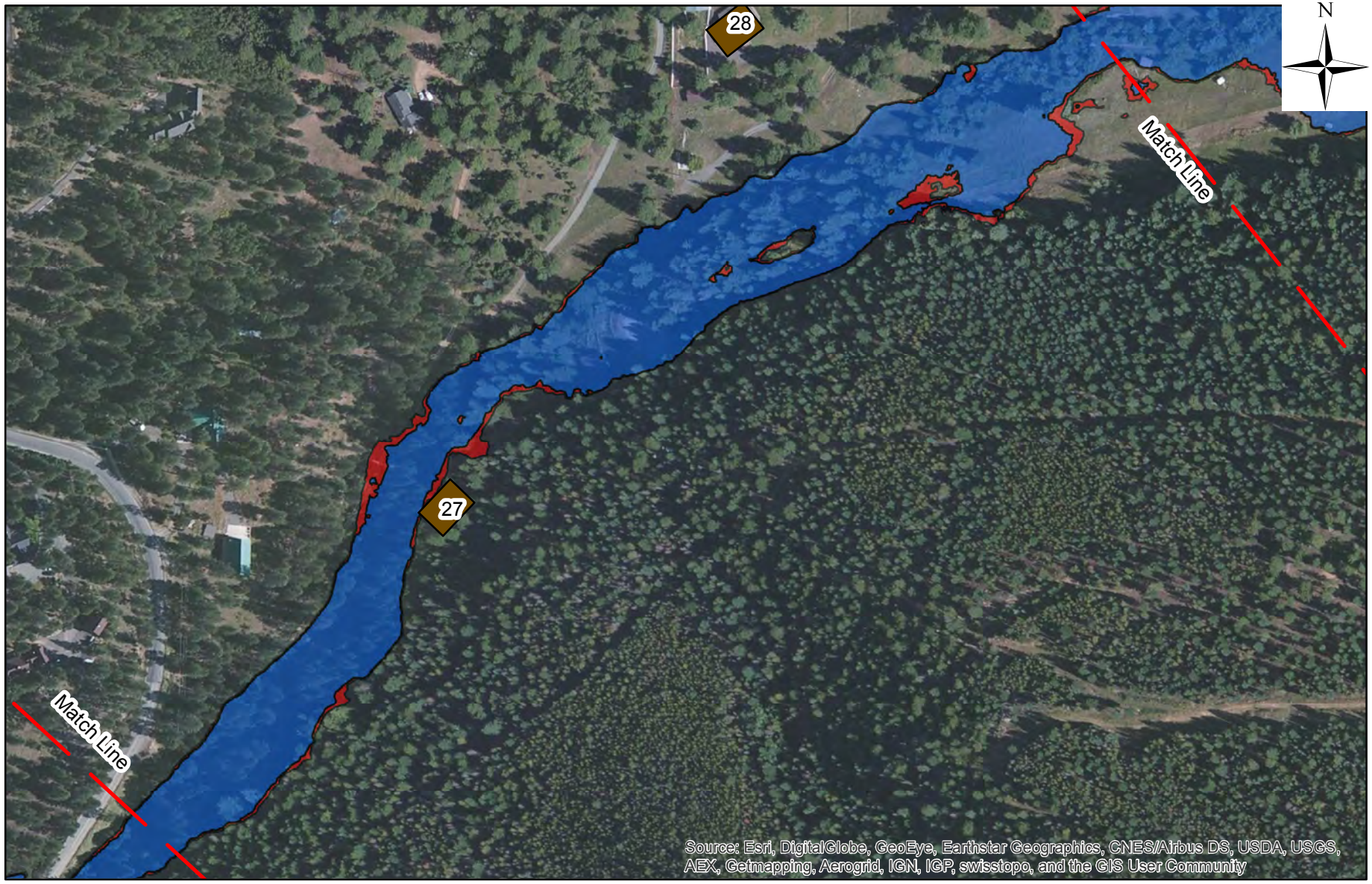
LOWER BEAVER BROOK
INUNDATION LIMITS
(1 OF 6)

September 2016 Figure 14

V:\Lookout Mountain Water District\Projects\Lower Beaver Brook IDA\GIS\Figures\Watershed and NAIP Aerial.mxd Sep 2014




0 80 160 320 480 640 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
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LOWER BEAVER BROOK
INUNDATION LIMITS
(2 OF 6)

Project 1410080 | September 2016 | Figure 15

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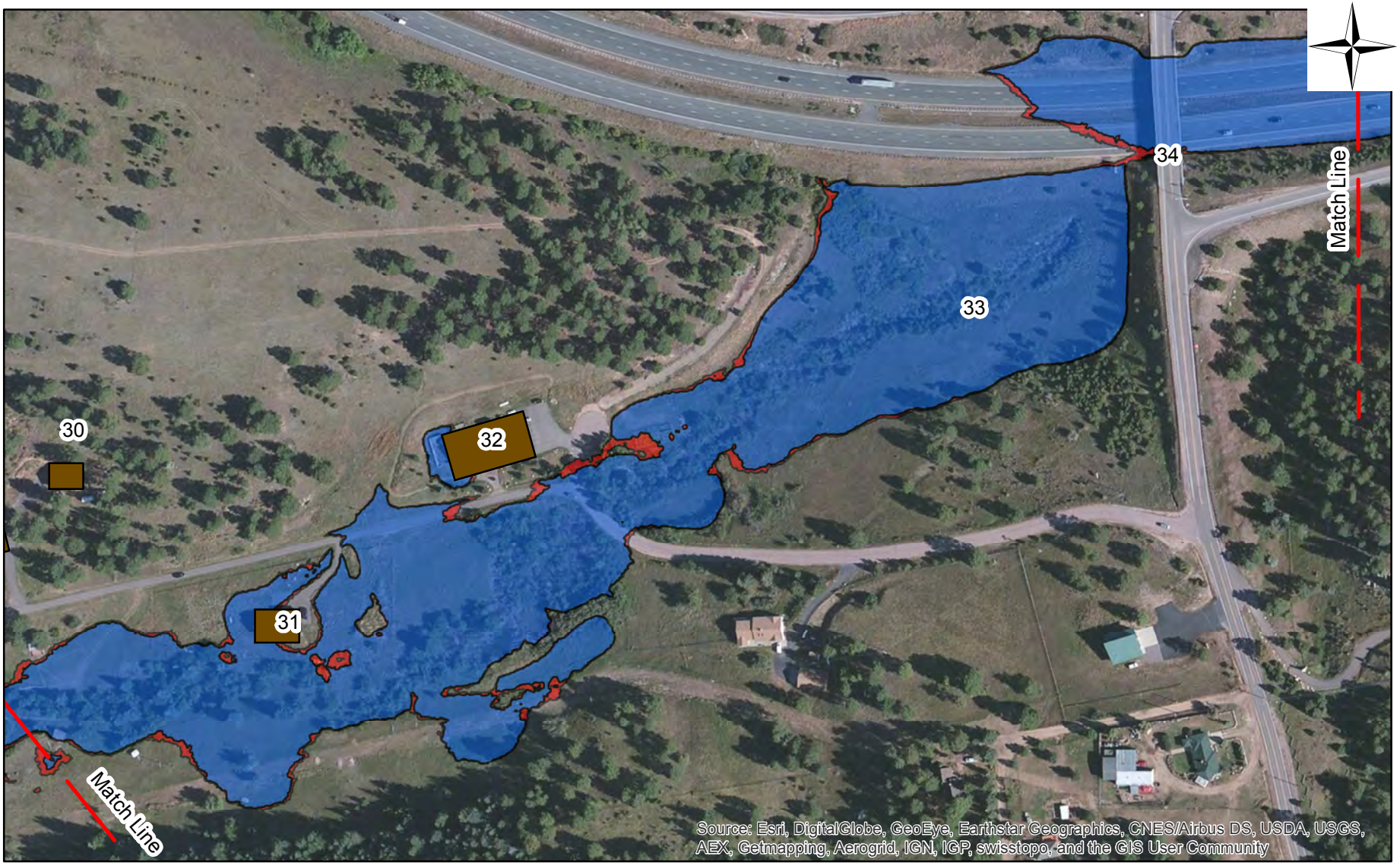


0 80 160 320 480 640 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
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LOWER BEAVER BROOK
INUNDATION LIMITS
(3 OF 6)

September 2016 Figure 16

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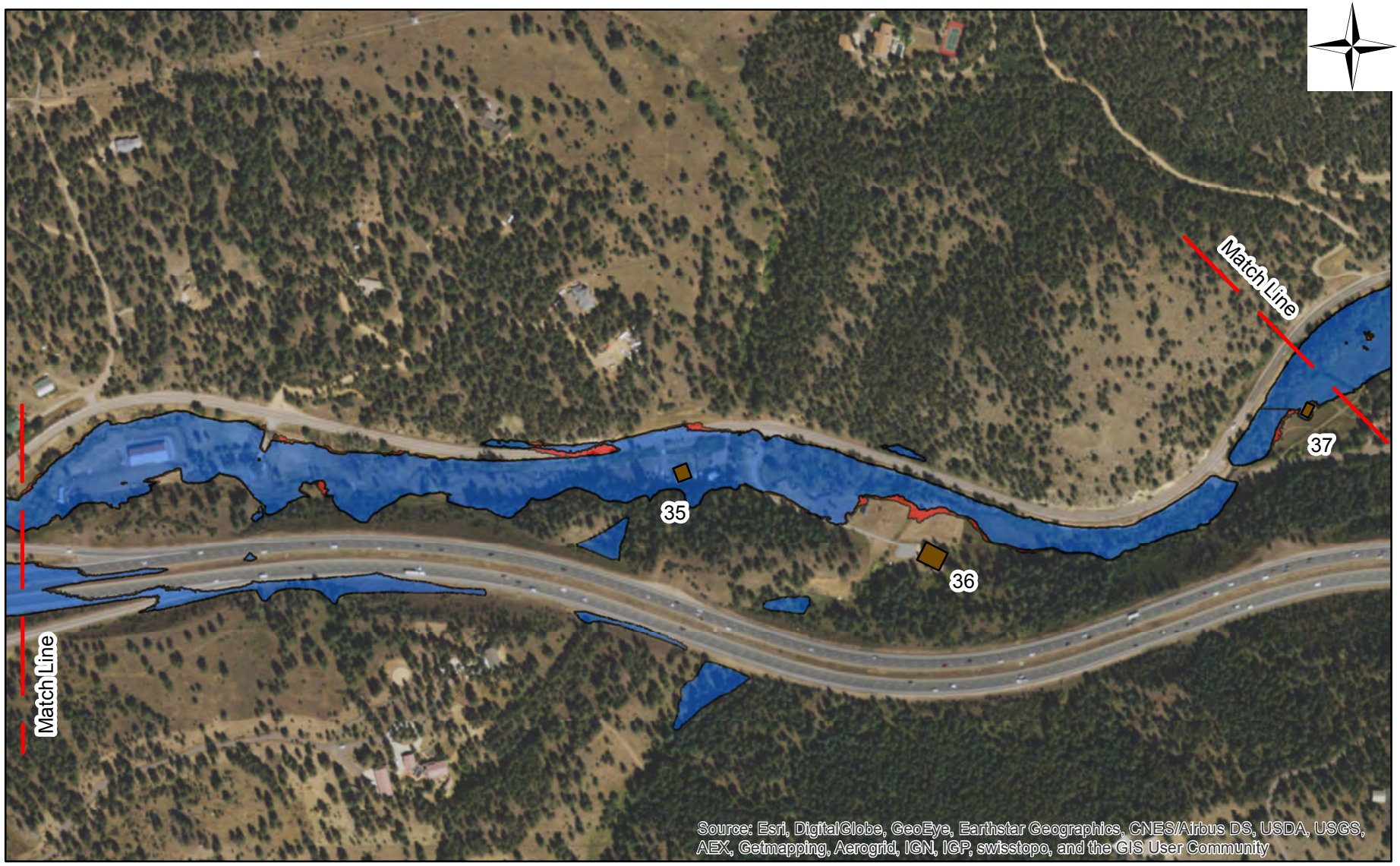


0 165 330 660 990 1,320 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
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LOWER BEAVER BROOK
INUNDATION LIMITS
(4 OF 6)

September 2016 Figure 17

V:\Lookout Mountain Water District\Projects\Lower Beaver Brook IDA\GIS\Figures\Watershed and NAIP Aerial.mxd Sep 2014

0 220 440 880 1,320 1,760
Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
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Lookout Mountain Water District
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LOWER BEAVER BROOK
INUNDATION LIMITS
(5 OF 6)

September 2016 Figure 18

V:\Lookout Mountain Water District\Projects\Lower Beaver Brook IDA\GIS\Figures\Watershed and NAIP Aerial.mxd Sep 2014

0 220 440 880 1,320 1,760
Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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LOWER BEAVER BROOK
INUNDATION LIMITS
(6 OF 6)

September 2016 Figure 19

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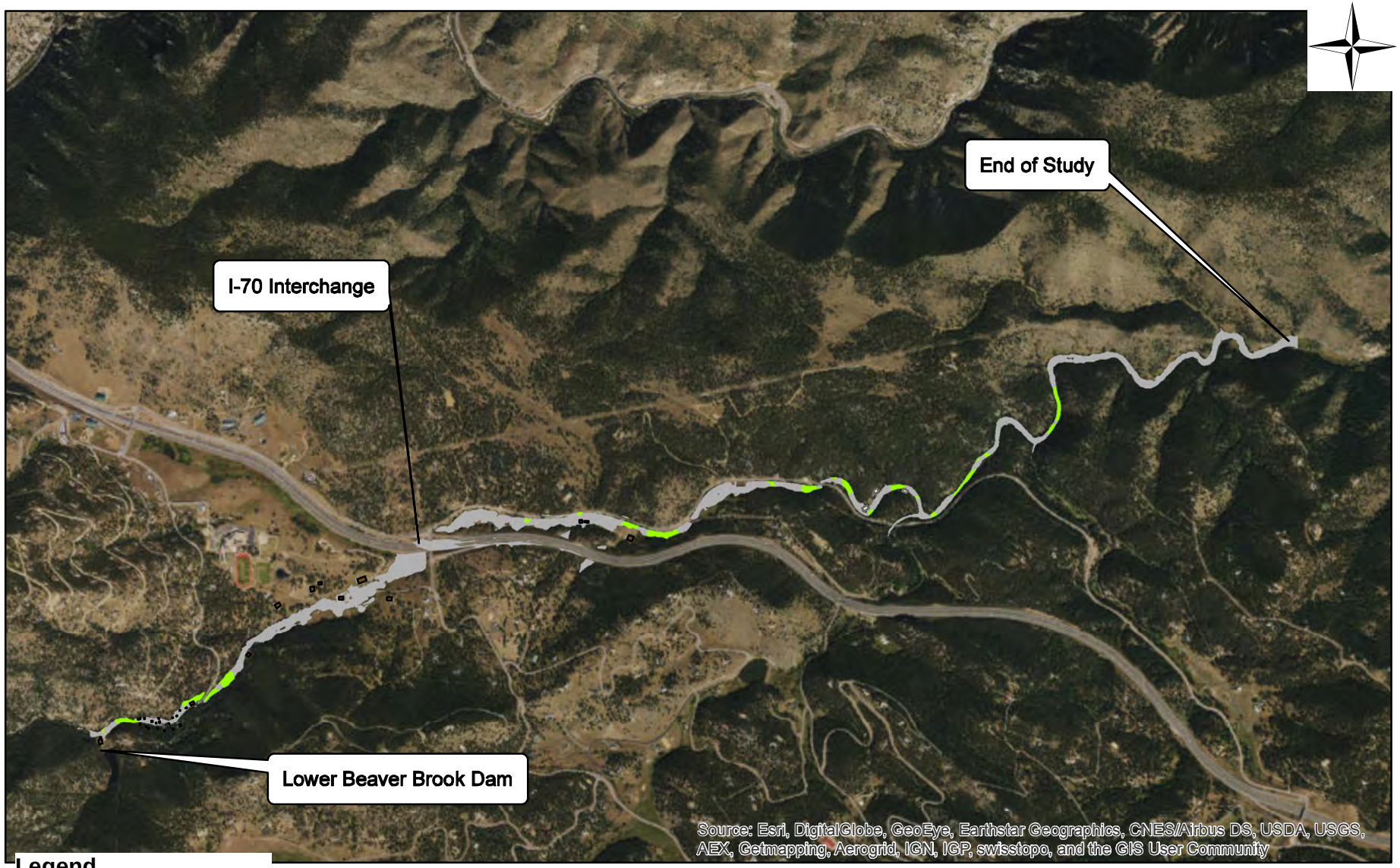


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Clear Creek County, Colorado

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LOWER BEAVER BROOK
INCREMENTAL
INUNDATION DEPTHS

Project 1410080 | September 2016 | Figure 20

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# Appendix A

## Hydrology Information

Appendix A.1 – Watershed, Reservoir, and Dam Documents
Appendix A.2 – 100-year Event Calculations
Appendix A.3 – General-Storm Event Calculations
Appendix A.4 – Local-Storm Event Calculations

# Appendix A.1

## Watershed, Reservoir, and Dam Documents

# REPAIRS FOR GOLDEN RESERVOIR AND DAM No 1

BEING

LOWER BEAVER BROOK DAM

INCLUDING

BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK BACKFILL FOR DAM

W P A PROJECT NO. 174

Irrigation Division No.1

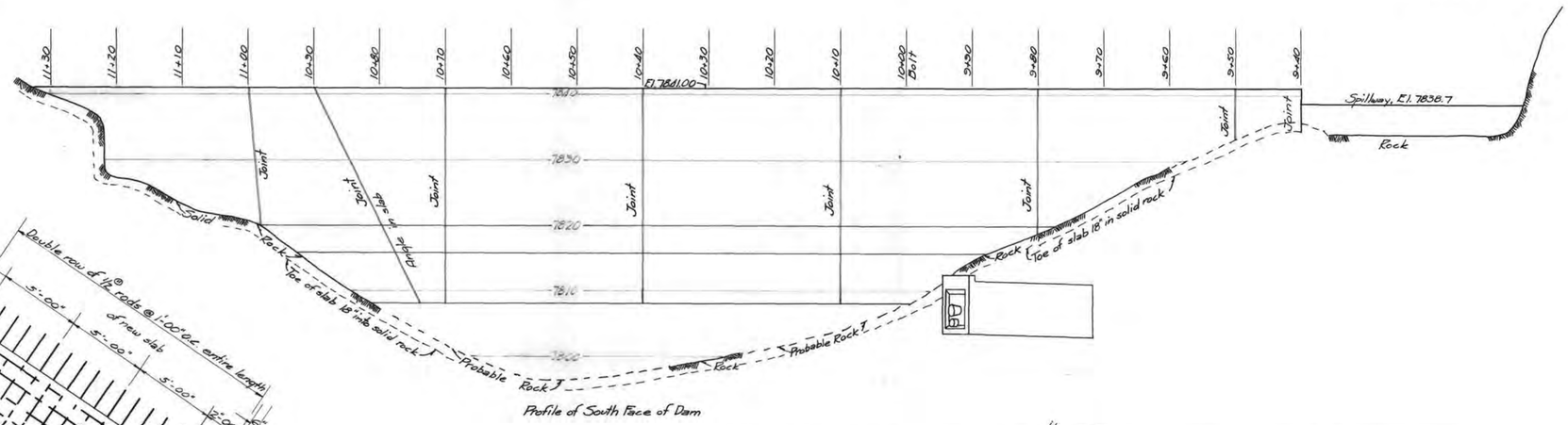
Water District No.7

October, 1935

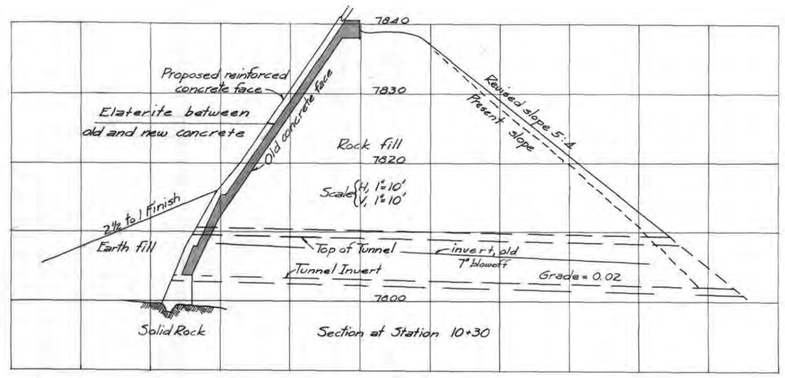
H. W. Gardner, City Engineer

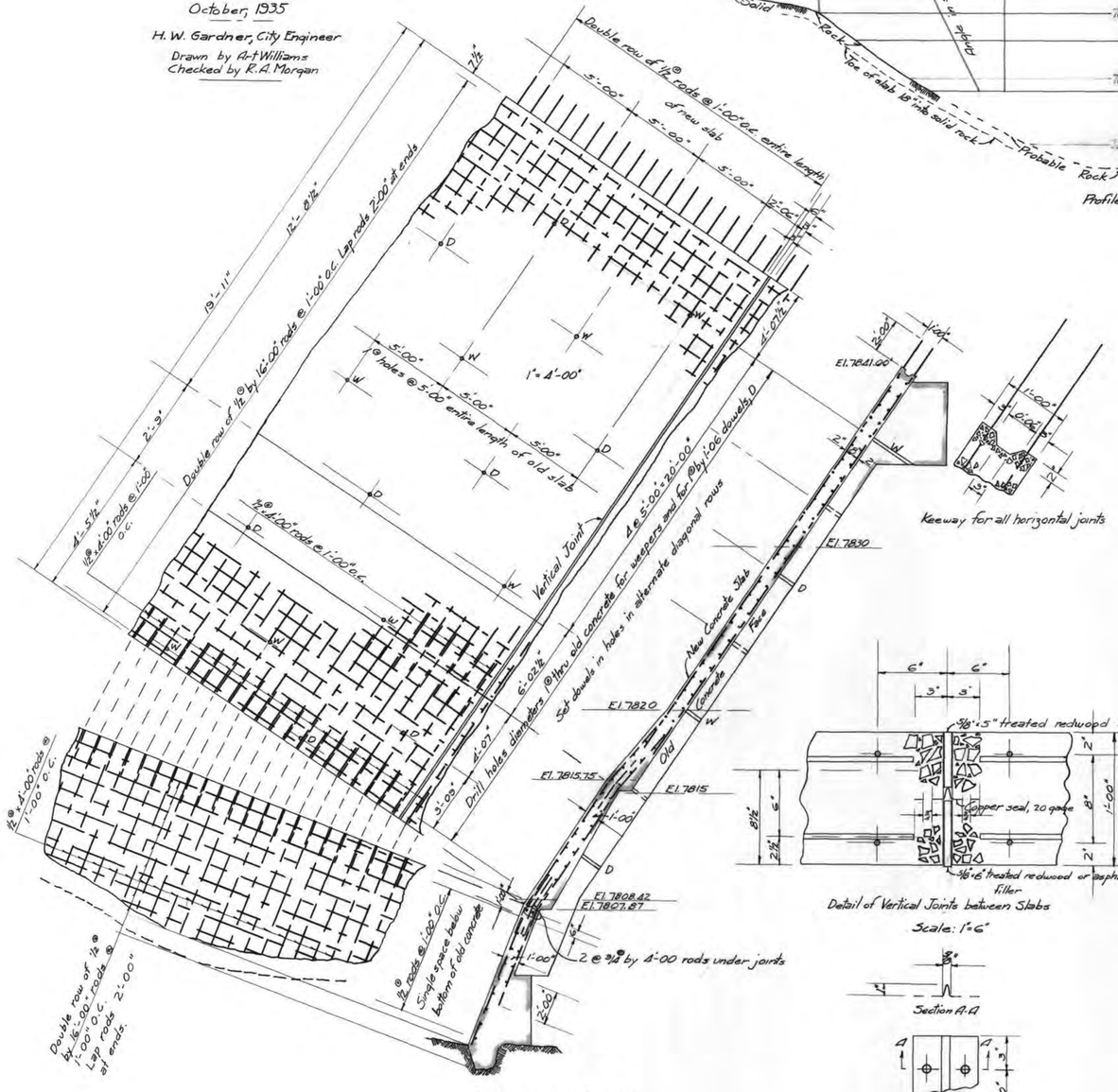
Drawn by A-t Williams

Checked by R.A. Morgan




Profile of South Face of Dam




Vertical Section Thru Slab

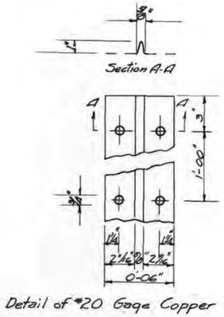



Keeway for all horizontal joints

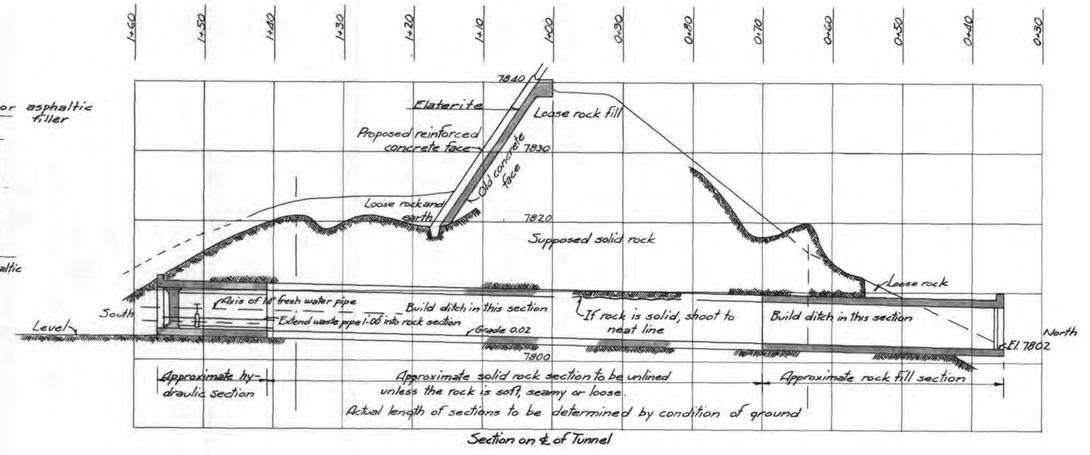



Detail of Vertical Joints between Slabs

Scale: 1"=6"




Detail of #20 Gage Copper Seal




Section on ℄ of Tunnel

Approved by the State Engineer of Colorado on this 22nd day of JANUARY A.D. 1938.

M. O. Fenderlider

State Engineer

By C. A. Signalness

Deputy

C-292

REPAIRS FOR

# GOLDEN RESERVOIR AND DAM No 1

BEING

LOWER BEAVER BROOK DAM

INCLUDING

BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK BACKFILL FOR DAM

W P A PROJECT NO. 174

Irrigation Division No.1

Water District No.7

October, 1935

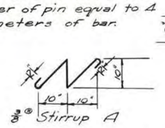
H. W. Gardner, City Engineer

Drawn by Art Williams

Checked by R.A Morgan

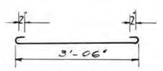
## BENDING DIAGRAMS

Note: All bending to be done cold around diameter of pin equal to 4 diameters of bar.




⅜" ® Stirrup A

Number to be determined



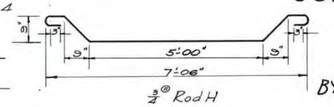

½" ® Stirrup B

14 required

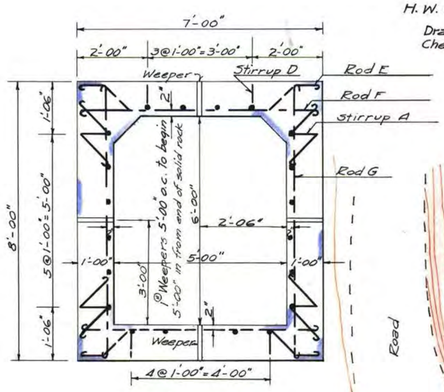
⅜" ® Stirrup C

14 required

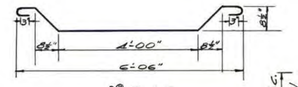
⅜" ® Stirrup D




¾" ® Rod H required




Typical Pressure Section adjacent to bulkhead



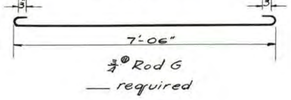

¾" ® Rod E

— required




¾" ® Rod F

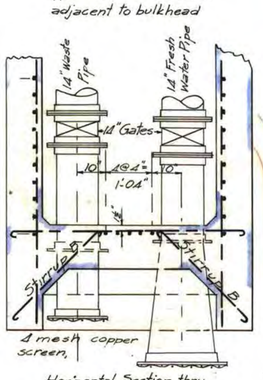
— required




¾" ® Rod G

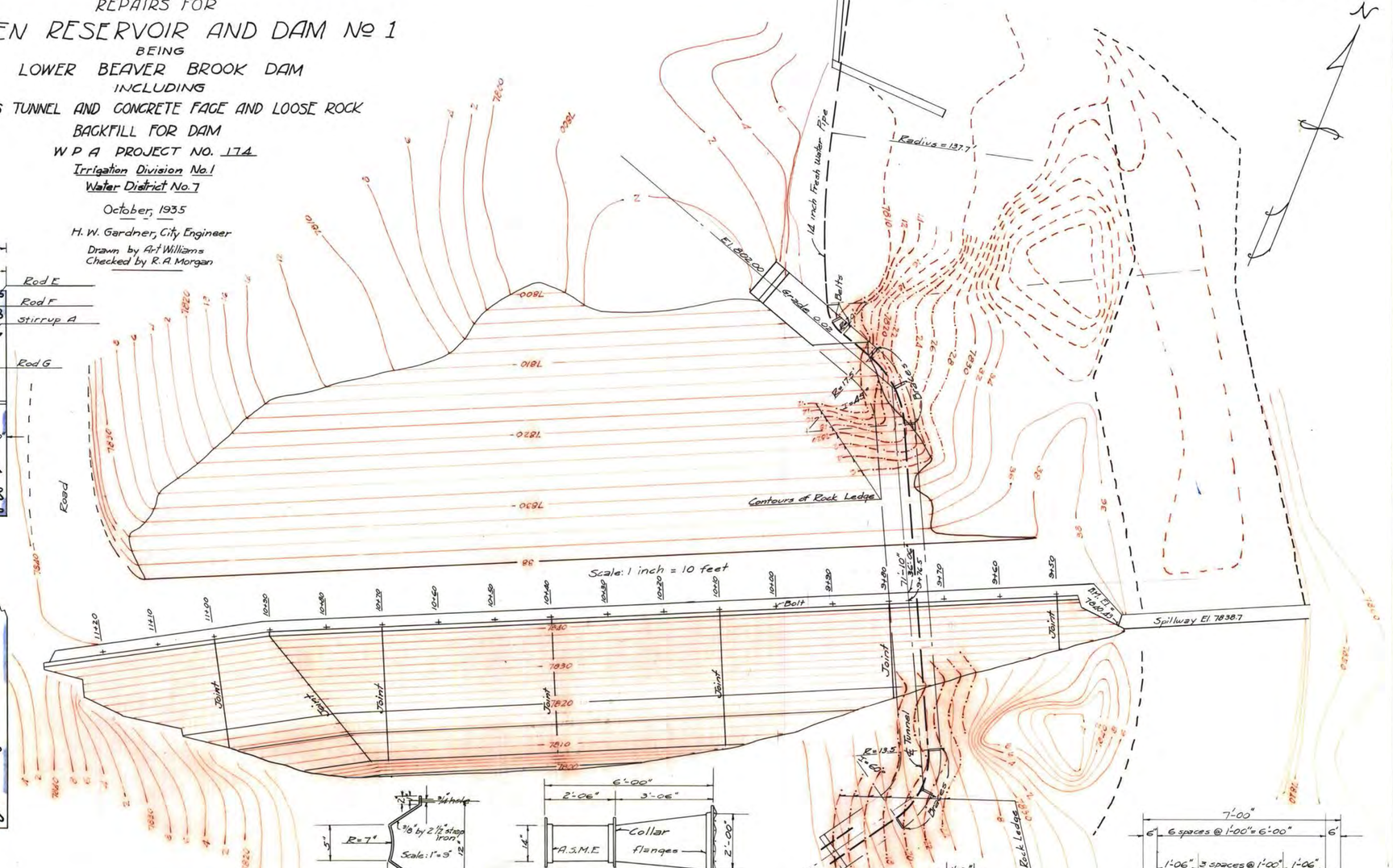
— required

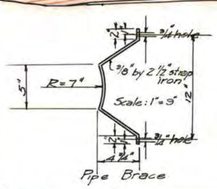
¾" ® Rods G at 0'-05" c.c. spacing from portal 10 feet into solid rock



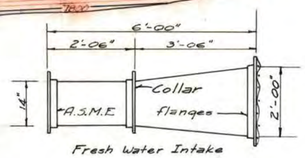

4 mesh copper screen.

Horizontal Section thru Bulkhead

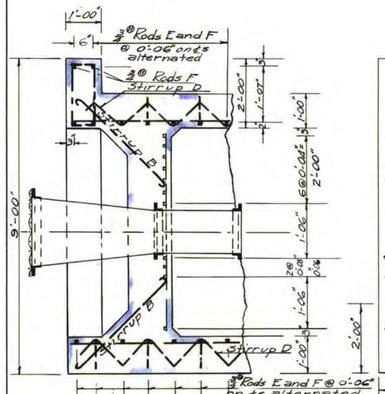


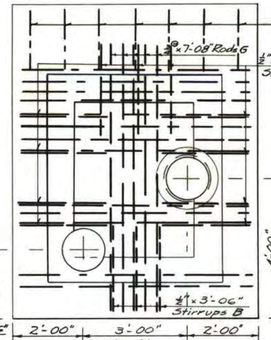

Pipe Brace




Fresh Water Intake

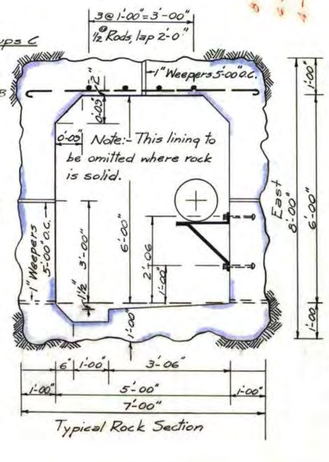



Vertical Section

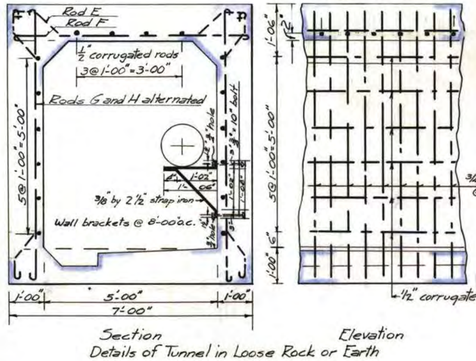



South End Elevation

Inlet Portal and Bulkhead




Typical Rock Section



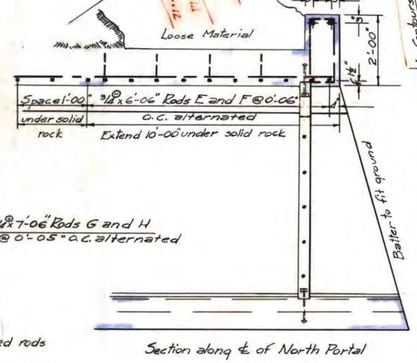

Section



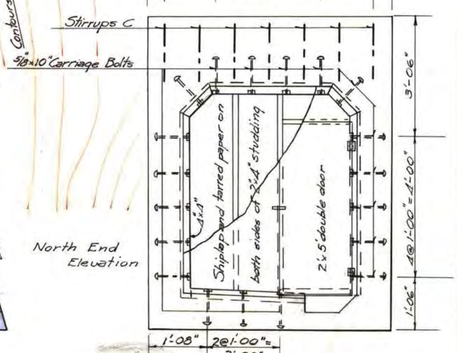

Elevation

Details of Tunnel in Loose Rock or Earth

Scale: 1 inch = 2 feet




Section along ℄ of North Portal




North End Elevation

Approved by the State Engineer of Colorado on this 27th day of JANUARY 1936.

M. O. Sundeen State Engineer

By C. C. Tyrrell Deputy

C-292

REPAIRS FOR

# GOLDEN RESERVOIR AND DAM Nº 1

BEING

## LOWER BEAVER BROOK DAM

INCLUDING

BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK BACKFILL FOR DAM

W P A PROJECT NO. 174

Irrigation Division No. 1

Water District No. 7

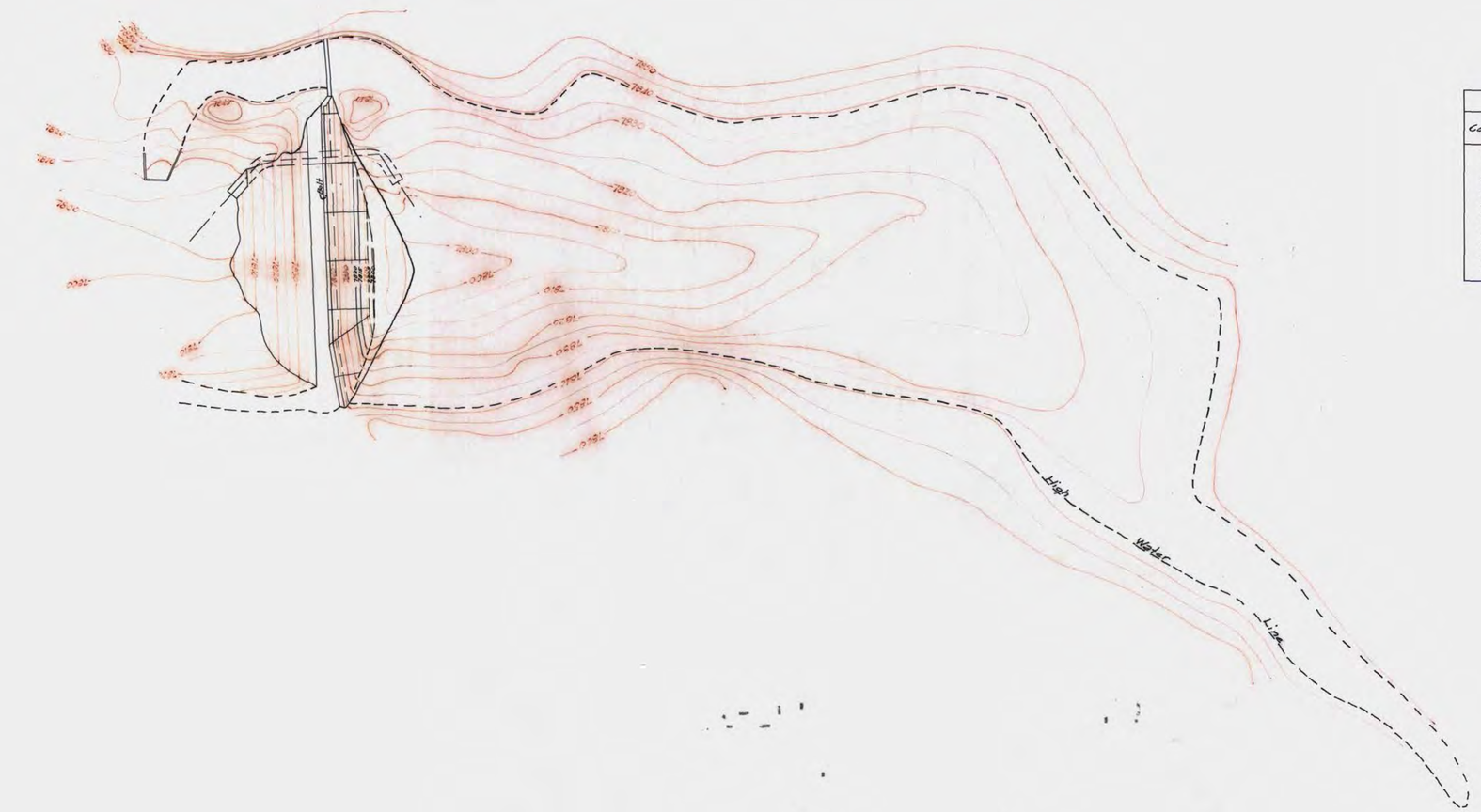
October, 1935

H. W. Gardner, City Engineer

Drawn by Art Williams

Checked by R. A. Morgan

Scale: 1 inch = 40 feet



AMENDED PLANS OF
REPAIRS FOR

# GOLDEN RESERVOIR AND DAM Nº 1

BEING

## LOWER BEAVER BROOK DAM

INCLUDING

BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK
BACKFILL FOR DAM

W P A PROJECT NO. 174

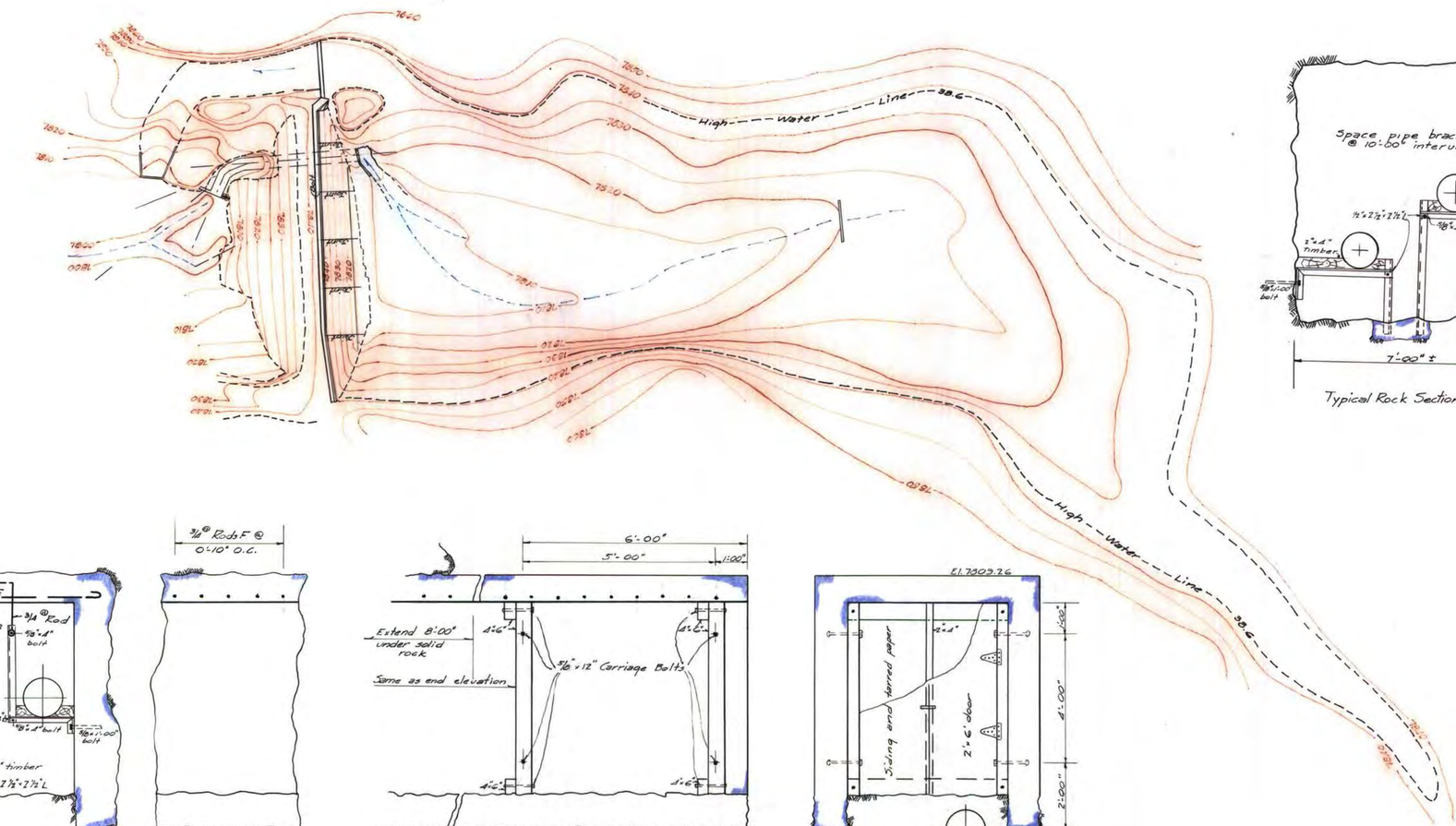
Irrigation Division No. I
Water District No. 7

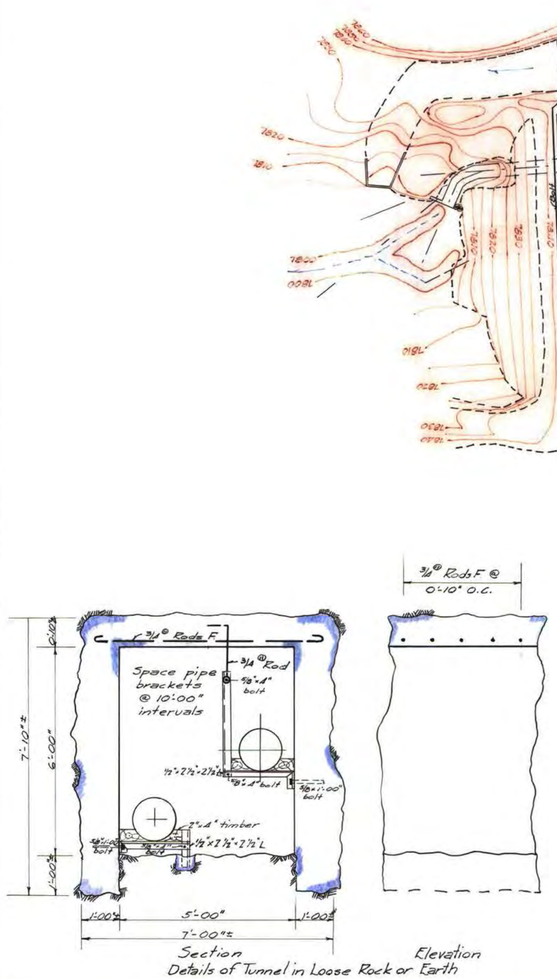
July, 1936

H. W. Gardner, City Engineer
Drawn by Art Williams
Checked by R. A. Morgan

Scale: 1 inch = 40 feet

| Volume of Reservoir | | | |
|---|---|---|---|
| Contour | Depth in feet from bottom | Area in Sq. Feet | Total Volume in Cu. feet from bottom |
| 7804 | 0 | 0 | 0 |
| 7805 | 1 | 112 | 34 |
| 7810 | 6 | 3488 | 1434 |
| 7815 | 11 | 18368 | 61074 |
| 7820 | 16 | 28608 | 178514 |
| 7825 | 21 | 44816 | 361074 |
| 7830 | 26 | 60928 | 624434 |
| 7835 | 31 | 78768 | 973674 |
| 7838.6 | 34.6 | 102.008 | 1300150 |

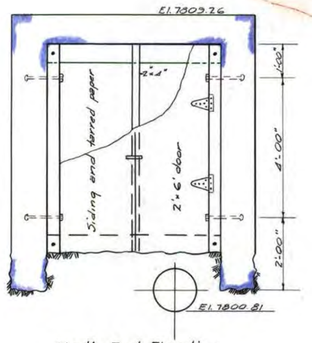


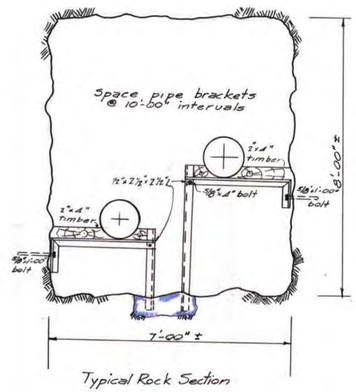

Section Elevation
Details of Tunnel in Loose Rock or Earth




Section along ℄ of North Portal
Scale: 1"=2'-00"




North End Elevation

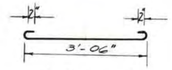



Typical Rock Section

## BENDING DIAGRAMS

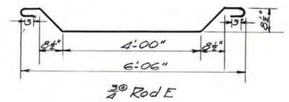
Note: All bending to be done cold around diameter of pin equal to 4 diameters of bar.

3/8 ⌀ Stirrup A

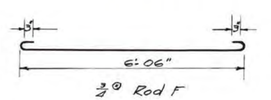



1/2 ⌀ Stirrup B

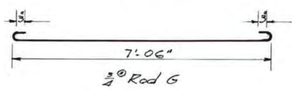
3/8 ⌀ Stirrup D




3/4 ⌀ Rod E




3/4 ⌀ Rod F




3/4 ⌀ Rod G

Scale: 1"=2'-00"

Approved by the State Engineer of Colorado on this 21st day of SEPT. A.D. 1936.
M. O. Sanderlin
State Engineer
By O. R. Ingmundson
Deputy

C-292

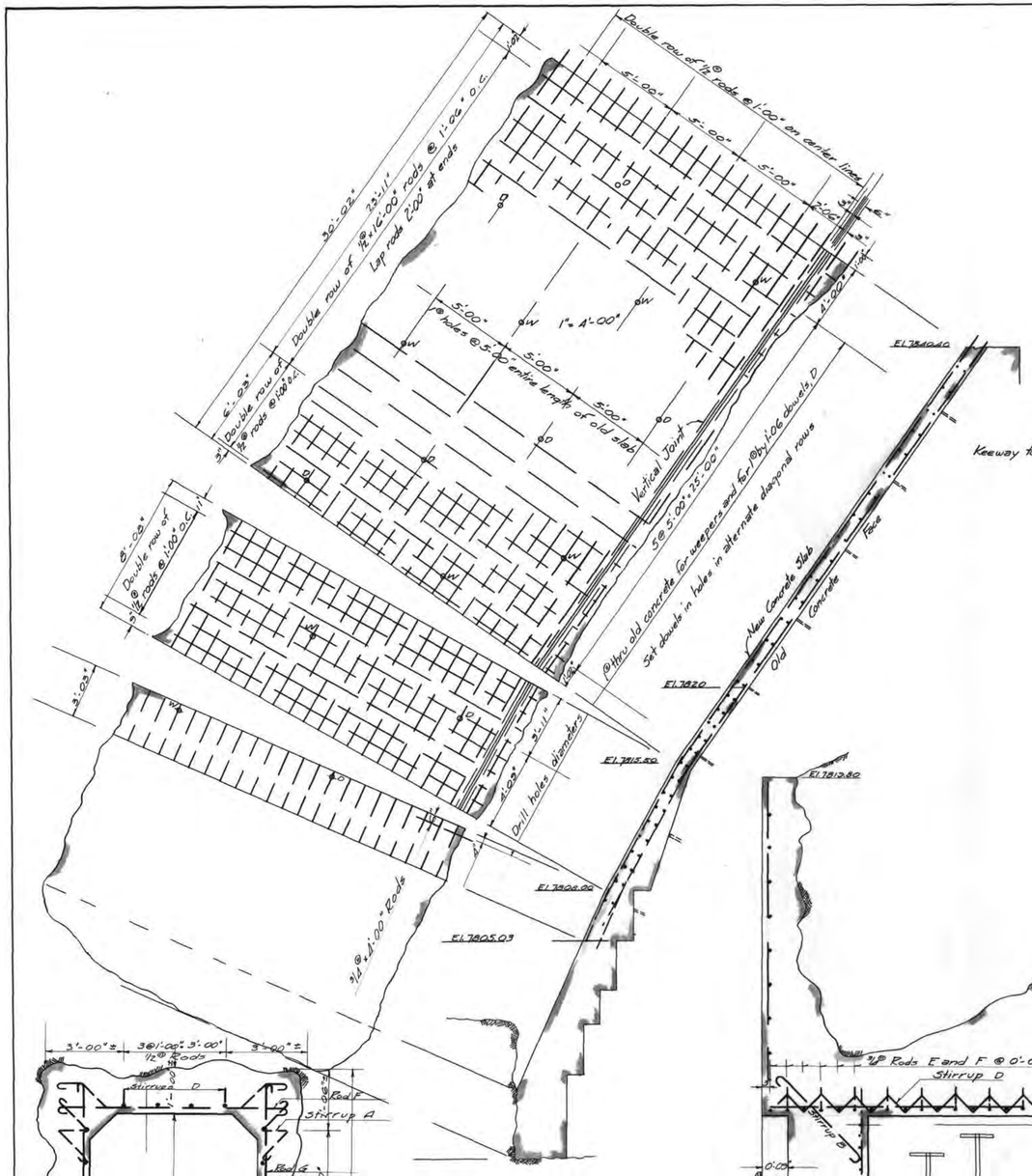
AMENDED PLANS OF
REPAIRS FOR

# GOLDEN RESERVOIR AND DAM No 1

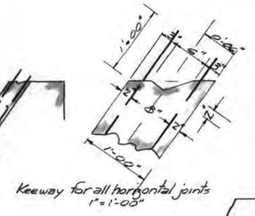
BEING
LOWER BEAVER BROOK DAM
INCLUDING
BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK
BACKFILL FOR DAM
W P A PROJECT NO. 174
Irrigation Division No.1
Water District No.7

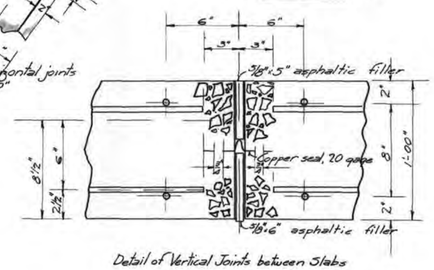
July, 1936

H. W. Gardner, City Engineer
Drawn by A.T. Williams
Checked by R.A. Morgan

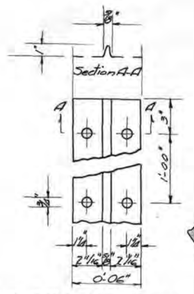



Vertical Section Thru Slab

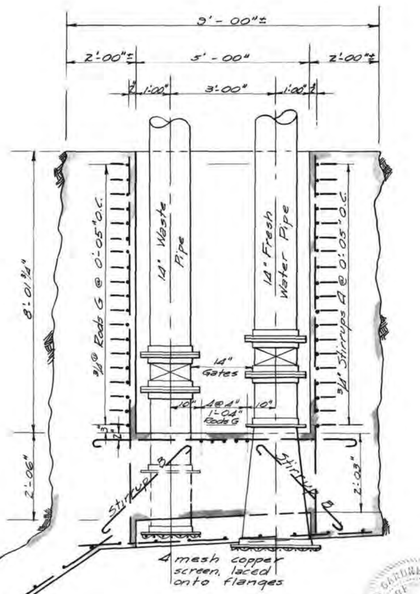


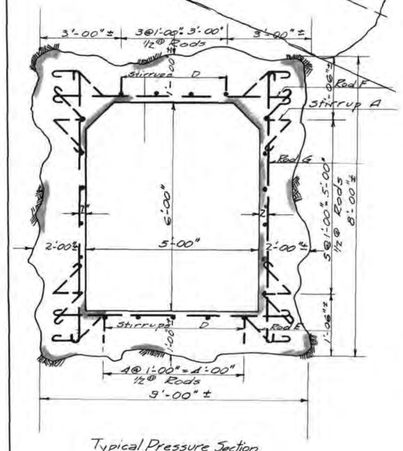

Detail of Vertical Joints between Slabs
Scale: 1"=6"



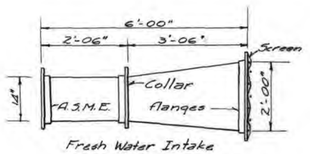

Detail of #20 Gage Copper Seal
Scale: 1"=6"



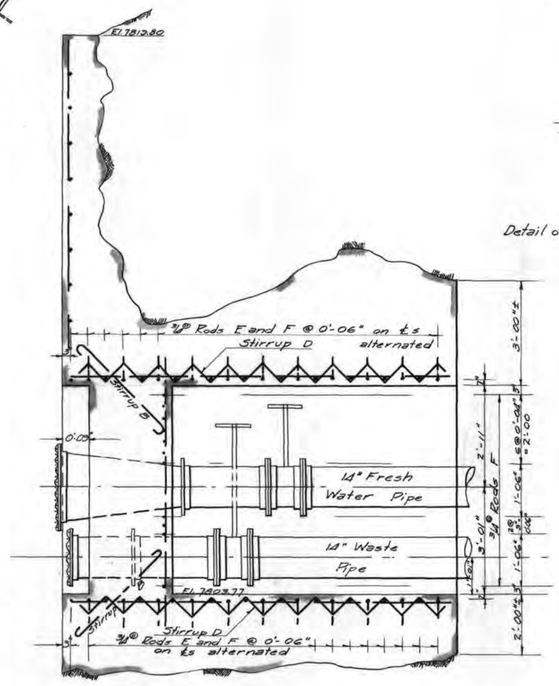

Horizontal Section thru Bulkhead



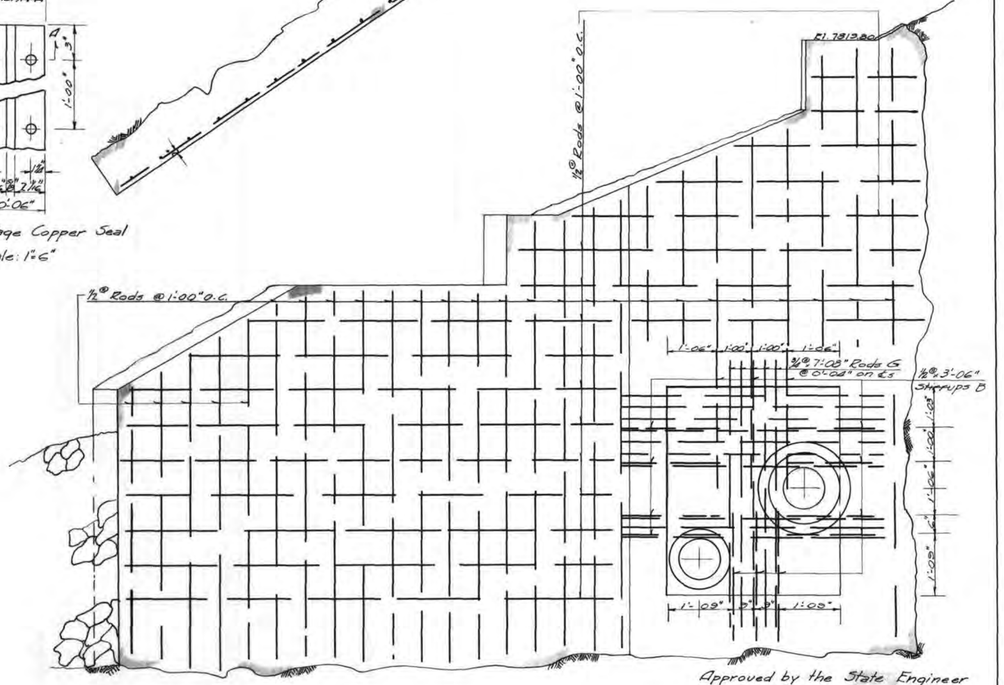

Typical Pressure Section adjacent to bulkhead




Fresh Water Intake




Vertical Section




Inlet Portal and Bulkhead
Scale: 1"=2'-00"

End Elevation

Approved by the State Engineer of Colorado on this 21ST day of SEPT A.D. 1936
M. C. Hinderlider
State Engineer
By O. R. Marshall
Deputy

C-292

# AMENDED PLANS OF REPAIRS FOR GOLDEN RESERVOIR AND DAM No 1

BEING

LOWER BEAVER BROOK DAM

INCLUDING

BYPASS TUNNEL AND CONCRETE FACE AND LOOSE ROCK BACKFILL FOR DAM

W P A PROJECT NO. 174

Irrigation Division No.1

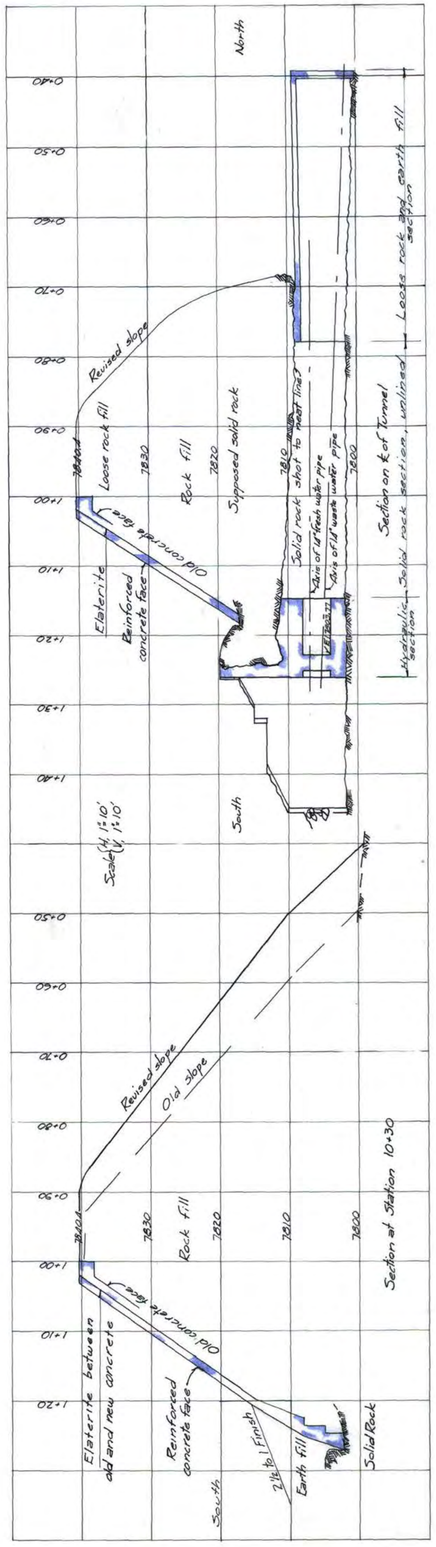
Water District No.7

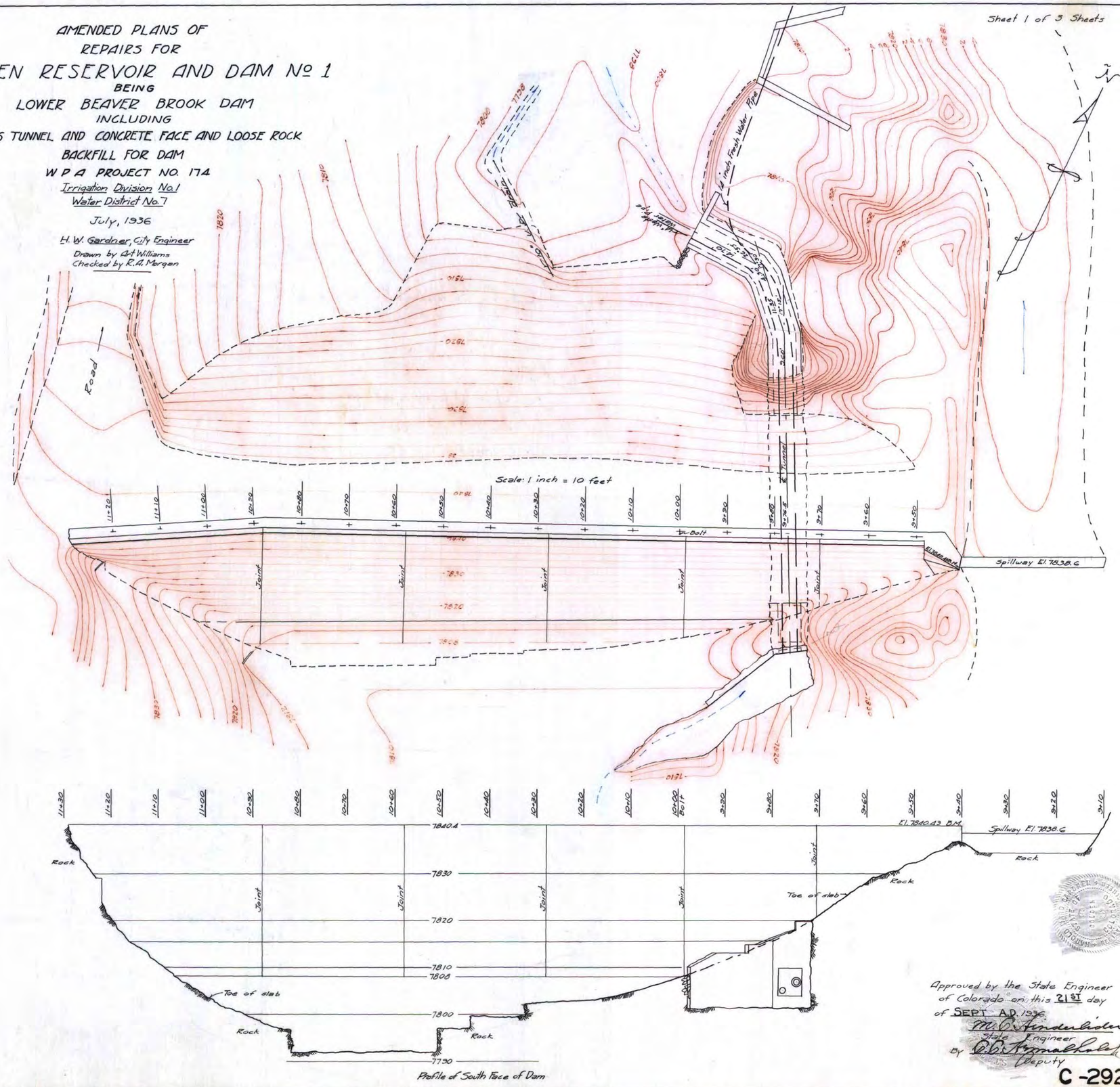
July, 1936

H. W. Gardner, City Engineer

Drawn by Art Williams

Checked by R.A. Morgan




Approved by the State Engineer of Colorado on this 21 ST day of SEPT A.D. 1936

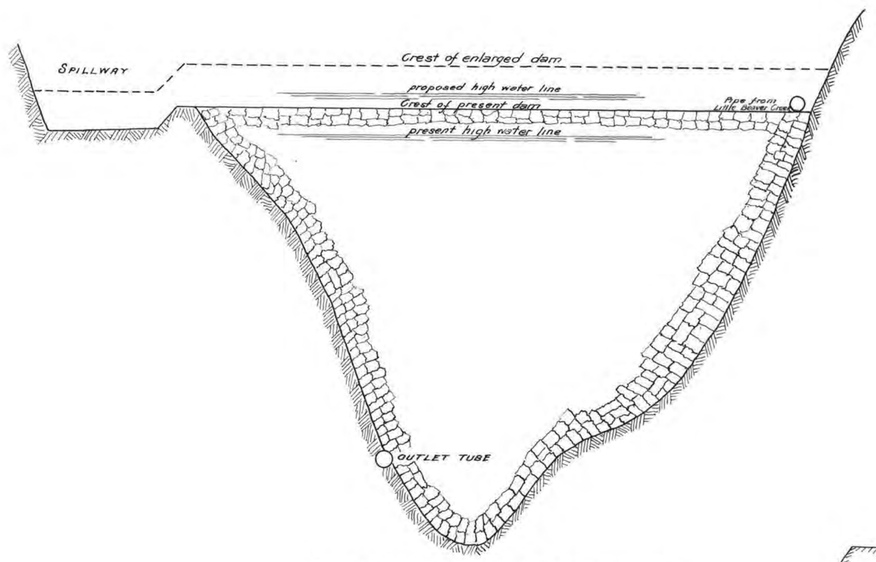
M. C. Hinderlider State Engineer

by D. C. Romalhalef Deputy

C-292

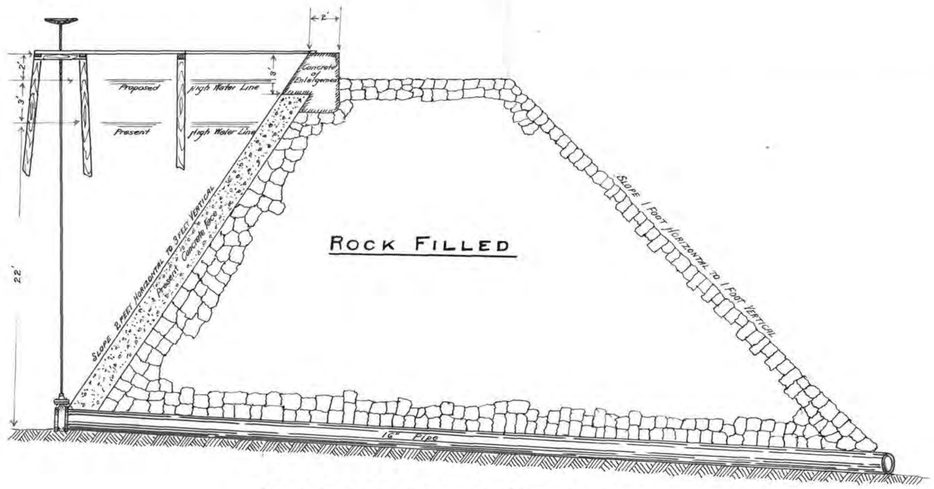
059885

# PLANS OF THE ENLARGEMENT OF
# BEAVER BROOK RESERVOIR DAM




## ELEVATION OF OUTER SLOPE

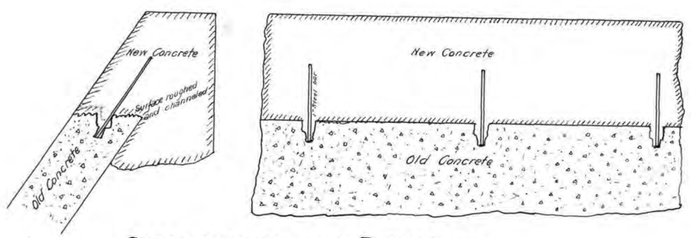
HORIZONTAL SCALE 20 FEET = ONE INCH
VERTICAL " 6 " = " "




ROCK FILLED

## CROSS-SECTION AT OUTLET TUBE

SCALE 6 FEET = 1 INCH




## CROSS-SECTION AND ELEVATION

SHOWING METHOD OF BONDING

## OLD WITH NEW CONCRETE

SCALE 2 FEET = 1 INCH

Approved on the 30th day of October A.D. 1917
Addison L. McCune
State Engineer

C-141

059756

ROY ROMER
Governor

HAROLD D. (AL) D. SIMPSON
State Engineer

DIVISION OF WATER RESOURCES
WATER DIVISION I

Alan D. Berryman
Division Engineer
800 8th Ave. Room 321 ARIX Bldg
Greeley, Colorado 80631
(303) 352 8712
July 16, 1993

Mr. J.M. Reynolds
Lookout Mountain Water District
P.O. Box 8008
Golden, CO 80401

RE: Beaver Brook Dams

Dear Mr. Reynolds;

On July 14, 1993 I performed my annual inspections for the Beaver Brook Dams, being #2, #3, and #3A. Mr. Roscoe requested I provide copies of my reports to your office, and these are attached.

I also would like to use this letter as the official documentation to correct and change the official names of these dams, as I have previously related by letter and in discussions with John. He has informed me that your Board is in agreement with doing so. To that end, the following names shall be used forever by the Division of Water Resources, and our files changed as appropriate!

| DAMID | New Name | Old Name |
|---|---|---|
| 070102 | Lower Beaver Brook Dam | Beaver Brook #2 |
| 070104 | Lookout Mountain Dam | Beaver Brook #3 |
| 070103 | Upper Beaver Brook Dam | Beaver Brook #3A |

With any luck this action should prevent future mis-communication and confusion. If you have any questions please fell free to call me.

Sincerely,

Gregory G Hammer, P.E.
Senior Professional Engineer

cc: Alan Berryman, Division Engineer(w/o enclosures)
Richard Robra, Water Commissioner(w/o enclosures)
Alan Pearson, Denver Dam Safety(w/o inspection reports)

enclosures: Inspections Reports dated July 14, 1993
Letter to John Roscoe dated June 26, 1992

# ENGINEERS INSPECTION REPORT

OFFICE OF THE STATE ENGINEER · DIVISION OF WAT[illegible] · SOURCES · DAM SAFETY BRANCH · 1313 SHERI[illegible] · STREET, ROOM 818, DENVER, CO 80203, (303) 866-3581

DAM NAME: BEAVER BROOK #2 (GULCH) · CLASS: 1 · EPP ON FILE: N Y · DATE OF INSPECTION: 7/14/93
DAM ID: 078102 · W.DIV: 1 · W.DIST: 7 · DATE OF LAST INSPECTION: 8/19/92
FOREST ID: 00000000 · LOCATION: Section 14, 4S, 72W SIXTH · Meridian
CURRENT RESTRICTION: 3.0 CREST · SURFACE AREA: 2 AC · CAPACITY: 30 AF
HEIGHT: 39.0 FT · CREST LENGTH: 224 FT · CREST WIDTH: 12.0 FT · SPILLWAY WIDTH: 29 FT · FED: 2.0

OWNER: LOOKOUT MOUNTAIN WATER DISTRICT
ADDRESS: P.O. BOX 6888, GOLDEN, CO 80401
CONTACT NAME: J. M. REYNOLDS
CONTACT PHONE: 303-526-2029
Owner #: 01748

INSPECTION PARTY REPRESENTING: [illegible] LMWD · MIKE DIARDORF TREATMENT PLT (LOOKOUT)

**FIELD CONDITIONS OBSERVED** — WATER LEVEL: BELOW DAM CREST 5½ FT. · BELOW SPILLWAY 3½ FT. · GAGE ROD READING ____
GROUND MOISTURE CONDITION: DRY ____ · WET X · SNOWCOVER ____ · OTHER RAIN LAST NIGHT

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

| | Conditions Observed: GOOD | ACCEPTABLE | POOR |
|---|---|---|---|

## 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 ____
Comments: IRREGULAR WATERLINE, SPALLS, CRACKING, Some MISSING JOINT FILLER

## 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 ____
Comments: GRASSED, SLOPES to DOWNSTREAM, ROUNDED SHOULDERS, IRREGULAR WIDTH, NOT AT SAME GRADE AS FACING

## DOWNSTREAM SLOPE

PROBLEMS NOTED: ☐ (20) NONE ☐ (21) LIVESTOCK DAMAGE ☐ (22) EROSION OR GULLIES ☐ (23) CRACKS WITH DISPLACEMENT ☐ (24) SINKHOLE
☒ (25) APPEARS TOO STEEP ☐ (26) DEPRESSION OR BULGES ☐ (27) SLIDE ☐ (28) SOFT AREAS ☐ (29) OTHER ____
Comments: HAND-PLACED ROCK SLOPE, "HUMMOCKY" APPEARANCE, BUT NO DISTRESS NOTED

## 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 __ ? cs. Show location of drains on sketch and indicate amount and quality of discharge ☐ (37) FLOW INCREASED/MUDDY ☐ (38) DRAIN DRY/OBSTRUCTED
☐ (39) OTHER ____
Comments: @ 13 on V-NOTCH, (4 gpm), MURKY with ALGAE, RUST, LIKELY FROM RAIN LAST NIGHT; SEEP ABOVE OUTLET ACCESS IS DRY, SOME MOISTURE IN GROUND, HOWEVER

## OUTLET

PROBLEMS NOTED: ☐ (40) NONE ☐ (41) NO OUTLET FOUND ☐ (42) POOR OPERATING ACCESS ☐ (43) INOPERABLE
☐ (44) UPSTREAM OR DOWNSTREAM STRUCTURE DETERIORATED (45) OUTLET OPERATED DURING INSPECTION ☐ YES ☒ NO
INTERIOR INSPECTED ☒ (120) NO ☐ (121) YES ☐ (46) CONDUIT DETERIORATED OR COLLAPSED ☐ (47) JOINTS DISPLACED ☐ (48) VALVE LEAKAGE
☐ (49) OTHER ____
Comments: CONDUIT IN ROCK TUNNEL

## SPILLWAY

PROBLEMS NOTED: ☐ (50) NONE ☐ (51) NO EMERGENCY SPILLWAY FOUND ☐ (52) EROSION WITH BACKCUTTING ☐ (53) CRACK WITH DISPLACEMENT
☒ (54) APPEARS TO BE STRUCTURALLY INADEQUATE ☒ (55) APPEARS TOO SMALL ☐ (56) INADEQUATE FREEBOARD ☐ (57) FLOW OBSTRUCTED
☐ (58) CONCRETE DETERIORATED ~~☐ (59) OTHER~~ ☐ (59) OTHER ____
Comments: SIDE WALL IS SEPARATED FROM DAM on LEFT FACE WAS "SPALLED",

See Guidelines on Back of this Sheet

DAM NAME Beaver Brook #2 DAM 27002 DATE 7/14/93

**MONITORING**

EXISTING INSTRUMENTATION FOUND ☐ (110) NONE ☐ (111) GAGE ROD ☐ (112) PIEZOMETERS ☒ (113) SEEPAGE WEIRS/FLUMES
☐ (114) SURVEY MONUMENTS ☐ (115) OTHER
MONITORING OF INSTRUMENTATION ☐ (116) NO ☒ (117) YES PERIODIC INSPECTIONS BY: ☒ (118) OWNER ☐ (119) ENGINEER
Comments:

GOOD ☐ ACCEPTABLE ☐ POOR ☒ **MONITORING**

**MAINTENANCE AND REPAIR**

PROBLEMS NOTED: ☒ (60) NONE ☐ (61) ACCESS ROAD NEEDS MAINTENANCE ☐ (62) CATTLE DAMAGE
☐ (63) BRUSH ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE ☐ (64) TREES ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE
☐ (65) RODENT ACTIVITY ON UPSTREAM SLOPE, CREST, DOWNSTREAM SLOPE, TOE ☐ (66) DETERIORATED CONCRETE-FACING, OUTLET, SPILLWAY
☐ (67) GATE AND OPERATING MECHANISM NEED MAINTENANCE ☐ (68) OTHER
Comments

GOOD ☒ ACCEPTABLE ☐ POOR ☐ **MAINTENANCE AND REPAIRS**

**OVERALL CONDITIONS**

REMARKS Inadequate Spillway, Good Condition Structurally

Based on this Safety Inspection and recent file review, the overall condition is determined to be:

☐ 71 SATISFACTORY ☐ 72 CONDITIONALLY SATISFACTORY ☒ 73 UNSATISFACTORY

**OVERALL CONDITIONS**

The State Engineer, by providing this dam safety inspection report, does not assume responsibility for any unsafe condition of the subject dam. The sole responsibility for the safety of this dam rests with the reservoir owner or operator, who should take every step necessary to prevent damages caused by leakage or overflow of waters from the reservoir or floods resulting from a failure of the dam.

## ITEMS REQUIRING ACTION BY OWNER TO IMPROVE THE SAFETY OF THE DAM

**MAINTENANCE - MINOR REPAIR - MONITORING**

☐ (80) PROVIDE ADDITIONAL RIPRAP
☐ (81) LUBRICATE AND OPERATE OUTLET GATES THROUGH FULL CYCLE
☐ (82) CLEAR TREES AND/OR BRUSH FROM
☐ (83) INITIATE RODENT CONTROL PROGRAM AND PROPERLY BACKFILL EXISTING HOLES
☐ (84) GRADE CREST TO A UNIFORM ELEVATION WITH DRAINAGE TO THE UPSTREAM SLOPE
☐ (85) PROVIDE SURFACE DRAINAGE FOR
☒ (86) MONITOR Seepage Flows & Submit Annual Report
☐ (87) DEVELOP AND SUBMIT AN EMERGENCY PREPAREDNESS PLAN
~~☐ (88) OTHER~~
☒ (89) OTHER Repair Joints & Cracks

**ENGINEERING - EMPLOY AN ENGINEER EXPERIENCED IN DESIGN AND CONSTRUCTION OF DAMS TO:** (Plans & Specification must be approved by State Engineer prior to construction)

☐ (90) PREPARE PLANS AND SPECIFICATIONS FOR THE REHABILITATION OF THE DAM
☐ (91) PREPARE AS-BUILT DRAWINGS OF
☒ (92) PERFORM A ~~GEOTECHNICAL~~ INVESTIGATION TO EVALUATE THE STABILITY OF THE DAM } Office will provide guidance
☒ (93) PERFORM A HYDROLOGIC STUDY TO DETERMINE REQUIRED SPILLWAY SIZE } with design standards
☒ (94) PREPARE PLANS AND SPECIFICATIONS FOR AN ADEQUATE SPILLWAY
☐ (95) SET UP A MONITORING SYSTEM INCLUDING WORK SHEETS, REDUCED DATA AND GRAPHED RESULTS
☐ (96) PERFORM AN INTERNAL INSPECTION OF THE OUTLET
☐ (97) OTHER
☐ (98) OTHER
☐ (99) OTHER

## SAFE STORAGE LEVEL RECOMMENDED AS A RESULT OF THIS INSPECTION

☐ (101) FULL STORAGE
☐ (102) CONDITIONAL FULL STORAGE
☒ (103) RECOMMENDED RESTRICTION

RESTRICTED LEVEL ~~OPTIONS GIVEN TO FOLLOW~~ 3' Continue

3 FT. BELOW DAMS CREST
___ FT. BELOW SPILLWAY CREST
___ FT. GAGE HEIGHT
___ NO STORAGE MAINTAIN OUTLET FULLY OPEN

REASON FOR RESTRICTION: Inadequate Spillway

ACTIONS REQUIRED FOR CONDITIONAL FULL STORAGE ~~OR CONTINUED STORAGE AT THE RESTRICTED LEVEL~~ Enlarge Spillway or Raise Dam for overtopping

Engineer's Signature [signature] INSPECTED BY

Owner's Signature John G. Kozac OWNER/OWNER'S REPRESENTATIVE DATE 7/14/93

CC-22-2549a-86

pg 2 of 2

U/S FACE

NOTE MARKED JOINTS - SEE NEXT PAGE

BEAVER BROOK #2
070102
7/14/93 GH

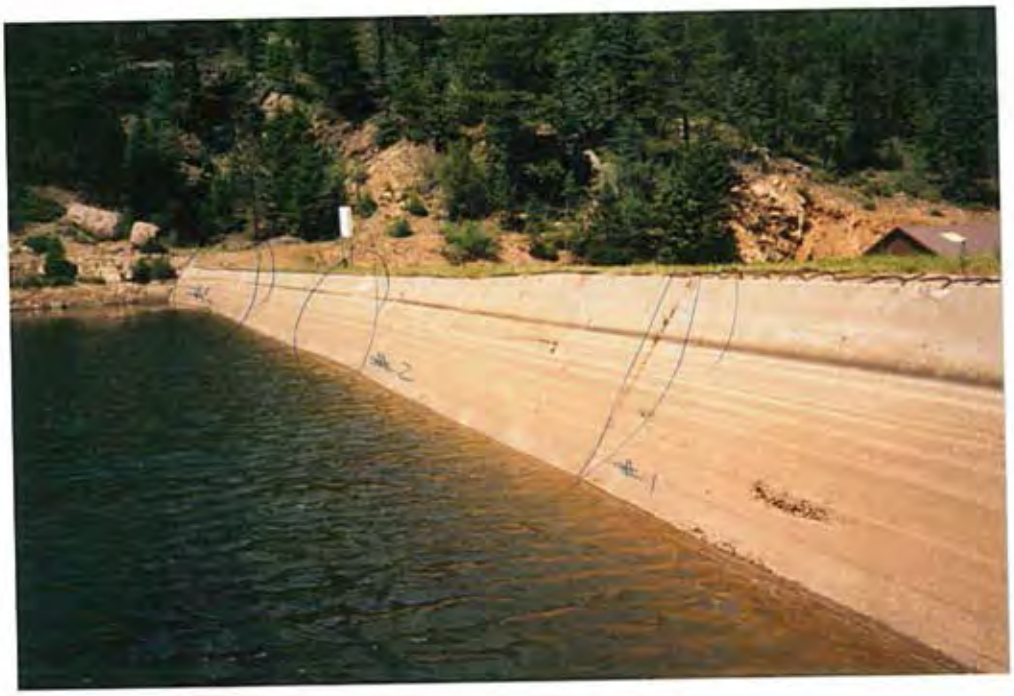
#1

#2

#3

VIEWS OF JOINT CRACKING/SPALLING

BEAVER BROOK #2
070102
7/14/93 GH

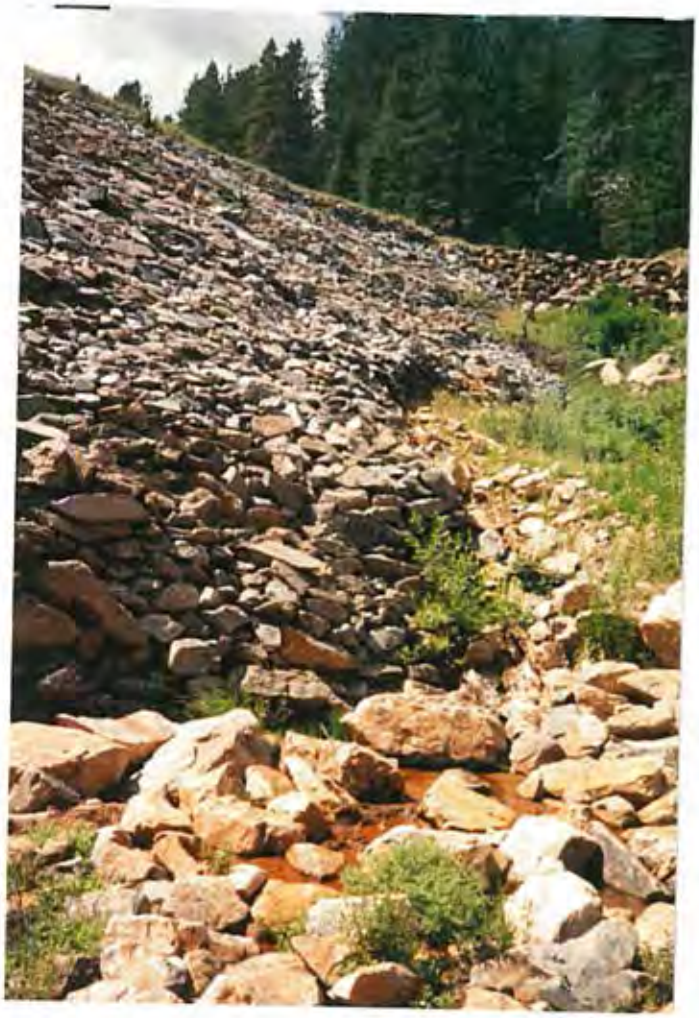



U/S FACE

BEAVER BROOK #2
070102
7/14/93 GH

U/S FACE OF
SPILLWAY SILL WALL

BEAVER BROOK #2
070102
7/14/93 GH



VIEW OF D/S LEFT GROIN

BEAVER BROOK #2
070102
7/14/93 GH

# Appendix A.2

## 100-year Event Calculations

GEI Consultants

| | | | |
|---|---|---|---|
| Client | Lookout Mountain Water District | Project 1410080 | Page 1 of 2 |
| Project | Lower Beaver Brook IDA | By KAP | Date 8/28/2014 |
| Subject | NOAA 14, Vol. 8 Rainfall Analysis | Checked | Date |
| | | Approved | Date |

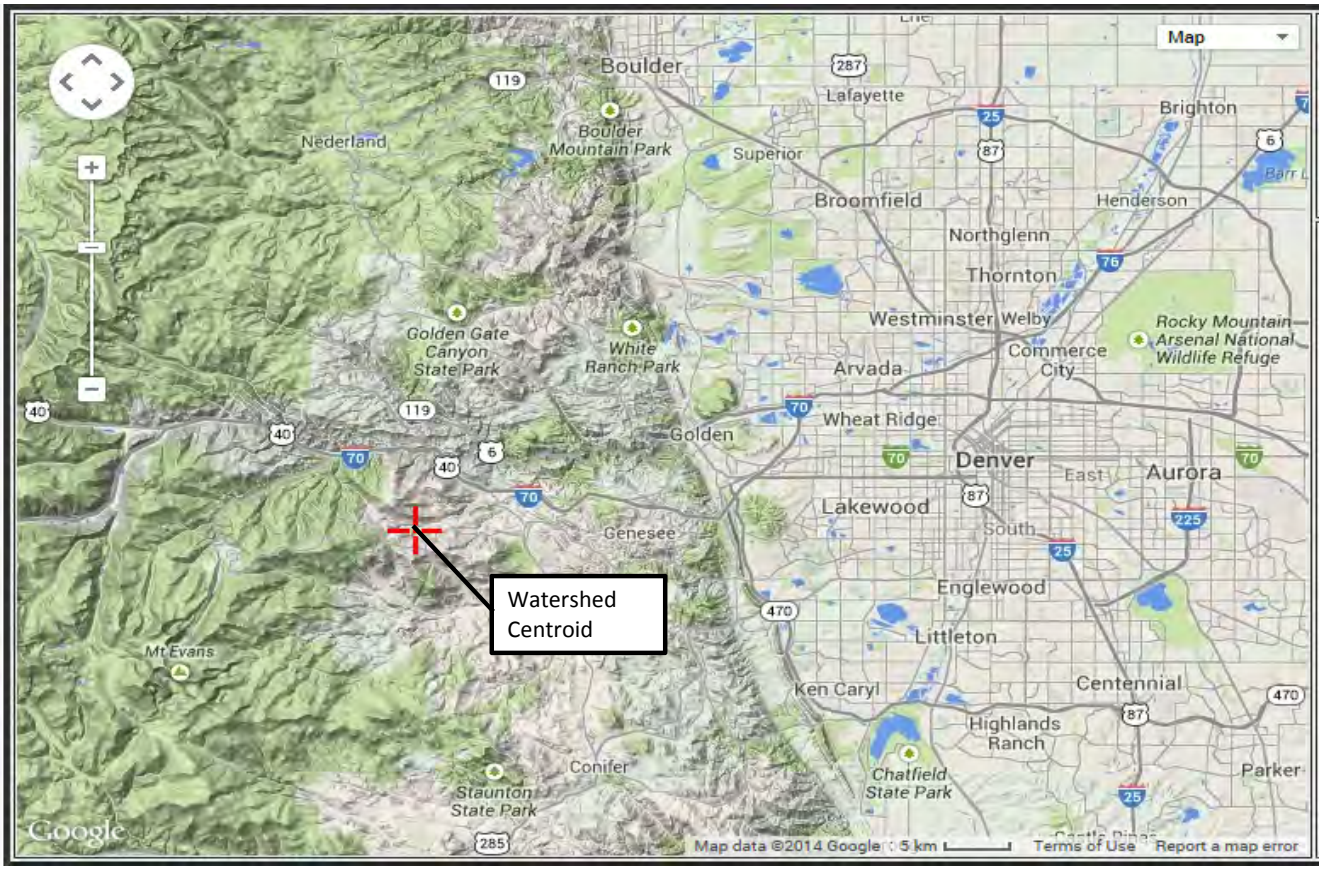
**Purpose:** This spreadsheet is used to estimate the 24-hr, 1-, 2-, 5-, 10-, 25-, 50-, 100-, 200-, 500-, and 1000-yr precipitations at Lower Beaver Brook Dam.

**Procedure:** The rainfall depth estimation follows the procedures outlined in Precipitation-Frequency Atlas of the United States (Atlas 14, Volume 8, Version 2: Colorado).

As instructed in Atlas 14, the user is referred to the NOAA Precipitation Frequency Data Server (PFDS) http://hdsc.nws.noaa.gov/hdsc/pfds/index.html. The Lower Beaver Brook watershed centroid location was used as the watershed centroid and was input into the PFDS and the PF estimates were returned.

**Watershed Centroid Coordinates:**

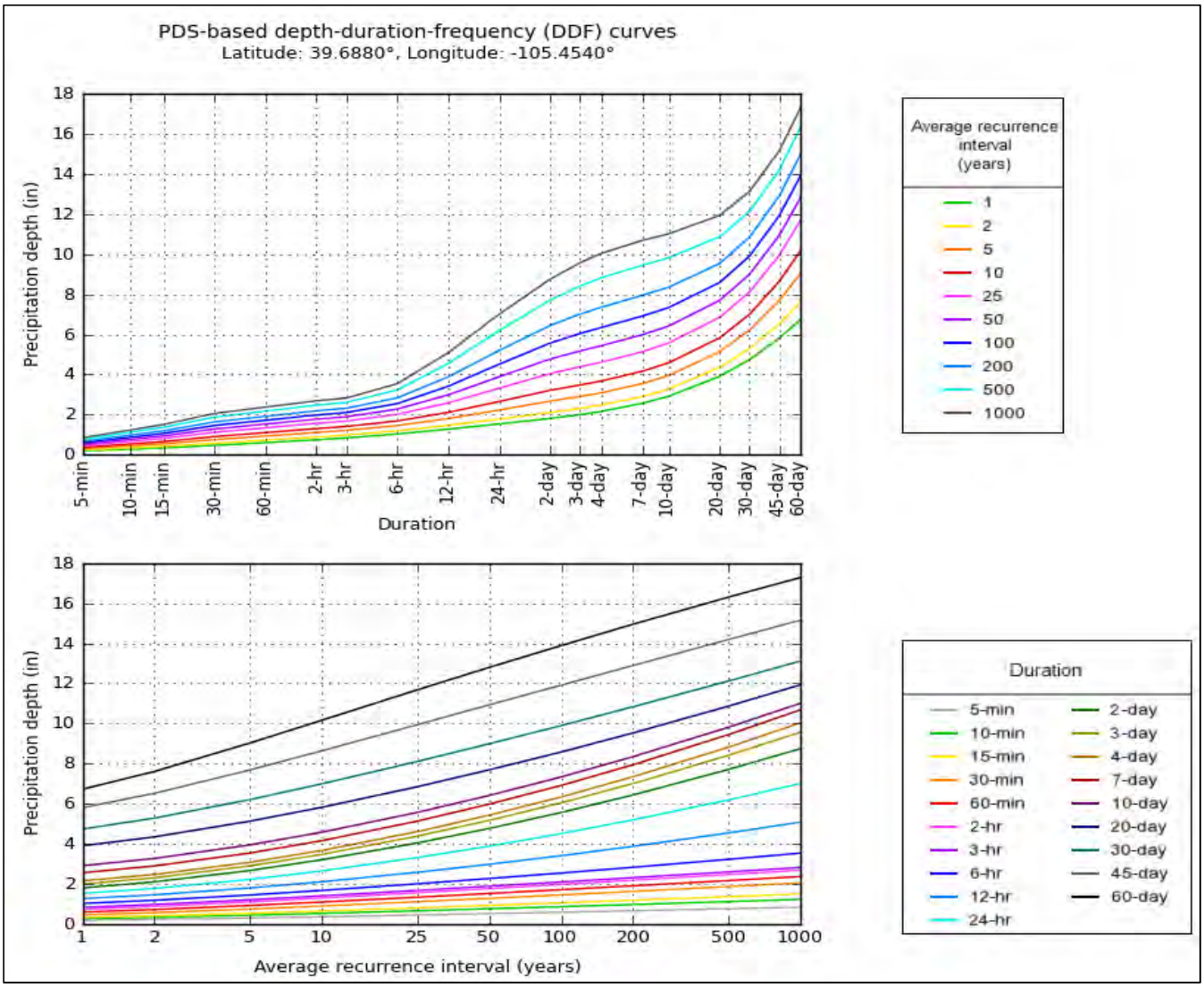
| | |
|---|---|
| 39° 41' 16.886" N | 39.69 º |
| 105° 27' 15.919" W | 105.45 º |



| | | | |
|---|---|---|---|
| Client | Lookout Mountain Water District | Project 1410080 | Page 2 of 2 |
| Project | Lower Beaver Brook IDA | By KAP | Date 8/28/2014 |
| Subject | NOAA 14, Vol. 8 Rainfall Analysis | Checked | Date |
| | | Approved | Date |

**Output from the PFDS:**

| | PRECIPITATION FREQUENCY ESTIMATES | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min: | 0.19 | 0.23 | 0.3 | 0.37 | 0.45 | 0.52 | 0.59 | 0.67 | 0.77 | 0.84 |
| 10-min: | 0.28 | 0.34 | 0.45 | 0.54 | 0.67 | 0.77 | 0.87 | 0.98 | 1.12 | 1.24 |
| 15-min: | 0.34 | 0.41 | 0.54 | 0.66 | 0.81 | 0.93 | 1.06 | 1.19 | 1.37 | 1.51 |
| 30-min: | 0.47 | 0.57 | 0.75 | 0.9 | 1.12 | 1.28 | 1.46 | 1.63 | 1.87 | 2.06 |
| 60-min: | 0.6 | 0.73 | 0.93 | 1.1 | 1.34 | 1.53 | 1.72 | 1.91 | 2.17 | 2.37 |
| 2-hr: | 0.74 | 0.88 | 1.11 | 1.3 | 1.56 | 1.77 | 1.98 | 2.19 | 2.47 | 2.69 |
| 3-hr: | 0.84 | 0.98 | 1.21 | 1.41 | 1.68 | 1.89 | 2.1 | 2.32 | 2.6 | 2.82 |
| 6-hr: | 1.03 | 1.19 | 1.45 | 1.68 | 2.01 | 2.27 | 2.55 | 2.83 | 3.23 | 3.54 |
| 12-hr: | 1.27 | 1.46 | 1.8 | 2.11 | 2.58 | 2.98 | 3.41 | 3.88 | 4.54 | 5.08 |
| 24-hr: | 1.53 | 1.78 | 2.23 | 2.65 | 3.31 | 3.89 | 4.51 | 5.2 | 6.19 | 7.01 |



**RAINFALL LOSSES SOIL PROPERTIES TABLE:**

**Project:** **Lower Beaver Brook Dam - Upper Subbasin**
By: KAP
Date: 9/12/2014

**Design Storm:** Frequency Storm (Extreme Storm/PMP, Frequency Storm)
**Soil Depth:** 6" (Analyze 18" soil depth for Extreme Storm/PMP; 6" depth for 100-YR and more frequent storm)

blue text = User Entry
red text = Excel calculation

| DATA SOURCE: | Soil Survey | ArcMap | Map Unit (MU) Description Report | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | ArcMap | =[E]+[H]+[K] | Eq. 2, Sabol 2008 =10^{[[E]*Log10[F]+[H]*Log10[G]+[K]*Log10[LL]]/[N]} | =[M]LOG10[O] | Aerial photo, Land Use Map, Site Visit | Weights Sand and Loamy Sand as 10% Vegetation Cover | =[R]*[M] | Engineering Properties Report or Aerial photo | =[T]*[M] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOTES: | [A] Soil Survey ID | [B] Map Unit (MU) | [C] Landform Description | [D] Component 1 Infiltration-Limiting Soil Texture | [E] % of MU | [F] Ksat1 (in/hr) | [G] Component 2 Infiltration-Limiting Soil Texture | [H] % of MU | [I] Ksat2 (in/hr) | [J] Component 3 Infiltration-Limiting Soil Texture | [K] % of MU | [L] Ksat3 (in/hr) | [M] MU Area ($m^2$) | [N] Sum % MU | [O] MU Avg. Ksat (in/hr) | [P] MU Area* Log10(MU Avg. Ksat) | [Q] % Vegetative Cover | [R] % Veg. Cover Adjusted for Sand & Loamy Sand* | [S] %Veg Cover *MU Area | [T] % Impervious | [U] % Imp *MU Area | [V] Ground Cover Notes |
| 15% minor components | CO645 | 7700C | Leighcan Family, 40-75% | silty loam | 100 | 0.15 | | | | | | | 1,461,598 | 100 | 0.15 | -1204224 | 85% | 85% | 1242358 | 0% | 0 | Dense evergreen forest |
| 15% minor components | CO645 | 7701C | Leighcan Family, warm, 40-75% | silty loam | 100 | 0.15 | | | | | | | 13,517 | 100 | 0.15 | -11137 | 85% | 85% | 11489 | 0% | 0 | Dense evergreen forest |
| 60% L, 25% R, 15% minor | CO645 | 7790B | Lithic Cryothents, subalpine-Rubble land | sandy loam | 71 | 0.40 | gravel | 29 | 1.2 | | | | 32,416 | 100 | 0.55 | -8353 | 85% | 85% | 27554 | 0% | 0 | Dense evergreen forest |
| 10% minor | CO645 | RR | Rubble Land | gravel | 100 | 1.20 | | | | | | | 83,570 | 100 | 1.20 | 6617 | 85% | 85% | 71034 | 0% | 0 | Dense evergreen forest |
| 45% A, 35% D, 20% minor - Dumps is "fragmental material" - used gravel | CO653 | 1 | Arents-Dumps, mine complex, 5 to 80 percent slopes | loamy sand | 56 | 1.20 | gravel | 44 | 1.2 | | | | 60,300 | 100 | 1.20 | 4775 | 80% | 80% | 48240 | 0% | 0 | Dense evergreen forest |
| 15% minor components | CO654 | 6 | Cumulic Cryaquolls, 0 to 3 percent slopes | loam | 100 | 0.25 | | | | | | | 2,914 | 100 | 0.25 | -1754 | 80% | 80% | 2331 | 0% | 0 | Dense evergreen forest |
| 40% I, 25% M, 20% L, 15% minor | CO653 | 17 | Ivywild-Mammoth-Legault complex, 30 to 60 percent slopes | loamy sand | 47 | 1.20 | sandy loam | 29 | 0.4 | loamy sand | 24 | 1.2 | 786,728 | 100 | 0.87 | -46562 | 80% | 63% | 497212 | 0% | 0 | Dense evergreen forest |
| 60% K, 25% G, 15% minor | CO653 | 19 | Kittredge-Guanella complex, 3 to 9 percent slopes | sandy loam | 71 | 0.40 | loam | 29.4 | 0.25 | | | | 54,229 | 100 | 0.35 | -24834 | 80% | 80% | 43383 | 0% | 0 | Dense evergreen forest |
| 45% K, 40% G, 15% minor | CO653 | 20 | Kittredge-Guanella complex, 9 to 30 percent slopes | sandy loam | 53 | 0.40 | loam | 47 | 0.25 | | | | 143,262 | 100 | 0.32 | -70754 | 80% | 80% | 114610 | 0% | 0 | Dense evergreen forest |
| 20% minor components | CO653 | 21 | Legault very gravelly sandy loam, 5 to 15 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 69,162 | 100 | 0.40 | -27523 | 80% | 80% | 55330 | 0% | 0 | Dense evergreen forest |
| 25% minor components | CO653 | 22 | Legault very gravelly sandy loam, 15 to 30 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 70,984 | 100 | 0.40 | -28247 | 80% | 80% | 56787 | 0% | 0 | Dense evergreen forest |
| 70% L, 20% Rock, 10% minor | CO653 | 23 | Legault-Rock outcrop complex, 30 to 80 percent slopes | loamy sand | 78 | 1.20 | Rock | 22 | 0.001 | | | | 206,395 | 100 | 0.25 | -124886 | 80% | 80% | 165116 | 0% | 0 | Dense evergreen forest and rock |
| 45% L, 40% B, 15% minor | CO653 | 24 | Lyninger-Breece gravelly sandy loams, 3 to 12 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 103,602 | 100 | 0.40 | -41227 | 80% | 80% | 82882 | 0% | 0 | Dense evergreen forest |
| 40% M, 35% O, 20% B, 5% minor | CO653 | 30 | Mammoth-Ohman-Bendemeere complex, 15 to 30 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 66,370 | 100 | 0.40 | -26411 | 80% | 80% | 53096 | 0% | 0 | Dense evergreen forest |
| 40% M, 35% O, 15% B, 10% minor | CO653 | 31 | Mammoth-Ohman-Bendemeere complex, 30 to 60 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 3,636,594 | 100 | 0.40 | -1447146 | 80% | 80% | 2909275 | 0% | 0 | Dense evergreen forest |
| 50% M, 25% O, 15% Rock, 10% minor | CO653 | 32 | Mammoth-Ohman-Rock outcrop complex, 30 to 60 percent slopes | sandy loam | 83 | 0.40 | Rock | 17 | 0.001 | | | | 843,183 | 100 | 0.15 | -701936 | 80% | 80% | 674546 | 0% | 0 | Dense evergreen forest and rock |
| 45% O, 35% I, 20% minor | CO653 | 33 | Ohman-Ivywild very gravelly sandy loams, 30 to 60 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 628,897 | 100 | 0.40 | -250263 | 85% | 85% | 534562 | 0% | 0 | Dense evergreen forest |
| 55% O, 35%L, 10% minor | CO653 | 34 | Ohman-Legault very gravelly sandy loams, 15 to 30 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 780,253 | 100 | 0.40 | -310494 | 80% | 80% | 624202 | 0% | 0 | Dense evergreen forest |
| 55% O, 45%L | CO653 | 35 | Ohman-Legault very gravelly sandy loams, 30 to 60 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 2,210,447 | 100 | 0.40 | -879625 | 85% | 85% | 1878880 | 0% | 0 | Dense evergreen forest |
| 45% R, 30% L, 25% minor | CO653 | 41 | Redfeather-Legault complex, 30 to 70 percent slopes | sandy loam | 60 | 0.40 | loamy sand | 40 | 1.2 | | | | 299,475 | 100 | 0.62 | -62019 | 80% | 52% | 155727 | 0% | 0 | Dense evergreen forest |
| 40% R, 25% L, 20% T, 15% minor | CO653 | 42 | Redfeather-Legault-Tolvar complex, 12 to 30 percent slopes | sandy loam | 47 | 0.40 | loamy sand | 29 | 1.2 | sandy loam | 24 | 0.4 | 58,681 | 100 | 0.55 | -15232 | 80% | 80% | 46945 | 0% | 0 | Dense evergreen forest |
| 50% R, 35% C, 15% minor | CO653 | 47 | Resort-Cathedral complex, 30 to 60 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 7,163 | 100 | 0.40 | -2850 | 80% | 80% | 5730 | 0% | 0 | Dense evergreen forest |
| 40% T, 30% L, 25% rock, 5% minor | CO653 | 56 | Tahana-Legault-Rock outcrop complex, 30 to 70 percent slopes | sandy loam | 42 | 0.40 | loamy sand | 32 | 1.2 | Rock | 26 | 0.001 | 5,143,680 | 100 | 0.12 | -4741427 | 80% | 80% | 4114944 | 0% | 0 | Dense evergreen forest and rock |
| 40% T, 25% R, 20% K, 15% minor | CO653 | 60 | Troutdale-Rogert-Kittredge complex, 3 to 15 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 40,267 | 100 | 0.40 | -16024 | 80% | 80% | 32214 | 0% | 0 | Dense evergreen forest |
| 95% water, 5% minor | CO653 | 64 | Water | water | 100 | 0.00 | | | | | | | 40,793 | 100 | 0.00 | -122380 | 0% | 0% | 0 | 100% | 40793 | Reservoir |

**Table 10 (Sabol 2008)**

| Soil Texture | Ksat (in/hr) |
|---|---|
| sand | 1.2 |
| Rock | 0.001 |
| water | 0.001 |
| gravel | 1.2 |
| loamy sand | 1.2 |
| sandy loam | 0.4 |
| loam | 0.25 |
| silty loam | 0.15 |
| silt | 0.1 |
| sandy clay loam | 0.06 |
| clay loam | 0.04 |
| silty clay loam | 0.04 |
| sandy clay | 0.02 |
| silty clay | 0.02 |
| clay | 0.01 |

**NOTE 1: No Vegetation Cover Adjustment allowed to bare ground Ksat for Sand & Loamy Sand. Therefore % Vegetation Cover must be adjusted to10% cover for Sand and Loamy Sand MU Components (Reference Figure 8, Sabol 2008).**

**SUB-BASIN RAINFALL LOSSES SUMMARY TABLE:**

| | | DATA SOURCE: |
|---|---|---|
| Total MU/Sub-basin area ($m^2$) | 16,844,478 | [AA]=Sum[M] |
| Sub-basin Weighted Avg Bare Ground Ksat, (in/hr) | 0.25 | [BB]=10^(Sum[P]/[AA]), Eq. 2 Sabol 2008 |
| Sub-basin Weighted Avg % Vegetation Cover | 80% | [CC]=Sum[S]/[AA], Eq. 1 Sabol 2008 |
| Average Sub-basin slope | 17.40% | [DD] From ArcMap, USGS Stream Stats, etc. |
| Antecedent Moisture Condition | saturated | [EE], Use engineering judgment. Dry=WP, Normal=FC, OR Saturated |
| Sub-basin Initial Abstraction (IA), (inches) | 0.40 | [FF], Table 8, Sabol 2008 |
| G&A Suction head at capillary front, PSIF, (inches) | 4.00 | [GG], Figure 4, Sabol 2008 |
| G&A soil moisture deficit, DTHETA (vol/vol) | 0 | [HH], Figure 4, Sabol 2008 |
| Vegetation Cover Factor | 1.78 | [JJ]=[%Veg Cover-10]/90 + 1. Figure 8, Sabol 2008 |
| Sub-basin Adjusted Ksat, XKSAT, (in/hr) | 0.44 | [KK]=[BB]*[JJ] |
| Sub-basin Weighted Avg. % Impervious (RTIMP) | 0.242% | [LL]=Sum[U]/[AA], Eq. 1 Sabol 2008 |

| | HMS Parameters | |
|---|---|---|
| = sat. content - DTHETA | Initial Content : | 0.41 |
| effective porousity for sandy loam | Saturated Content : | 0.41 |
| [GG] | Suction (IN) : | 4.0 |
| [KK] | Conductivity (IN/HR) : | 0.44 |
| [LL] | Impervious (%) | 0.24% |

| Soil type | Porosity | Effective porosity | Suction head | Hydraulic conductivity |
|---|---|---|---|---|
| | | | mm | mm / h |
| Sand | 0.437 | 0.417 | 49.5 | 117.8 |
| loamy sand | 0.437 | 0.401 | 61.3 | 29.9 |
| sandy loam | 0.453 | 0.412 | 110.1 | 10.9 |
| loam | 0.463 | 0.434 | 88.9 | 3.4 |
| silt loam | 0.501 | 0.486 | 166.8 | 6.5 |
| sandy clay loam | 0.398 | 0.33 | 218.5 | 1.5 |
| clay loam | 0.464 | 0.309 | 208.8 | 1 |
| silty clay loam | 0.471 | 0.432 | 273 | 1 |
| sandy clay | 0.43 | 0.321 | 239 | 0.6 |
| silty clay | 0.479 | 0.423 | 292.2 | 0.5 |
| clay | 0.475 | 0.385 | 316.3 | 0.3 |

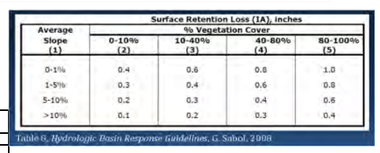


Table 8, *Hydrologic Basin Response Guidelines*, G. Sabol, 2008

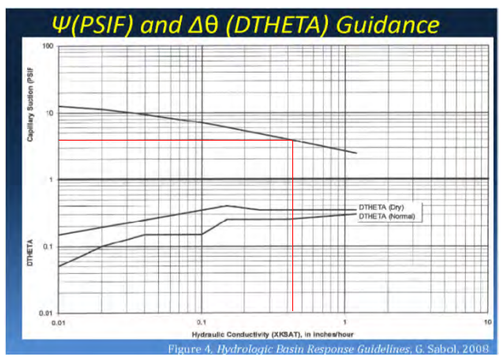


Figure 4, *Hydrologic Basin Response Guidelines*, G. Sabol, 2008

**RAINFALL LOSSES SOIL PROPERTIES TABLE:**

**Project:** **Lower Beaver Brook Dam - Lower Subbasin**
By: KAP
Date: 9/12/2014

**Design Storm:** Frequency Storm (Extreme Storm/PMP, Frequency Storm)
**Soil Depth:** 6" (Analyze 18" soil depth for Extreme Storm/PMP; 6" depth for 100-YR and more frequent storm)

blue text = User Entry
red text = Excel calculation

| DATA SOURCE: | Soil Survey | ArcMap | Map Unit (MU) Description Report | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | Engineering Properties Report | Component Legend Report | Table 10 (Sabol 2008), VLOOKUP | ArcMap | =[E]+[H]+[K] | Eq. 2, Sabol 2008 =10^{([E]*Log10[F]+[H]Log10[I]+[K]Log10[L])/[N]} | =[M]LOG10[O] | Aerial photo, Land Use Map, Site Visit | Weights Sand and Loamy Sand as 10% Vegetation Cover | =[R]*[M] | Engineering Properties Report or Aerial photo | =[T]*[M] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| NOTES: | [A] Soil Survey ID | [B] Map Unit (MU) | [C] Landform Description | [D] Component 1 Infiltration-Limiting Soil Texture | [E] % of MU | [F] Ksat1 (in/hr) | [G] Component 2 Infiltration-Limiting Soil Texture | [H] % of MU | [I] Ksat2 (in/hr) | [J] Component 3 Infiltration-Limiting Soil Texture | [K] % of MU | [L] Ksat3 (in/hr) | [M] MU Area ($m^2$) | [N] Sum % MU | [O] MU Avg. Ksat (in/hr) | [P] MU Area* Log10(MU Avg. Ksat) | [Q] % Vegetative Cover | [R] % Veg. Cover Adjusted for Sand & Loamy Sand[1] | [S] %Veg Cover *MU Area | [T] % Impervious | [U] % Imp *MU Area | [V] Ground Cover Notes |
| 80% L, 20% minor components | CO653 | 21 | Legault very gravelly sandy loam, 5 to 15 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 99,150 | 100 | 0.40 | -39456 | 80% | 80% | 79320 | 0% | 0 | Dense evergreen forest |
| 75% L, 25% minor components | CO653 | 22 | Legault very gravelly sandy loam, 15 to 30 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 184,136 | 100 | 0.40 | -73275 | 80% | 80% | 147309 | 0% | 0 | Dense evergreen forest |
| 70% L, 20% Rock, 10% minor | CO653 | 23 | Legault-Rock outcrop complex, 30 to 80 percent slopes | loamy sand | 78 | 1.20 | Rock | 22.2 | 0.001 | | | | 57,467 | 100 | 0.25 | -34772 | 80% | 80% | 45973 | 0% | 0 | Dense evergreen forest with rock |
| 45% M, 35% O, 15% B, 5% minor | CO653 | 31 | Mammoth-Ohman-Bendemeere complex, 30 to 60 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 61,918 | 100 | 0.40 | -24640 | 80% | 80% | 49535 | 0% | 0 | Dense evergreen forest |
| 50% M, 25% O, 15% Rock, 10% minor | CO653 | 32 | Mammoth-Ohman-Rock outcrop complex, 30 to 60 percent slopes | sandy loam | 83 | 0.40 | Rock | 16.7 | 0.001 | | | | 1,072,443 | 100 | 0.15 | -892792 | 85% | 85% | 911577 | 0% | 0 | Dense evergreen forest with rock |
| 55% O, 35% L, 10% minor | CO653 | 34 | Ohman-Legault very gravelly sandy loams, 15 to 30 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 222,178 | 100 | 0.40 | -88413 | 80% | 80% | 177742 | 0% | 0 | Dense evergreen forest |
| 35% R, 30% C, 20% Rubble, 15% minor - used Ksat from Soils Report for Rubble | CO653 | 48 | Resort-Cathedral-Rubble complex, 30 to 60 percent slopes | sandy loam | 77 | 0.40 | Rubble | 23.5 | 20 | | | | 5,666 | 100 | 1.00 | 7 | 80% | 80% | 4533 | 0% | 0 | Dense evergreen forest |
| 40% T, 30% L, 25% Rock, 5% minor | CO653 | 56 | Tahana-Legault-Rock outcrop complex, 30 to 70 percent slopes | sandy loam | 42 | 0.40 | loamy sand | 32 | 1.2 | Rock | 26 | 0.001 | 747,068 | 100 | 0.12 | -688645 | 80% | 80% | 597654 | 0% | 0 | Dense evergreen forest with rock |
| 40% T, 25% R, 20% K, 15% minor | CO653 | 60 | Troutdale-Rogert-Kittredge complex, 3 to 15 percent slopes | sandy loam | 100 | 0.40 | | | | | | | 162 | 100 | 0.40 | -64 | 80% | 80% | 130 | 0% | 0 | Dense evergreen forest |
| 95% water, 5% minor | CO653 | 64 | Water | water | 100 | 0.00 | | | | | | | 1,214 | 100 | 0.00 | -3642 | 0% | 0% | 0 | 100% | 1214 | Reservoir |

**NOTE 1: No Vegetation Cover Adjustment allowed to bare ground Ksat for Sand & Loamy Sand. Therefore % Vegetation Cover must be adjusted to10% cover for Sand and Loamy Sand MU Components (Reference Figure 8, Sabol 2008).**

**Table 10 (Sabol 2008)**

| Soil Texture | Ksat (in/hr) |
|---|---|
| sand | 1.2 |
| Rubble | 20 |
| Rock | 0.001 |
| water | 0.001 |
| gravel | 1.2 |
| loamy sand | 1.2 |
| sandy loam | 0.4 |
| loam | 0.25 |
| silty loam | 0.15 |
| silt | 0.1 |
| sandy clay loam | 0.06 |
| clay loam | 0.04 |
| silty clay loam | 0.04 |
| sandy clay | 0.02 |
| silty clay | 0.02 |
| clay | 0.01 |

**SUB-BASIN RAINFALL LOSSES SUMMARY TABLE:**

| | | DATA SOURCE: |
|---|---|---|
| Total MU/Sub-basin area ($m^2$) | 2,451,402 | [AA]=Sum[M] |
| Sub-basin Weighted Avg Bare Ground Ksat, (in/hr) | 0.18 | [BB]=10^(Sum[P]/[AA]), Eq. 2 Sabol 2008 |
| Sub-basin Weighted Avg % Vegetation Cover | 82% | [CC]=Sum[S]/[AA], Eq. 1 Sabol 2008 |
| Average Sub-basin slope | 34.20% | [DD] From ArcMap, USGS Stream Stats, etc. |
| Antecedent Moisture Condition | Saturated | [EE], Use engineering judgment. Dry=WP, Normal=FC, OR Saturated |
| Sub-basin Initial Abstraction (IA), (inches) | 0.4 | [FF], Table 8, Sabol 2008 |
| G&A Suction head at capillary front, PSIF, (inches) | 4.5 | [GG], Figure 4, Sabol 2008 |
| G&A soil moisture deficit, DTHETA (vol/vol) | 0 | [HH], Figure 4, Sabol 2008 |
| Vegetation Cover Factor | 1.80 | [JJ]=(%Veg Cover-10)/90 + 1. Figure 8, Sabol 2008 |
| Sub-basin Adjusted Ksat, XKSAT, (in/hr) | 0.32 | [KK]=[BB]*[JJ] |
| Sub-basin Weighted Avg. % Impervious (RTIMP) | 0.05% | [LL]=Sum[U]/[AA], Eq. 1 Sabol 2008 |

| HMS Parameters | | |
|---|---|---|
| = sat. content - DTHETA | Initial Content : | 0.41 |
| effective porosity for sandy loam | Saturated Content : | 0.41 |
| [GG] | Suction (IN) : | 4.5 |
| [KK] | Conductivity (IN/HR) : | 0.32 |
| [LL] | Impervious (%) | 0.05% |

**Surface Retention Loss (IA), inches**

| Average Slope (1) | % Vegetation Cover 0-10% (2) | 10-40% (3) | 40-80% (4) | 80-100% (5) |
|---|---|---|---|---|
| 0-1% | 0.4 | 0.6 | 0.8 | 1.0 |
| 1-5% | 0.3 | 0.4 | 0.6 | 0.8 |
| 5-10% | 0.2 | 0.3 | 0.4 | 0.6 |
| >10% | 0.1 | 0.2 | 0.3 | 0.4 |

Table 8, *Hydrologic Basin Response Guidelines*, G. Sabol, 2008

| Soil type | Porosity | Effective porosity | Suction head | Hydraulic conductivity |
|---|---|---|---|---|
| | | | mm | mm / h |
| Sand | 0.437 | 0.417 | 49.5 | 117.8 |
| loamy sand | 0.437 | 0.401 | 61.3 | 29.9 |
| sandy loam | 0.453 | 0.412 | 110.1 | 10.9 |
| loam | 0.463 | 0.434 | 88.9 | 3.4 |
| silt loam | 0.501 | 0.486 | 166.8 | 6.5 |
| sandy clay loam | 0.398 | 0.33 | 218.5 | 1.5 |
| clay loam | 0.464 | 0.309 | 208.8 | 1 |
| silty clay loam | 0.471 | 0.432 | 273 | 1 |
| sandy clay | 0.43 | 0.321 | 239 | 0.6 |
| silty clay | 0.479 | 0.423 | 292.2 | 0.5 |
| clay | 0.475 | 0.385 | 316.3 | 0.3 |

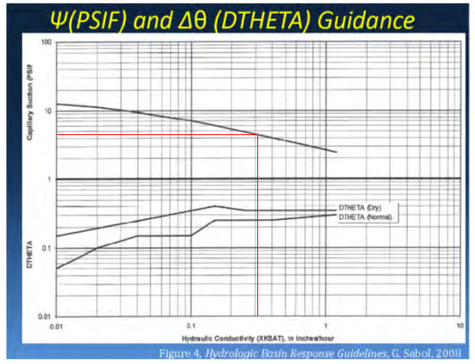


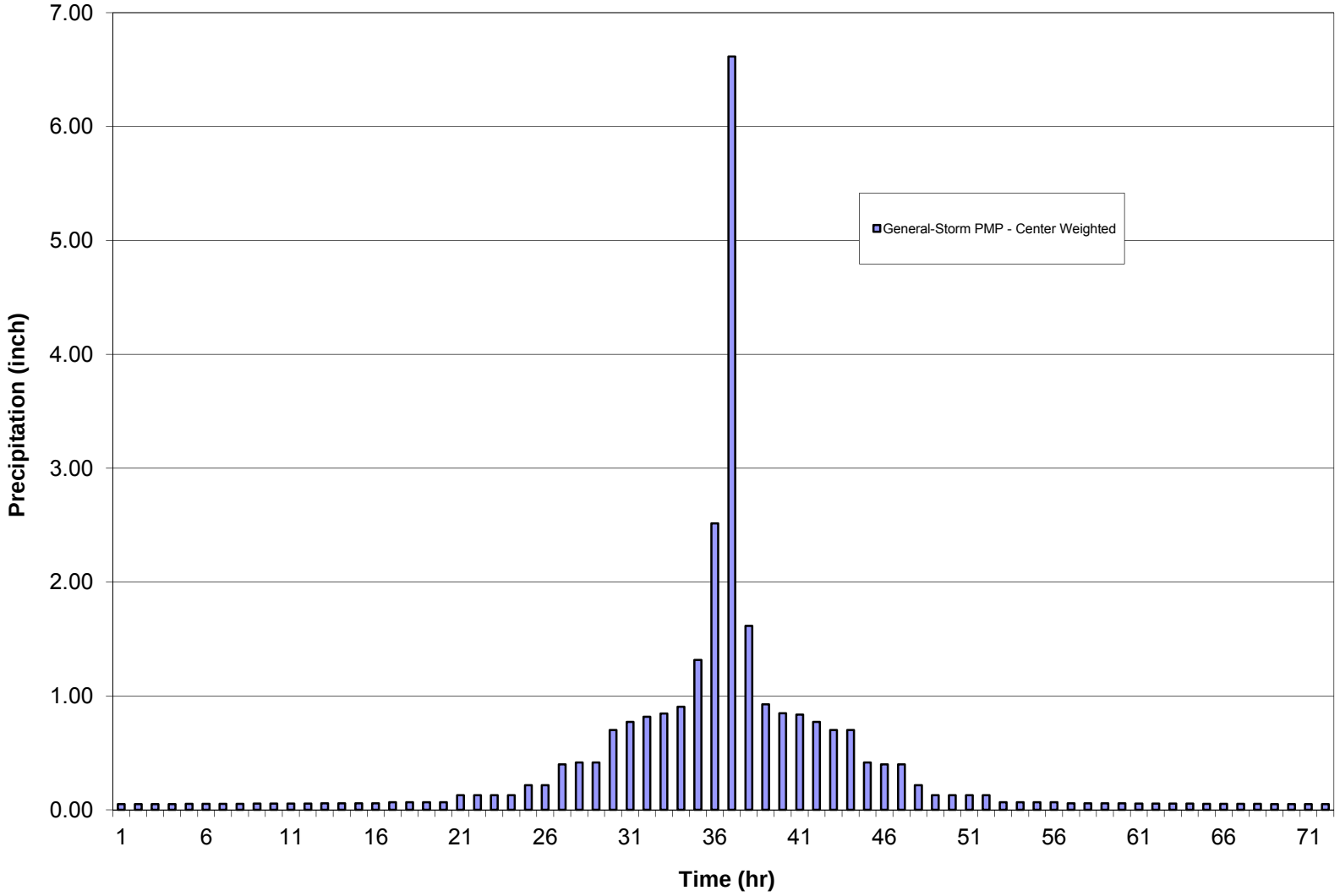
Figure 4, *Hydrologic Basin Response Guidelines*, G. Sabol, 2008

Table 9. For areas that are presently undeveloped but for which flood estimates are desired for future urbanized conditions, estimates of effective impervious area should be obtained based on regional planning and land-use zoning as determined by the local jurisdiction. Estimates of the effective impervious area for urbanizing areas should be selected from local guidance, if available, along with the general guidance that is provided in Table 9. For undeveloped areas, the effective impervious area is often 0 percent. However, in some watersheds there could be extensive rock outcrop or areas of water such as reservoirs that would increase the imperviousness of the watershed. Care must be exercised when estimating effective impervious area for rock outcrop. Often the rock outcrop is relatively small (in terms of the total drainage area) and is of isolated units surrounded by soils of relatively high infiltration capacities. Relatively small, isolated rock outcrop may not be effective impervious area because runoff must pass over pervious surfaces before reaching the point of discharge concentration. However, impervious areas that are not hydraulically directly connected may still be included in the estimate of sub-basin RTIMP if the intended result includes a conservative estimate of rainfall-runoff volume. Often, the RTIMP value for such areas is reduced by a factor determined using engineering judgment.

# Appendix A.3

## General-Storm Event Calculations

## General-Storm Distribution - LOWER SUBBASIN




Lower subbasin PMP DISTRIBUTIONS, 72 Cntr

## GENERAL STORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK

| DEPTH (inches) FOR DURATION HEADINGS (hrs) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 6 | 12 | 24 | 48 | 72 |
| 0.00 | 6.70 | 9.30 | 11.00 | 14.40 | 19.80 | 26.00 | 29.93 | 32.80 |
| 0.00 | 6.62 | 9.13 | 10.75 | 13.90 | 18.80 | 24.01 | 26.05 | 27.33 |

| | |
|---|---|
| Total Drainage Area = | 0.9 |
| 72-hr PMP (before losses, inch) = | 32.80 |
| HSG-Adjusted 72-hr Excess Rainfall (inch) = | 27.33 |
| HSG-Based Distributed Losses (inch) = | 5.47 |

HSG ADJUSTMENTS (HEC LOSS RATE = ZERO) OR ENTER ZERO LOSS RATES (or 5 zero areas) HERE

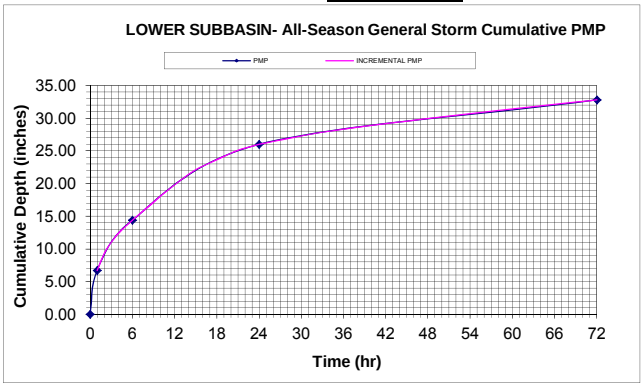
| HSG A | HSG B | HSG C | HSG D | IM-PERM-EABLE | UN-KNOWN | |
|---|---|---|---|---|---|---|
| 0.00% | 55.30% | 0.07% | 44.58% | 0.05% | 0.00% | <== % OF SUBBASIN AREA |
| 0.300 | 0.150 | 0.050 | 0.000 | 0.00 | 0.083 | <== ASSIGNED LOSS RATE (inches/hr) |

| TIME (hr) | CUM DEPTH (inch) |
|---|---|
| 0 | 0.00 |
| 1 | 6.70 |
| 6 | 14.40 |
| 24 | 26.00 |
| 72 | 32.80 |

*FILL IN BLUE FROM GRAPH; SMOOTH HIGHLIGHTS

**1-HR TIME STEP**

| TIME (hr) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | HSG ADJUSTED INC. DEPTH (inch) | CENTER-WEIGHTED PMP (inches) | 2-THIRDS WEIGHTED PMP Peak at Hour 48 (inches) | FERC/ HMR 59 6-HR MID-END WEIGHTED (inches) | USBR Flood Hydrgy Manual (inches) |
|---|---|---|---|---|---|---|---|
| 1 | 6.70 | 6.70 | 6.62 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 2 | 9.3 | 2.60 | 2.52 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 3 | 11.0 | 1.70 | 1.62 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 4 | 12.4 | 1.40 | 1.32 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 5 | 13.4 | 1.01 | 0.93 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 6 | 14.40 | 0.99 | 0.91 | 0.05 | 0.05 | 0.0506 | 0.05 |
| 7 | 15.3 | 0.93 | 0.85 | 0.05 | 0.05 | 0.0536 | 0.05 |
| 8 | 16.3 | 0.93 | 0.85 | 0.05 | 0.05 | 0.0536 | 0.05 |
| 9 | 17.2 | 0.92 | 0.84 | 0.06 | 0.05 | 0.0536 | 0.05 |
| 10 | 18.1 | 0.90 | 0.82 | 0.06 | 0.05 | 0.0536 | 0.05 |
| 11 | 18.9 | 0.86 | 0.77 | 0.06 | 0.05 | 0.0559 | 0.06 |
| 12 | 19.80 | 0.86 | 0.77 | 0.06 | 0.05 | 0.0559 | 0.06 |
| 13 | 20.58 | 0.78 | 0.70 | 0.06 | 0.05 | 0.0571 | 0.06 |
| 14 | 21.37 | 0.78 | 0.70 | 0.06 | 0.05 | 0.0571 | 0.06 |
| 15 | 22.1 | 0.78 | 0.70 | 0.06 | 0.05 | 0.0571 | 0.06 |
| 16 | 22.65 | 0.50 | 0.42 | 0.06 | 0.05 | 0.0571 | 0.06 |
| 17 | 23.15 | 0.50 | 0.42 | 0.07 | 0.06 | 0.0571 | 0.06 |
| 18 | 23.6 | 0.50 | 0.42 | 0.07 | 0.06 | 0.0571 | 0.06 |
| 19 | 24.13 | 0.48 | 0.40 | 0.07 | 0.06 | 0.0683 | 0.06 |
| 20 | 24.62 | 0.48 | 0.40 | 0.07 | 0.06 | 0.0683 | 0.06 |
| 21 | 25.1 | 0.48 | 0.40 | 0.13 | 0.06 | 0.0683 | 0.06 |
| 22 | 25.40 | 0.30 | 0.22 | 0.13 | 0.06 | 0.0683 | 0.07 |
| 23 | 25.70 | 0.30 | 0.22 | 0.13 | 0.06 | 0.1295 | 0.07 |
| 24 | 26.00 | 0.30 | 0.22 | 0.13 | 0.06 | 0.1295 | 0.07 |
| 25 | 26.21 | 0.21 | 0.13 | 0.22 | 0.06 | 0.2170 | 0.07 |
| 26 | 26.43 | 0.21 | 0.13 | 0.22 | 0.06 | 0.2170 | 0.07 |
| 27 | 26.64 | 0.21 | 0.13 | 0.40 | 0.06 | 0.2170 | 0.13 |
| 28 | 26.85 | 0.21 | 0.13 | 0.42 | 0.06 | 0.4003 | 0.13 |
| 29 | 27.06 | 0.21 | 0.13 | 0.42 | 0.07 | 0.4003 | 0.13 |
| 30 | 27.28 | 0.21 | 0.13 | 0.70 | 0.07 | 0.4003 | 0.13 |
| 31 | 27.49 | 0.21 | 0.13 | 0.77 | 0.07 | 0.7726 | 0.13 |
| 32 | 27.7 | 0.21 | 0.13 | 0.82 | 0.07 | 0.7730 | 0.22 |
| 33 | 27.85 | 0.15 | 0.07 | 0.85 | 0.13 | 0.8191 | 0.22 |
| 34 | 28.00 | 0.15 | 0.07 | 0.91 | 0.13 | 0.8382 | 0.40 |
| 35 | 28.15 | 0.15 | 0.07 | 1.32 | 0.13 | 0.8475 | 0.40 |
| 36 | 28.31 | 0.15 | 0.07 | 2.52 | 0.13 | 0.8500 | 0.42 |
| 37 | 28.46 | 0.15 | 0.07 | 6.62 | 0.22 | 0.9072 | 0.42 |
| 38 | 28.61 | 0.15 | 0.07 | 1.62 | 0.40 | 0.9269 | 0.70 |
| 39 | 28.76 | 0.15 | 0.07 | 0.93 | 0.40 | 1.3170 | 0.70 |
| 40 | 28.9 | 0.15 | 0.07 | 0.85 | 0.42 | 1.6170 | 0.77 |
| 41 | 29.04 | 0.13 | 0.06 | 0.84 | 0.70 | 2.5170 | 0.77 |
| 42 | 29.17 | 0.13 | 0.06 | 0.77 | 0.70 | 6.6170 | 0.84 |
| 43 | 29.29 | 0.13 | 0.06 | 0.70 | 0.77 | 0.7009 | 0.85 |
| 44 | 29.42 | 0.13 | 0.06 | 0.70 | 0.84 | 0.7009 | 0.91 |
| 45 | 29.55 | 0.13 | 0.06 | 0.42 | 0.85 | 0.7009 | 0.93 |
| 46 | 29.68 | 0.13 | 0.06 | 0.40 | 0.93 | 0.4170 | 1.62 |
| 47 | 29.81 | 0.13 | 0.06 | 0.40 | 1.62 | 0.4170 | 2.52 |
| 48 | 29.93 | 0.13 | 0.06 | 0.22 | 6.62 | 0.4170 | 6.62 |
| 49 | 30.06 | 0.13 | 0.06 | 0.13 | 2.52 | 0.1295 | 1.32 |
| 50 | 30.18 | 0.13 | 0.06 | 0.13 | 1.32 | 0.1295 | 0.85 |
| 51 | 30.31 | 0.13 | 0.06 | 0.13 | 0.91 | 0.1295 | 0.82 |
| 52 | 30.43 | 0.13 | 0.06 | 0.13 | 0.85 | 0.1295 | 0.70 |
| 53 | 30.56 | 0.13 | 0.06 | 0.07 | 0.82 | 0.1295 | 0.42 |
| 54 | 30.68 | 0.13 | 0.06 | 0.07 | 0.77 | 0.1295 | 0.40 |
| 55 | 30.81 | 0.13 | 0.06 | 0.07 | 0.70 | 0.0683 | 0.22 |
| 56 | 30.9 | 0.13 | 0.06 | 0.07 | 0.42 | 0.0683 | 0.13 |
| 57 | 31.05 | 0.12 | 0.05 | 0.06 | 0.42 | 0.0683 | 0.13 |
| 58 | 31.17 | 0.12 | 0.05 | 0.06 | 0.40 | 0.0683 | 0.13 |
| 59 | 31.29 | 0.12 | 0.05 | 0.06 | 0.22 | 0.0571 | 0.07 |
| 60 | 31.41 | 0.12 | 0.05 | 0.06 | 0.22 | 0.0571 | 0.07 |
| 61 | 31.53 | 0.12 | 0.05 | 0.06 | 0.13 | 0.0559 | 0.07 |
| 62 | 31.65 | 0.12 | 0.05 | 0.06 | 0.13 | 0.0559 | 0.06 |
| 63 | 31.77 | 0.12 | 0.05 | 0.06 | 0.13 | 0.0559 | 0.06 |
| 64 | 31.9 | 0.12 | 0.05 | 0.06 | 0.13 | 0.0559 | 0.06 |
| 65 | 32.01 | 0.11 | 0.05 | 0.05 | 0.07 | 0.0559 | 0.06 |
| 66 | 32.12 | 0.11 | 0.05 | 0.05 | 0.07 | 0.0559 | 0.06 |
| 67 | 32.23 | 0.11 | 0.05 | 0.05 | 0.07 | 0.0536 | 0.05 |
| 68 | 32.35 | 0.11 | 0.05 | 0.05 | 0.07 | 0.0536 | 0.05 |
| 69 | 32.46 | 0.11 | 0.05 | 0.05 | 0.06 | 0.0536 | 0.05 |
| 70 | 32.57 | 0.11 | 0.05 | 0.05 | 0.06 | 0.0536 | 0.05 |
| 71 | 32.69 | 0.11 | 0.05 | 0.05 | 0.06 | 0.0506 | 0.05 |
| 72 | 32.80 | 0.11 | 0.05 | 0.05 | 0.06 | 0.0506 | 0.05 |
| *96* | *36.427* | | | | | | |



**Project Name:** **Lower Beaver Brook Dam and Reservoir**
**Client:** **Lookout Mountain Water District**
**Date:** **9/11/2014**

**Objective:** Estimate PMP for the Lower Subbasin for Lower Beaver Brook Dam

**Region:** Generally in the central part of Colorado, located approximately 7.1 miles northwest of Evergreen, Colorado.

**References:** Hydrometeorological Report No. 55A

## GENERAL STORM PMP - HMR No. 55A - Lower Subbasin

**STEP 1: Subbasin location and area**

**Location:**

**Upper Beaver Brook Dam Watershed**

North subbasin boundry: 39.706° N
South subbasin boudry: 39.692° N
East subbasin boundry: 105.407° W
West subbasin boundry: 105.437° W
**Subbasin Centroid: 39.6988° N, 105.42203° W**

**Subbasin Areas:**

| Name | Description | Area ($mi^2$) |
|---|---|---|
| Total Basin | SW to NE | 0.948 |

**Subbasin Boundary Drawing**

**STEP 2: Determination of 1, 6, 24, and 72 hour index PMP values**

| GENERAL STORM PMP INDEX VALUES | | |
|---|---|---|
| **PLATE** | **10 $mi^2$ DURATION** | **Precipitation (in) Single Basin** |
| IB | 1-hr | 6.70 |
| IIB | 6-hr | 14.40 |
| IIIB | 24-hr | 26.00 |
| IVB | 72-hr | 32.80 |

**STEP 3: Selection of appropriate subregion and subdivision**

| SUBREGION | | Percent of Subregion |
|---|---|---|
| **PLATE** | **REGION** | **Single Basin** |
| VB | Subregion C | 100.0 |

**STEP 4: Determination of area reduction factors**

**Reference:** Figure 11.11. --DAD relation, C orographic subunit.
(Contributing area is less than 10 $mi^2$ and no area reduction is allowed)

| Region | Aerial Reduction Factors | | | |
|---|---|---|---|---|
| | **1-hr** | **6-hr** | **24-hr** | **72-hr** |
| **Subregion C** | 100.0 | 100.0 | 100.0 | 100.0 |

**Project Name:** **Lower Beaver Brook Dam and Reservoir**
**Client:** **Lookout Mountain Water District**
**Date:** **9/11/2014**

**Objective:** Estimate PMP for the Lower Subbasin for Lower Beaver Brook Dam

**Region:** Generally in the central part of Colorado, located approximately 7.1 miles northwest of Evergreen, Colorado.

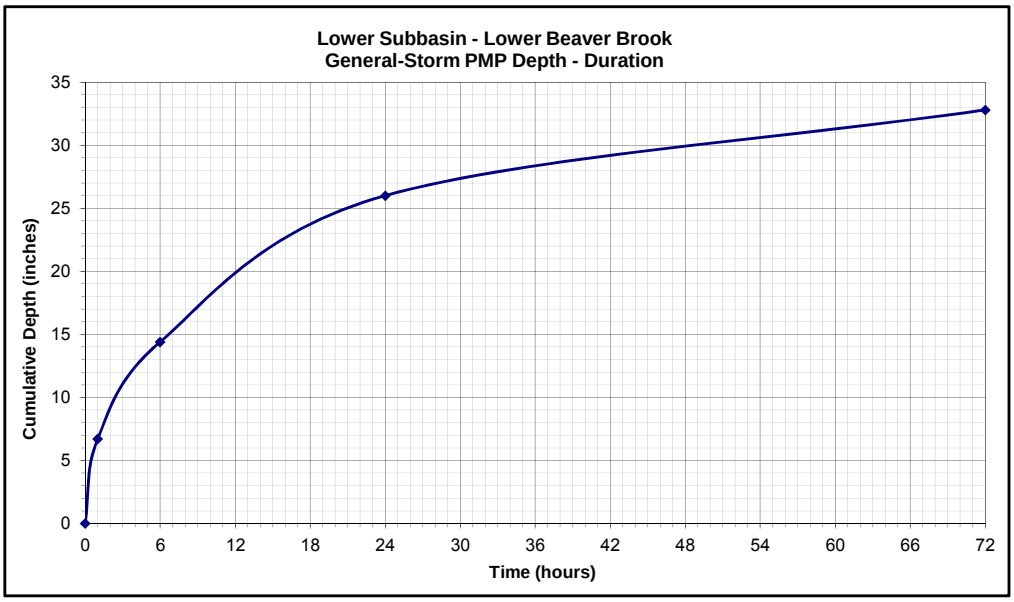
**References:** Hydrometeorological Report No. 55A

## GENERAL STORM PMP - HMR No. 55A - Lower Subbasin

**STEP 5: Compute average 1, 6, 24, and 72 hour PMP values**

| ADJUSTED STORM PMP INDEX VALUES | |
|---|---|
| **10 mi$^2$ DURATION** | **Single Basin** |
| 1-hr | 6.70 |
| 6-hr | 14.40 |
| 24-hr | 26.00 |
| 72-hr | 32.80 |

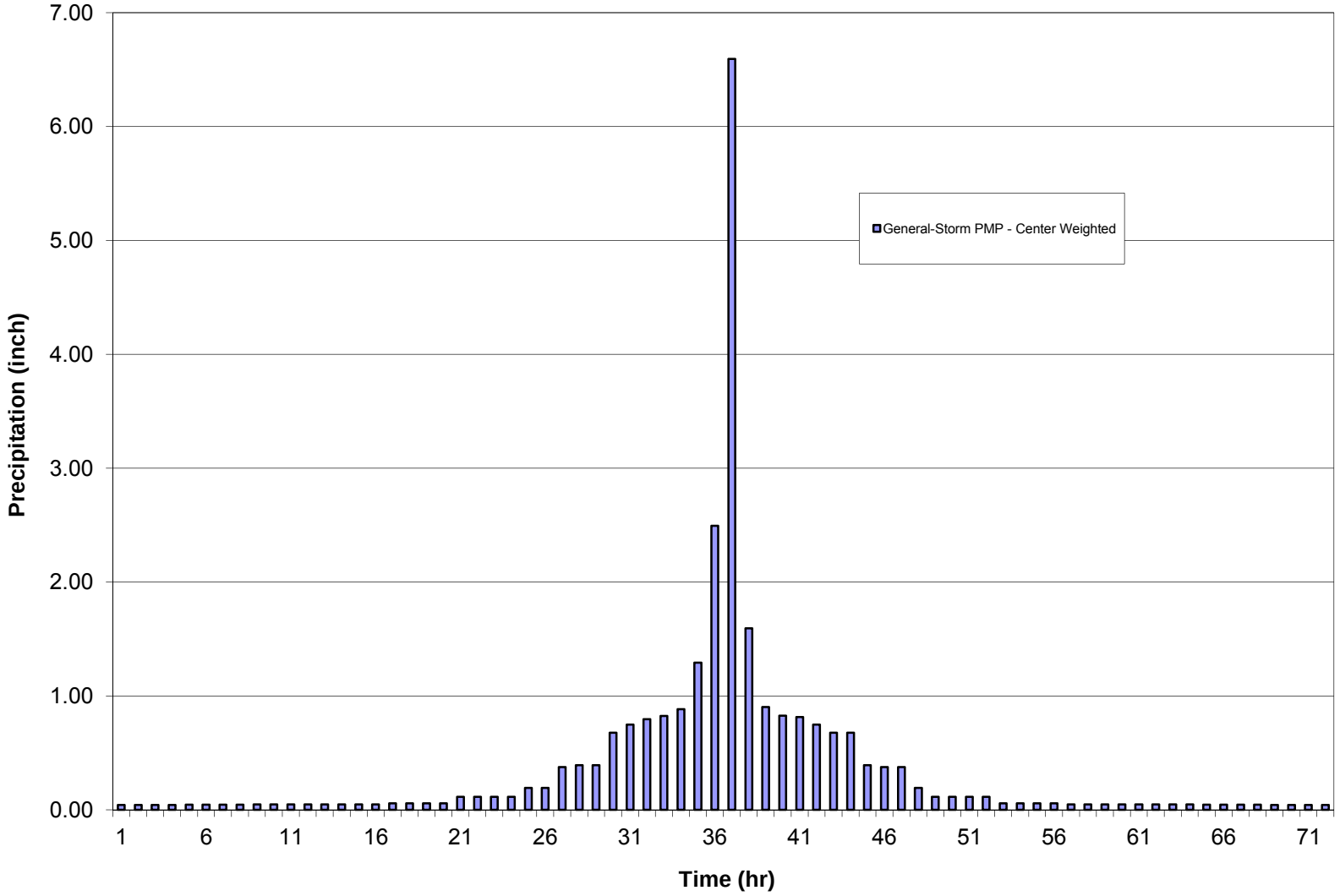
**STEP 6: Plot Depth-Duration curve**




**STEP 7: Interpolate intermediate durations**

**STEP 8: Determine incremental depths**

## General-Storm Distribution - Upper Subbasin




Upper subbasin PMP DISTRIBUTIONS, 72 Cntr

## GENERAL STORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK

| DEPTH (inches) FOR DURATION HEADINGS (hrs) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 0 | 1 | 2 | 3 | 6 | 12 | 24 | 48 | 72 |
| 0.00 | 6.70 | 9.30 | 11.00 | 14.40 | 19.80 | 26.00 | 29.93 | 32.80 |
| 0.00 | 6.59 | 9.09 | 10.68 | 13.76 | 18.52 | 23.45 | 25.24 | 26.33 |

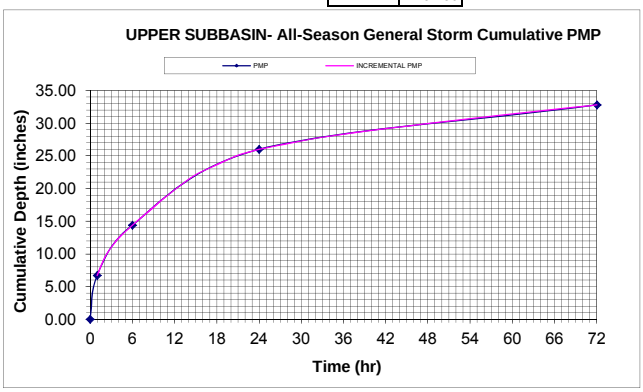
| | |
|---|---|
| Total Drainage Area = | 6.5 |
| 72-hr PMP (before losses, inch) = | 32.80 |
| HSG-Adjusted 72-hr Excess Rainfall (inch) = | 26.33 |
| HSG-Based Distributed Losses (inch) = | 6.47 |

HSG ADJUSTMENTS (HEC LOSS RATE = ZERO) OR ENTER ZERO LOSS RATES (or 5 zero areas) HERE

| HSG A | HSG B | HSG C | HSG D | IM-PERM-EABLE | UN-KNOWN | |
|---|---|---|---|---|---|---|
| 9.46% | 50.00% | 5.53% | 34.77% | 0.24% | 0.00% | <== % OF SUBBASIN AREA |
| 0.300 | 0.150 | 0.050 | 0.000 | 0.00 | 0.106 | <== ASSIGNED LOSS RATE (inches/hr) |

| TIME (hr) | CUM DEPTH (inch) |
|---|---|
| 0 | 0.00 |
| 1 | 6.70 |
| 6 | 14.40 |
| 24 | 26.00 |
| 72 | 32.80 |

*FILL IN BLUE FROM GRAPH; SMOOTH HIGHLIGHTS




**1-HR TIME STEP**

| TIME (hr) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | HSG ADJUSTED INC. DEPTH (inch) | CENTER-WEIGHTED PMP (inches) | 2-THIRDS WEIGHTED PMP Peak at Hour 48 (inches) | FERC/ HMR 59 6-HR MID-END WEIGHTED (inches) | USBR Flood Hydrgy Manual (inches) |
|---|---|---|---|---|---|---|---|
| 1 | 6.70 | 6.70 | 6.59 | 0.04 | 0.04 | 0.0432 | 0.04 |
| 2 | 9.3 | 2.60 | 2.49 | 0.04 | 0.04 | 0.0432 | 0.04 |
| 3 | 11.0 | 1.70 | 1.59 | 0.04 | 0.04 | 0.0432 | 0.04 |
| 4 | 12.4 | 1.40 | 1.29 | 0.04 | 0.04 | 0.0432 | 0.04 |
| 5 | 13.4 | 1.01 | 0.90 | 0.05 | 0.04 | 0.0432 | 0.04 |
| 6 | 14.40 | 0.99 | 0.88 | 0.05 | 0.04 | 0.0432 | 0.05 |
| 7 | 15.3 | 0.93 | 0.83 | 0.05 | 0.04 | 0.0459 | 0.05 |
| 8 | 16.3 | 0.93 | 0.82 | 0.05 | 0.04 | 0.0459 | 0.05 |
| 9 | 17.2 | 0.92 | 0.82 | 0.05 | 0.05 | 0.0459 | 0.05 |
| 10 | 18.1 | 0.90 | 0.80 | 0.05 | 0.05 | 0.0459 | 0.05 |
| 11 | 18.9 | 0.86 | 0.75 | 0.05 | 0.05 | 0.0480 | 0.05 |
| 12 | 19.80 | 0.86 | 0.75 | 0.05 | 0.05 | 0.0480 | 0.05 |
| 13 | 20.58 | 0.78 | 0.68 | 0.05 | 0.05 | 0.0491 | 0.05 |
| 14 | 21.37 | 0.78 | 0.68 | 0.05 | 0.05 | 0.0491 | 0.05 |
| 15 | 22.1 | 0.78 | 0.68 | 0.05 | 0.05 | 0.0491 | 0.05 |
| 16 | 22.65 | 0.50 | 0.39 | 0.05 | 0.05 | 0.0491 | 0.05 |
| 17 | 23.15 | 0.50 | 0.39 | 0.06 | 0.05 | 0.0491 | 0.05 |
| 18 | 23.6 | 0.50 | 0.39 | 0.06 | 0.05 | 0.0491 | 0.05 |
| 19 | 24.13 | 0.48 | 0.38 | 0.06 | 0.05 | 0.0592 | 0.05 |
| 20 | 24.62 | 0.48 | 0.38 | 0.06 | 0.05 | 0.0592 | 0.05 |
| 21 | 25.1 | 0.48 | 0.38 | 0.11 | 0.05 | 0.0592 | 0.05 |
| 22 | 25.40 | 0.30 | 0.19 | 0.11 | 0.05 | 0.0592 | 0.06 |
| 23 | 25.70 | 0.30 | 0.19 | 0.11 | 0.05 | 0.1146 | 0.06 |
| 24 | 26.00 | 0.30 | 0.19 | 0.11 | 0.05 | 0.1146 | 0.06 |
| 25 | 26.21 | 0.21 | 0.11 | 0.19 | 0.05 | 0.1939 | 0.06 |
| 26 | 26.43 | 0.21 | 0.11 | 0.19 | 0.05 | 0.1939 | 0.06 |
| 27 | 26.64 | 0.21 | 0.11 | 0.38 | 0.05 | 0.1939 | 0.11 |
| 28 | 26.85 | 0.21 | 0.11 | 0.39 | 0.05 | 0.3772 | 0.11 |
| 29 | 27.06 | 0.21 | 0.11 | 0.39 | 0.06 | 0.3772 | 0.11 |
| 30 | 27.28 | 0.21 | 0.11 | 0.68 | 0.06 | 0.3772 | 0.11 |
| 31 | 27.49 | 0.21 | 0.11 | 0.75 | 0.06 | 0.7495 | 0.11 |
| 32 | 27.7 | 0.21 | 0.11 | 0.80 | 0.06 | 0.7498 | 0.19 |
| 33 | 27.85 | 0.15 | 0.06 | 0.82 | 0.11 | 0.7959 | 0.19 |
| 34 | 28.00 | 0.15 | 0.06 | 0.88 | 0.11 | 0.8150 | 0.38 |
| 35 | 28.15 | 0.15 | 0.06 | 1.29 | 0.11 | 0.8244 | 0.38 |
| 36 | 28.31 | 0.15 | 0.06 | 2.49 | 0.11 | 0.8268 | 0.39 |
| 37 | 28.46 | 0.15 | 0.06 | 6.59 | 0.19 | 0.8840 | 0.39 |
| 38 | 28.61 | 0.15 | 0.06 | 1.59 | 0.38 | 0.9037 | 0.68 |
| 39 | 28.76 | 0.15 | 0.06 | 0.90 | 0.38 | 1.2939 | 0.68 |
| 40 | 28.9 | 0.15 | 0.06 | 0.83 | 0.39 | 1.5939 | 0.75 |
| 41 | 29.04 | 0.13 | 0.05 | 0.82 | 0.68 | 2.4939 | 0.75 |
| 42 | 29.17 | 0.13 | 0.05 | 0.75 | 0.68 | 6.5939 | 0.82 |
| 43 | 29.29 | 0.13 | 0.05 | 0.68 | 0.75 | 0.6778 | 0.82 |
| 44 | 29.42 | 0.13 | 0.05 | 0.68 | 0.82 | 0.6778 | 0.88 |
| 45 | 29.55 | 0.13 | 0.05 | 0.39 | 0.83 | 0.6778 | 0.90 |
| 46 | 29.68 | 0.13 | 0.05 | 0.38 | 0.90 | 0.3939 | 1.59 |
| 47 | 29.81 | 0.13 | 0.05 | 0.38 | 1.59 | 0.3939 | 2.49 |
| 48 | 29.93 | 0.13 | 0.05 | 0.19 | 6.59 | 0.3939 | 6.59 |
| 49 | 30.06 | 0.13 | 0.05 | 0.11 | 2.49 | 0.1146 | 1.29 |
| 50 | 30.18 | 0.13 | 0.05 | 0.11 | 1.29 | 0.1146 | 0.83 |
| 51 | 30.31 | 0.13 | 0.05 | 0.11 | 0.88 | 0.1146 | 0.80 |
| 52 | 30.43 | 0.13 | 0.05 | 0.11 | 0.82 | 0.1146 | 0.68 |
| 53 | 30.56 | 0.13 | 0.05 | 0.06 | 0.80 | 0.1146 | 0.39 |
| 54 | 30.68 | 0.13 | 0.05 | 0.06 | 0.75 | 0.1146 | 0.38 |
| 55 | 30.81 | 0.13 | 0.05 | 0.06 | 0.68 | 0.0592 | 0.19 |
| 56 | 30.9 | 0.13 | 0.05 | 0.06 | 0.39 | 0.0592 | 0.11 |
| 57 | 31.05 | 0.12 | 0.05 | 0.05 | 0.39 | 0.0592 | 0.11 |
| 58 | 31.17 | 0.12 | 0.05 | 0.05 | 0.38 | 0.0592 | 0.11 |
| 59 | 31.29 | 0.12 | 0.05 | 0.05 | 0.19 | 0.0491 | 0.06 |
| 60 | 31.41 | 0.12 | 0.05 | 0.05 | 0.19 | 0.0491 | 0.06 |
| 61 | 31.53 | 0.12 | 0.05 | 0.05 | 0.11 | 0.0480 | 0.06 |
| 62 | 31.65 | 0.12 | 0.05 | 0.05 | 0.11 | 0.0480 | 0.05 |
| 63 | 31.77 | 0.12 | 0.05 | 0.05 | 0.11 | 0.0480 | 0.05 |
| 64 | 31.9 | 0.12 | 0.05 | 0.05 | 0.11 | 0.0480 | 0.05 |
| 65 | 32.01 | 0.11 | 0.04 | 0.05 | 0.06 | 0.0480 | 0.05 |
| 66 | 32.12 | 0.11 | 0.04 | 0.05 | 0.06 | 0.0480 | 0.05 |
| 67 | 32.23 | 0.11 | 0.04 | 0.05 | 0.06 | 0.0459 | 0.05 |
| 68 | 32.35 | 0.11 | 0.04 | 0.05 | 0.06 | 0.0459 | 0.05 |
| 69 | 32.46 | 0.11 | 0.04 | 0.04 | 0.05 | 0.0459 | 0.05 |
| 70 | 32.57 | 0.11 | 0.04 | 0.04 | 0.05 | 0.0459 | 0.04 |
| 71 | 32.69 | 0.11 | 0.04 | 0.04 | 0.05 | 0.0432 | 0.04 |
| 72 | 32.80 | 0.11 | 0.04 | 0.04 | 0.05 | 0.0432 | 0.04 |
| *96* | *36.427* | | | | | | |

**Project Name:** **Lower Beaver Brook Dam and Reservoir**
**Client:** **Lookout Mountain Water District**
**Date:** **9/10/2014**

**Objective:** Estimate PMP for the upper subbasin for Lower Beaver Brook Dam

**Region:** Generally in the central part of Colorado, located approximately 7.4 miles northwest of Evergreen, Colorado.

**References:** Hydrometeorological Report No. 55A

## GENERAL STORM PMP - HMR No. 55A - Upper Subbasin

**STEP 1: Subbasin location and area**

**Location:**

**Upper Subbasin Watershed**

North subbasin boundry: 39.7078° N
South subbasin boudry: 39.667° N
East subbasin boundry: 105.422° W
West subbasin boundry: 105.496° W
**Subbasin Centroid: 39.6865° N, 105.4586° W**

**Subbasin Areas:**

| Name | Description | Area ($mi^2$) |
|---|---|---|
| Total Basin | W to E | 6.503 |

**Subbasin Boundary Drawing**

**STEP 2: Determination of 1, 6, 24, and 72 hour index PMP values**

| GENERAL STORM PMP INDEX VALUES | | |
|---|---|---|
| PLATE | 10 $mi^2$ DURATION | Precipitation (in) Single Basin |
| IB | 1-hr | 6.70 |
| IIB | 6-hr | 14.40 |
| IIIB | 24-hr | 26.00 |
| IVB | 72-hr | 32.80 |

**STEP 3: Selection of appropriate subregion and subdivision**

| SUBREGION | | Percent of Subregion |
|---|---|---|
| PLATE | REGION | Single Basin |
| VB | Subregion C | 100.0 |

**STEP 4: Determination of area reduction factors**

**Reference:** Figure 11.11. --DAD relation, C orographic subunit.
(Contributing area is less than 10 $mi^2$ and no area reduction is allowed)

| Region | Aerial Reduction Factors | | | |
|---|---|---|---|---|
| | 1-hr | 6-hr | 24-hr | 72-hr |
| Subregion C | 100.0 | 100.0 | 100.0 | 100.0 |

**Project Name:** **Lower Beaver Brook Dam and Reservoir**
**Client:** **Lookout Mountain Water District**
**Date:** **9/10/2014**

**Objective:** Estimate PMP for the upper subbasin for Lower Beaver Brook Dam

**Region:** Generally in the central part of Colorado, located approximately 7.4 miles northwest of Evergreen, Colorado.

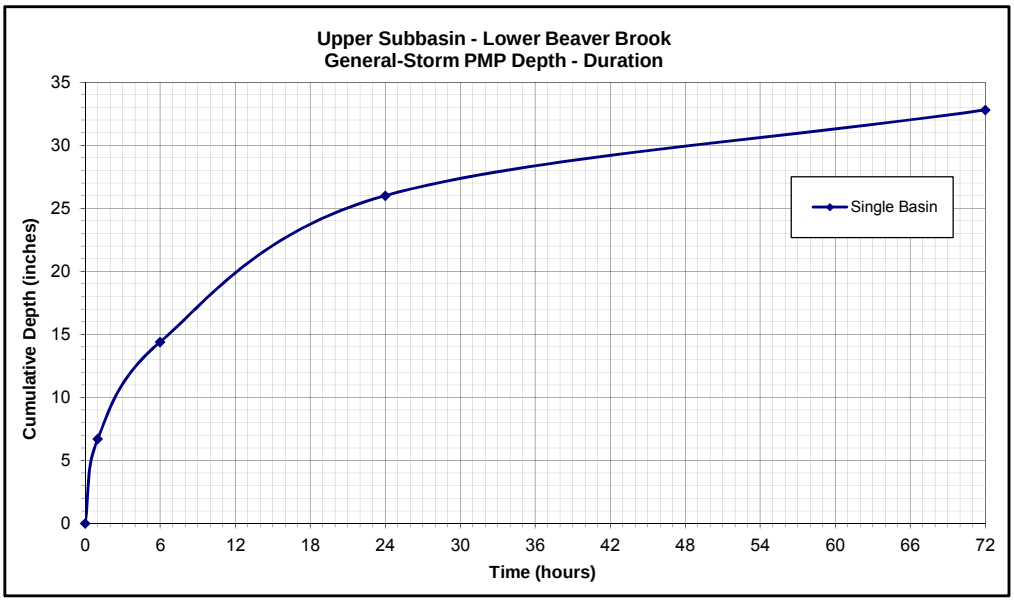
**References:** Hydrometeorological Report No. 55A

## GENERAL STORM PMP - HMR No. 55A - Upper Subbasin

**STEP 5: Compute average 1, 6, 24, and 72 hour PMP values**

| ADJUSTED STORM PMP INDEX VALUES | |
|---|---|
| **10 mi$^2$ DURATION** | **Single Basin** |
| 1-hr | 6.70 |
| 6-hr | 14.40 |
| 24-hr | 26.00 |
| 72-hr | 32.80 |

**STEP 6: Plot Depth-Duration curve**




**STEP 7: Interpolate intermediate durations**

**STEP 8: Determine incremental depths**

# Appendix A.4

## Local-Storm Event Calculations

## LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK

| DEPTH (inches) FOR DURATION HEADINGS (hrs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 |
| 0.00 | 4.25 | 5.72 | 6.41 | 6.90 | 8.09 | 8.68 | 9.14 | 9.53 | 9.86 |
| 0.00 | 4.22 | 5.67 | 6.33 | 6.79 | 7.88 | 8.36 | 8.71 | 9.00 | 9.22 |

HSG ADJUSTMENTS (HEC LOSS RATE = ZERO) OR ENTER ZERO LOSS RATES (or 5 zero areas) HERE

| HSG A | HSG B | HSG C | HSG D | IM-PERM-EABLE | UN-KNOWN | |
|---|---|---|---|---|---|---|
| 9.46% | 50.00% | 5.53% | 34.77% | 0.24% | 0.00% | <== % OF SUBBASIN AREA |
| 0.300 | 0.150 | 0.050 | 0.000 | 0.00 | 0.106148 | <== ASSIGNED LOSS RATE (inches/hr) |

*FILL IN BLUE FROM GRAPH

Conversion (hours to minutes) = 60

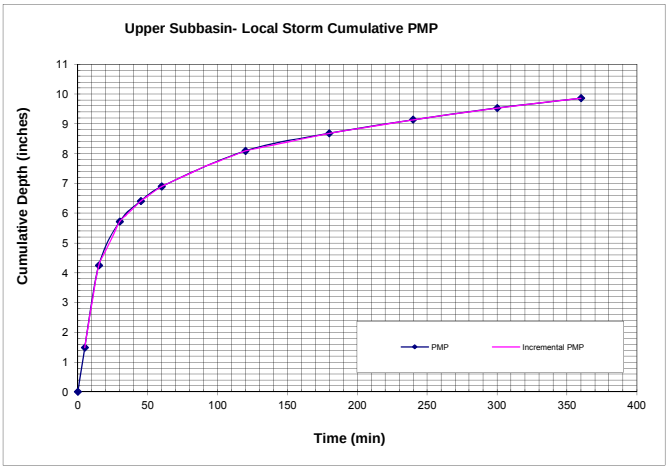
**5-MINUTE TIME STEP**

| TIME (min) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | HSG ADJUSTED INC. DEPTH [FRONT-WEIGHTED] (inch) | CENTER-WEIGHTED PMP (inches) | HMR 49, 55A (inches) |
|---|---|---|---|---|---|
| 5 | 1.49 | 1.49 | 1.48 | 0.018 | 0.018 |
| 10 | 2.96 | 1.47 | 1.46 | 0.018 | 0.018 |
| 15 | 4.25 | 1.29 | 1.28 | 0.018 | 0.018 |
| 20 | 4.74 | 0.49 | 0.48 | 0.018 | 0.018 |
| 25 | 5.23 | 0.49 | 0.48 | 0.018 | 0.018 |
| 30 | 5.72 | 0.49 | 0.48 | 0.018 | 0.018 |
| 35 | 5.95 | 0.23 | 0.22 | 0.024 | 0.018 |
| 40 | 6.18 | 0.23 | 0.22 | 0.024 | 0.018 |
| 45 | 6.41 | 0.23 | 0.22 | 0.024 | 0.018 |
| 50 | 6.57 | 0.16 | 0.15 | 0.024 | 0.018 |
| 55 | 6.73 | 0.16 | 0.15 | 0.024 | 0.018 |
| 60 | 6.90 | 0.16 | 0.15 | 0.024 | 0.018 |
| 65 | 7.01 | 0.11 | 0.10 | 0.029 | 0.029 |
| 70 | 7.11 | 0.11 | 0.10 | 0.029 | 0.029 |
| 75 | 7.22 | 0.11 | 0.10 | 0.029 | 0.029 |
| 80 | 7.33 | 0.11 | 0.10 | 0.029 | 0.029 |
| 85 | 7.44 | 0.11 | 0.10 | 0.029 | 0.029 |
| 90 | 7.55 | 0.11 | 0.10 | 0.029 | 0.029 |
| 95 | 7.64 | 0.09 | 0.08 | 0.040 | 0.029 |
| 100 | 7.73 | 0.09 | 0.08 | 0.040 | 0.029 |
| 105 | 7.82 | 0.09 | 0.08 | 0.040 | 0.029 |
| 110 | 7.91 | 0.09 | 0.08 | 0.040 | 0.029 |
| 115 | 8.00 | 0.09 | 0.08 | 0.040 | 0.029 |
| 120 | 8.09 | 0.09 | 0.08 | 0.040 | 0.029 |
| 125 | 8.14 | 0.05 | 0.04 | 0.082 | 0.082 |
| 130 | 8.19 | 0.05 | 0.04 | 0.082 | 0.082 |
| 135 | 8.24 | 0.05 | 0.04 | 0.082 | 0.082 |
| 140 | 8.29 | 0.05 | 0.04 | 0.100 | 0.082 |
| 145 | 8.34 | 0.05 | 0.04 | 0.100 | 0.082 |
| 150 | 8.39 | 0.05 | 0.04 | 0.100 | 0.082 |
| 155 | 8.44 | 0.05 | 0.04 | 0.154 | 0.100 |
| 160 | 8.49 | 0.05 | 0.04 | 0.154 | 0.100 |
| 165 | 8.53 | 0.05 | 0.04 | 0.219 | 0.100 |
| 170 | 8.58 | 0.05 | 0.04 | 0.482 | 0.100 |
| 175 | 8.63 | 0.05 | 0.04 | 0.482 | 0.100 |
| 180 | 8.68 | 0.05 | 0.04 | 1.464 | 0.100 |
| 185 | 8.72 | 0.04 | 0.03 | 1.478 | 1.478 |
| 190 | 8.76 | 0.04 | 0.03 | 1.279 | 1.464 |
| 195 | 8.80 | 0.04 | 0.03 | 0.482 | 1.279 |
| 200 | 8.83 | 0.04 | 0.03 | 0.219 | 0.482 |
| 205 | 8.87 | 0.04 | 0.03 | 0.219 | 0.482 |
| 210 | 8.91 | 0.04 | 0.03 | 0.154 | 0.482 |
| 215 | 8.95 | 0.04 | 0.03 | 0.100 | 0.219 |
| 220 | 8.99 | 0.04 | 0.03 | 0.100 | 0.219 |
| 225 | 9.02 | 0.04 | 0.03 | 0.100 | 0.219 |
| 230 | 9.06 | 0.04 | 0.03 | 0.082 | 0.154 |
| 235 | 9.10 | 0.04 | 0.03 | 0.082 | 0.154 |
| 240 | 9.14 | 0.04 | 0.03 | 0.082 | 0.154 |
| 245 | 9.17 | 0.03 | 0.02 | 0.040 | 0.040 |
| 250 | 9.20 | 0.03 | 0.02 | 0.040 | 0.040 |
| 255 | 9.24 | 0.03 | 0.02 | 0.040 | 0.040 |
| 260 | 9.27 | 0.03 | 0.02 | 0.040 | 0.040 |
| 265 | 9.30 | 0.03 | 0.02 | 0.040 | 0.040 |
| 270 | 9.33 | 0.03 | 0.02 | 0.040 | 0.040 |
| 275 | 9.37 | 0.03 | 0.02 | 0.029 | 0.040 |
| 280 | 9.40 | 0.03 | 0.02 | 0.029 | 0.040 |
| 285 | 9.43 | 0.03 | 0.02 | 0.029 | 0.040 |
| 290 | 9.47 | 0.03 | 0.02 | 0.029 | 0.040 |
| 295 | 9.50 | 0.03 | 0.02 | 0.029 | 0.040 |
| 300 | 9.53 | 0.03 | 0.02 | 0.029 | 0.040 |
| 305 | 9.56 | 0.03 | 0.02 | 0.024 | 0.024 |
| 310 | 9.59 | 0.03 | 0.02 | 0.024 | 0.024 |
| 315 | 9.61 | 0.03 | 0.02 | 0.024 | 0.024 |
| 320 | 9.64 | 0.03 | 0.02 | 0.024 | 0.024 |
| 325 | 9.67 | 0.03 | 0.02 | 0.024 | 0.024 |
| 330 | 9.69 | 0.03 | 0.02 | 0.024 | 0.024 |
| 335 | 9.72 | 0.03 | 0.02 | 0.018 | 0.024 |
| 340 | 9.75 | 0.03 | 0.02 | 0.018 | 0.024 |
| 345 | 9.78 | 0.03 | 0.02 | 0.018 | 0.024 |
| 350 | 9.80 | 0.03 | 0.02 | 0.018 | 0.024 |
| 355 | 9.83 | 0.03 | 0.02 | 0.018 | 0.024 |
| 360 | 9.86 | 0.03 | 0.02 | 0.018 | 0.024 |

**15-MINUTE TIME STEP**

| TIME (min) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | INC. DEPTH [FRONT WEIGHTED] (inch) |
|---|---|---|---|
| 15 | 4.25 | 4.25 | 4.22 |
| 30 | 5.72 | 1.47 | 1.45 |
| 45 | 6.41 | 0.68 | 0.66 |
| 60 | 6.90 | 0.49 | 0.46 |
| 75 | 7.223 | 0.33 | 0.30 |
| 90 | 7.55 | 0.33 | 0.30 |
| 105 | 7.822 | 0.27 | 0.25 |
| 120 | 8.09 | 0.27 | 0.25 |
| 135 | 8.241 | 0.15 | 0.12 |
| 150 | 8.388 | 0.15 | 0.12 |
| 165 | 8.535 | 0.15 | 0.12 |
| 180 | 8.68 | 0.15 | 0.12 |
| 195 | 8.796 | 0.11 | 0.09 |
| 210 | 8.910 | 0.11 | 0.09 |
| 225 | 9.024 | 0.11 | 0.09 |
| 240 | 9.14 | 0.11 | 0.09 |
| 255 | 9.237 | 0.10 | 0.07 |
| 270 | 9.335 | 0.10 | 0.07 |
| 285 | 9.433 | 0.10 | 0.07 |
| 300 | 9.53 | 0.10 | 0.07 |
| 315 | 9.613 | 0.08 | 0.05 |
| 330 | 9.694 | 0.08 | 0.05 |
| 345 | 9.776 | 0.08 | 0.05 |
| 360 | 9.86 | 0.08 | 0.05 |

| (min) | DEPTH |
|---|---|
| 0 | 0 |
| 5 | 1.49 |
| 15 | 4.24797 |
| 30 | 5.72129 |
| 45 | 6.40602 |
| 60 | 6.89605 |
| 120 | 8.09353 |
| 180 | 8.68172 |
| 240 | 9.13848 |
| 300 | 9.53115 |
| 360 | 9.8573 |




WILL AUTOMATICALLY COPY TO "PMP FOR HEC1" WORKSHEET

LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK
* (15-min incr.; FRONT-WEIGHTED, HMR 59; EXCESS RAINFALL ONLY)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 4.221 | 1.447 | 0.658 | 0.463 | 0.300 | 0.300 | 0.245 | 0.245 | 0.121 | 0.121 |
| PI | 0.121 | 0.121 | 0.088 | 0.088 | 0.088 | 0.088 | 0.072 | 0.072 | 0.072 | 0.072 |
| PI | 0.055 | 0.055 | 0.055 | 0.055 | 0.0 | | | | | |

LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; FRONT-WEIGHTED, HMR 59; EXCESS RAINFALL ONLY)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 1.478 | 1.464 | 1.279 | 0.482 | 0.482 | 0.482 | 0.219 | 0.219 | 0.219 | 0.154 |
| PI | 0.154 | 0.154 | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.082 | 0.082 |
| PI | 0.082 | 0.082 | 0.082 | 0.082 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 |
| PI | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.029 | 0.029 | 0.029 | 0.029 |
| PI | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.024 | 0.024 |
| PI | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 |
| PI | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 |
| PI | 0.018 | 0.018 | 0.0 | | | | | | | |

LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; CENTER-WEIGHTED; EXCESS RAINFALL ONLY)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.024 | 0.024 | 0.024 | 0.024 |
| PI | 0.024 | 0.024 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.040 | 0.040 |
| PI | 0.040 | 0.040 | 0.040 | 0.040 | 0.082 | 0.082 | 0.082 | 0.100 | 0.100 | 0.100 |
| PI | 0.154 | 0.154 | 0.219 | 0.482 | 0.482 | 1.464 | 1.478 | 1.279 | 0.482 | 0.219 |
| PI | 0.219 | 0.154 | 0.100 | 0.100 | 0.100 | 0.082 | 0.082 | 0.082 | 0.040 | 0.040 |
| PI | 0.040 | 0.040 | 0.040 | 0.040 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 |
| PI | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.018 | 0.018 | 0.018 | 0.018 |
| PI | 0.018 | 0.018 | 0.0 | | | | | | | |

LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; HMR 49/55A - UNIQUE WEIGHTING; EXCESS RAINFALL ONLY)

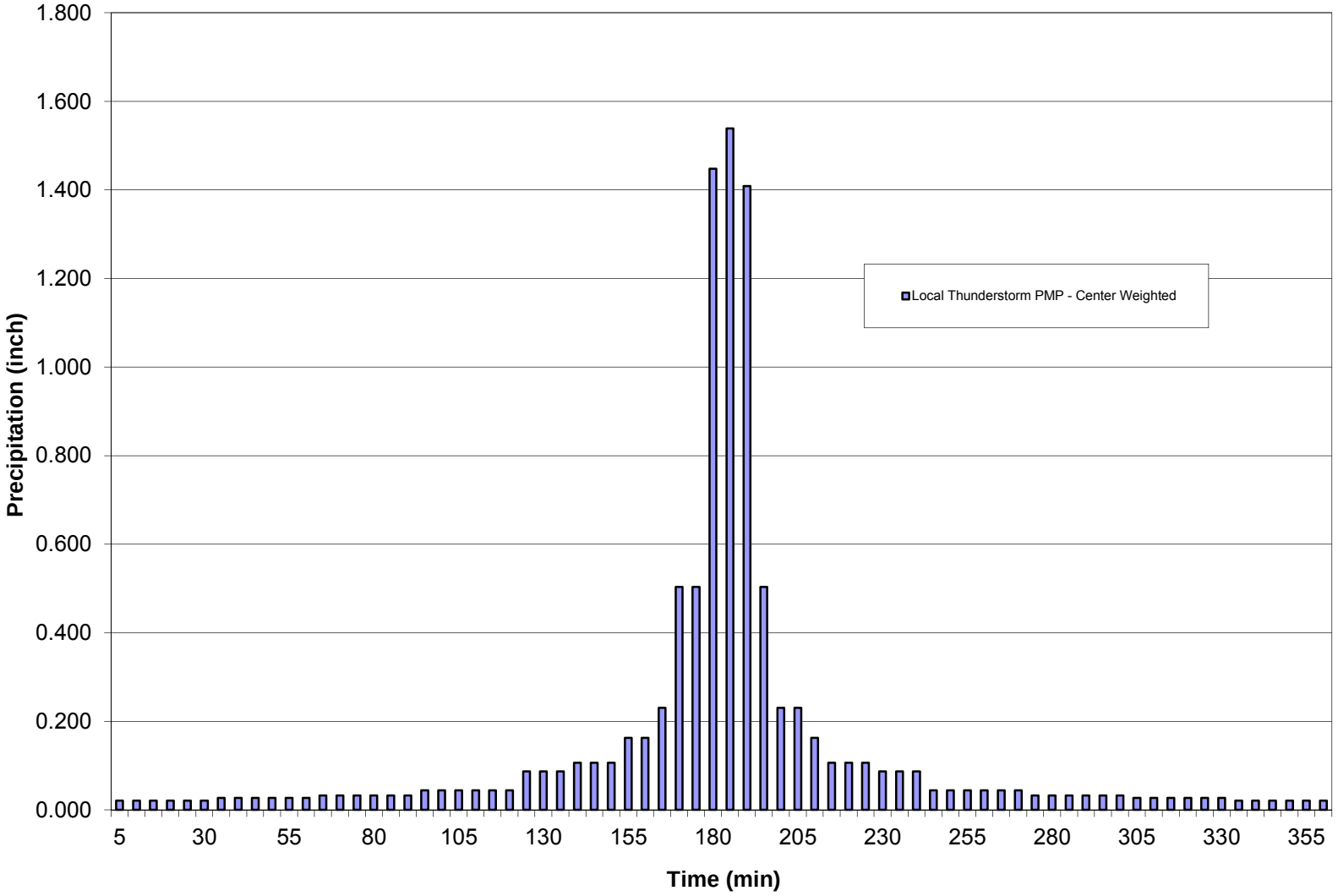
| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 | 0.018 |
| PI | 0.018 | 0.018 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 | 0.029 |
| PI | 0.029 | 0.029 | 0.029 | 0.029 | 0.082 | 0.082 | 0.082 | 0.082 | 0.082 | 0.082 |
| PI | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 0.100 | 1.478 | 1.464 | 1.279 | 0.482 |
| PI | 0.482 | 0.482 | 0.219 | 0.219 | 0.219 | 0.154 | 0.154 | 0.154 | 0.040 | 0.040 |
| PI | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 | 0.040 |
| PI | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 | 0.024 |
| PI | 0.024 | 0.024 | 0.0 | | | | | | | |

LESS THAN 1 HOUR FROM p. II-7 of SEO Project Review Guide

| | Blank | Area F | 5-min | 15-min | 1-hr | 2-hr | 3-hr | 6-hr | 12-hr | 24-hr | )6-h |
|---|---|---|---|---|---|---|---|---|---|---|---|
| PH | | 0.01 | 1.912 | 4.25 | 6.90 | 8.09 | 8.68 | 9.86 | | | |

LOCAL THUNDERSTORM PMP - UPPER SUBBASIN FOR LOWER BEAVER BROOK
* (CENTER-WT, CO SEO Guidelines HMR 49/55A, IT/IN t-step; EXCESS RAINFALL ONLY)

## Local-Storm Distribution - Lower Subbasin




Lower subbasin PMP DISTRIBUTIONS, 6 Cntr

## LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK

| DEPTH (inches) FOR DURATION HEADINGS (hrs) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 0 | 0.25 | 0.5 | 0.75 | 1 | 2 | 3 | 4 | 5 | 6 |
| 0.00 | 4.42 | 5.95 | 6.66 | 7.17 | 8.41 | 9.02 | 9.50 | 9.91 | 10.25 |
| 0.00 | 4.39 | 5.91 | 6.60 | 7.09 | 8.25 | 8.78 | 9.17 | 9.49 | 9.75 |

**HSG ADJUSTMENTS (HEC LOSS RATE = ZERO) OR ENTER ZERO LOSS RATES (or 5 zero areas) HERE**

| HSG A | HSG B | HSG C | HSG D | IM-PERM-EABLE | UN-KNOWN | |
|---|---|---|---|---|---|---|
| 0.00% | 55.30% | 0.07% | 44.58% | 0.05% | 0.00% | <== % OF SUBBASIN AREA |
| 0.300 | 0.150 | 0.050 | 0.000 | 0.00 | 0.082985 | <== ASSIGNED LOSS RATE (inches/hr) |

*FILL IN BLUE FROM GRAPH

Conversion (hours to minutes) = 60

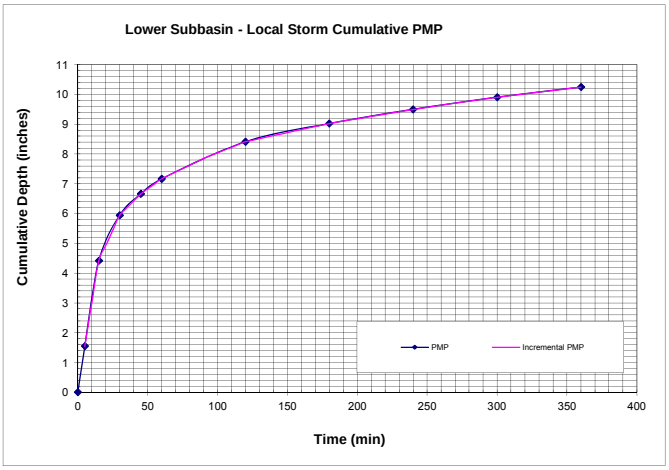
**5-MINUTE TIME STEP**

| TIME (min) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | HSG ADJUSTED INC. DEPTH [FRONT-WEIGHTED] (inch) | CENTER-WEIGHTED PMP (inches) | HMR 49, 55A (inches) |
|---|---|---|---|---|---|
| 5 | 1.55 | 1.55 | 1.54 | 0.021 | 0.021 |
| 10 | 3.00 | 1.45 | 1.45 | 0.021 | 0.021 |
| 15 | 4.42 | 1.42 | 1.41 | 0.021 | 0.021 |
| 20 | 4.93 | 0.51 | 0.50 | 0.021 | 0.021 |
| 25 | 5.44 | 0.51 | 0.50 | 0.021 | 0.021 |
| 30 | 5.95 | 0.51 | 0.50 | 0.021 | 0.021 |
| 35 | 6.18 | 0.24 | 0.23 | 0.027 | 0.021 |
| 40 | 6.42 | 0.24 | 0.23 | 0.027 | 0.021 |
| 45 | 6.66 | 0.24 | 0.23 | 0.027 | 0.021 |
| 50 | 6.83 | 0.17 | 0.16 | 0.027 | 0.021 |
| 55 | 7.00 | 0.17 | 0.16 | 0.027 | 0.021 |
| 60 | 7.17 | 0.17 | 0.16 | 0.027 | 0.021 |
| 65 | 7.28 | 0.11 | 0.11 | 0.033 | 0.033 |
| 70 | 7.40 | 0.11 | 0.11 | 0.033 | 0.033 |
| 75 | 7.51 | 0.11 | 0.11 | 0.033 | 0.033 |
| 80 | 7.62 | 0.11 | 0.11 | 0.033 | 0.033 |
| 85 | 7.74 | 0.11 | 0.11 | 0.033 | 0.033 |
| 90 | 7.85 | 0.11 | 0.11 | 0.033 | 0.033 |
| 95 | 7.94 | 0.09 | 0.09 | 0.044 | 0.033 |
| 100 | 8.04 | 0.09 | 0.09 | 0.044 | 0.033 |
| 105 | 8.13 | 0.09 | 0.09 | 0.044 | 0.033 |
| 110 | 8.23 | 0.09 | 0.09 | 0.044 | 0.033 |
| 115 | 8.32 | 0.09 | 0.09 | 0.044 | 0.033 |
| 120 | 8.41 | 0.09 | 0.09 | 0.044 | 0.033 |
| 125 | 8.46 | 0.05 | 0.04 | 0.087 | 0.087 |
| 130 | 8.51 | 0.05 | 0.04 | 0.087 | 0.087 |
| 135 | 8.57 | 0.05 | 0.04 | 0.087 | 0.087 |
| 140 | 8.62 | 0.05 | 0.04 | 0.107 | 0.087 |
| 145 | 8.67 | 0.05 | 0.04 | 0.107 | 0.087 |
| 150 | 8.72 | 0.05 | 0.04 | 0.107 | 0.087 |
| 155 | 8.77 | 0.05 | 0.04 | 0.163 | 0.107 |
| 160 | 8.82 | 0.05 | 0.04 | 0.163 | 0.107 |
| 165 | 8.87 | 0.05 | 0.04 | 0.230 | 0.107 |
| 170 | 8.92 | 0.05 | 0.04 | 0.504 | 0.107 |
| 175 | 8.97 | 0.05 | 0.04 | 0.504 | 0.107 |
| 180 | 9.02 | 0.05 | 0.04 | 1.448 | 0.107 |
| 185 | 9.06 | 0.04 | 0.03 | 1.539 | 1.539 |
| 190 | 9.10 | 0.04 | 0.03 | 1.409 | 1.448 |
| 195 | 9.14 | 0.04 | 0.03 | 0.504 | 1.409 |
| 200 | 9.18 | 0.04 | 0.03 | 0.230 | 0.504 |
| 205 | 9.22 | 0.04 | 0.03 | 0.230 | 0.504 |
| 210 | 9.26 | 0.04 | 0.03 | 0.163 | 0.504 |
| 215 | 9.30 | 0.04 | 0.03 | 0.107 | 0.230 |
| 220 | 9.34 | 0.04 | 0.03 | 0.107 | 0.230 |
| 225 | 9.38 | 0.04 | 0.03 | 0.107 | 0.230 |
| 230 | 9.42 | 0.04 | 0.03 | 0.087 | 0.163 |
| 235 | 9.46 | 0.04 | 0.03 | 0.087 | 0.163 |
| 240 | 9.50 | 0.04 | 0.03 | 0.087 | 0.163 |
| 245 | 9.53 | 0.03 | 0.03 | 0.044 | 0.044 |
| 250 | 9.57 | 0.03 | 0.03 | 0.044 | 0.044 |
| 255 | 9.60 | 0.03 | 0.03 | 0.044 | 0.044 |
| 260 | 9.64 | 0.03 | 0.03 | 0.044 | 0.044 |
| 265 | 9.67 | 0.03 | 0.03 | 0.044 | 0.044 |
| 270 | 9.70 | 0.03 | 0.03 | 0.044 | 0.044 |
| 275 | 9.74 | 0.03 | 0.03 | 0.033 | 0.044 |
| 280 | 9.77 | 0.03 | 0.03 | 0.033 | 0.044 |
| 285 | 9.81 | 0.03 | 0.03 | 0.033 | 0.044 |
| 290 | 9.84 | 0.03 | 0.03 | 0.033 | 0.044 |
| 295 | 9.87 | 0.03 | 0.03 | 0.033 | 0.044 |
| 300 | 9.91 | 0.03 | 0.03 | 0.033 | 0.044 |
| 305 | 9.94 | 0.03 | 0.02 | 0.027 | 0.027 |
| 310 | 9.96 | 0.03 | 0.02 | 0.027 | 0.027 |
| 315 | 9.99 | 0.03 | 0.02 | 0.027 | 0.027 |
| 320 | 10.02 | 0.03 | 0.02 | 0.027 | 0.027 |
| 325 | 10.05 | 0.03 | 0.02 | 0.027 | 0.027 |
| 330 | 10.08 | 0.03 | 0.02 | 0.027 | 0.027 |
| 335 | 10.11 | 0.03 | 0.02 | 0.021 | 0.027 |
| 340 | 10.13 | 0.03 | 0.02 | 0.021 | 0.027 |
| 345 | 10.16 | 0.03 | 0.02 | 0.021 | 0.027 |
| 350 | 10.19 | 0.03 | 0.02 | 0.021 | 0.027 |
| 355 | 10.22 | 0.03 | 0.02 | 0.021 | 0.027 |
| 360 | 10.25 | 0.03 | 0.02 | 0.021 | 0.027 |

**15-MINUTE TIME STEP**

| TIME (min) | CUM DEPTH FROM GRAPH* (inch) | UNADJ-USTED (PMP) INC. DEPTH (inch) | INC. DEPTH [FRONT WEIGHTED] (inch) |
|---|---|---|---|
| 15 | 4.42 | 4.42 | 4.39 |
| 30 | 5.95 | 1.53 | 1.51 |
| 45 | 6.66 | 0.71 | 0.69 |
| 60 | 7.17 | 0.51 | 0.49 |
| 75 | 7.509 | 0.34 | 0.32 |
| 90 | 7.85 | 0.34 | 0.32 |
| 105 | 8.132 | 0.28 | 0.26 |
| 120 | 8.41 | 0.28 | 0.26 |
| 135 | 8.566 | 0.15 | 0.13 |
| 150 | 8.719 | 0.15 | 0.13 |
| 165 | 8.872 | 0.15 | 0.13 |
| 180 | 9.02 | 0.15 | 0.13 |
| 195 | 9.143 | 0.12 | 0.10 |
| 210 | 9.262 | 0.12 | 0.10 |
| 225 | 9.381 | 0.12 | 0.10 |
| 240 | 9.50 | 0.12 | 0.10 |
| 255 | 9.601 | 0.10 | 0.08 |
| 270 | 9.703 | 0.10 | 0.08 |
| 285 | 9.805 | 0.10 | 0.08 |
| 300 | 9.91 | 0.10 | 0.08 |
| 315 | 9.992 | 0.08 | 0.06 |
| 330 | 10.077 | 0.08 | 0.06 |
| 345 | 10.162 | 0.08 | 0.06 |
| 360 | 10.25 | 0.08 | 0.06 |

| (min) | DEPTH |
|---|---|
| 0 | 0 |
| 5 | 1.55 |
| 15 | 4.41565 |
| 30 | 5.94713 |
| 45 | 6.65889 |
| 60 | 7.16826 |
| 120 | 8.41301 |
| 180 | 9.02442 |
| 240 | 9.49921 |
| 300 | 9.90738 |
| 360 | 10.2464 |




WILL AUTOMATICALLY COPY TO "PMP FOR HEC1" WORKSHEET

LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK
* (15-min incr.; FRONT-WEIGHTED, HMR 59; EXCESS RAINFALL ONLY)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 4.395 | 1.511 | 0.691 | 0.489 | 0.320 | 0.320 | 0.261 | 0.261 | 0.132 | 0.132 |
| PI | 0.132 | 0.132 | 0.098 | 0.098 | 0.098 | 0.098 | 0.081 | 0.081 | 0.081 | 0.081 |
| PI | 0.064 | 0.064 | 0.064 | 0.064 | 0.0 | | | | | |

LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; FRONT-WEIGHTED, HMR 59; EXCESS RAINFALL ONLY)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 1.539 | 1.448 | 1.409 | 0.504 | 0.504 | 0.504 | 0.230 | 0.230 | 0.230 | 0.163 |
| PI | 0.163 | 0.163 | 0.107 | 0.107 | 0.107 | 0.107 | 0.107 | 0.107 | 0.087 | 0.087 |
| PI | 0.087 | 0.087 | 0.087 | 0.087 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 |
| PI | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.033 | 0.033 | 0.033 | 0.033 |
| PI | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.027 | 0.027 |
| PI | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 |
| PI | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 |
| PI | 0.021 | 0.021 | 0.0 | | | | | | | |

LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; CENTER-WEIGHTED; EXCESS RAINFALL ONLY)

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.027 | 0.027 | 0.027 | 0.027 |
| PI | 0.027 | 0.027 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.044 | 0.044 |
| PI | 0.044 | 0.044 | 0.044 | 0.044 | 0.087 | 0.087 | 0.087 | 0.107 | 0.107 | 0.107 |
| PI | 0.163 | 0.163 | 0.230 | 0.504 | 0.504 | 1.448 | 1.539 | 1.409 | 0.504 | 0.230 |
| PI | 0.230 | 0.163 | 0.107 | 0.107 | 0.107 | 0.087 | 0.087 | 0.087 | 0.044 | 0.044 |
| PI | 0.044 | 0.044 | 0.044 | 0.044 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| PI | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.021 | 0.021 | 0.021 | 0.021 |
| PI | 0.021 | 0.021 | 0.0 | | | | | | | |

LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK
* (5-min incr.; HMR 49/55A - UNIQUE WEIGHTING; EXCESS RAINFALL ONLY)

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| PI | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 | 0.021 |
| PI | 0.021 | 0.021 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 |
| PI | 0.033 | 0.033 | 0.033 | 0.033 | 0.087 | 0.087 | 0.087 | 0.087 | 0.087 | 0.087 |
| PI | 0.107 | 0.107 | 0.107 | 0.107 | 0.107 | 0.107 | 1.539 | 1.448 | 1.409 | 0.504 |
| PI | 0.504 | 0.504 | 0.230 | 0.230 | 0.230 | 0.163 | 0.163 | 0.163 | 0.044 | 0.044 |
| PI | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 | 0.044 |
| PI | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 | 0.027 |
| PI | 0.027 | 0.027 | 0.0 | | | | | | | |

**LESS THAN 1 HOUR FROM p. II-7 of SEO Project Review Guide**

| | Blank | Area F | 5-min | 15-min | 1-hr | 2-hr | 3-hr | 6-hr | 12-hr | 24-hr | 96-h |
|---|---|---|---|---|---|---|---|---|---|---|---|

LOCAL THUNDERSTORM PMP - LOWER SUBBASIN FOR LOWER BEAVER BROOK
* (CENTER-WT, CO SEO Guidelines HMR 49/55A, IT/IN t-step; EXCESS RAINFALL ONLY)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PH | 0.01 | 1.987 | 4.42 | 7.17 | 8.41 | 9.02 | 10.25 |

**Project Name:** Lower Beaver Brook
**Client:** Lookout Mountain Water District
**Date:** 9/11/2014

## LOCAL STORM PMP - Lower Subbasin- HMR No. 55A

**STEP 1: Determination of 1 hour 1 sq. mi. PMP value at 5000 feet**

| LOCAL STORM PMP INDEX VALUE | | |
|---|---|---|
| PLATE | 1 $mi^2$ DURATION | Total Basin Precipitation (in) |
| VI B | 1-hr | 10.68 |

**STEP 2: Adjustment for mean elevation**

| BASIN | Ave. Elevation (ft) | Adjustment Factor |
|---|---|---|
| Lower Subbasin | 8087 | 0.79 |

**Reference:** (fig 14.3. - Adjustment for elevation for local storms; pg. 219)

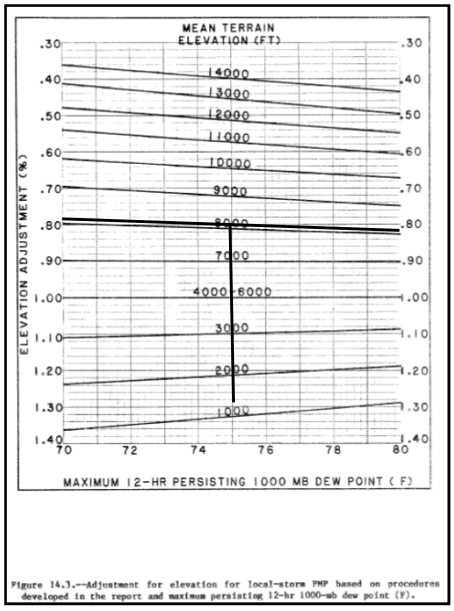


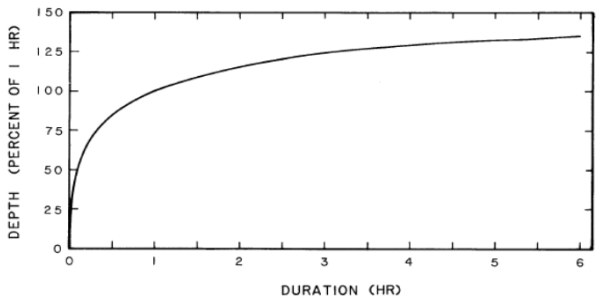
Figure 14.3.--Adjustment for elevation for local-storm PMP based on procedures developed in the report and maximum persisting 12-hr 1000-mb dew point (F).

**STEP 3: Calculate adjusted 1 hour 1 sq. mi. PMP value**

| ELEVATION ADJUSTED PMP VALUE | |
|---|---|
| 1 $mi^2$ DURATION | Total Basin Precipitation (in) |
| 1-hr | 8.43 |

**STEP 4: Plot Depth-Duration curve**
(See Attachment 1)

| DURATION FACTORED PMP VALUES | | |
|---|---|---|
| Duration (hr) | Percent of 1-hr | Precipitation (in) |
| 0 | 0.00 | 0.00 |
| 0.25 | 0.68 | 5.73 |
| 0.5 | 0.86 | 7.25 |
| 0.75 | 0.94 | 7.93 |
| 1 | 1.00 | 8.43 |
| 2 | 1.16 | 9.78 |
| 3 | 1.23 | 10.37 |
| 4 | 1.28 | 10.79 |
| 5 | 1.32 | 11.13 |
| 6 | 1.35 | 11.38 |




**Reference:** (Table 12.4. - Depth-Duration curve for 6-/1-hr ratio; pg. 200)

**Project Name:** **Lower Beaver Brook**
**Client:** **Lookout Mountain Water District**
**Date:** **9/11/2014**

## LOCAL STORM PMP - Lower Subbasin- HMR No. 55A

**STEPS 5 & 6: Areal reduction factors and estimated PMP values**

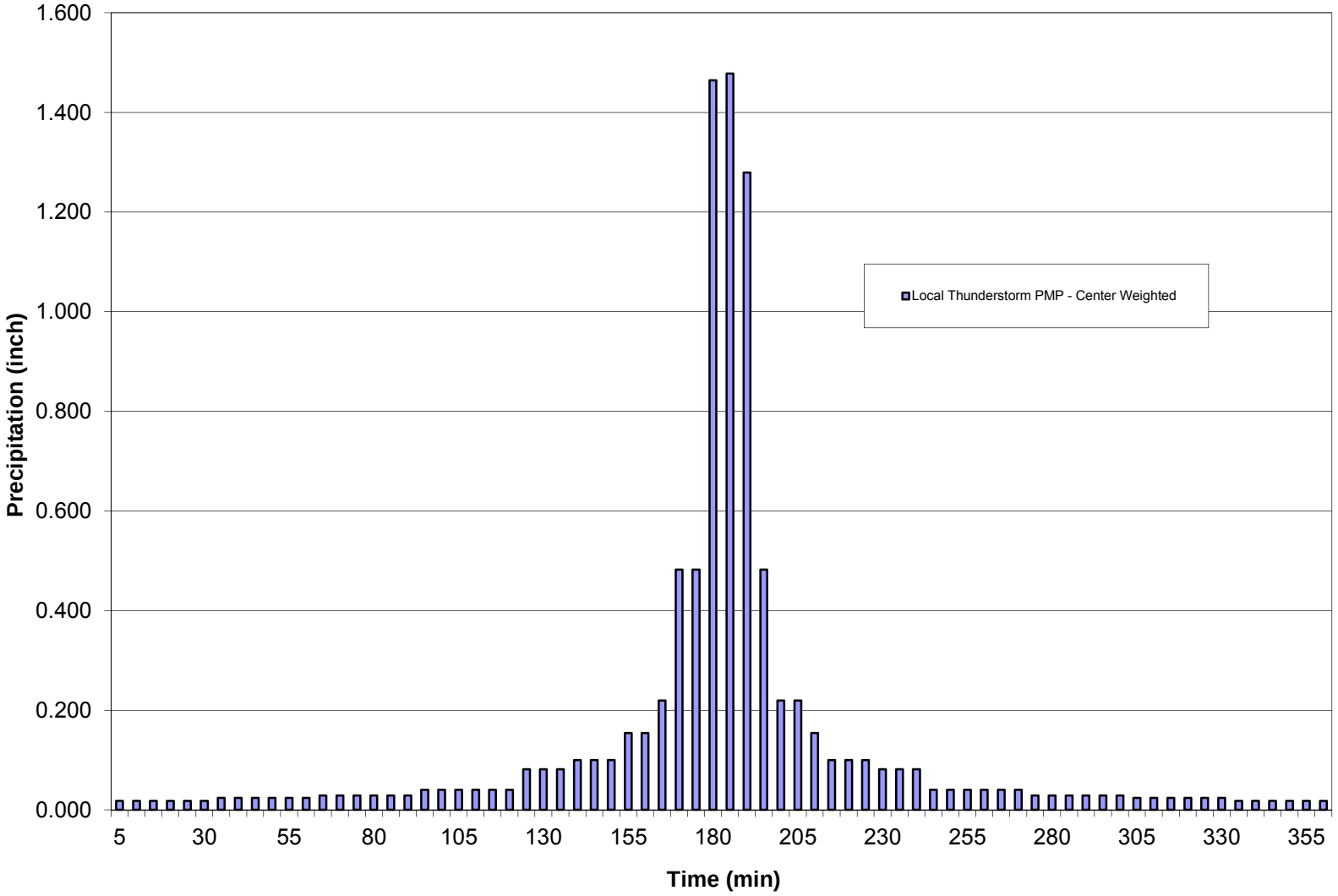
| BASIN | Basin Area ($mi^2$) |
|---|---|
| Total Basin | 7.45 |

| FINAL ADJUSTED PMP VALUES | | |
|---|---|---|
| Duration (hr) | Areal Adjustment % | Precipitation (in) |
| 0 | 0.0 | 0.00 |
| 0.25 | 77.0 | 4.42 |
| 0.5 | 82.0 | 5.95 |
| 0.75 | 84.0 | 6.66 |
| 1 | 85.0 | 7.17 |
| 2 | 86.0 | 8.41 |
| 3 | 87.0 | 9.02 |
| 4 | 88.0 | 9.50 |
| 5 | 89.0 | 9.91 |
| 6 | 90.0 | 10.25 |

**Reference:** (Figure 12.12. - Depth-Area relation for loacal storm PMP; pg. 203)

**STEP 7: Determine incremental depths**

## Local-Storm Distribution - Upper Subbasin




Upper subbasin PMP DISTRIBUTIONS, 6 Cntr

**Project Name:** Lower Beaver Brook
**Client:** Lookout Mountain Water District
**Date:** 9/10/2014

## LOCAL STORM PMP - HMR No. 55A - Upper Subbasin

**STEP 1: Determination of 1 hour 1 sq. mi. PMP value at 5000 feet**

| LOCAL STORM PMP INDEX VALUE | | |
|---|---|---|
| PLATE | 1 $mi^2$ DURATION | Total Basin Precipitation (in) |
| VI B | 1-hr | 10.68 |

**STEP 2: Adjustment for mean elevation**

| BASIN | Ave. Elevation (ft) | Adjustment Factor |
|---|---|---|
| Total Basin | 8399 | 0.76 |

**Reference:** (fig 14.3. - Adjustment for elevation for local storms; pg. 219)

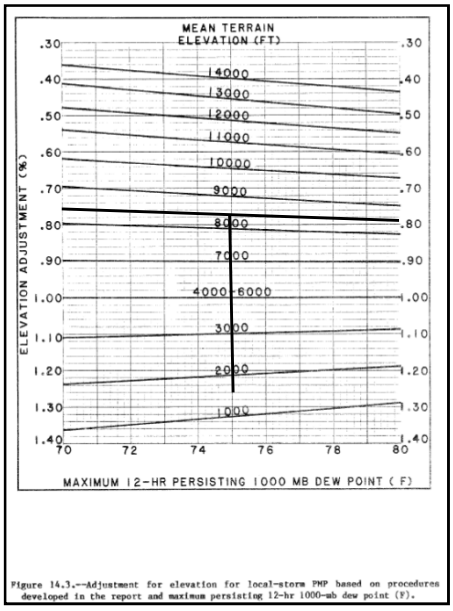


Figure 14.3.--Adjustment for elevation for local-storm PMP based on procedures developed in the report and maximum persisting 12-hr 1000-mb dew point (F).

**STEP 3: Calculate adjusted 1 hour 1 sq. mi. PMP value**

| ELEVATION ADJUSTED PMP VALUE | |
|---|---|
| 1 $mi^2$ DURATION | Total Basin Precipitation (in) |
| 1-hr | 8.11 |

**STEP 4: Plot Depth-Duration curve**
(See Attachment 1)

| DURATION FACTORED PMP VALUES | | |
|---|---|---|
| Duration (hr) | Percent of 1-hr | Precipitation (in) |
| 0 | 0.00 | 0.00 |
| 0.25 | 0.68 | 5.52 |
| 0.5 | 0.86 | 6.98 |
| 0.75 | 0.94 | 7.63 |
| 1 | 1.00 | 8.11 |
| 2 | 1.16 | 9.41 |
| 3 | 1.23 | 9.98 |
| 4 | 1.28 | 10.38 |
| 5 | 1.32 | 10.71 |
| 6 | 1.35 | 10.95 |

**Reference:** (Table 12.4. - Depth-Duration curve for 6-/1-hr ratio; pg. 200)

**Project Name:** **Lower Beaver Brook**
**Client:** **Lookout Mountain Water District**
**Date:** **9/10/2014**

## LOCAL STORM PMP - HMR No. 55A - Upper Subbasin

**STEPS 5 & 6: Areal reduction factors and estimated PMP values**

| BASIN | Basin Area ($mi^2$) |
|---|---|
| Total Basin | 7.45 |

| FINAL ADJUSTED PMP VALUES | | |
|---|---|---|
| Duration (hr) | Areal Adjustment % | Precipitation (in) |
| 0 | 0.0 | 0.00 |
| 0.25 | 77.0 | 4.25 |
| 0.5 | 82.0 | 5.72 |
| 0.75 | 84.0 | 6.41 |
| 1 | 85.0 | 6.90 |
| 2 | 86.0 | 8.09 |
| 3 | 87.0 | 8.68 |
| 4 | 88.0 | 9.14 |
| 5 | 89.0 | 9.53 |
| 6 | 90.0 | 9.86 |

**Reference:** (Figure 12.12. - Depth-Area relation for local storm PMP; pg. 203)

**STEP 7: Determine incremental depths**

# Appendix B

## HEC-HMS Input and Output Summary

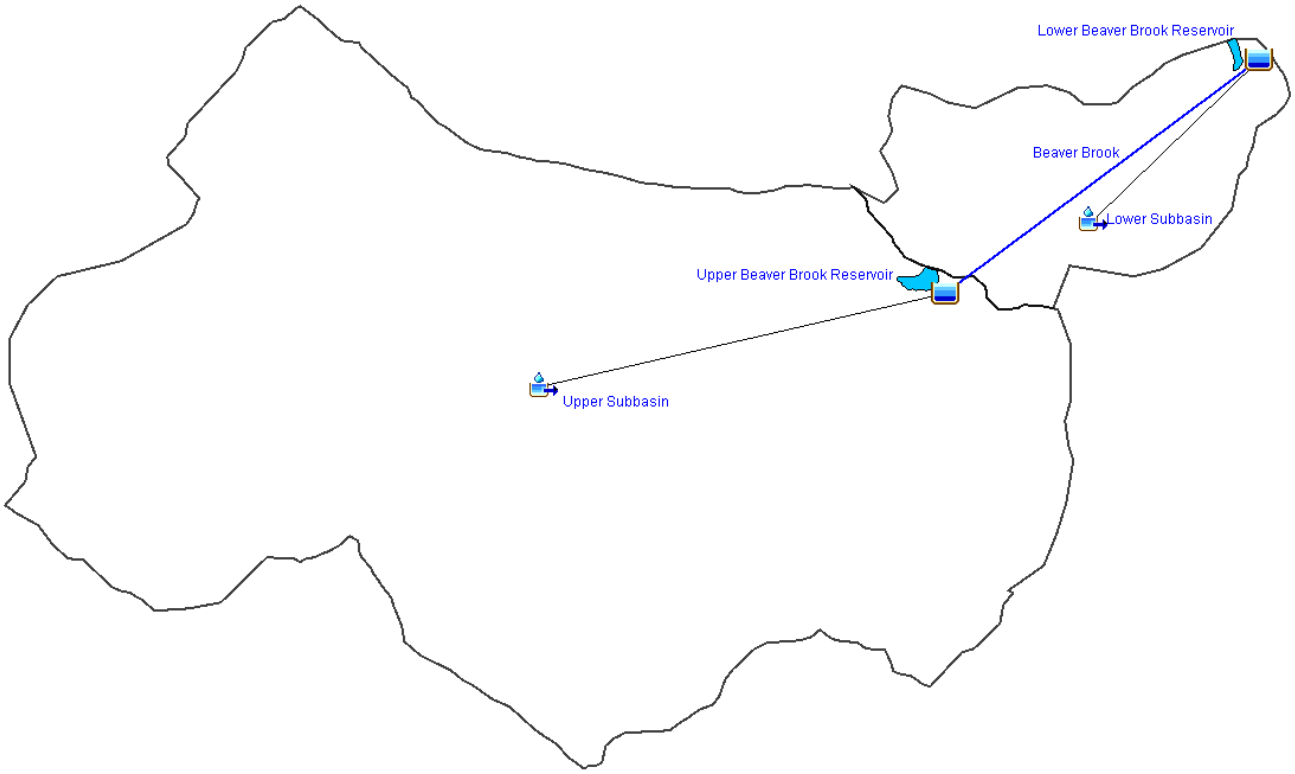
# Appendix B HEC-HMS Input and Output

**HEC-HMS Inputs – Lower Beaver Brook Watershed .....2**
Lower Beaver Brook Watershed Geometry .....2
Upper Beaver Brook Reservoir and Proposed Spillway.....3
Lower Beaver Brook Reservoir and Spillway .....5
Beaver Brook Routing between Upper and Lower Beaver Brook Reservoirs ..6
Upper Subbasin Loss and Transform .....7
Frequency Storms.....7
General and Local Storms .....7
Lower Subbasin Loss and Transform .....8
Frequency Storms.....8
General and Local Storms .....8
HEC-HMS Meteorological Model Input Data.....9
NOAA Atlas 14 Frequency Storms:.....9
HMR 55A – General Storm .....10
HMR 55A – Local Storm .....11
HEC-HMS Unit Hydrographs .....12
NOAA Atlas 14 – Frequency Storms: .....12
HMR 55A – General Storm.....13
HMR 55A – Local Storm.....14

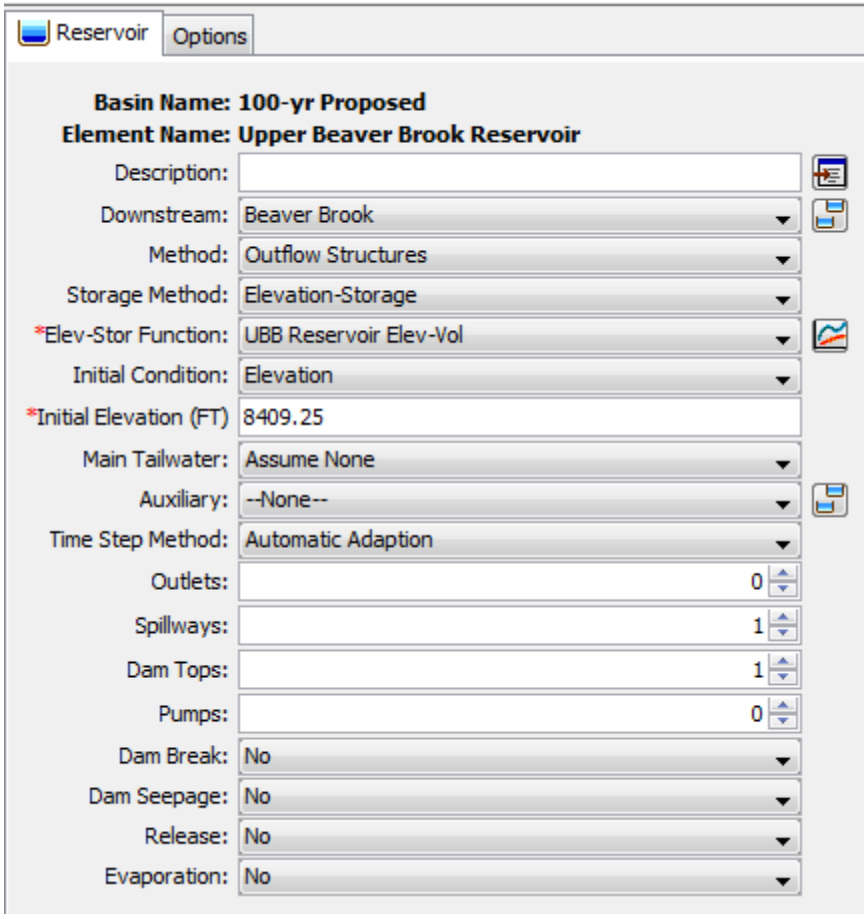
**HEC-HMS Model Results - Lower Beaver Brook Watershed .....15**
NOAA Atlas 14 Frequency Storms.....15
2-yr Event – Global Summary and Lower Beaver Brook Hydrographs .....15
5-yr Event – Global Summary and Lower Beaver Brook Hydrographs .....16
10-yr Event – Global Summary and Lower Beaver Brook Hydrographs ....17
25-yr Event – Global Summary and Lower Beaver Brook Hydrographs ....18
50-yr Event – Global Summary and Lower Beaver Brook Hydrographs ....19
100-yr Event – Global Summary and Lower Beaver Brook Hydrographs ..20
HMR 55A – Local Storm .....21
HMR 55A – General Storm .....22

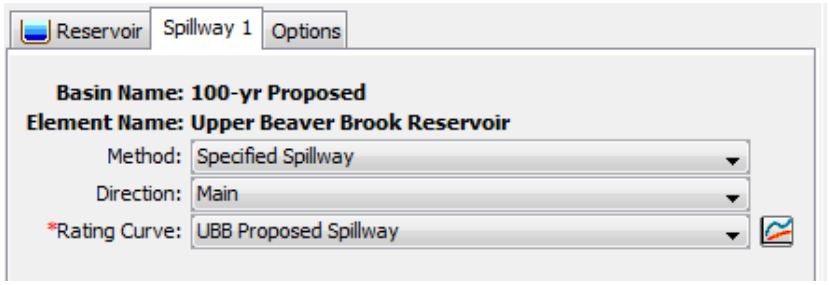
# HEC-HMS Inputs – Lower Beaver Brook Watershed

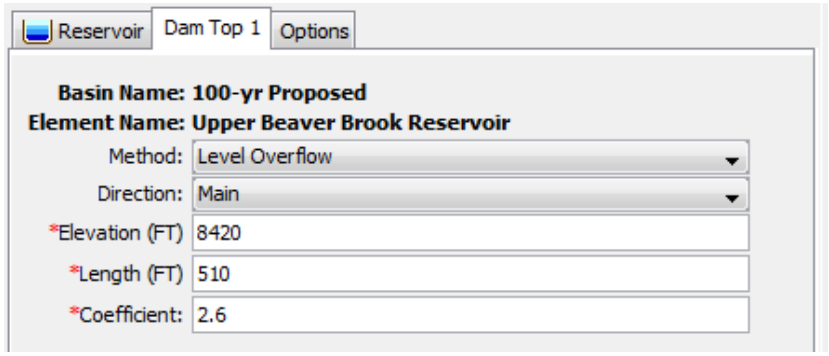
## Lower Beaver Brook Watershed Geometry



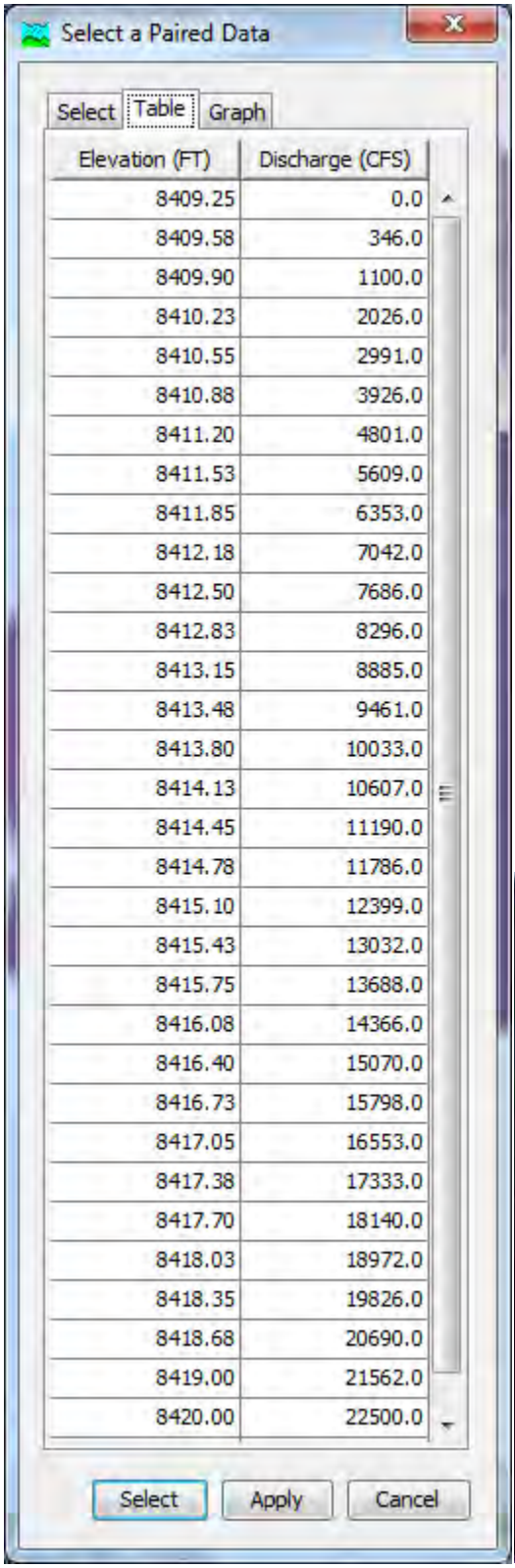
## Upper Beaver Brook Reservoir and Proposed Spillway

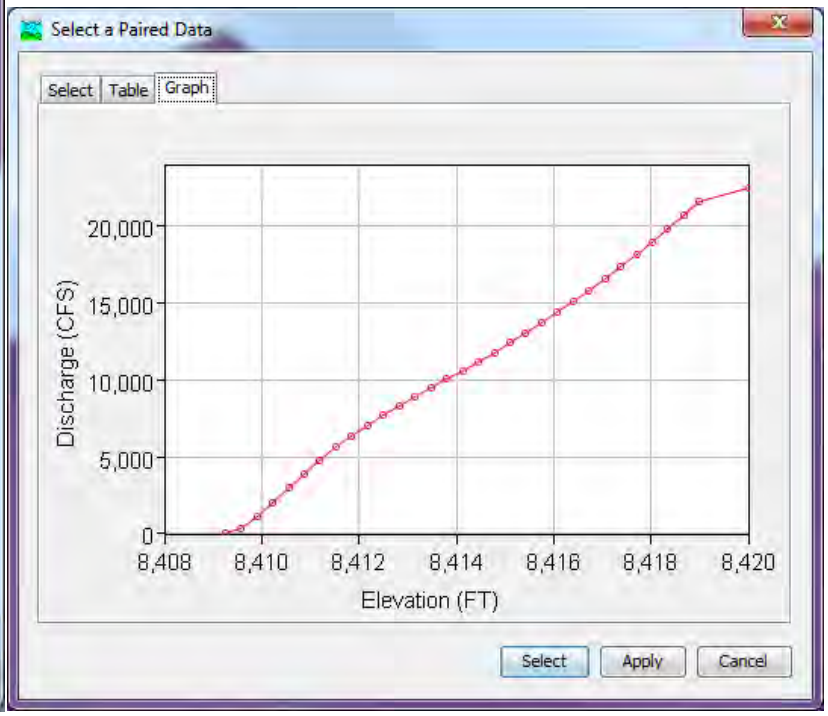


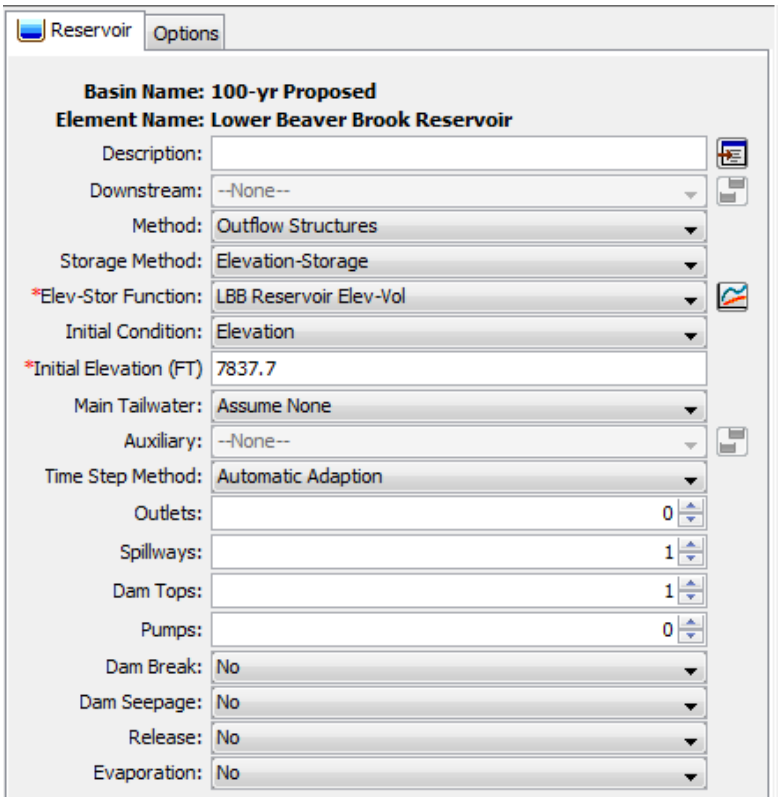



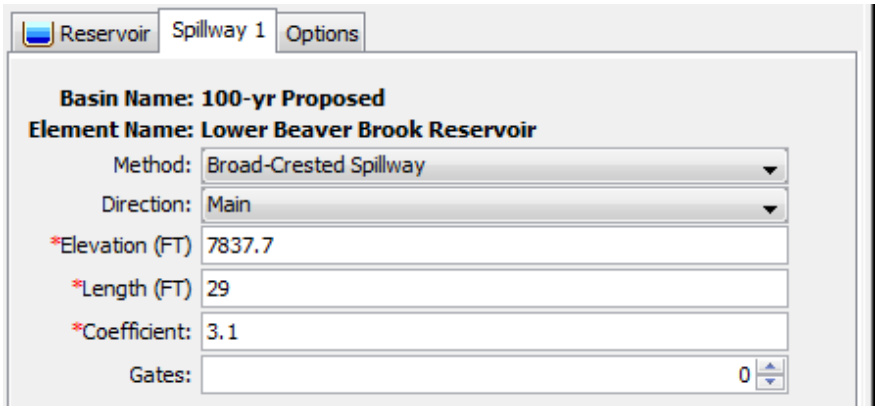
Upper Beaver Brook Proposed Spillway Rating Curve

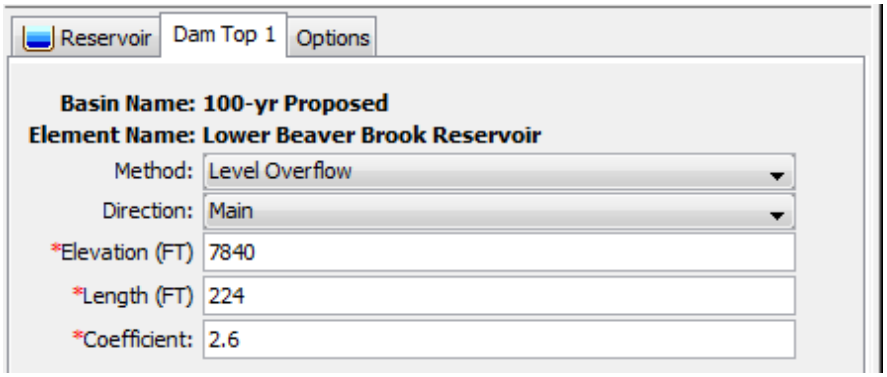


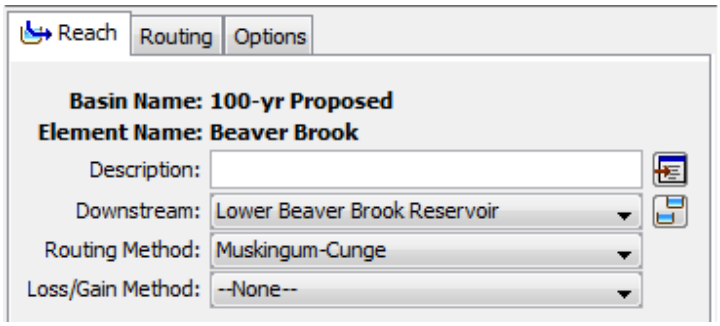
# Lower Beaver Brook Reservoir and Spillway

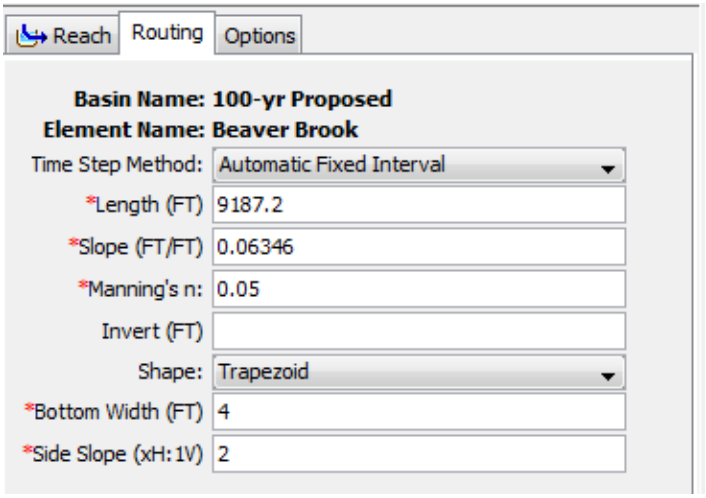


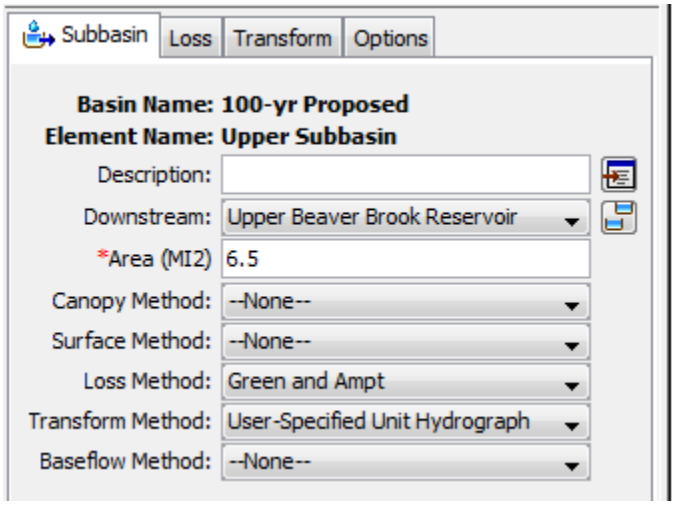
## Beaver Brook Routing between Upper and Lower Beaver Brook Reservoirs

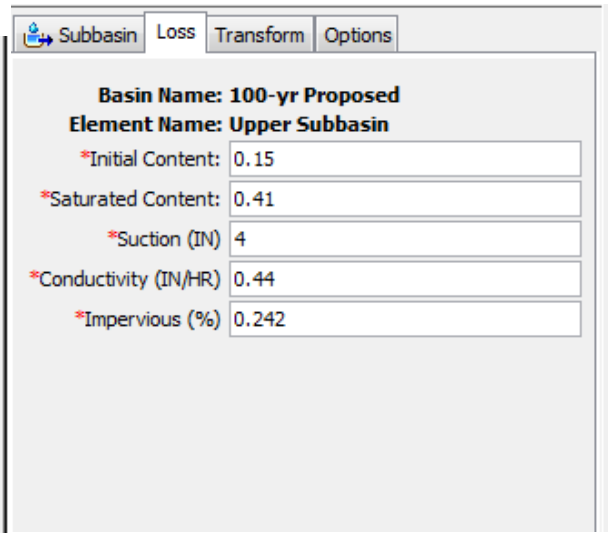


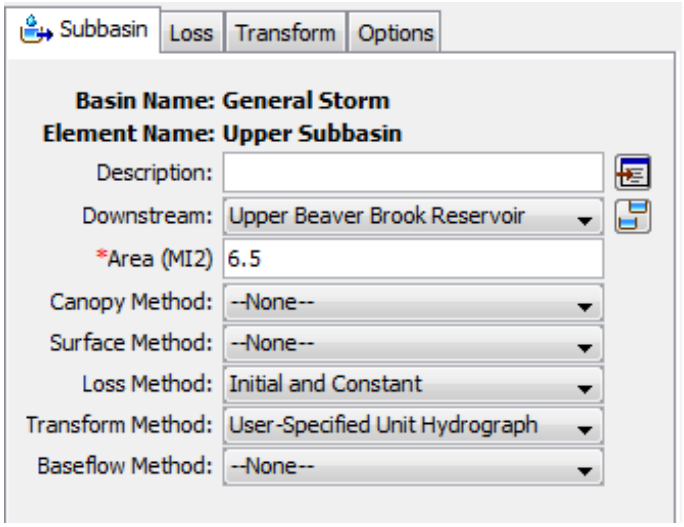
# Upper Subbasin Loss and Transform

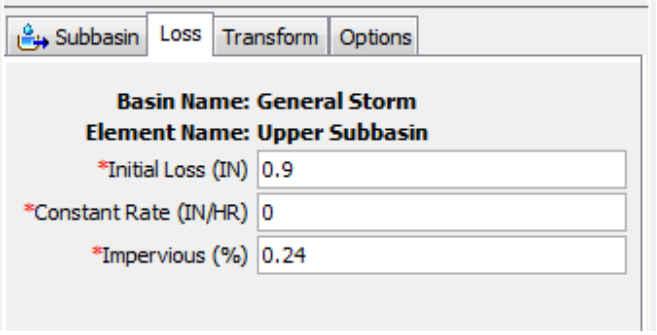
## *Frequency Storms*



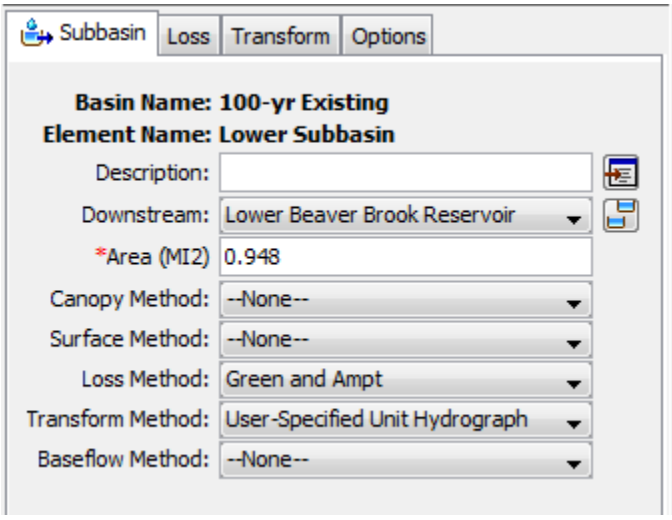

## *General and Local Storms*

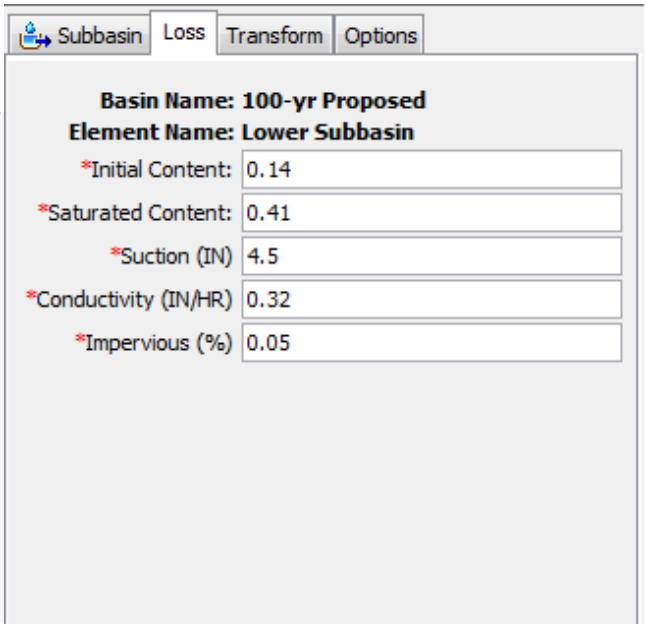


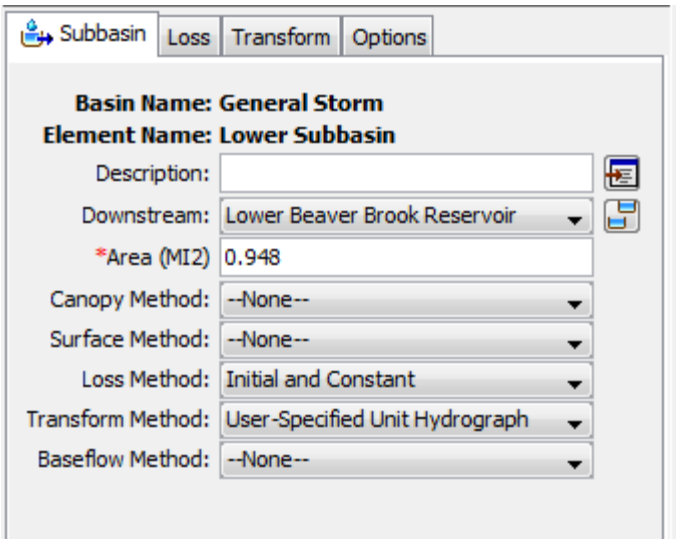
# Lower Subbasin Loss and Transform

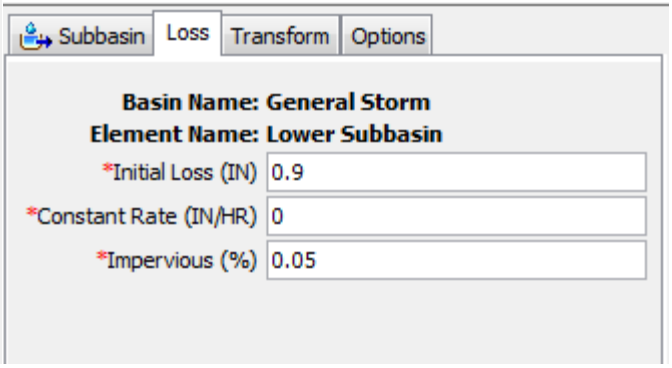
## *Frequency Storms*



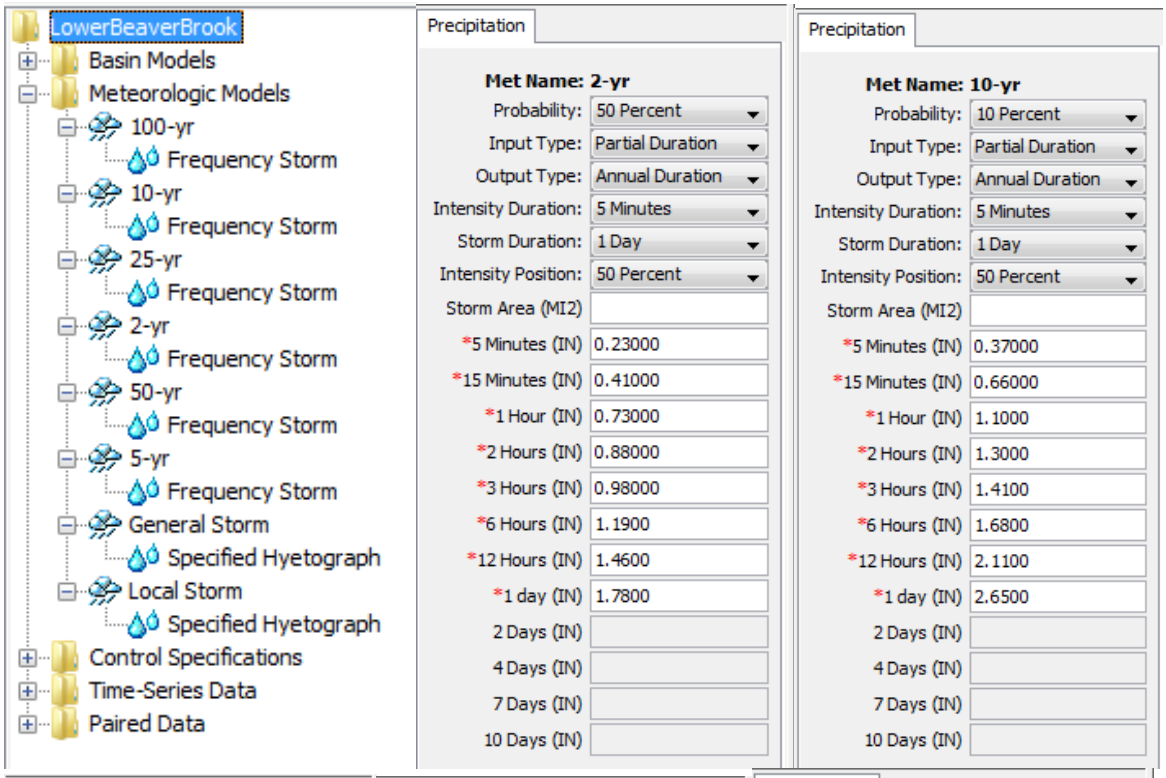

## *General and Local Storms*

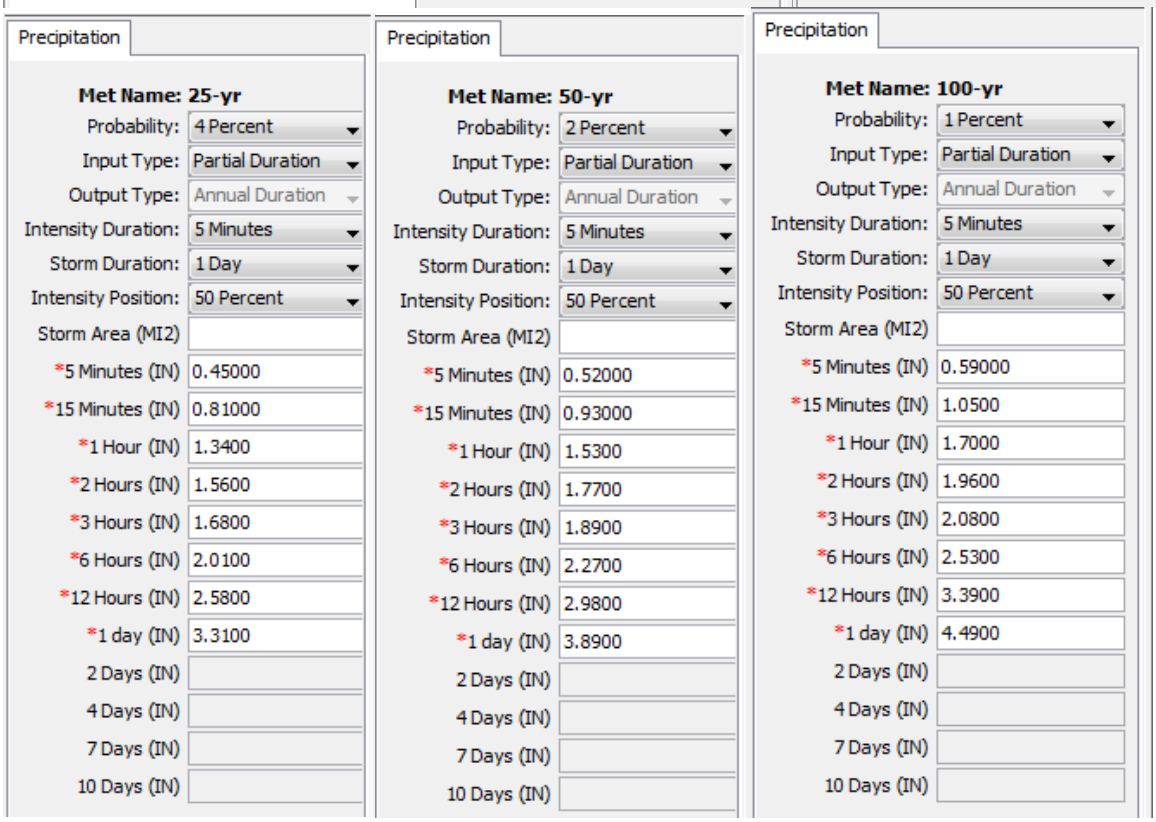


# HEC-HMS Meteorological Model Input Data

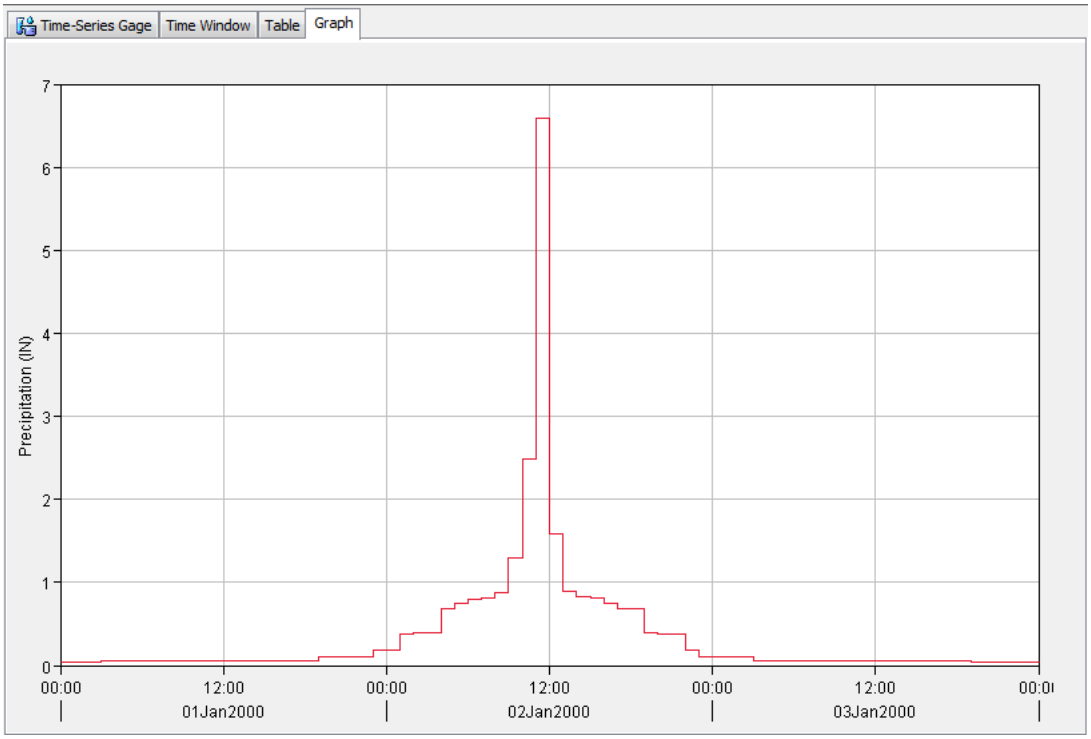
## *NOAA Atlas 14 Frequency Storms:*



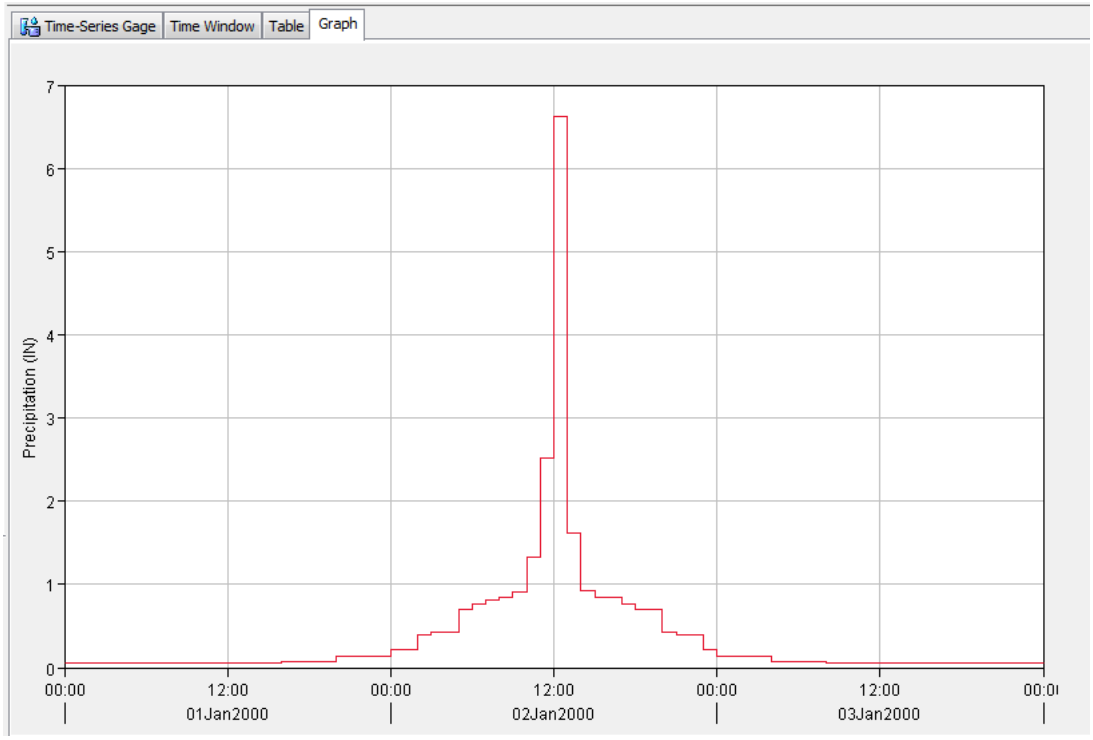



## *HMR 55A – General Storm*

Upper Subbasin General Storm

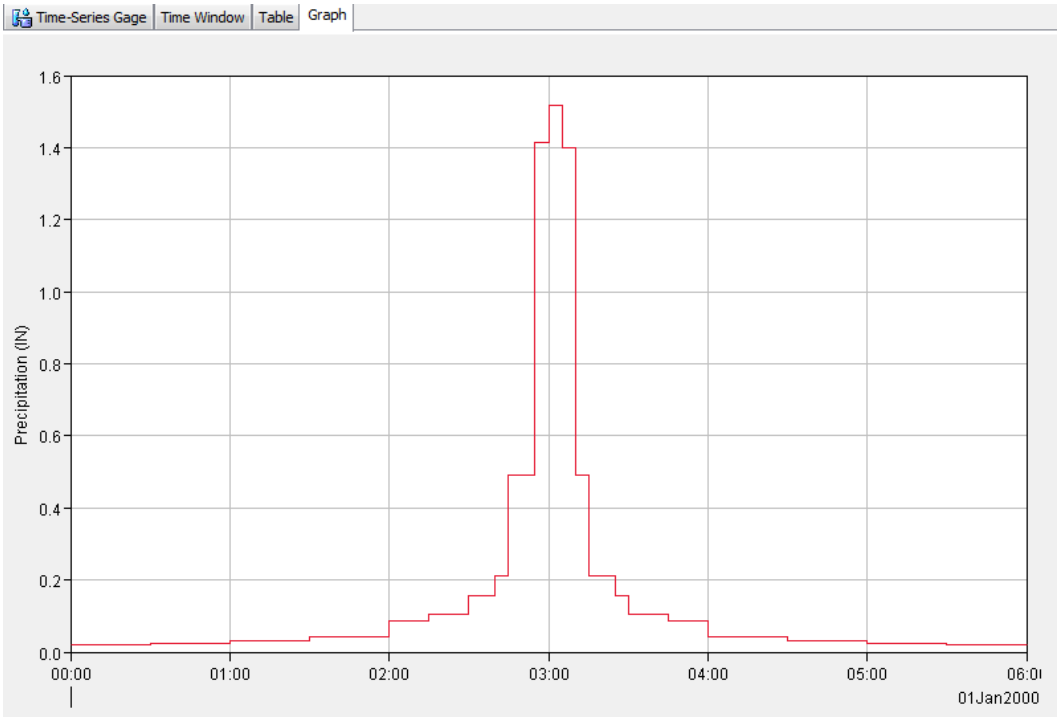



Lower Subbasin General Storm

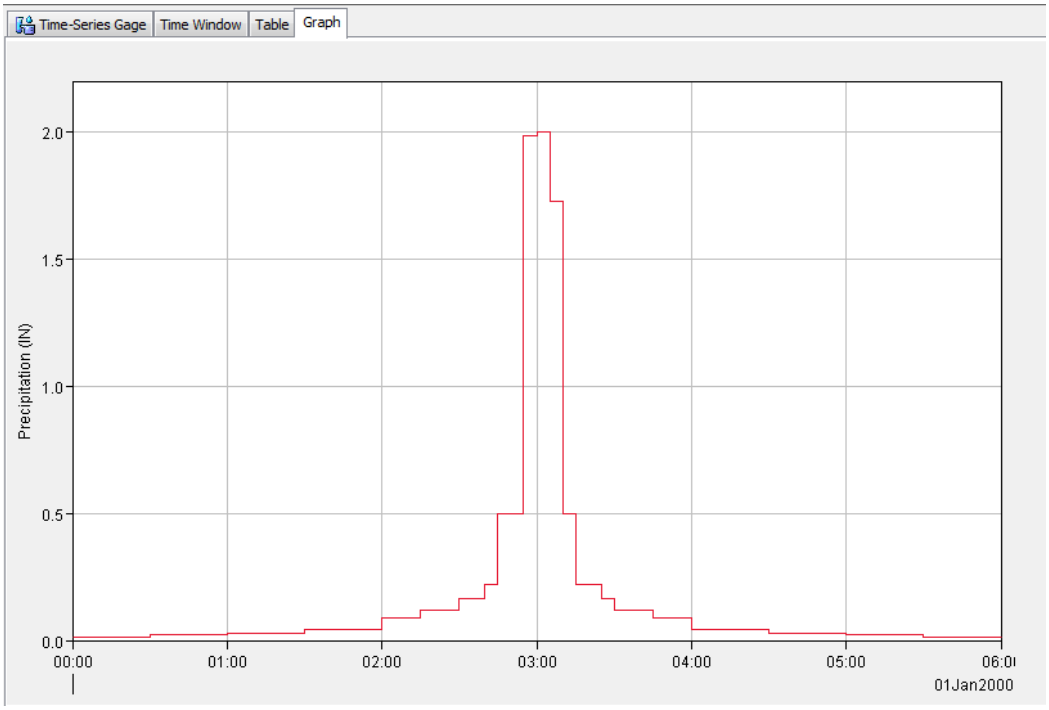


## *HMR 55A – Local Storm*

Upper Subbasin Local Storm



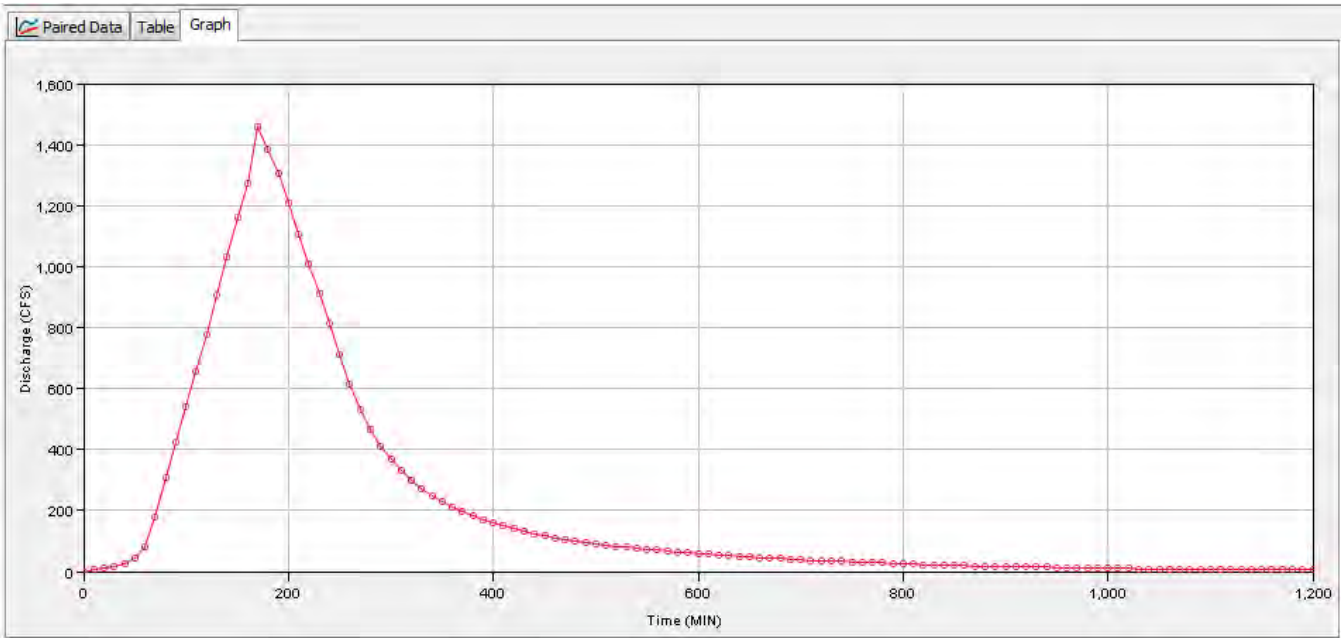

Lower Subbasin Local Storm



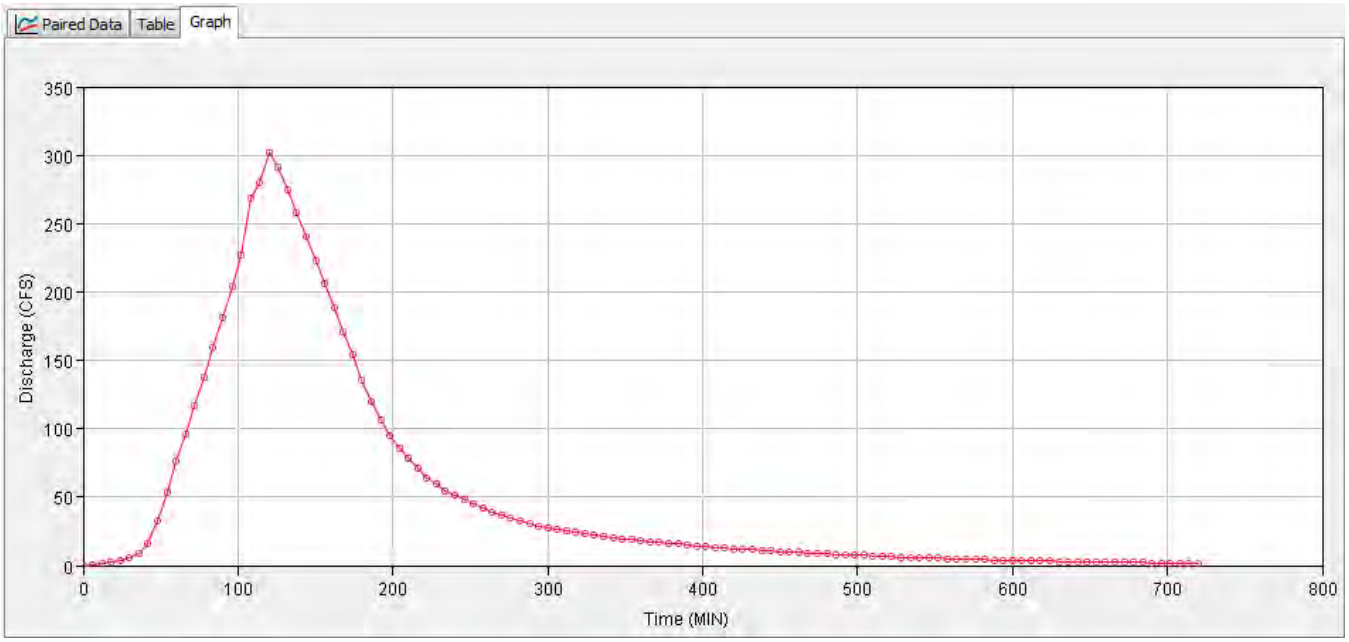
# HEC-HMS Unit Hydrographs

## *NOAA Atlas 14 – Frequency Storms:*

Upper Subbasin

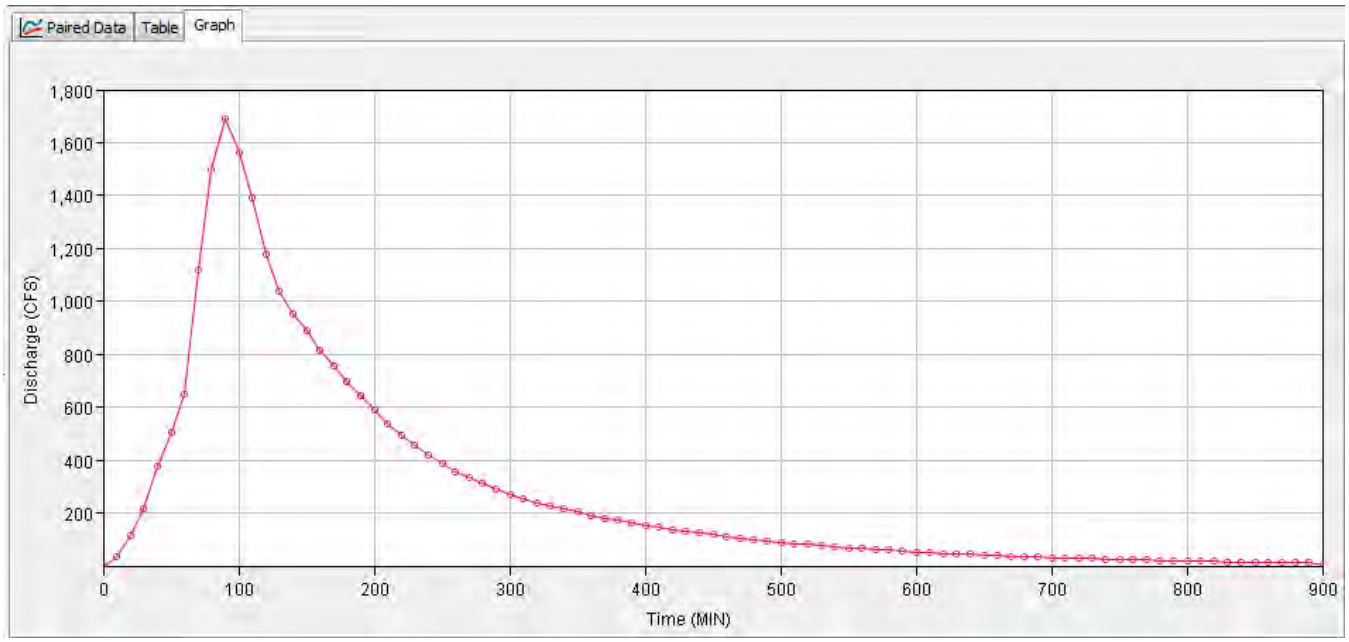



Lower Subbasin

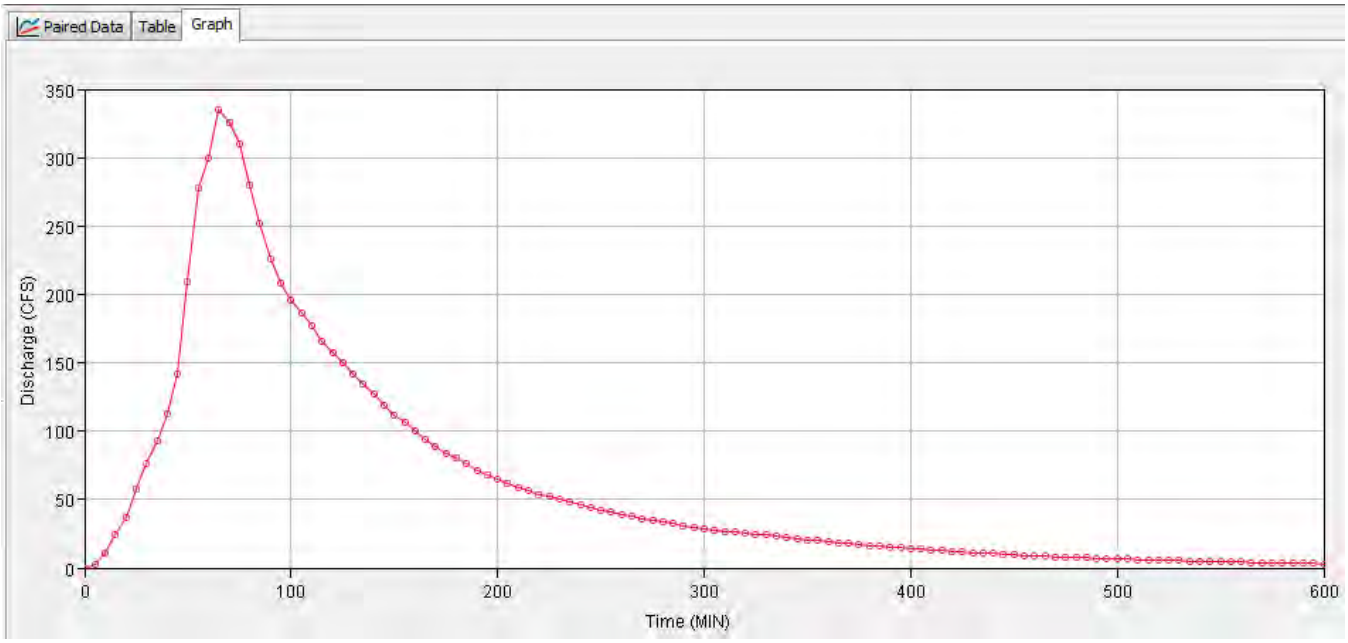


## *HMR 55A – General Storm*

Upper Subbasin

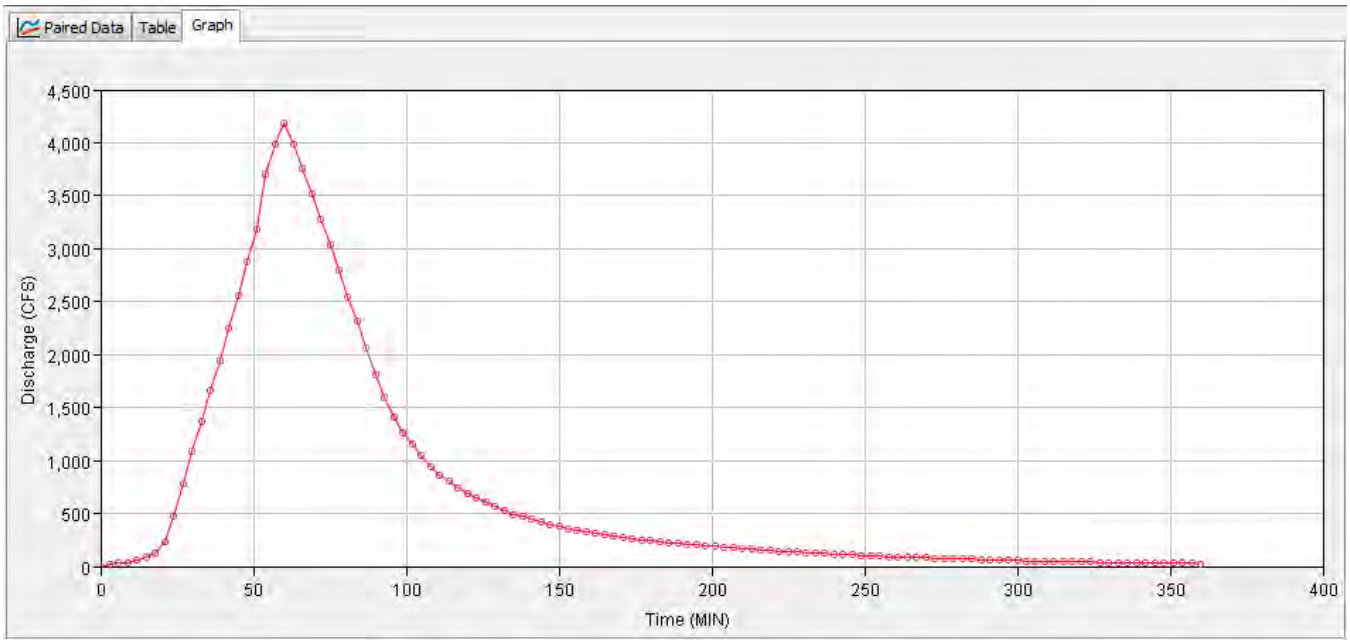



Lower Subbasin

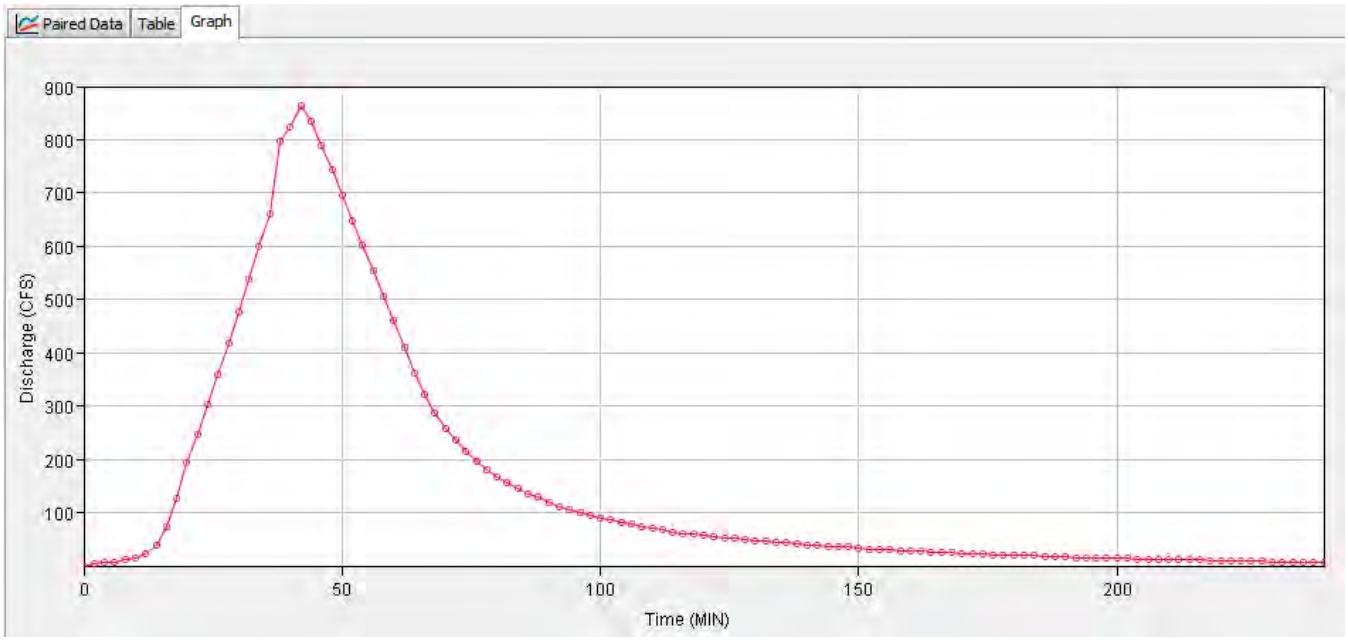


## *HMR 55A – Local Storm*

Upper Subbasin




Lower Subbasin



# HEC-HMS Model Results - Lower Beaver Brook Watershed

## NOAA Atlas 14 Frequency Storms

### *2-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "2-yr Proposed"

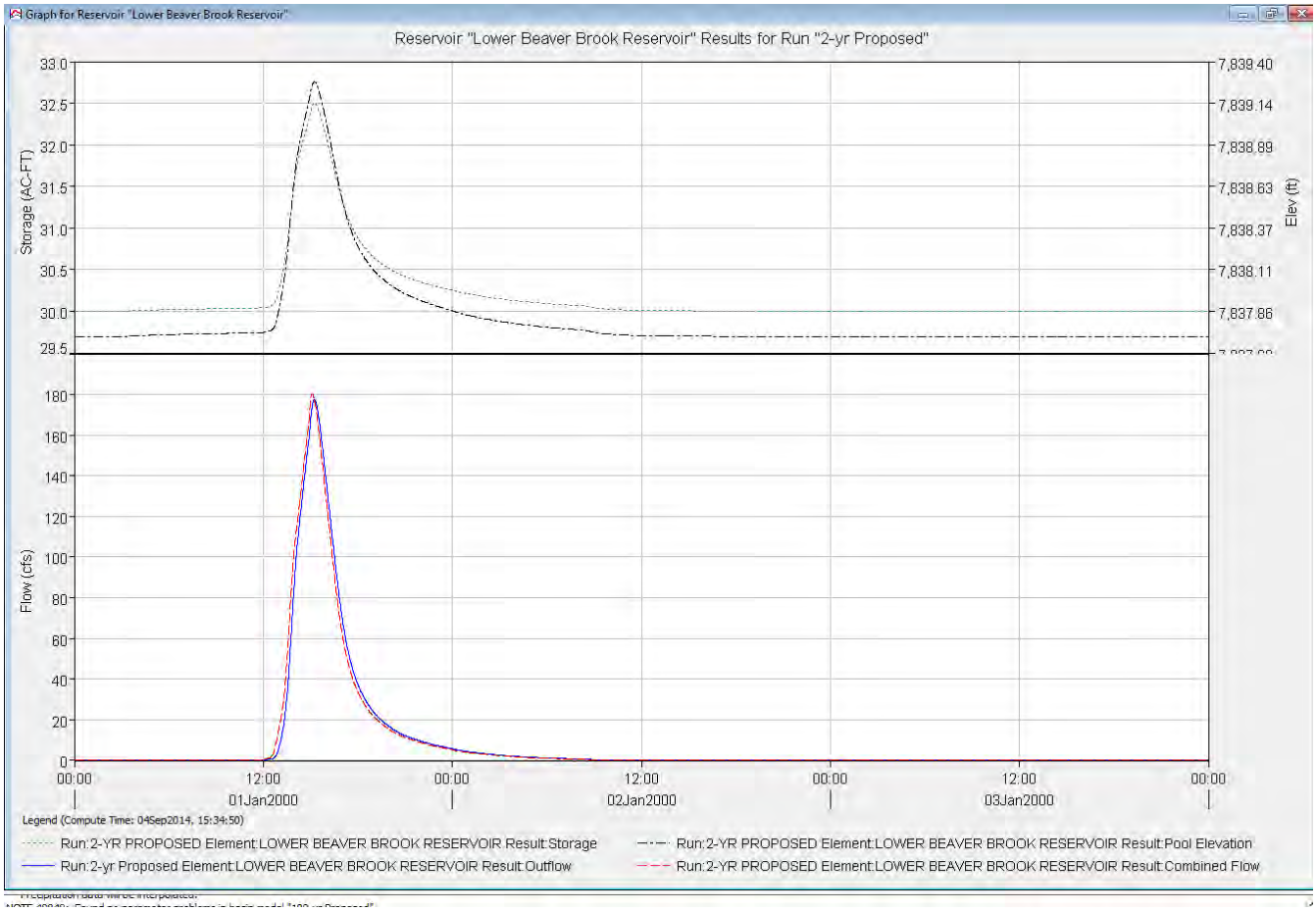
Project: LowerBeaverBrook  Simulation Run: 2-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:34:50

Basin Model: 100-yr Proposed
Meteorologic Model: 2-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 176.44 | 01Jan2000, 14:46 | 42.0 |
| Upper Beaver Brook ... | 6.500 | 163.88 | 01Jan2000, 14:58 | 42.0 |
| Beaver Brook | 6.500 | 163.87 | 01Jan2000, 15:10 | 42.0 |
| Lower Subbasin | 0.948 | 45.05 | 01Jan2000, 13:58 | 7.6 |
| Lower Beaver Brook ... | 7.448 | 177.53 | 01Jan2000, 15:15 | 49.6 |



## *5-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "5-yr Proposed"

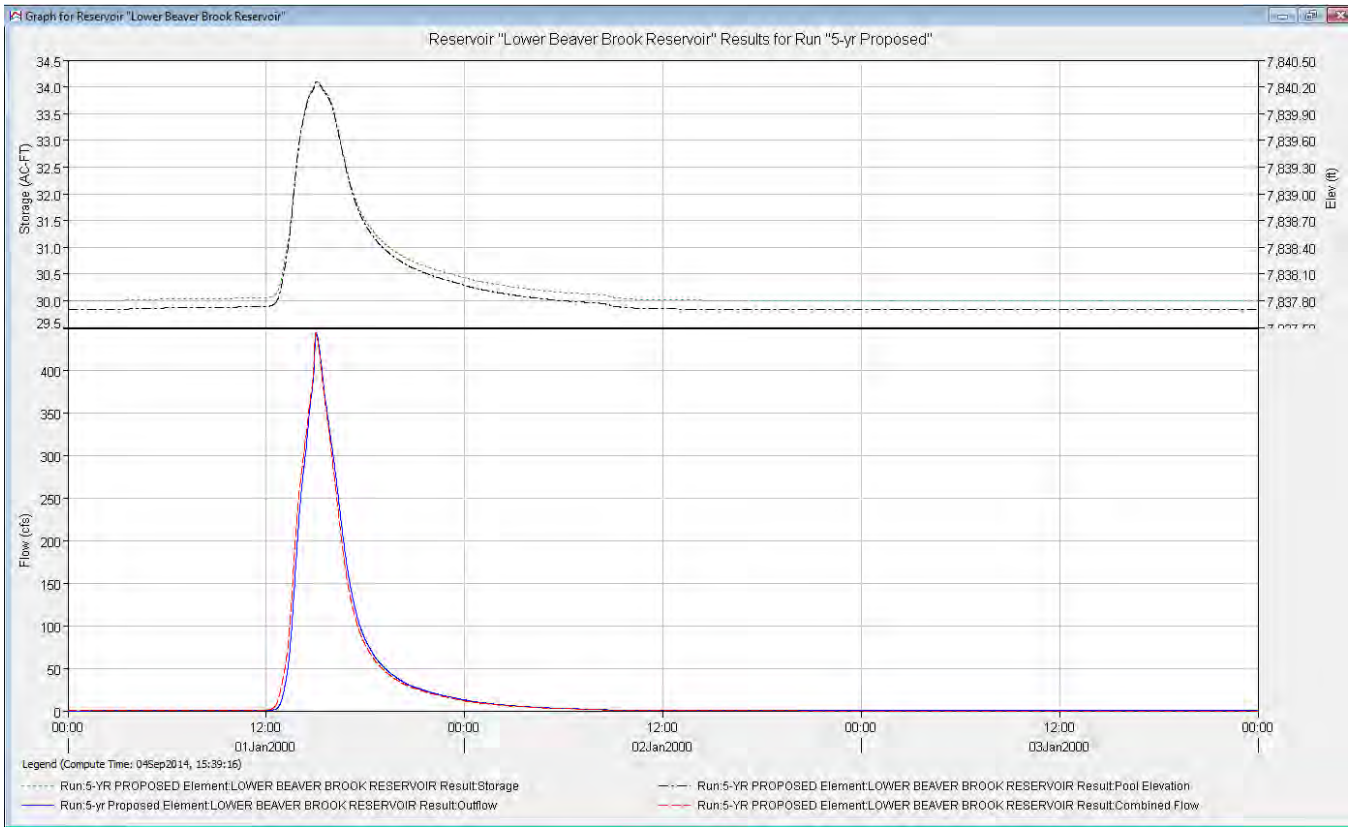
Project: LowerBeaverBrook  Simulation Run: 5-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:39:16

Basin Model: 100-yr Proposed
Meteorologic Model: 5-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 416.64 | 01Jan2000, 14:46 | 99.4 |
| Upper Beaver Brook Reservoir | 6.500 | 402.60 | 01Jan2000, 14:51 | 99.4 |
| Beaver Brook | 6.500 | 402.43 | 01Jan2000, 15:01 | 99.4 |
| Lower Subbasin | 0.948 | 100.12 | 01Jan2000, 13:58 | 17.0 |
| Lower Beaver Brook Reservoir | 7.448 | 443.59 | 01Jan2000, 15:02 | 116.3 |



## *10-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "10-yr Proposed"

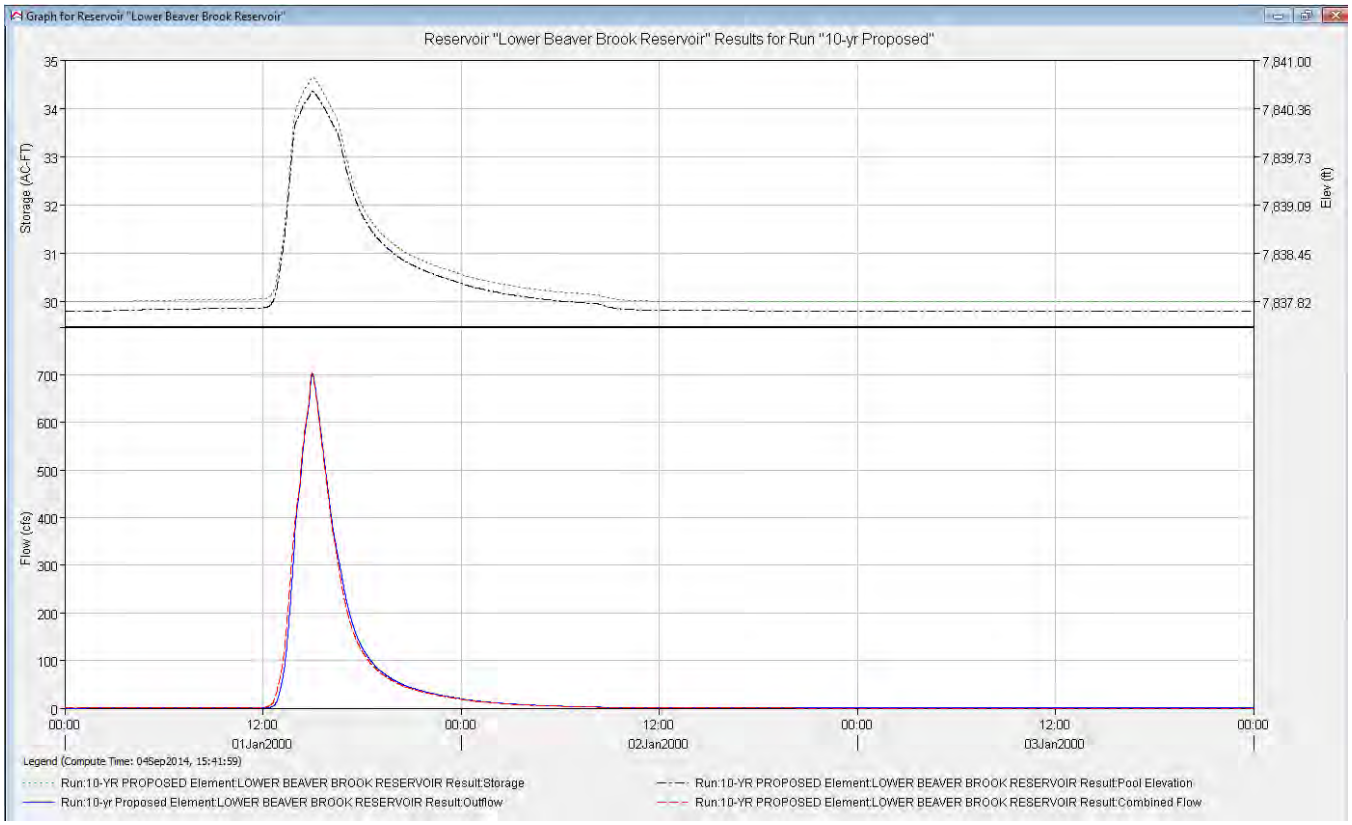
Project: LowerBeaverBrook  Simulation Run: 10-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:41:59

Basin Model: 100-yr Proposed
Meteorologic Model: 10-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 651.11 | 01Jan2000, 14:46 | 155.9 |
| Upper Beaver Brook Res... | 6.500 | 635.48 | 01Jan2000, 14:51 | 155.9 |
| Beaver Brook | 6.500 | 635.29 | 01Jan2000, 15:00 | 155.9 |
| Lower Subbasin | 0.948 | 153.32 | 01Jan2000, 13:58 | 26.1 |
| Lower Beaver Brook Res... | 7.448 | 702.57 | 01Jan2000, 15:00 | 182.0 |



## *25-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "25-yr Proposed"

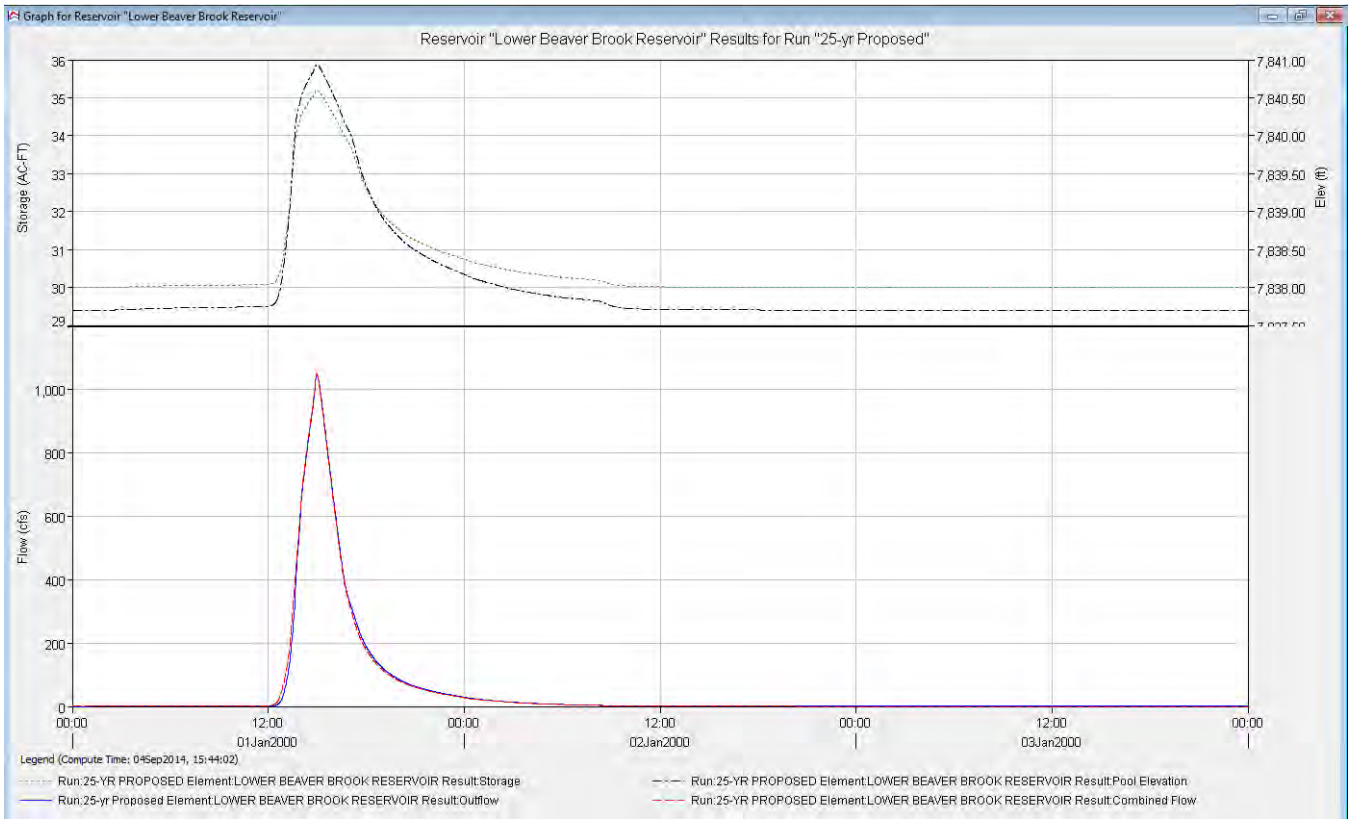
Project: LowerBeaverBrook  Simulation Run: 25-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:44:02

Basin Model: 100-yr Proposed
Meteorologic Model: 25-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 969.55 | 01Jan2000, 14:46 | 233.9 |
| Upper Beaver Brook Res... | 6.500 | 949.45 | 01Jan2000, 14:51 | 233.9 |
| Beaver Brook | 6.500 | 949.19 | 01Jan2000, 14:59 | 233.9 |
| Lower Subbasin | 0.948 | 222.24 | 01Jan2000, 13:58 | 38.2 |
| Lower Beaver Brook Res... | 7.448 | 1049.19 | 01Jan2000, 14:59 | 272.1 |



## *50-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "50-yr Proposed"

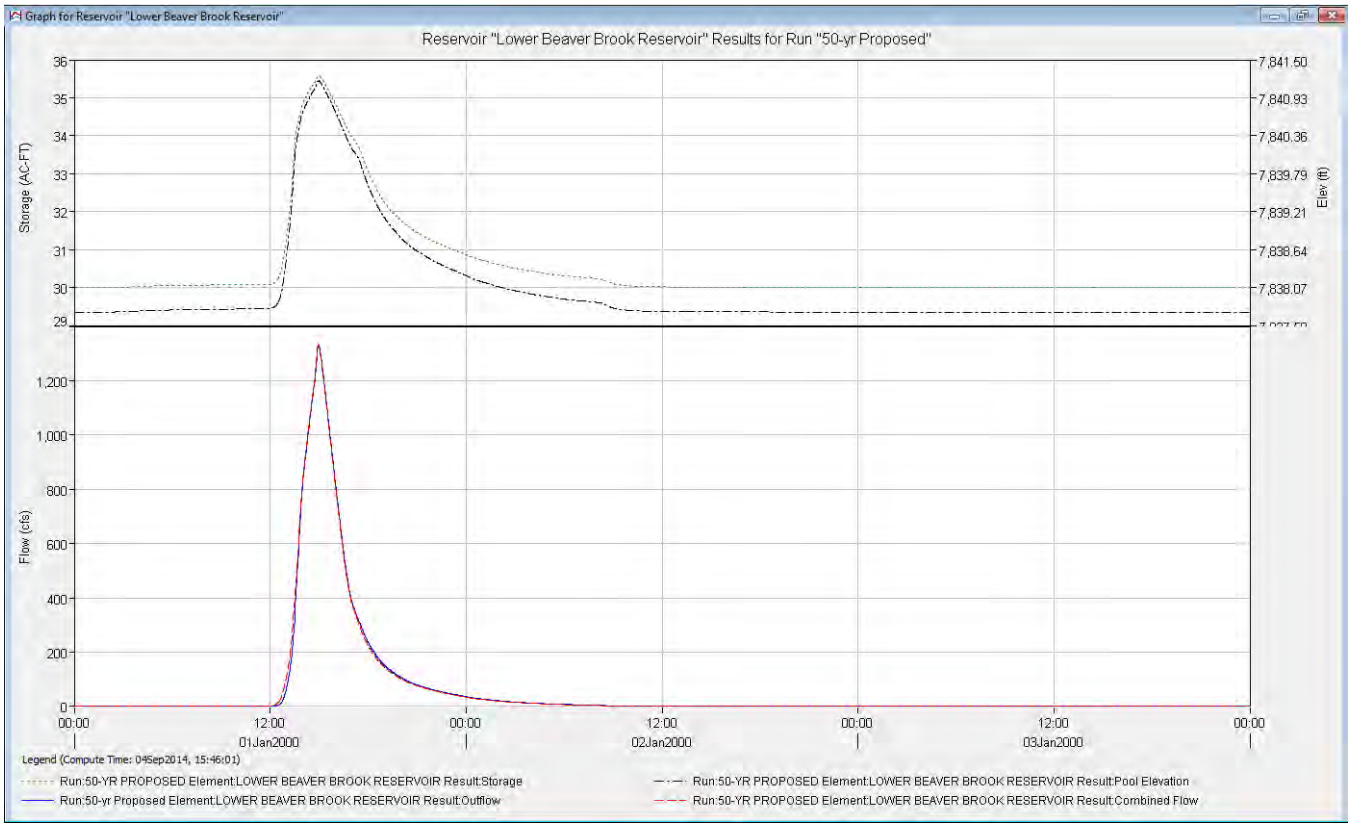
Project: LowerBeaverBrook  Simulation Run: 50-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:46:01

Basin Model: 100-yr Proposed
Meteorologic Model: 50-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 1222.98 | 01Jan2000, 14:46 | 296.2 |
| Upper Beaver Brook Res... | 6.500 | 1203.64 | 01Jan2000, 14:51 | 296.3 |
| Beaver Brook | 6.500 | 1203.29 | 01Jan2000, 14:58 | 296.3 |
| Lower Subbasin | 0.948 | 278.01 | 01Jan2000, 13:58 | 48.1 |
| Lower Beaver Brook Res... | 7.448 | 1332.08 | 01Jan2000, 14:58 | 344.3 |



## *100-yr Event – Global Summary and Lower Beaver Brook Hydrographs*

Global Summary Results for Run "100-yr Proposed"

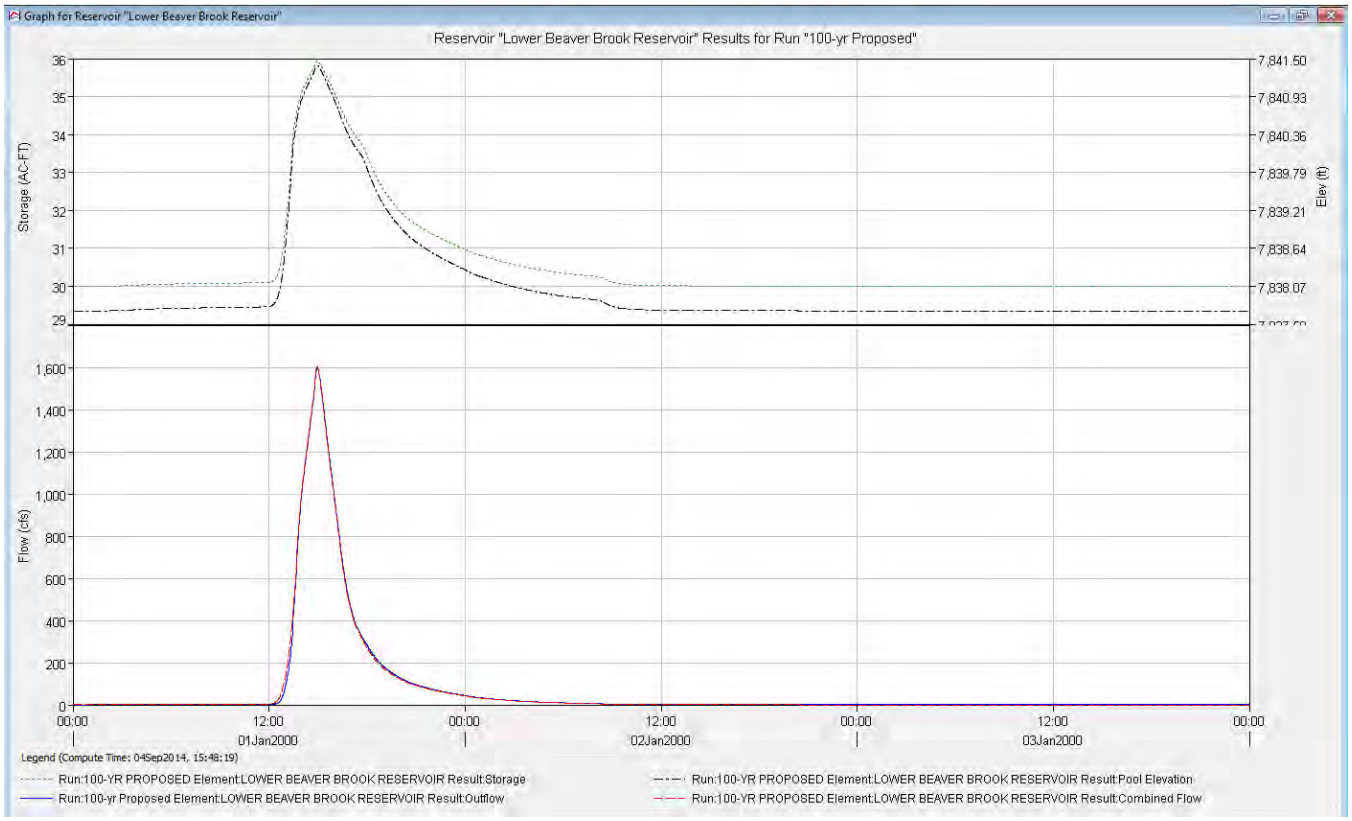
Project: LowerBeaverBrook  Simulation Run: 100-yr Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 15:53:22

Basin Model: 100-yr Proposed
Meteorologic Model: 100-yr
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (IN) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 1467.43 | 01Jan2000, 14:46 | 1.03 |
| Upper Beaver Brook Res... | 6.500 | 1445.51 | 01Jan2000, 14:51 | 1.03 |
| Beaver Brook | 6.500 | 1445.25 | 01Jan2000, 14:58 | 1.03 |
| Lower Subbasin | 0.948 | 332.02 | 01Jan2000, 13:58 | 1.14 |
| Lower Beaver Brook Res... | 7.448 | 1601.30 | 01Jan2000, 14:57 | 1.04 |



## HMR 55A – Local Storm

Global Summary Results for Run "Local Storm - Proposed"

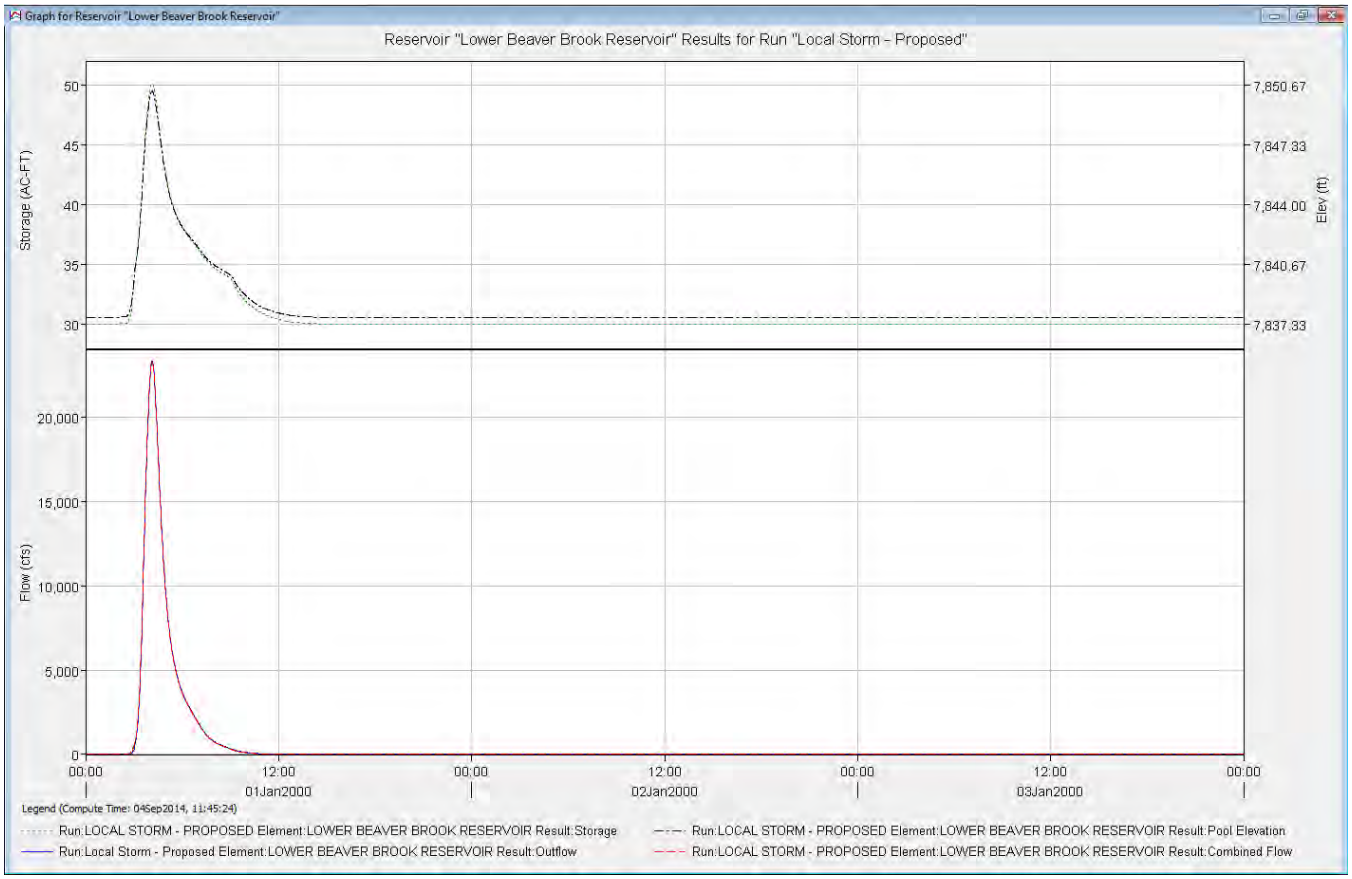
Project: LowerBeaverBrook  Simulation Run: Local Storm - Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 11:45:24

Basin Model: Local Storm
Meteorologic Model: Local Storm
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 22253.42 | 01Jan2000, 04:02 | 2634.5 |
| Upper Beaver Brook Reservoir | 6.500 | 20680.84 | 01Jan2000, 04:10 | 2634.4 |
| Beaver Brook | 6.500 | 20680.81 | 01Jan2000, 04:10 | 2634.4 |
| Lower Subbasin | 0.948 | 5155.91 | 01Jan2000, 03:45 | 449.4 |
| Lower Beaver Brook Reservoir | 7.448 | 23316.10 | 01Jan2000, 04:08 | 3083.4 |



# HMR 55A – General Storm

Global Summary Results for Run "General Storm - Proposed"

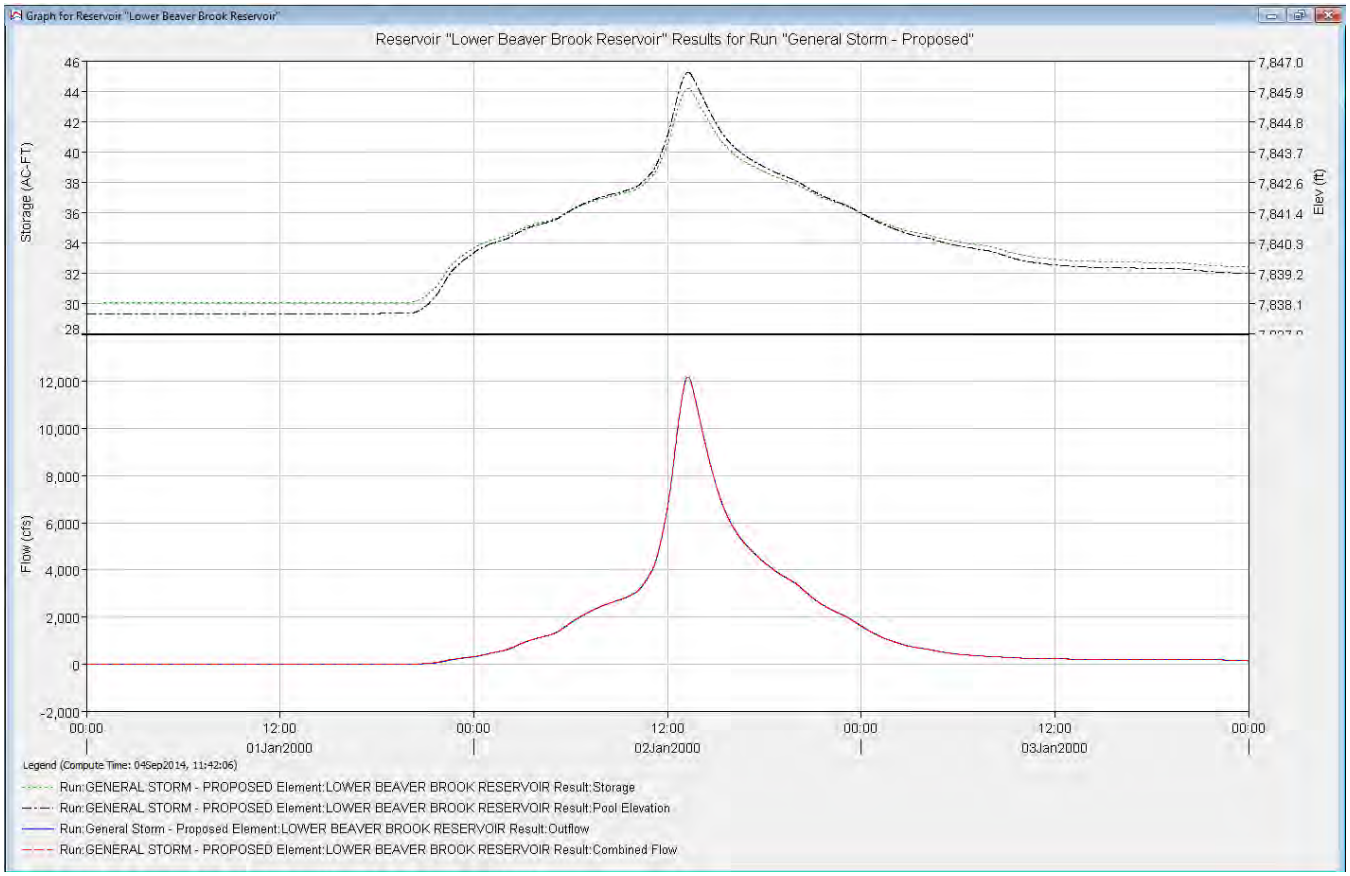
Project: LowerBeaverBrook  Simulation Run: General Storm - Proposed

Start of Run: 01Jan2000, 00:00
End of Run: 04Jan2000, 00:00
Compute Time: 04Sep2014, 11:42:06

Basin Model: General Storm
Meteorologic Model: General Storm
Control Specifications: Control 1

Show Elements: All Elements  Volume Units: IN AC-FT  Sorting: Hydrologic

| Hydrologic Element | Drainage Area (MI2) | Peak Discharge (CFS) | Time of Peak | Volume (AC-FT) |
|---|---|---|---|---|
| Upper Subbasin | 6.500 | 10743.11 | 02Jan2000, 13:04 | 6951.9 |
| Upper Beaver Brook Reservoir | 6.500 | 10639.81 | 02Jan2000, 13:11 | 6949.8 |
| Beaver Brook | 6.500 | 10639.81 | 02Jan2000, 13:11 | 6949.7 |
| Lower Subbasin | 0.948 | 1839.84 | 02Jan2000, 13:46 | 1058.3 |
| Lower Beaver Brook Reservoir | 7.448 | 12185.29 | 02Jan2000, 13:16 | 8005.6 |



# Appendix C

## Proposed Spillway Information

## Proposed Spillway Design

The hydrologic analysis previously presented in this report is based on the existing condition of the spillway and dam. The following hydrologic analysis reflects the design of the proposed spillway improvement project which raises the existing normal pool and reduces the available head for discharging the IDF.

### *Raised Spillway*

LMWD has acquired water rights to store an additional 102 AF in the reservoir (water surface of El. 8406.7). To provide the additional storage, the existing spillway will be reconstructed to raise the normal pool elevation at Upper Beaver Brook Dam. The new spillway will be designed to accommodate the IDF, per SEO Regulations for a High Hazard dam. The spillway and dam alignments are not expected to be significantly modified.

The proposed spillway crest will be constructed as a two-stage labyrinth type weir. The first stage of the weir will be a small notch through one of the wall sections, and be set at a crest elevation of 8406.7 to accommodate the existing normal pool storage right of 102 AF. The second stage of the weir will be set at El. 8409.25 to provide the potential for increased storage (total reservoir storage of 391 AF) in the future, while still passing the recommended IDF. Should LMWD acquire the additional storage rights, the first stage notch can be raised to match the second stage of the weir at El. 8409.25.

Based on hydraulic analyses, the proposed spillway will be a 3-cycle labyrinth weir. Each cycle will be 30 feet wide and 109 feet long with a crest elevation of El. 8409.25. The angle of side legs will be 6.05 degrees and the wall height will be 10.25 feet. The total spillway width will be increased to 90 feet, which will require enlarging the existing spillway by 10 feet. The elevation of the top of the footing will match the existing spillway crest elevation of El. 8399. Figure 8 depicts the proposed spillway configuration, and Table 6-1 summarizes the proposed geometry for the spillway. The calculations and figures related to the proposed spillway are contained in Appendix C.

**Table C-1: Proposed Spillway Parameters**

| Design Parameter | |
|---|---|
| No. of Cycles | 3 |
| Maximum Reservoir Elevation (ft) | 8,419.0 |
| Crest Elevation (ft) | 8,409.25 |
| Floor (top of slab) Elevation (ft) | 8,399.0 |
| Spillway Width (ft) | 90 |
| Wall Angle (degree) | 6.05 |
| Crest Shape | Half Round |
| Maximum Discharge (cfs) | 21,559 |
| Lde/B | 0.40 |
| Ho/P | 0.95 |
| w/P | 2.93 |
| A/w | 0.12 |
| P/tw | 5.59 |
| Length of Apron (ft) | 109.0 |
| Apex Width (ft) | 3.65 |
| Wall Thickness at Crest (inches) | 22 |
| Wall Thickness at Base (inches) | 28 |
| Wall Height (ft) | 10.25 |

Routing the IDF through the proposed spillway increases the peak outflow from 20,680 cfs to 21,570 cfs and increases the peak reservoir water surface elevation from El. 8418.95 to El. 8419.0. The rating curve for the proposed spillway is shown in Figure 9 and the inflow and outflow hydrographs for the proposed spillway are illustrated in Figure 10.

# Appendix D

## Dam Breach Inputs and HEC-RAS Summary

# HEC-RAS Input and Output

**HEC-RAS Inputs – Lower Beaver Brook**

- Lower Beaver Brook Model Geometry
- Dam Breach Parameters from HEC-HMS
- Dam Base Flood Hydrographs from HEC-HMS
- Dam Breach Flood Hydrographs from HEC-HMS
- Beaver Brook Profile – 0.275PMP Base Flood
- Beaver Brook Profile – 0.275PMP Breach Flood
- HEC-RAS Tabular Results
- HEC-RAS Cross Sections
- HEC-RAS Hydrographs

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

**PROJECT:** Lower Beaver Brook Dam and Reservoir

**BREACH INPUT PARAMETERS:**

| | | |
|---|---|---|
| Select Embankment Type From Drop-Down Menu: | ROCKFILL | |
| Height of water over base elevation of breach ($H_w$) = | 34.9 | Feet |
| Volume of water stored in reservoir at time of failure ($V_w$) = | 46.4 | Acre-Feet |
| Reservoir Surface Area at $H_w$ ($S_a$) = | 3.5 | Acres |
| Crest width of dam (C) = | 12.0 | Feet |
| Height of breach from dam crest to base elevation of breach ($H_b$) = | 31.2 | Feet |
| Slope of upstream dam face ($Z_u$) = | 0.7 | Z(H):1(V) |
| Slope of downstream dam face ($Z_d$) = | 1.3 | Z(H):1(V) |
| Breach side-slope ratio ($Z_b$) = | 0.3 | Z(H):1(V) |
| Piping Orifice Coefficient ($C_p$) = | 0.66 | Used To Calculate Peak Discharge Through Piping Hole |
| Dam Size Class: | Small | Assumes Full Reservoir At Time of Breach |

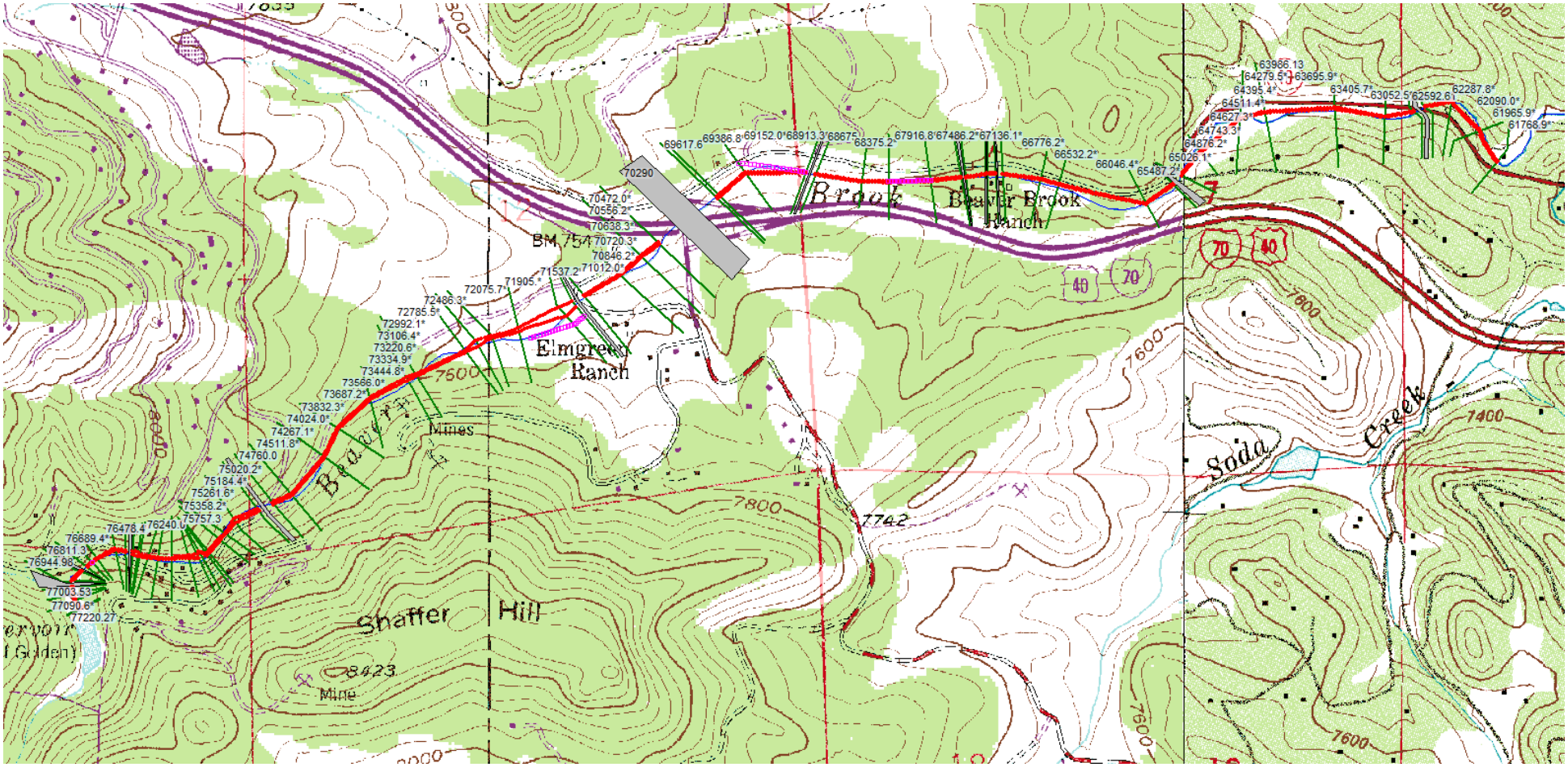
**CALCULATED BREACH CHARACTERISTICS:**

| | | |
|---|---|---|
| Breach Formation Factor (BFF) = | 1619.36 | |
| Embankment Volume Eroded ($V_{er}$) = | 387.3 | Cubic Yards |
| Average Dam Width ($W_{avg}$) = | 42.4 | Feet (In Direction of Flow) |
| Average Breach Width ($B_{avg}$) = | 7.9 | Feet |
| Bottom Width of Breach ($B_b$) = | 0.1 | Feet |
| Breach Formation Time ($T_f$) = | 0.17 | Hours |
| Storage Intensity (SI) = | 1.3 | Acre Feet/Foot |
| Peak Breach Discharge ($Q_p$) = | 3821 | Cubic Feet per Second |

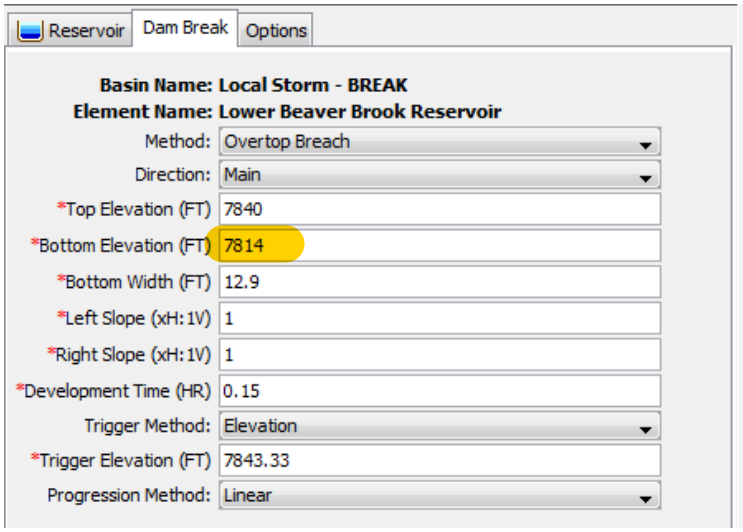
**RESULTS CHECK: This spreadsheet does not contain calculations to check results for rockfill dams**

# HEC-RAS Inputs – Lower Beaver Brook

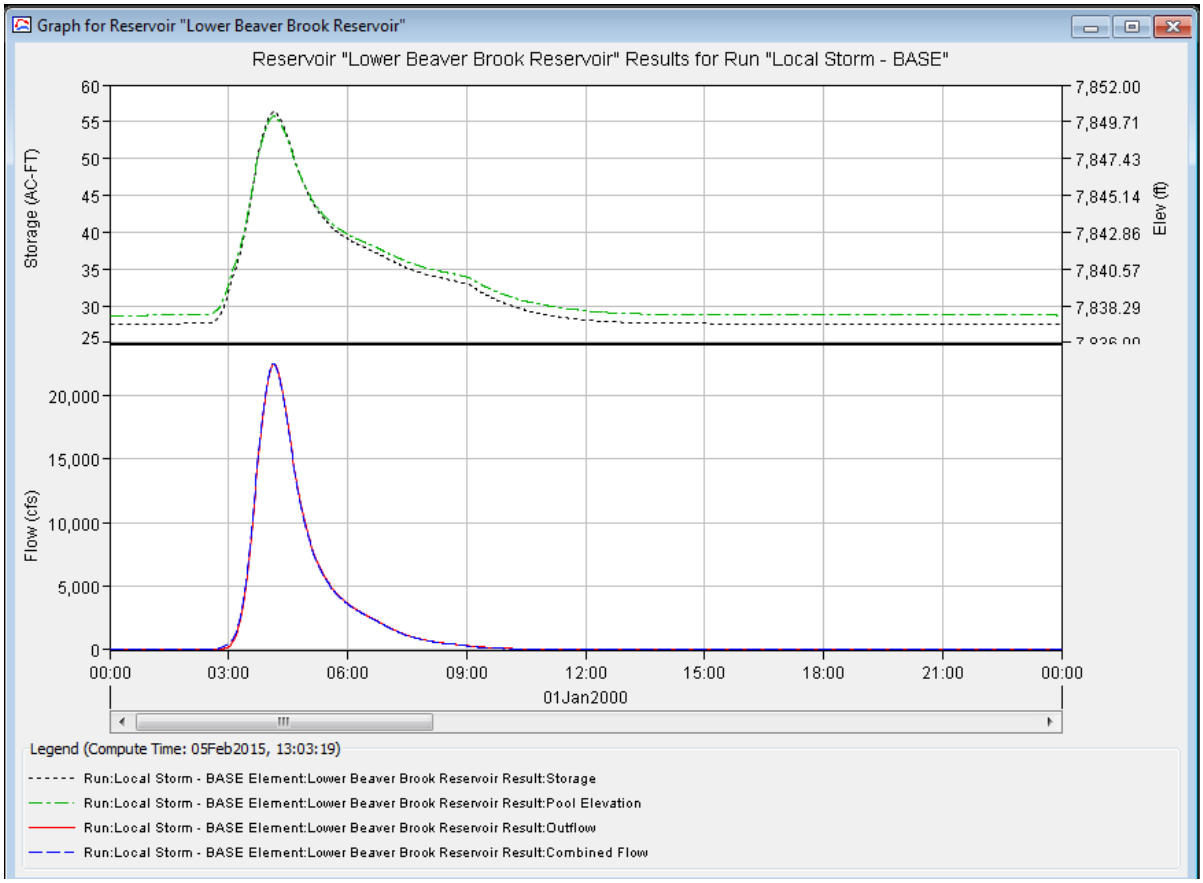
## Lower Beaver Brook Model Geometry



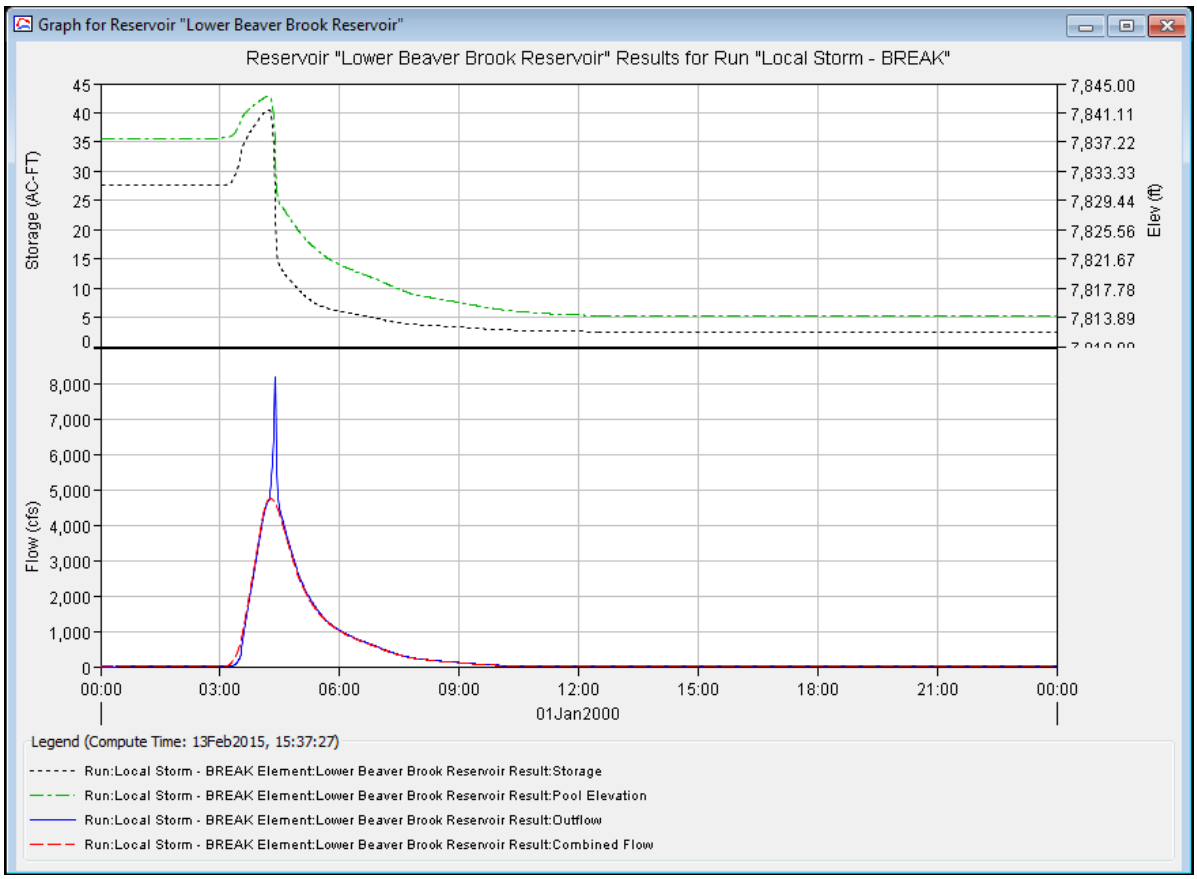
## Dam Breach Parameters from HEC-HMS



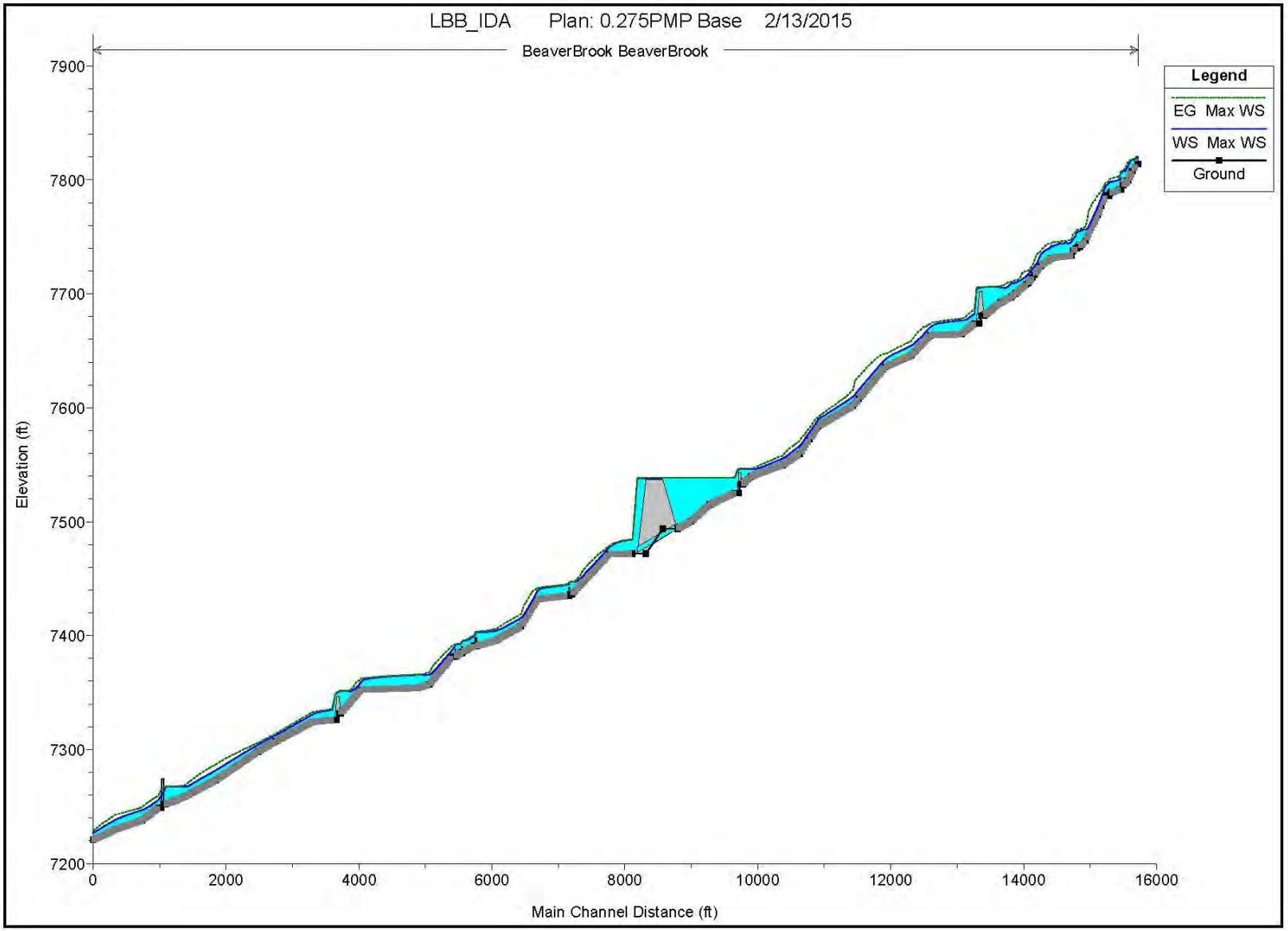

## Dam Base Flood Hydrographs from HEC-HMS



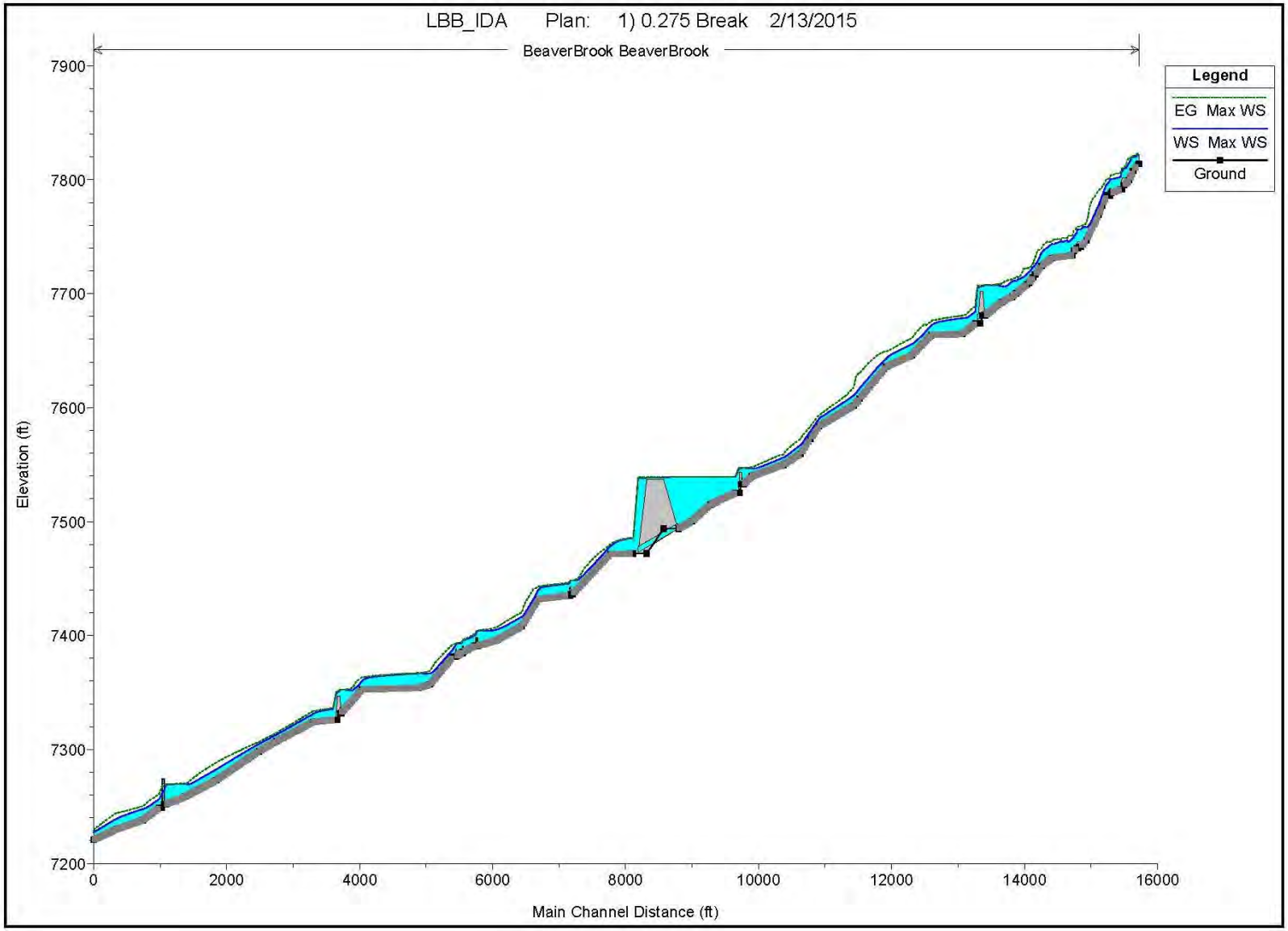
# Dam Breach Flood Hydrographs from HEC-HMS



## Beaver Brook Profile – 0.275PMP Base Flood



## Beaver Brook Profile – 0.275PMP Breach Flood



# HEC-RAS Tabular Results

HEC-RAS River: BeaverBrook Reach: BeaverBrook Profile: Max WS

| Reach | River Sta | Profile | Plan | 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 | Max Chl Dpth | Vel Left | Vel Right |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft) | (ft) | (ft) | (ft/ft) | (ft/s) | (sq ft) | (ft) | | (ft) | (ft/s) | (ft/s) |
| BeaverBrook | 77220.27 | Max WS | 0.275 Base | 4752.20 | 7814.00 | 7820.13 | | 7821.33 | 0.040768 | 9.90 | 563.28 | 125.26 | 0.71 | 6.13 | 7.63 | 6.33 |
| BeaverBrook | 77220.27 | Max WS | 0.275 Break | 8174.60 | 7814.00 | 7822.05 | | 7823.73 | 0.040656 | 11.90 | 821.79 | 142.21 | 0.75 | 8.05 | 9.07 | 7.66 |
| BeaverBrook | 77215.13 | Max WS | 0.275 Base | 4752.18 | 7814.00 | 7819.69 | | 7821.13 | 0.056168 | 11.10 | 509.83 | 122.94 | 0.83 | 5.69 | 8.93 | 7.16 |
| BeaverBrook | 77215.13 | Max WS | 0.275 Break | 8168.39 | 7814.00 | 7821.65 | | 7823.53 | 0.050338 | 12.84 | 769.74 | 140.19 | 0.82 | 7.65 | 10.24 | 8.40 |
| BeaverBrook | 77132.59 | Max WS | 0.275 Base | 4751.53 | 7807.60 | 7817.43 | | 7817.80 | 0.008571 | 6.31 | 992.76 | 153.23 | 0.35 | 9.83 | 4.57 | 4.67 |
| BeaverBrook | 77132.59 | Max WS | 0.275 Break | 8008.43 | 7807.60 | 7820.14 | | 7820.64 | 0.008405 | 7.35 | 1434.02 | 172.26 | 0.37 | 12.54 | 5.29 | 5.51 |
| BeaverBrook | 77069.6 | Max WS | 0.275 Base | 4751.05 | 7799.60 | 7811.79 | 7812.69 | 7815.77 | 0.091678 | 20.70 | 350.18 | 64.20 | 1.07 | 12.19 | 9.35 | 11.97 |
| BeaverBrook | 77069.6 | Max WS | 0.275 Break | 8003.17 | 7799.60 | 7814.32 | 7814.78 | 7818.99 | 0.089438 | 23.30 | 524.74 | 73.85 | 1.09 | 14.72 | 12.12 | 13.53 |
| BeaverBrook | 77003.53 | Max WS | 0.275 Base | 4750.73 | 7795.13 | 7808.04 | | 7808.55 | 0.010226 | 7.46 | 862.55 | 124.32 | 0.37 | 12.91 | 4.35 | 5.31 |
| BeaverBrook | 77003.53 | Max WS | 0.275 Break | 7996.51 | 7795.13 | 7810.26 | | 7811.06 | 0.012765 | 9.31 | 1156.27 | 138.97 | 0.43 | 15.13 | 5.51 | 6.76 |
| BeaverBrook | 77000 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 76944.98 | Max WS | 0.275 Base | 4750.73 | 7791.62 | 7800.10 | 7800.48 | 7803.06 | 0.016881 | 17.88 | 572.50 | 126.01 | 1.16 | 8.48 | 3.94 | 5.18 |
| BeaverBrook | 76944.98 | Max WS | 0.275 Break | 7996.51 | 7791.62 | 7802.36 | 7802.77 | 7806.00 | 0.015943 | 20.74 | 885.65 | 151.26 | 1.17 | 10.74 | 4.75 | 6.05 |
| BeaverBrook | 76811.3 | Max WS | 0.275 Base | 4749.47 | 7788.26 | 7798.26 | | 7800.91 | 0.013673 | 17.62 | 614.01 | 116.70 | 1.03 | 10.00 | 4.36 | 5.21 |
| BeaverBrook | 76811.3 | Max WS | 0.275 Break | 7944.07 | 7788.26 | 7800.54 | | 7803.98 | 0.014437 | 21.03 | 899.63 | 134.50 | 1.10 | 12.28 | 5.42 | 6.32 |
| BeaverBrook | 76800 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 76731.09 | Max WS | 0.275 Base | 4749.47 | 7786.24 | 7794.05 | 7794.96 | 7797.47 | 0.148964 | 18.76 | 338.33 | 90.92 | 1.28 | 7.81 | 12.00 | 13.06 |
| BeaverBrook | 76731.09 | Max WS | 0.275 Break | 7944.07 | 7786.24 | 7795.60 | 7796.79 | 7800.08 | 0.145610 | 21.31 | 485.81 | 99.89 | 1.31 | 9.35 | 14.59 | 15.54 |
| BeaverBrook | 76668.55 | Max WS | 0.275 Base | 4749.49 | 7777.27 | 7784.33 | 7786.15 | 7789.97 | 0.157377 | 26.48 | 287.95 | 71.19 | 1.86 | 7.06 | 13.95 | 13.76 |
| BeaverBrook | 76668.55 | Max WS | 0.275 Break | 7933.22 | 7777.27 | 7785.98 | 7788.38 | 7793.48 | 0.160999 | 31.24 | 412.42 | 80.31 | 1.95 | 8.71 | 16.53 | 16.53 |
| BeaverBrook | 76611.79 | Max WS | 0.275 Base | 4749.47 | 7769.35 | 7775.70 | 7778.53 | 7785.89 | 0.121182 | 37.84 | 304.35 | 88.51 | 2.80 | 6.35 | 11.05 | 11.18 |
| BeaverBrook | 76611.79 | Max WS | 0.275 Break | 7923.75 | 7769.35 | 7777.17 | 7780.72 | 7789.99 | 0.122702 | 44.41 | 442.69 | 99.43 | 2.93 | 7.82 | 13.31 | 13.47 |
| BeaverBrook | 76434.02 | Max WS | 0.275 Base | 4749.22 | 7746.92 | 7756.11 | 7756.77 | 7759.50 | 0.019592 | 19.45 | 531.95 | 111.73 | 1.23 | 9.19 | 4.40 | 5.78 |
| BeaverBrook | 76434.02 | Max WS | 0.275 Break | 7880.41 | 7746.92 | 7757.99 | 7758.95 | 7762.58 | 0.021549 | 23.56 | 751.83 | 122.44 | 1.33 | 11.06 | 5.75 | 7.23 |
| BeaverBrook | 76346.7 | Max WS | 0.275 Base | 4748.87 | 7740.97 | 7754.77 | | 7756.42 | 0.031947 | 12.11 | 528.32 | 96.91 | 0.63 | 13.79 | 6.05 | 6.36 |
| BeaverBrook | 76346.7 | Max WS | 0.275 Break | 7835.84 | 7740.97 | 7756.61 | | 7759.03 | 0.041065 | 15.18 | 729.50 | 124.74 | 0.74 | 15.64 | 6.95 | 8.30 |
| BeaverBrook | 76330 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 76288.5 | Max WS | 0.275 Base | 4748.87 | 7739.96 | 7751.23 | 7751.31 | 7754.60 | 0.060126 | 15.81 | 357.26 | 58.84 | 0.88 | 11.27 | 7.29 | 7.55 |
| BeaverBrook | 76288.5 | Max WS | 0.275 Break | 7835.84 | 7739.96 | 7753.50 | 7754.92 | 7758.14 | 0.067804 | 19.23 | 515.69 | 85.82 | 0.97 | 13.54 | 9.21 | 9.36 |
| BeaverBrook | 76240.0 | Max WS | 0.275 Base | 4748.76 | 7737.64 | 7747.29 | 7748.56 | 7751.93 | 0.138383 | 17.71 | 287.35 | 61.70 | 1.27 | 9.65 | 4.77 | 8.44 |
| BeaverBrook | 76240.0 | Max WS | 0.275 Break | 7818.49 | 7737.64 | 7749.46 | 7751.12 | 7755.16 | 0.118279 | 20.09 | 437.58 | 77.17 | 1.23 | 11.82 | 6.92 | 10.52 |
| BeaverBrook | 76220.6 | Max WS | 0.275 Base | 4748.70 | 7733.70 | 7745.74 | | 7747.40 | 0.021985 | 12.91 | 528.05 | 72.82 | 0.69 | 12.04 | 7.10 | 6.79 |
| BeaverBrook | 76220.6 | Max WS | 0.275 Break | 7810.81 | 7733.70 | 7748.05 | | 7750.60 | 0.027473 | 16.42 | 712.38 | 86.61 | 0.80 | 14.35 | 8.97 | 8.14 |
| BeaverBrook | 76143.17 | Max WS | 0.275 Base | 4748.24 | 7733.00 | 7744.73 | | 7745.96 | 0.004021 | 11.44 | 902.93 | 136.07 | 0.60 | 11.73 | 2.44 | 3.15 |
| BeaverBrook | 76143.17 | Max WS | 0.275 Break | 7771.64 | 7733.00 | 7746.74 | | 7748.63 | 0.005257 | 14.61 | 1184.94 | 144.57 | 0.71 | 13.74 | 3.30 | 4.21 |
| BeaverBrook | 76046.3 | Max WS | 0.275 Base | 4747.42 | 7732.64 | 7744.33 | | 7745.01 | 0.011376 | 9.78 | 826.92 | 131.83 | 0.52 | 11.69 | 5.28 | 4.77 |
| BeaverBrook | 76046.3 | Max WS | 0.275 Break | 7709.27 | 7732.64 | 7746.33 | | 7747.28 | 0.013005 | 11.67 | 1095.74 | 137.65 | 0.57 | 13.69 | 6.54 | 6.10 |
| BeaverBrook | 75917.1 | Max WS | 0.275 Base | 4745.71 | 7731.36 | 7741.69 | 7742.01 | 7743.94 | 0.021514 | 19.00 | 659.45 | 157.82 | 1.07 | 10.33 | 4.25 | 5.82 |
| BeaverBrook | 75917.1 | Max WS | 0.275 Break | 7624.38 | 7731.36 | 7743.56 | 7743.49 | 7745.81 | 0.019578 | 20.38 | 966.52 | 168.41 | 1.06 | 12.20 | 5.45 | 6.78 |
| BeaverBrook | 75757.3 | Max WS | 0.275 Base | 4745.58 | 7724.40 | 7734.18 | 7734.97 | 7737.48 | 0.125583 | 16.15 | 349.07 | 81.91 | 1.02 | 9.78 | 10.73 | 7.36 |
| BeaverBrook | 75757.3 | Max WS | 0.275 Break | 7512.36 | 7724.40 | 7735.72 | 7736.75 | 7739.92 | 0.129696 | 18.49 | 483.97 | 94.02 | 1.06 | 11.31 | 13.53 | 9.49 |
| BeaverBrook | 75662.1 | Max WS | 0.275 Base | 4745.45 | 7716.90 | 7724.02 | 7725.55 | 7728.93 | 0.059642 | 19.23 | 336.41 | 97.44 | 1.39 | 7.12 | 6.07 | 5.52 |
| BeaverBrook | 75662.1 | Max WS | 0.275 Break | 7473.20 | 7716.90 | 7725.39 | 7727.47 | 7731.73 | 0.062498 | 22.61 | 479.97 | 112.07 | 1.47 | 8.49 | 7.98 | 6.94 |
| BeaverBrook | 75630.3 | Max WS | 0.275 Base | 4745.38 | 7714.40 | 7721.81 | 7722.64 | 7724.86 | 0.081558 | 22.79 | 436.06 | 126.85 | 1.56 | 7.41 | 9.21 | 9.25 |
| BeaverBrook | 75630.3 | Max WS | 0.275 Break | 7456.26 | 7714.40 | 7723.15 | 7724.11 | 7726.69 | 0.080293 | 25.55 | 620.86 | 149.61 | 1.59 | 8.75 | 10.44 | 10.47 |
| BeaverBrook | 75566.91 | Max WS | 0.275 Base | 4745.25 | 7709.39 | 7717.19 | 7717.86 | 7720.27 | 0.054585 | 18.98 | 432.44 | 105.13 | 1.32 | 7.80 | 8.25 | 8.09 |
| BeaverBrook | 75566.91 | Max WS | 0.275 Break | 7423.94 | 7709.39 | 7718.66 | 7719.51 | 7722.54 | 0.054987 | 21.87 | 594.59 | 115.01 | 1.37 | 9.27 | 9.72 | 9.59 |
| BeaverBrook | 75538.7 | Max WS | 0.275 Base | 4745.17 | 7708.04 | 7715.59 | 7716.86 | 7719.81 | 0.059740 | 20.01 | 383.17 | 101.45 | 1.39 | 7.55 | 6.79 | 8.24 |
| BeaverBrook | 75538.7 | Max WS | 0.275 Break | 7408.56 | 7708.04 | 7717.08 | 7718.54 | 7722.14 | 0.058413 | 22.74 | 542.67 | 112.70 | 1.43 | 9.04 | 8.37 | 9.69 |
| BeaverBrook | 75380.8 | Max WS | 0.275 Base | 4744.47 | 7700.47 | 7709.33 | 7709.42 | 7712.17 | 0.013261 | 16.83 | 566.97 | 109.06 | 1.05 | 8.86 | 4.43 | 4.75 |
| BeaverBrook | 75380.8 | Max WS | 0.275 Break | 7358.30 | 7700.47 | 7710.70 | 7711.41 | 7714.97 | 0.016865 | 21.08 | 722.90 | 117.26 | 1.21 | 10.23 | 5.68 | 6.05 |
| BeaverBrook | 75313.13 | Max WS | 0.275 Base | 4743.94 | 7697.22 | 7708.85 | | 7710.40 | 0.026158 | 16.86 | 599.60 | 116.16 | 0.91 | 11.63 | 7.63 | 5.84 |
| BeaverBrook | 75313.13 | Max WS | 0.275 Break | 7347.13 | 7697.22 | 7710.66 | 7709.71 | 7712.50 | 0.027216 | 19.10 | 828.66 | 135.19 | 0.95 | 13.44 | 8.65 | 6.94 |
| BeaverBrook | 75158.7 | Max WS | 0.275 Base | 4742.13 | 7692.69 | 7705.62 | | 7706.78 | 0.002674 | 9.47 | 830.95 | 143.93 | 0.50 | 12.93 | 1.93 | 1.99 |
| BeaverBrook | 75158.7 | Max WS | 0.275 Break | 7308.82 | 7692.69 | 7706.65 | | 7708.82 | 0.004548 | 13.10 | 994.86 | 166.29 | 0.66 | 13.96 | 2.71 | 2.54 |
| BeaverBrook | 74909.5 | Max WS | 0.275 Base | 4741.43 | 7680.96 | 7706.09 | | 7706.14 | 0.000398 | 2.39 | 2720.08 | 198.71 | 0.09 | 25.13 | 1.40 | 1.65 |
| BeaverBrook | 74909.5 | Max WS | 0.275 Break | 7212.07 | 7680.96 | 7707.47 | | 7707.57 | 0.000727 | 3.35 | 3004.52 | 213.19 | 0.12 | 26.51 | 1.99 | 2.20 |
| BeaverBrook | 74900 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 74760.0 | Max WS | 0.275 Base | 4741.43 | 7673.92 | 7682.51 | 7683.59 | 7686.67 | 0.046558 | 19.19 | 375.21 | 83.08 | 1.27 | 8.59 | 6.53 | 7.85 |
| BeaverBrook | 74760.0 | Max WS | 0.275 Break | 7212.07 | 7673.92 | 7684.14 | 7685.32 | 7689.27 | 0.046209 | 21.95 | 519.27 | 93.80 | 1.31 | 10.22 | 7.78 | 9.12 |
| BeaverBrook | 74560.73 | Max WS | 0.275 Base | 4737.59 | 7664.54 | 7676.56 | | 7678.18 | 0.006301 | 13.61 | 766.19 | 113.66 | 0.73 | 12.02 | 3.67 | 4.08 |
| BeaverBrook | 74560.73 | Max WS | 0.275 Break | 7043.09 | 7664.54 | 7678.37 | | 7680.59 | 0.007375 | 16.34 | 983.07 | 126.24 | 0.81 | 13.83 | 4.41 | 4.87 |
| BeaverBrook | 74095.91 | Max WS | 0.275 Base | 4736.47 | 7663.75 | 7670.71 | 7671.45 | 7673.57 | 0.066550 | 19.44 | 454.21 | 132.98 | 1.43 | 6.96 | 7.82 | 8.60 |
| BeaverBrook | 74095.91 | Max WS | 0.275 Break | 6986.14 | 7663.75 | 7671.80 | 7672.59 | 7675.15 | 0.065101 | 21.60 | 604.09 | 143.31 | 1.46 | 8.05 | 9.07 | 9.76 |
| BeaverBrook | 73808.41 | Max WS | 0.275 Base | 4735.40 | 7646.06 | 7654.37 | 7655.48 | 7658.56 | 0.027998 | 21.72 | 469.02 | 103.75 | 1.44 | 8.31 | 6.45 | 5.93 |
| BeaverBrook | 73808.41 | Max WS | 0.275 Break | 6941.72 | 7646.06 | 7655.78 | 7657.19 | 7660.95 | 0.028642 | 24.81 | 623.08 | 115.13 | 1.50 | 9.72 | 7.42 | 6.82 |
| BeaverBrook | 73420.61 | Max WS | 0.275 Base | 4733.40 | 7635.78 | 7642.30 | 7643.99 | 7647.69 | 0.060515 | 25.77 | 435.41 | 146.60 | 2.01 | 6.52 | 6.84 | 7.33 |
| BeaverBrook | 73420.61 | Max WS | 0.275 Break | 6838.54 | 7635.78 | 7643.25 | 7645.22 | 7649.46 | 0.059708 | 28.69 | 583.13 | 164.02 | 2.05 | 7.47 | 7.62 | 8.50 |
| BeaverBrook | 73020.7 | Max WS | 0.275 Base | 4732.47 | 7607.89 | 7615.71 | 7618.71 | 7627.48 | 0.074121 | 28.01 | 214.71 | 107.95 | 2.20 | 7.82 | 3.28 | 3.11 |
| BeaverBrook | 73020.7 | Max WS | 0.275 Break | 6818.53 | 7607.89 | 7616.73 | 7619.94 | 7630.11 | 0.071218 | 31.03 | 351.42 | 151.56 | 2.22 | 8.84 | 4.48 | 4.73 |

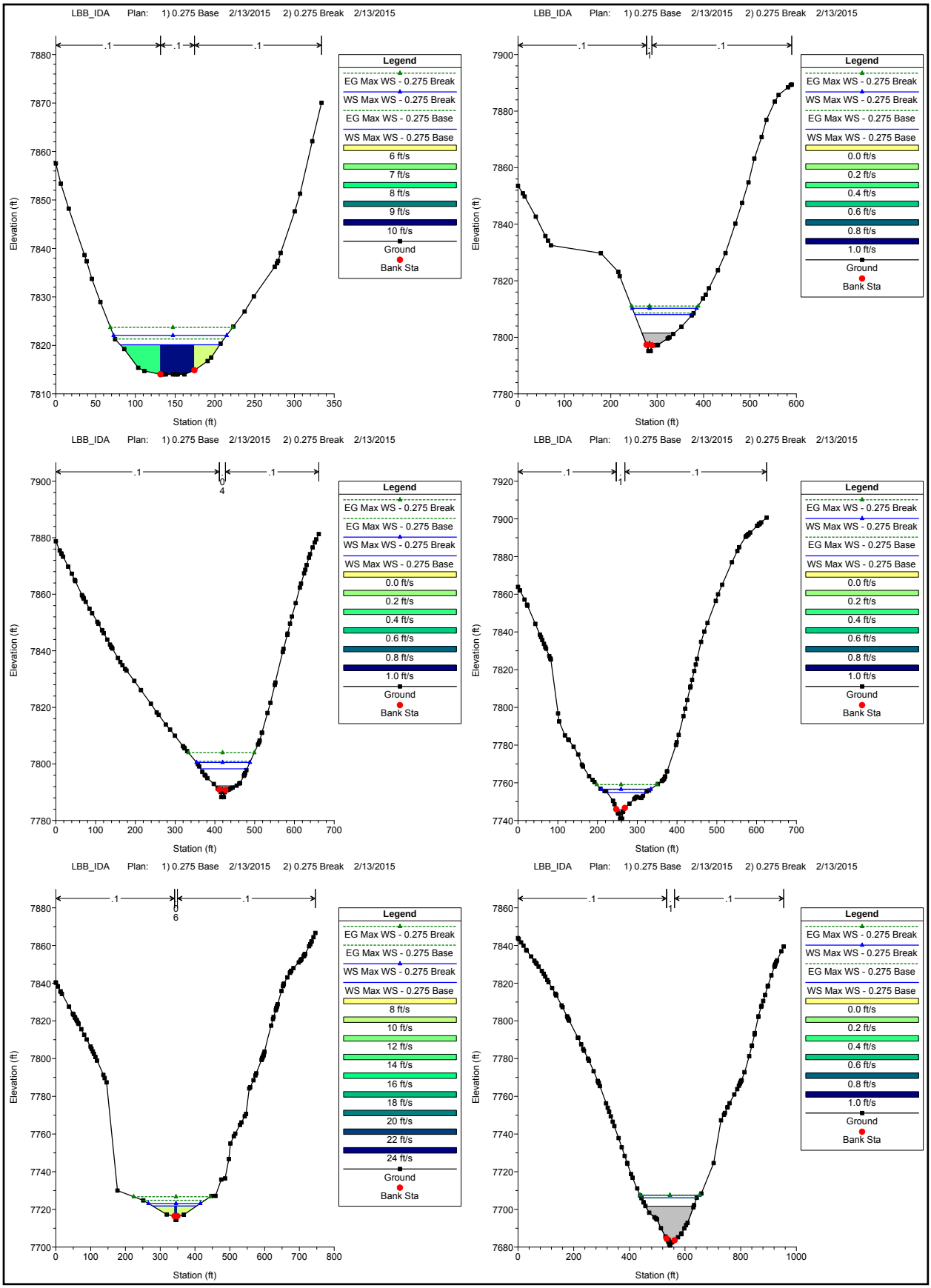
HEC-RAS River: BeaverBrook Reach: BeaverBrook Profile: Max WS (Continued)

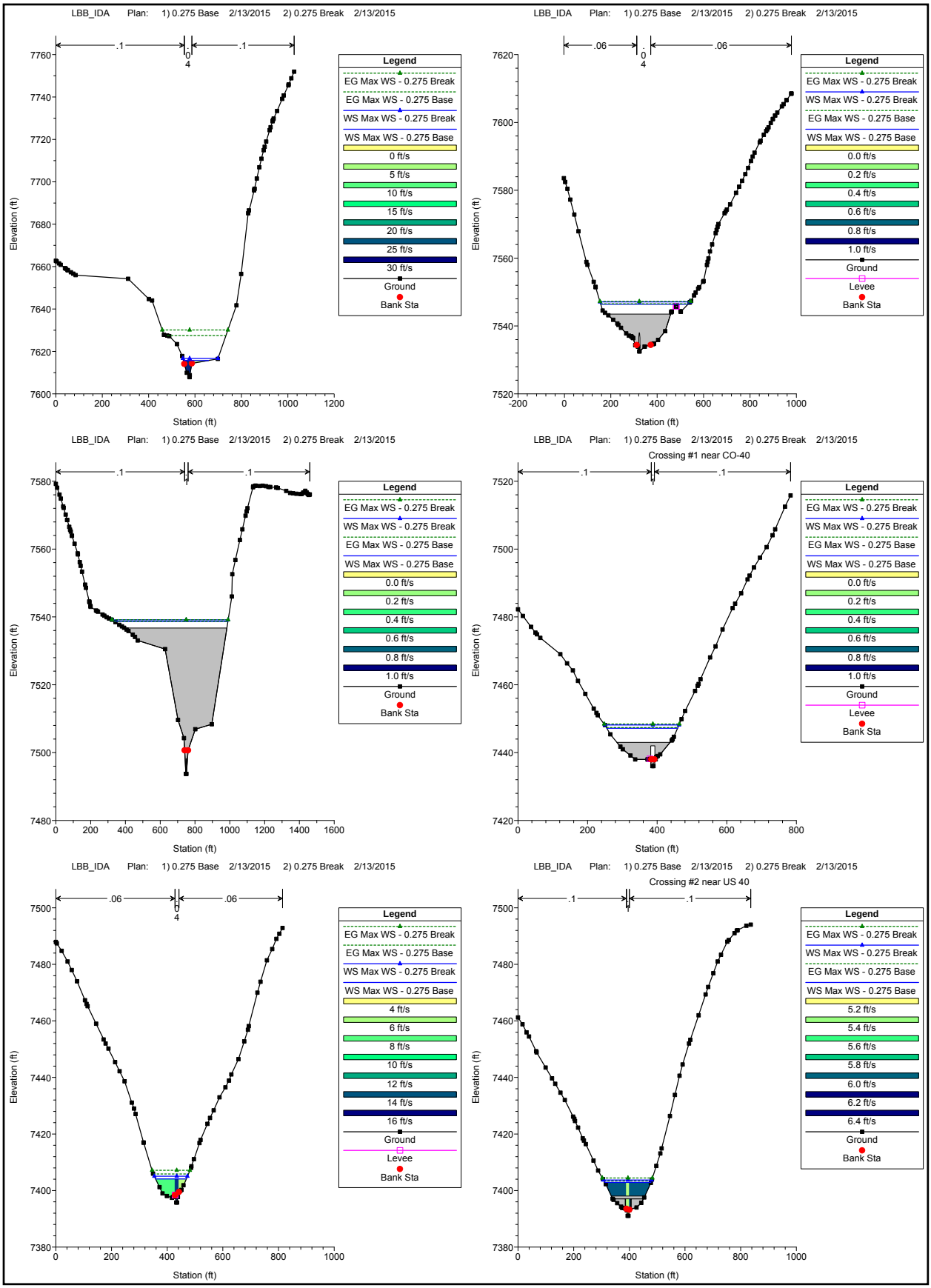
| Reach | River Sta | Profile | Plan | Q Total | Min Ch El | W.S. Elev | Crit W.S. | E.G. Elev | E.G. Slope | Vel Chnl | Flow Area | Top Width | Froude # Chl | Max Chl Dpth | Vel Left | Vel Right |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft) | (ft) | (ft) | (ft/ft) | (ft/s) | (sq ft) | (ft) | | (ft) | (ft/s) | (ft/s) |
| BeaverBrook | 72935.1 | Max WS | 0.275 Base | 4732.15 | 7601.91 | 7609.82 | 7611.74 | 7615.86 | 0.042580 | 24.86 | 422.62 | 128.46 | 1.74 | 7.91 | 5.92 | 6.25 |
| BeaverBrook | 72935.1 | Max WS | 0.275 Break | 6810.45 | 7601.91 | 7610.86 | 7613.09 | 7617.97 | 0.044238 | 28.04 | 565.15 | 144.96 | 1.82 | 8.95 | 6.80 | 7.42 |
| BeaverBrook | 72411.56 | Max WS | 0.275 Base | 4730.32 | 7583.91 | 7589.59 | 7590.21 | 7591.99 | 0.080310 | 18.01 | 432.10 | 163.57 | 1.51 | 5.68 | 9.25 | 9.84 |
| BeaverBrook | 72411.56 | Max WS | 0.275 Break | 6725.20 | 7583.91 | 7590.32 | 7591.13 | 7593.17 | 0.079608 | 19.87 | 557.25 | 178.14 | 1.54 | 6.41 | 10.54 | 10.86 |
| BeaverBrook | 72282.0 | Max WS | 0.275 Base | 4730.04 | 7572.64 | 7578.52 | 7579.77 | 7582.34 | 0.084576 | 17.25 | 347.53 | 180.65 | 1.57 | 5.88 | 4.03 | 7.88 |
| BeaverBrook | 72282.0 | Max WS | 0.275 Break | 6714.36 | 7572.64 | 7579.19 | 7580.52 | 7583.29 | 0.078415 | 18.54 | 483.25 | 222.75 | 1.55 | 6.55 | 5.74 | 9.01 |
| BeaverBrook | 72132.69 | Max WS | 0.275 Base | 4729.59 | 7559.64 | 7566.38 | 7567.81 | 7570.94 | 0.045052 | 22.70 | 349.56 | 115.13 | 1.74 | 6.74 | 10.81 | 8.96 |
| BeaverBrook | 72132.69 | Max WS | 0.275 Break | 6710.49 | 7559.64 | 7567.23 | 7568.91 | 7572.57 | 0.045455 | 25.19 | 451.84 | 124.95 | 1.79 | 7.59 | 12.13 | 10.57 |
| BeaverBrook | 71876.54 | Max WS | 0.275 Base | 4728.41 | 7549.85 | 7555.36 | 7556.10 | 7557.69 | 0.023023 | 16.15 | 526.22 | 210.65 | 1.29 | 5.51 | 5.25 | 6.50 |
| BeaverBrook | 71876.54 | Max WS | 0.275 Break | 6692.65 | 7549.85 | 7556.15 | 7557.01 | 7558.82 | 0.023226 | 17.92 | 719.82 | 280.67 | 1.32 | 6.30 | 4.83 | 7.26 |
| BeaverBrook | 71395.82 | Max WS | 0.275 Base | 4726.63 | 7539.89 | 7546.04 | | 7546.76 | 0.004253 | 7.29 | 780.69 | 189.80 | 0.56 | 6.15 | 3.02 | 3.18 |
| BeaverBrook | 71395.82 | Max WS | 0.275 Break | 6609.28 | 7539.89 | 7546.49 | | 7547.65 | 0.006160 | 9.27 | 868.68 | 209.46 | 0.69 | 6.60 | 3.49 | 4.16 |
| BeaverBrook | 71275.0 | Max WS | 0.275 Base | 4725.98 | 7532.50 | 7546.42 | | 7546.51 | 0.000242 | 3.14 | 2616.32 | 376.79 | 0.16 | 13.92 | 1.31 | 1.18 |
| BeaverBrook | 71275.0 | Max WS | 0.275 Break | 6604.50 | 7532.50 | 7547.10 | | 7547.25 | 0.000369 | 4.01 | 2877.17 | 388.80 | 0.19 | 14.60 | 1.71 | 1.53 |
| BeaverBrook | 71250 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 71154.28 | Max WS | 0.275 Base | 4658.38 | 7525.12 | 7538.69 | | 7538.80 | 0.002216 | 3.55 | 1773.64 | 246.93 | 0.18 | 13.57 | 2.60 | 2.43 |
| BeaverBrook | 71154.28 | Max WS | 0.275 Break | 6464.94 | 7525.12 | 7539.17 | | 7539.36 | 0.003573 | 4.63 | 1895.10 | 255.07 | 0.23 | 14.05 | 3.39 | 3.15 |
| BeaverBrook | 70775.11 | Max WS | 0.275 Base | 4655.16 | 7515.00 | 7538.65 | | 7538.66 | 0.000050 | 1.59 | 5037.04 | 345.36 | 0.06 | 23.65 | 0.87 | 0.88 |
| BeaverBrook | 70775.11 | Max WS | 0.275 Break | 6446.76 | 7515.00 | 7539.12 | | 7539.14 | 0.000088 | 2.13 | 5199.49 | 349.96 | 0.08 | 24.12 | 1.16 | 1.18 |
| BeaverBrook | 70501.48 | Max WS | 0.275 Base | 4651.48 | 7500.34 | 7538.65 | | 7538.66 | 0.000005 | 0.83 | 10786.54 | 520.21 | 0.02 | 38.31 | 0.36 | 0.44 |
| BeaverBrook | 70501.48 | Max WS | 0.275 Break | 6418.31 | 7500.34 | 7539.12 | | 7539.13 | 0.000009 | 1.13 | 11037.41 | 546.86 | 0.03 | 38.78 | 0.47 | 0.60 |
| BeaverBrook | 70295.2 | Max WS | 0.275 Base | 4647.31 | 7493.73 | 7538.65 | | 7538.66 | 0.000017 | 0.63 | 10630.20 | 652.21 | 0.02 | 44.92 | 0.28 | 0.52 |
| BeaverBrook | 70295.2 | Max WS | 0.275 Break | 6385.63 | 7493.73 | 7539.12 | | 7539.13 | 0.000030 | 0.85 | 10939.87 | 667.68 | 0.02 | 45.39 | 0.38 | 0.69 |
| BeaverBrook | 70290 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 69617.6 | Max WS | 0.275 Base | 4647.31 | 7472.00 | 7484.28 | | 7484.59 | 0.006828 | 5.64 | 1085.80 | 169.98 | 0.31 | 12.28 | 3.88 | 4.05 |
| BeaverBrook | 69617.6 | Max WS | 0.275 Break | 6385.63 | 7472.00 | 7485.60 | | 7486.00 | 0.007431 | 6.37 | 1317.95 | 181.54 | 0.33 | 13.60 | 4.45 | 4.60 |
| BeaverBrook | 69588.7 | Max WS | 0.275 Base | 4646.35 | 7471.96 | 7484.06 | | 7484.39 | 0.007352 | 5.80 | 1055.89 | 167.64 | 0.32 | 12.10 | 3.99 | 4.17 |
| BeaverBrook | 69588.7 | Max WS | 0.275 Break | 6379.36 | 7471.96 | 7485.36 | | 7485.77 | 0.008021 | 6.55 | 1280.70 | 179.31 | 0.34 | 13.40 | 4.57 | 4.73 |
| BeaverBrook | 69271.4 | Max WS | 0.275 Base | 4640.29 | 7471.56 | 7477.43 | 7477.60 | 7479.03 | 0.061609 | 13.90 | 485.67 | 173.24 | 1.14 | 5.87 | 7.95 | 8.99 |
| BeaverBrook | 69271.4 | Max WS | 0.275 Break | 6325.26 | 7471.56 | 7478.11 | 7478.34 | 7479.98 | 0.060408 | 15.09 | 609.98 | 188.67 | 1.16 | 6.55 | 8.64 | 9.88 |
| BeaverBrook | 68704.48 | Max WS | 0.275 Base | 4634.80 | 7436.02 | 7447.19 | | 7447.39 | 0.004768 | 4.52 | 1305.15 | 203.51 | 0.25 | 11.17 | 3.62 | 3.12 |
| BeaverBrook | 68704.48 | Max WS | 0.275 Break | 6299.46 | 7436.02 | 7448.16 | | 7448.44 | 0.005801 | 5.29 | 1508.26 | 213.16 | 0.28 | 12.14 | 4.26 | 3.71 |
| BeaverBrook | 68675 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 68612.77 | Max WS | 0.275 Base | 4634.80 | 7434.92 | 7444.43 | | 7444.89 | 0.014982 | 7.07 | 868.05 | 173.67 | 0.42 | 9.51 | 4.94 | 5.32 |
| BeaverBrook | 68612.77 | Max WS | 0.275 Break | 6262.73 | 7434.92 | 7445.57 | | 7446.12 | 0.015126 | 7.71 | 1074.45 | 189.57 | 0.43 | 10.65 | 5.41 | 5.84 |
| BeaverBrook | 68185.19 | Max WS | 0.275 Base | 4623.84 | 7432.00 | 7438.92 | 7439.66 | 7441.77 | 0.117819 | 19.84 | 382.17 | 114.95 | 1.40 | 6.92 | 10.69 | 10.81 |
| BeaverBrook | 68185.19 | Max WS | 0.275 Break | 6238.07 | 7432.00 | 7439.67 | 7440.56 | 7442.99 | 0.120050 | 21.61 | 472.09 | 124.62 | 1.44 | 7.67 | 11.76 | 12.09 |
| BeaverBrook | 67940.91 | Max WS | 0.275 Base | 4623.01 | 7408.25 | 7415.53 | 7416.53 | 7418.97 | 0.033213 | 21.56 | 372.51 | 100.03 | 1.50 | 7.28 | 11.29 | 8.08 |
| BeaverBrook | 67940.91 | Max WS | 0.275 Break | 6228.06 | 7408.25 | 7416.42 | 7417.47 | 7420.33 | 0.033087 | 23.46 | 464.83 | 107.39 | 1.53 | 8.17 | 12.25 | 9.52 |
| BeaverBrook | 67555.72 | Max WS | 0.275 Base | 4616.96 | 7395.75 | 7404.12 | 7403.67 | 7405.84 | 0.013905 | 14.78 | 505.63 | 110.04 | 0.98 | 8.37 | 8.27 | 5.68 |
| BeaverBrook | 67555.72 | Max WS | 0.275 Break | 6192.10 | 7395.75 | 7405.08 | 7404.71 | 7407.17 | 0.014638 | 16.52 | 615.28 | 118.88 | 1.03 | 9.33 | 9.20 | 6.52 |
| BeaverBrook | 67277.9 | Max WS | 0.275 Base | 4614.41 | 7391.05 | 7403.29 | 7398.40 | 7403.54 | 0.005476 | 5.12 | 1163.89 | 169.48 | 0.27 | 12.24 | 3.74 | 3.93 |
| BeaverBrook | 67277.9 | Max WS | 0.275 Break | 6175.69 | 7391.05 | 7404.23 | 7399.21 | 7404.57 | 0.006770 | 6.00 | 1326.82 | 177.92 | 0.30 | 13.18 | 4.38 | 4.64 |
| BeaverBrook | 67275 | | | Bridge | | | | | | | | | | | | |
| BeaverBrook | 67236.17 | Max WS | 0.275 Base | 4614.41 | 7391.00 | 7399.36 | | 7400.43 | 0.033786 | 12.23 | 598.33 | 133.76 | 0.78 | 8.36 | 7.06 | 7.19 |
| BeaverBrook | 67236.17 | Max WS | 0.275 Break | 6175.69 | 7391.00 | 7400.31 | | 7401.58 | 0.034468 | 13.36 | 730.91 | 143.58 | 0.80 | 9.31 | 7.80 | 7.94 |
| BeaverBrook | 67061.2 | Max WS | 0.275 Base | 4611.03 | 7385.74 | 7395.32 | | 7395.66 | 0.010496 | 6.10 | 1012.28 | 196.29 | 0.36 | 9.58 | 4.47 | 4.37 |
| BeaverBrook | 67061.2 | Max WS | 0.275 Break | 6158.93 | 7385.74 | 7396.13 | | 7396.56 | 0.012294 | 6.98 | 1173.72 | 206.93 | 0.39 | 10.38 | 5.14 | 5.06 |
| BeaverBrook | 67057 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 67041.67 | Max WS | 0.275 Base | 4611.03 | 7384.96 | 7392.63 | | 7393.47 | 0.019347 | 11.76 | 682.70 | 172.17 | 0.78 | 7.67 | 6.24 | 6.34 |
| BeaverBrook | 67041.67 | Max WS | 0.275 Break | 6158.93 | 7384.96 | 7393.42 | | 7394.44 | 0.020372 | 12.95 | 824.01 | 184.23 | 0.81 | 8.46 | 6.99 | 7.03 |
| BeaverBrook | 66960.58 | Max WS | 0.275 Base | 4608.72 | 7382.12 | 7392.29 | | 7392.57 | 0.004519 | 6.90 | 1164.61 | 217.48 | 0.39 | 10.17 | 3.63 | 3.88 |
| BeaverBrook | 66960.58 | Max WS | 0.275 Break | 6146.96 | 7382.12 | 7393.06 | | 7393.44 | 0.005437 | 7.98 | 1336.69 | 227.78 | 0.44 | 10.94 | 4.25 | 4.51 |
| BeaverBrook | 66950 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 66898.35 | Max WS | 0.275 Base | 4608.51 | 7381.32 | 7386.85 | 7388.12 | 7390.90 | 0.067917 | 25.65 | 344.90 | 133.84 | 2.04 | 5.53 | 11.80 | 11.29 |
| BeaverBrook | 66898.35 | Max WS | 0.275 Break | 6146.96 | 7381.32 | 7387.42 | 7388.86 | 7392.01 | 0.068501 | 27.73 | 424.25 | 144.20 | 2.09 | 6.10 | 12.94 | 12.55 |
| BeaverBrook | 66556.48 | Max WS | 0.275 Base | 4580.02 | 7357.03 | 7365.64 | 7365.65 | 7367.74 | 0.016703 | 17.31 | 480.04 | 110.93 | 1.10 | 8.61 | 8.26 | 7.66 |
| BeaverBrook | 66556.48 | Max WS | 0.275 Break | 6055.13 | 7357.03 | 7366.68 | 7366.61 | 7368.96 | 0.015980 | 18.41 | 600.69 | 121.31 | 1.09 | 9.65 | 8.88 | 8.27 |
| BeaverBrook | 66386.96 | Max WS | 0.275 Base | 4574.04 | 7354.07 | 7365.46 | | 7365.90 | 0.002641 | 8.48 | 982.23 | 154.53 | 0.46 | 11.39 | 4.10 | 4.26 |
| BeaverBrook | 66386.96 | Max WS | 0.275 Break | 6037.59 | 7354.07 | 7366.64 | | 7367.16 | 0.002833 | 9.42 | 1169.75 | 164.70 | 0.48 | 12.56 | 4.63 | 4.73 |
| BeaverBrook | 65535.64 | Max WS | 0.275 Base | 4543.65 | 7352.64 | 7359.38 | 7360.13 | 7362.29 | 0.086623 | 18.81 | 358.07 | 108.31 | 1.36 | 6.74 | 11.93 | 10.60 |
| BeaverBrook | 65535.64 | Max WS | 0.275 Break | 5931.70 | 7352.64 | 7360.02 | 7360.93 | 7363.40 | 0.088259 | 20.33 | 429.51 | 115.01 | 1.40 | 7.38 | 13.15 | 11.68 |
| BeaverBrook | 65220.88 | Max WS | 0.275 Base | 4539.03 | 7331.75 | 7351.54 | | 7351.65 | 0.000308 | 4.26 | 1946.66 | 167.82 | 0.17 | 19.79 | 2.16 | 2.04 |
| BeaverBrook | 65220.88 | Max WS | 0.275 Break | 5914.56 | 7331.75 | 7352.43 | | 7352.59 | 0.000425 | 5.17 | 2098.11 | 172.84 | 0.20 | 20.68 | 2.62 | 2.47 |
| BeaverBrook | 65190.88 | | | Culvert | | | | | | | | | | | | |
| BeaverBrook | 65101.07 | Max WS | 0.275 Base | 4539.03 | 7325.96 | 7334.65 | | 7335.53 | 0.008062 | 12.11 | 724.67 | 177.34 | 0.76 | 8.69 | 6.27 | 5.02 |
| BeaverBrook | 65101.07 | Max WS | 0.275 Break | 5914.56 | 7325.96 | 7335.42 | | 7336.43 | 0.008360 | 13.13 | 865.87 | 187.44 | 0.79 | 9.46 | 6.83 | 5.64 |
| BeaverBrook | 64801.29 | Max WS | 0.275 Base | 4532.44 | 7324.28 | 7330.59 | 7331.23 | 7332.87 | 0.034374 | 20.00 | 470.10 | 183.09 | 1.49 | 6.31 | 7.08 | 8.96 |

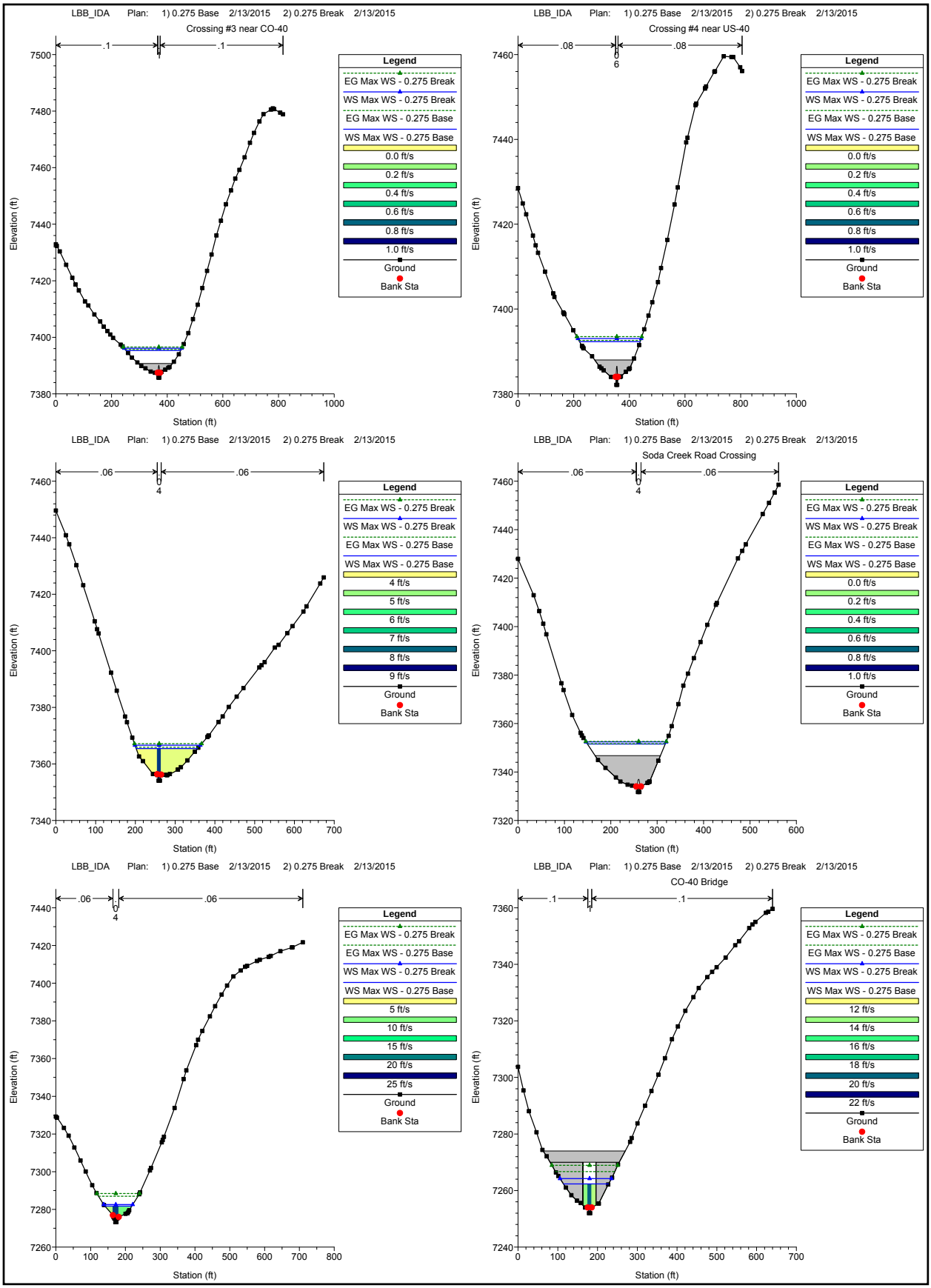
HEC-RAS River: BeaverBrook Reach: BeaverBrook Profile: Max WS (Continued)

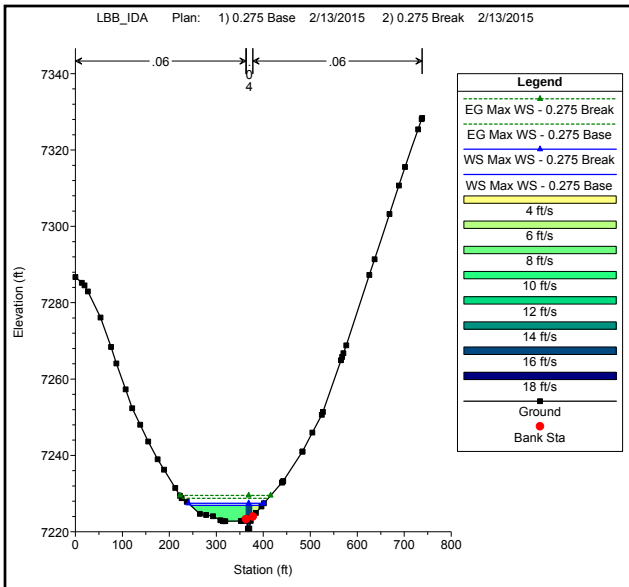
| Reach | River Sta | Profile | Plan | Q Total | Min Ch El | W.S. Elev | Crit W.S. | E.G. Elev | E.G. Slope | Vel Chnl | Flow Area | Top Width | Froude # Chl | Max Chl Dpth | Vel Left | Vel Right |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | (cfs) | (ft) | (ft) | (ft) | (ft) | (ft/ft) | (ft/s) | (sq ft) | (ft) | | (ft) | (ft/s) | (ft/s) |
| BeaverBrook | 64801.29 | Max WS | 0.275 Break | 5886.66 | 7324.28 | 7331.13 | 7331.78 | 7333.59 | 0.034221 | 21.22 | 573.31 | 197.61 | 1.51 | 6.85 | 7.89 | 9.66 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 64250.51 | Max WS | 0.275 Base | 4526.45 | 7307.30 | 7312.62 | 7312.91 | 7314.07 | 0.032545 | 17.19 | 555.92 | 250.69 | 1.40 | 5.32 | 7.74 | 7.03 |
| BeaverBrook | 64250.51 | Max WS | 0.275 Break | 5852.84 | 7307.30 | 7313.03 | 7313.34 | 7314.66 | 0.032925 | 18.30 | 661.02 | 261.28 | 1.43 | 5.73 | 8.48 | 7.80 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 63986.13 | Max WS | 0.275 Base | 4522.83 | 7298.47 | 7304.22 | 7304.72 | 7305.94 | 0.033747 | 18.21 | 534.76 | 240.87 | 1.44 | 5.75 | 7.41 | 7.52 |
| BeaverBrook | 63986.13 | Max WS | 0.275 Break | 5843.15 | 7298.47 | 7304.73 | 7305.11 | 7306.50 | 0.031742 | 18.86 | 665.24 | 265.90 | 1.42 | 6.26 | 7.70 | 8.12 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 63347.68 | Max WS | 0.275 Base | 4515.43 | 7273.24 | 7281.73 | 7283.37 | 7286.95 | 0.032357 | 22.62 | 310.24 | 77.03 | 1.52 | 8.49 | 7.91 | 10.63 |
| BeaverBrook | 63347.68 | Max WS | 0.275 Break | 5808.00 | 7273.24 | 7282.54 | 7284.39 | 7288.45 | 0.032796 | 24.52 | 375.29 | 83.34 | 1.56 | 9.30 | 8.89 | 11.67 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 62880.44 | Max WS | 0.275 Base | 4462.78 | 7258.75 | 7267.62 | | 7268.71 | 0.009210 | 13.39 | 625.65 | 135.95 | 0.82 | 8.87 | 6.50 | 5.91 |
| BeaverBrook | 62880.44 | Max WS | 0.275 Break | 5663.95 | 7258.75 | 7269.69 | | 7270.45 | 0.005032 | 11.49 | 931.43 | 159.79 | 0.63 | 10.94 | 5.67 | 5.15 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 62592.61 | Max WS | 0.275 Base | 4466.49 | 7252.00 | 7267.21 | 7260.23 | 7267.41 | 0.003306 | 4.69 | 1276.23 | 152.91 | 0.22 | 15.21 | 3.37 | 3.33 |
| BeaverBrook | 62592.61 | Max WS | 0.275 Break | 5602.45 | 7252.00 | 7269.43 | 7260.99 | 7269.62 | 0.002625 | 4.59 | 1633.73 | 169.25 | 0.20 | 17.43 | 3.33 | 3.27 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 62560 | | | Bridge | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 62483.41 | Max WS | 0.275 Base | 4466.49 | 7248.84 | 7255.66 | 7256.81 | 7259.55 | 0.041086 | 23.05 | 332.44 | 88.73 | 1.65 | 6.82 | 11.60 | 11.24 |
| BeaverBrook | 62483.41 | Max WS | 0.275 Break | 5602.45 | 7248.84 | 7256.33 | 7257.60 | 7260.65 | 0.040808 | 24.63 | 393.50 | 94.80 | 1.67 | 7.49 | 12.46 | 12.00 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 62239 | Max WS | 0.275 Base | 4463.95 | 7238.00 | 7246.82 | 7247.09 | 7249.22 | 0.017350 | 17.51 | 446.74 | 104.70 | 1.12 | 8.82 | 8.65 | 7.20 |
| BeaverBrook | 62239 | Max WS | 0.275 Break | 5585.79 | 7238.00 | 7247.59 | 7247.83 | 7250.20 | 0.017124 | 18.54 | 530.01 | 111.23 | 1.13 | 9.59 | 9.32 | 7.78 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 61841.81 | Max WS | 0.275 Base | 4460.06 | 7230.07 | 7238.32 | 7239.78 | 7243.04 | 0.033462 | 22.94 | 319.51 | 78.23 | 1.53 | 8.25 | 10.90 | 9.23 |
| BeaverBrook | 61841.81 | Max WS | 0.275 Break | 5579.12 | 7230.07 | 7239.03 | 7240.68 | 7244.32 | 0.034127 | 24.70 | 376.90 | 84.21 | 1.57 | 8.96 | 11.75 | 10.09 |
| | | | | | | | | | | | | | | | | |
| BeaverBrook | 61501.68 | Max WS | 0.275 Base | 4455.19 | 7220.85 | 7226.92 | 7227.16 | 7228.76 | 0.027712 | 16.06 | 463.97 | 152.47 | 1.31 | 6.06 | 8.79 | 5.30 |
| BeaverBrook | 61501.68 | Max WS | 0.275 Break | 5568.59 | 7220.85 | 7227.44 | 7227.69 | 7229.50 | 0.027155 | 17.08 | 546.37 | 160.32 | 1.32 | 6.59 | 9.43 | 5.92 |

## HEC-RAS Cross Sections

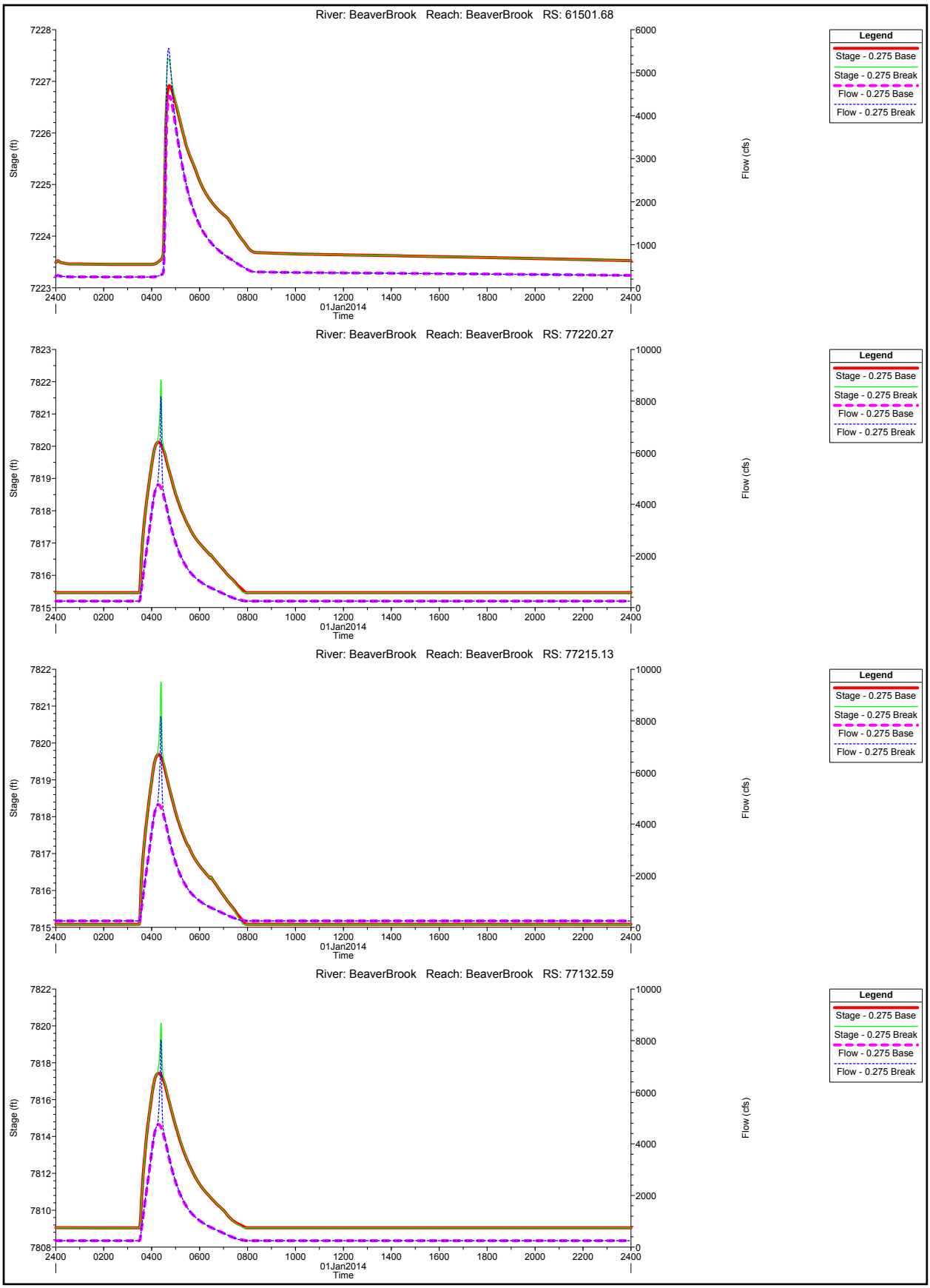

LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
6 ft/s
7 ft/s
8 ft/s
9 ft/s
10 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
8 ft/s
10 ft/s
12 ft/s
14 ft/s
16 ft/s
18 ft/s
20 ft/s
22 ft/s
24 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)

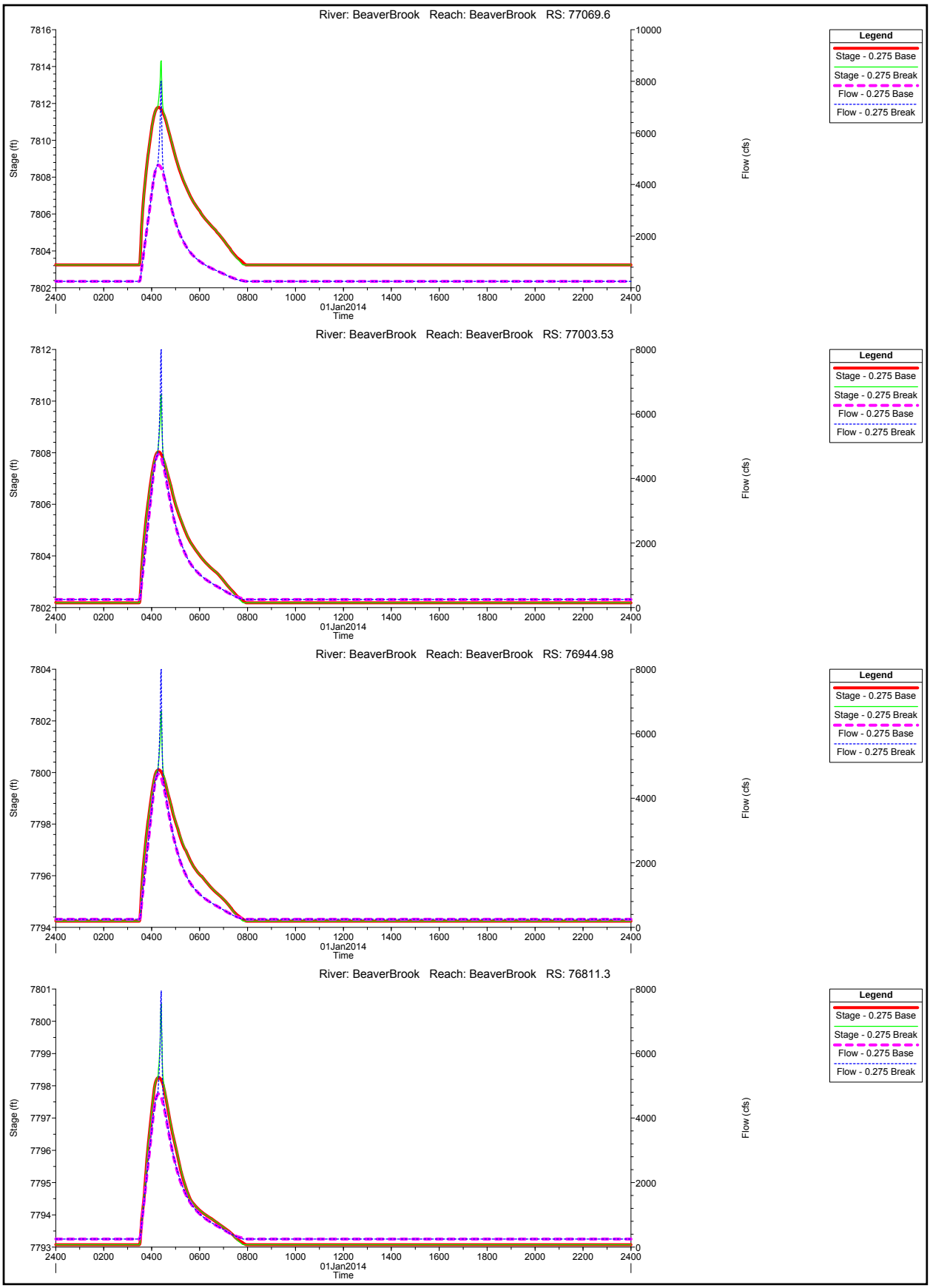

LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.1
.1
0
4
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
0 ft/s
5 ft/s
10 ft/s
15 ft/s
20 ft/s
25 ft/s
30 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.06
.06
0
4
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Levee
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.1
.1
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Crossing #1 near CO-40
.1
.1
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Levee
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.06
.06
0
4
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
14 ft/s
16 ft/s
Ground
Levee
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Crossing #2 near US 40
.1
.1
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
5.2 ft/s
5.4 ft/s
5.6 ft/s
5.8 ft/s
6.0 ft/s
6.2 ft/s
6.4 ft/s
Ground
Bank Sta

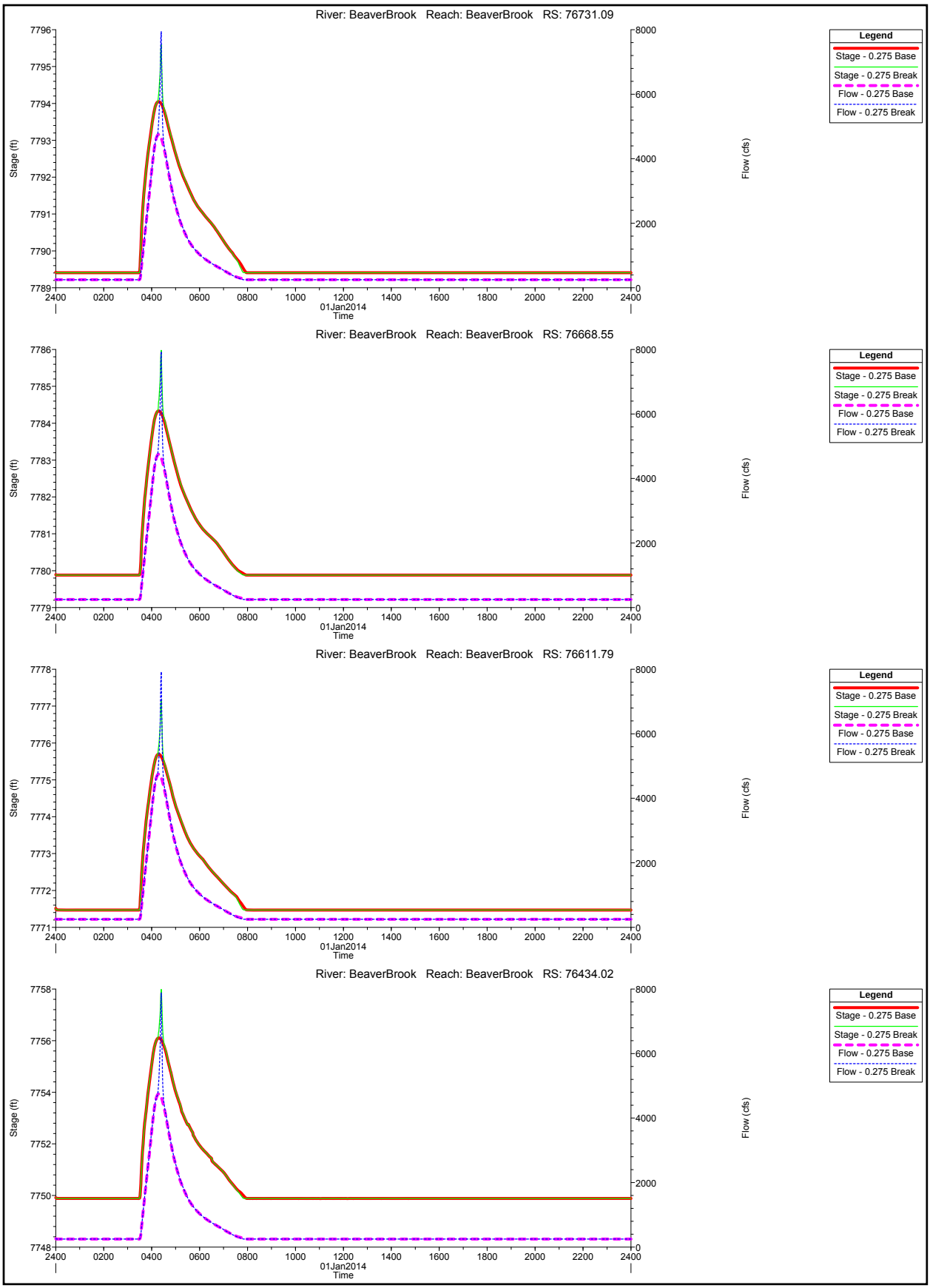

LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Crossing #3 near CO-40
.1
.1
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Crossing #4 near US-40
.08
.08
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.06
.06
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
4 ft/s
5 ft/s
6 ft/s
7 ft/s
8 ft/s
9 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
Soda Creek Road Crossing
.06
.06
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
WS Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Base
0.0 ft/s
0.2 ft/s
0.4 ft/s
0.6 ft/s
0.8 ft/s
1.0 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.06
.06
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
5 ft/s
10 ft/s
15 ft/s
20 ft/s
25 ft/s
Ground
Bank Sta
LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
CO-40 Bridge
.1
.1
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
12 ft/s
14 ft/s
16 ft/s
18 ft/s
20 ft/s
22 ft/s
Ground
Bank Sta

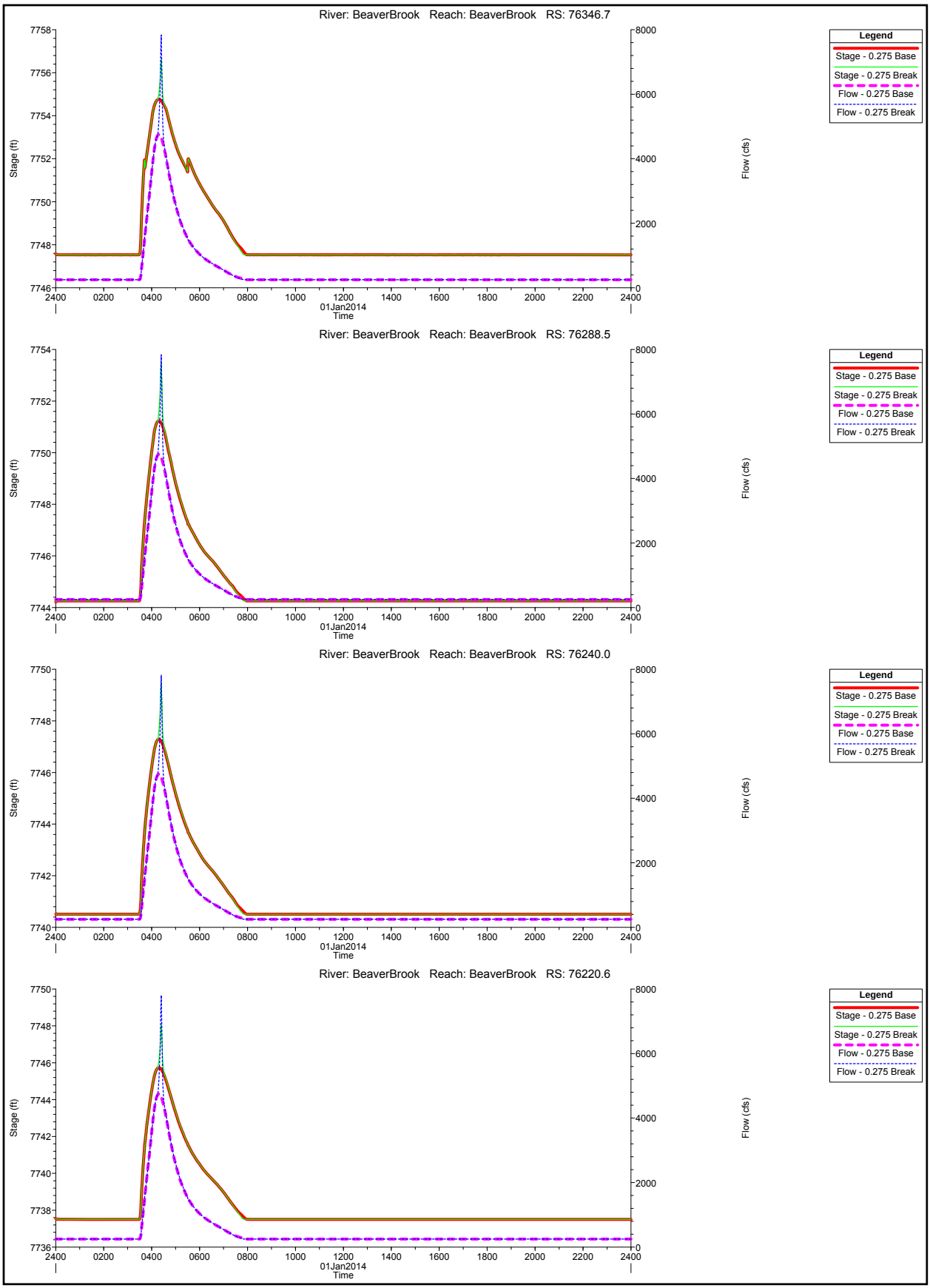

LBB_IDA Plan: 1) 0.275 Base 2/13/2015 2) 0.275 Break 2/13/2015
.06
.06
0.04
Elevation (ft)
Station (ft)
Legend
EG Max WS - 0.275 Break
EG Max WS - 0.275 Base
WS Max WS - 0.275 Break
WS Max WS - 0.275 Base
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
14 ft/s
16 ft/s
18 ft/s
Ground
Bank Sta

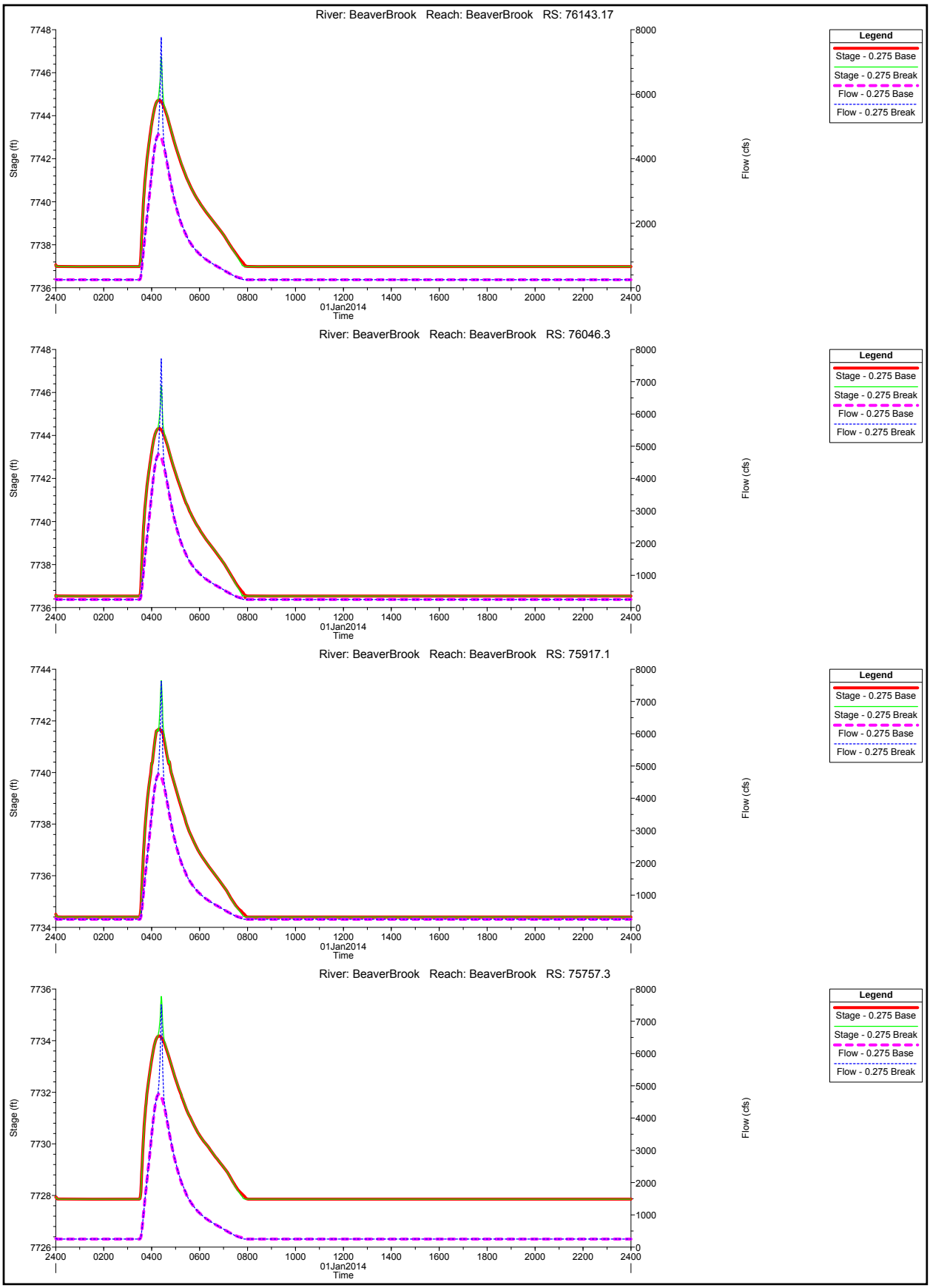
## HEC-RAS Hydrographs

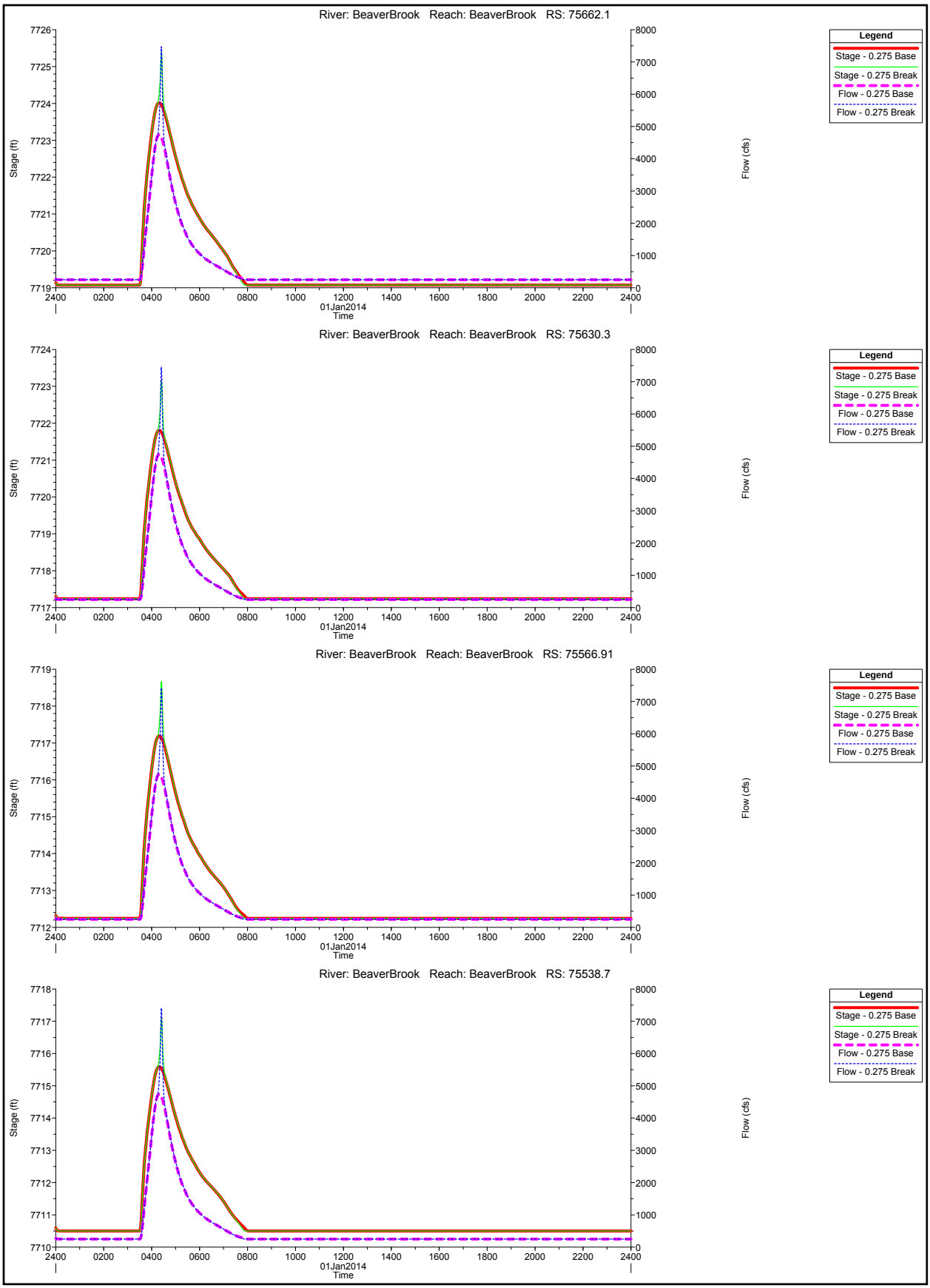

River: BeaverBrook Reach: BeaverBrook RS: 61501.68
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 77220.27
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 77215.13
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 77132.59
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

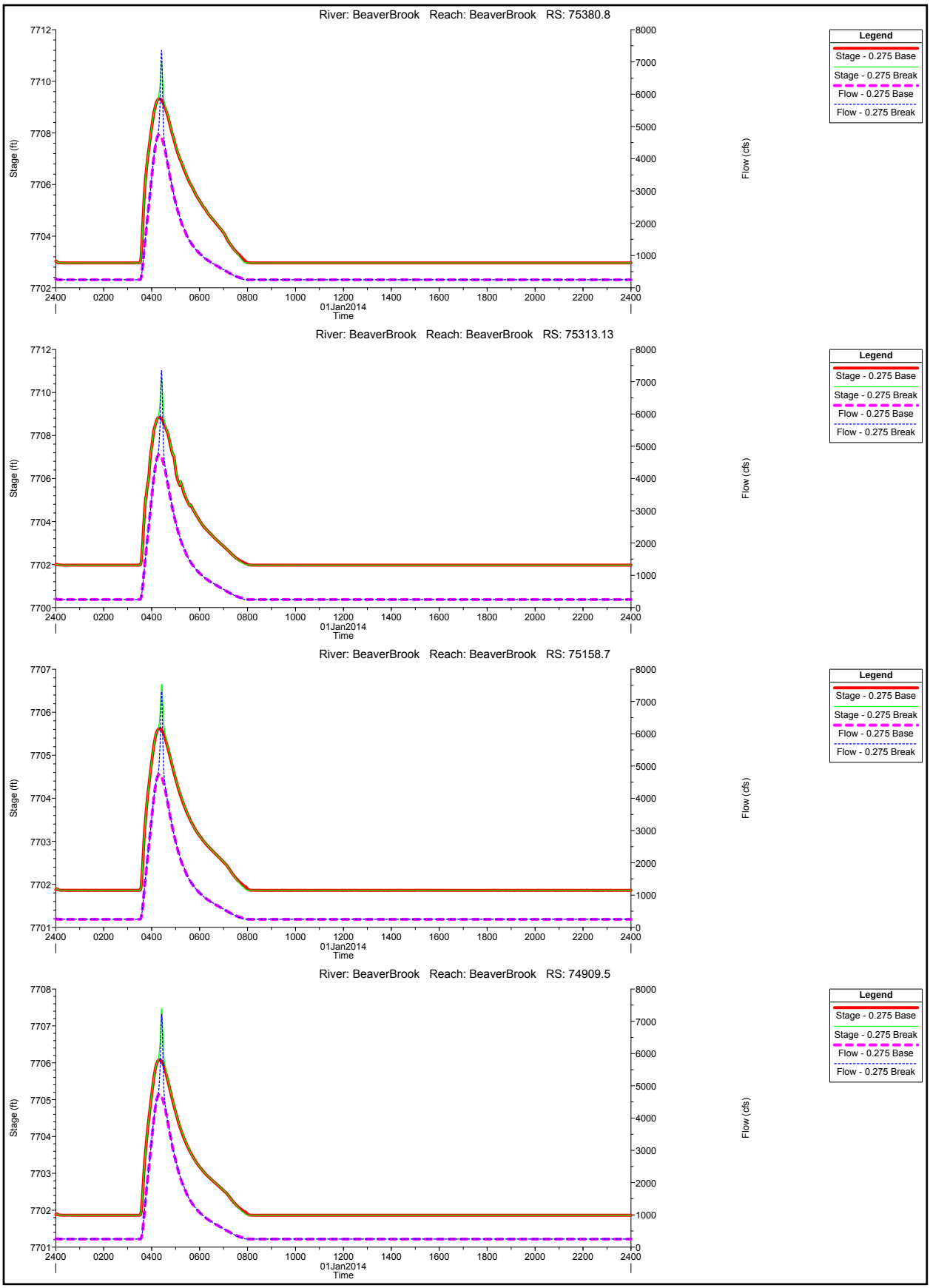

River: BeaverBrook Reach: BeaverBrook RS: 77069.6
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 77003.53
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76944.98
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76811.3
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

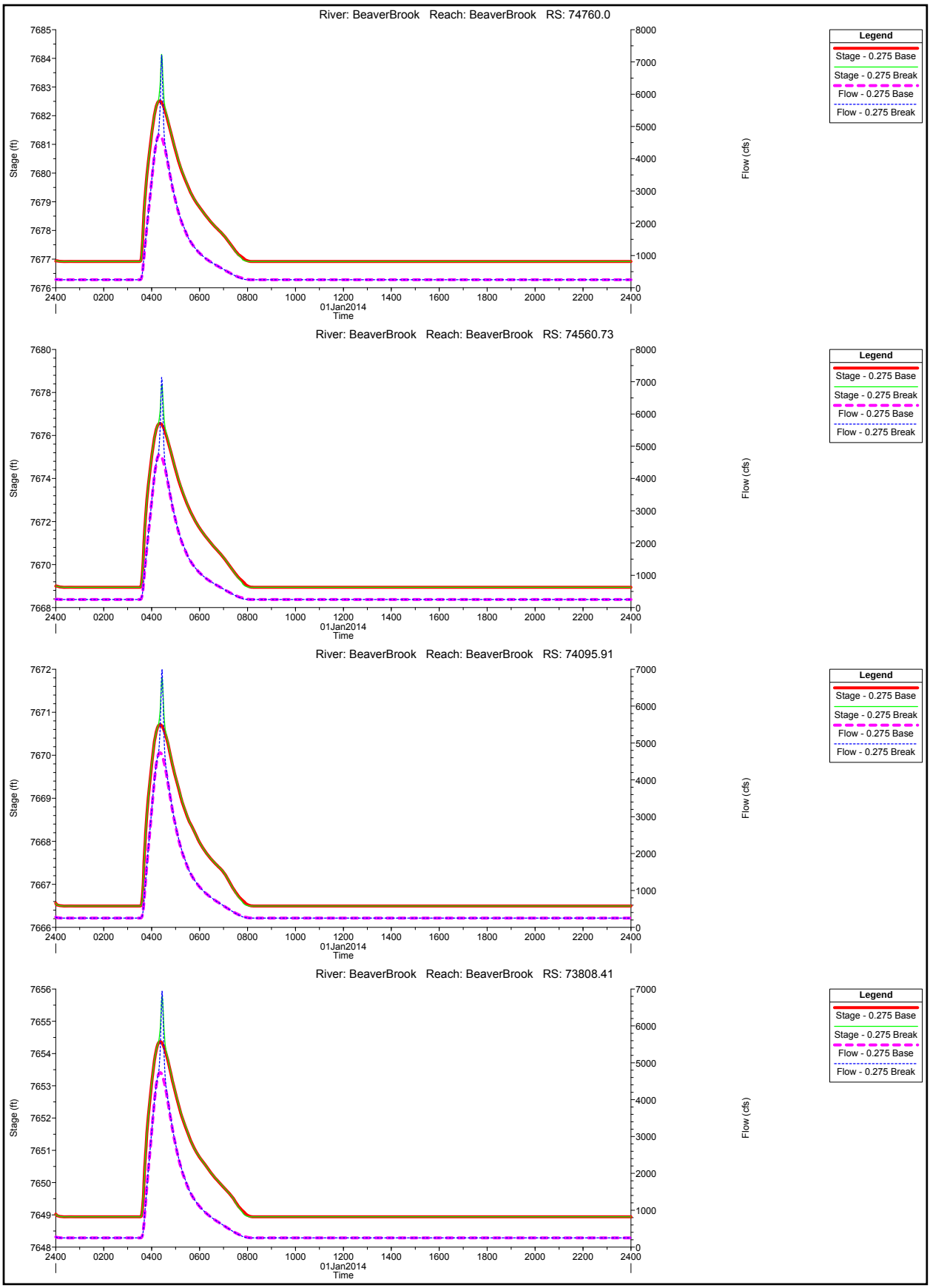

River: BeaverBrook Reach: BeaverBrook RS: 76731.09
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76668.55
River: BeaverBrook Reach: BeaverBrook RS: 76611.79
River: BeaverBrook Reach: BeaverBrook RS: 76434.02

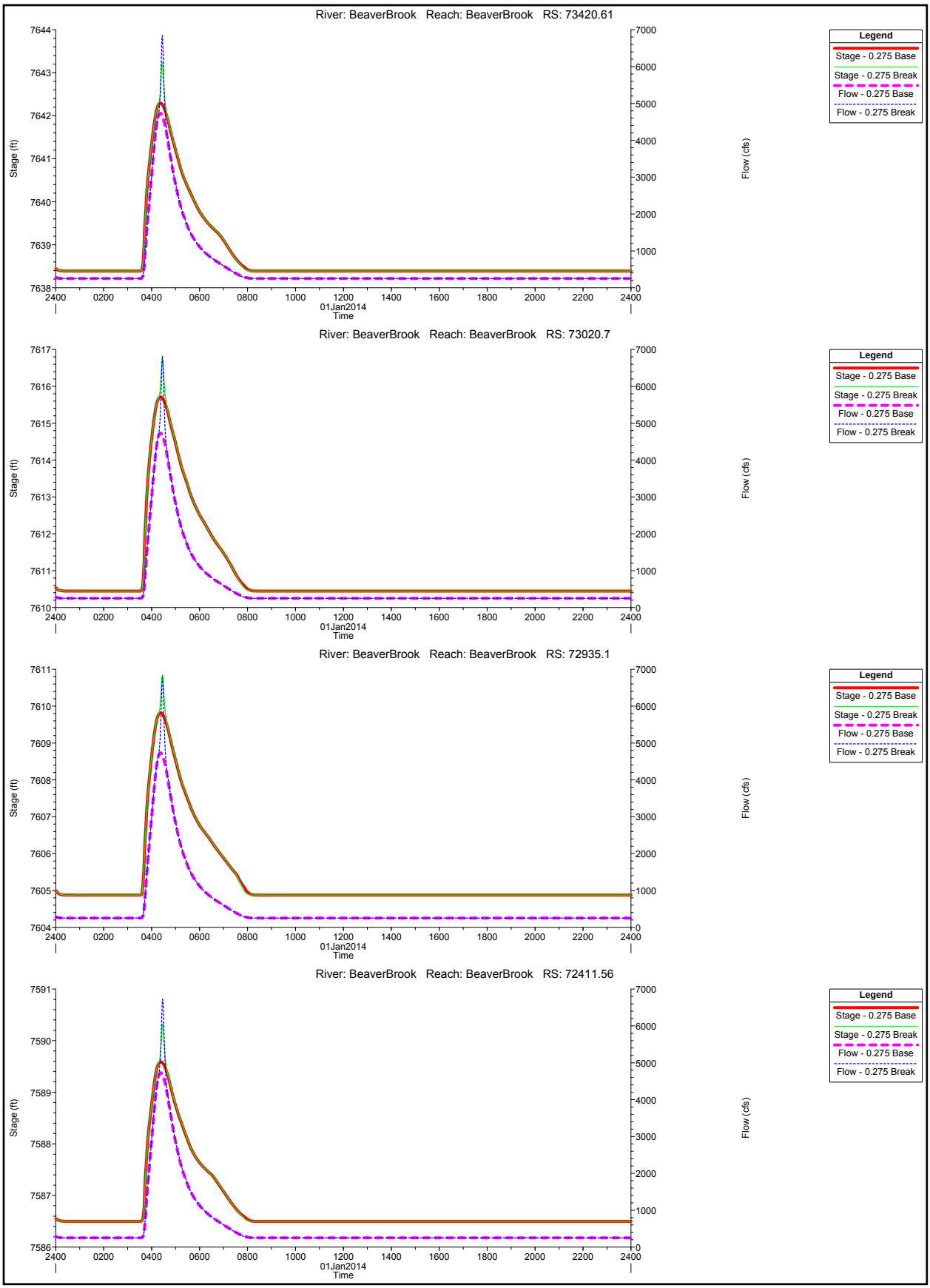

River: BeaverBrook Reach: BeaverBrook RS: 76346.7
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76288.5
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76240.0
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76220.6
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

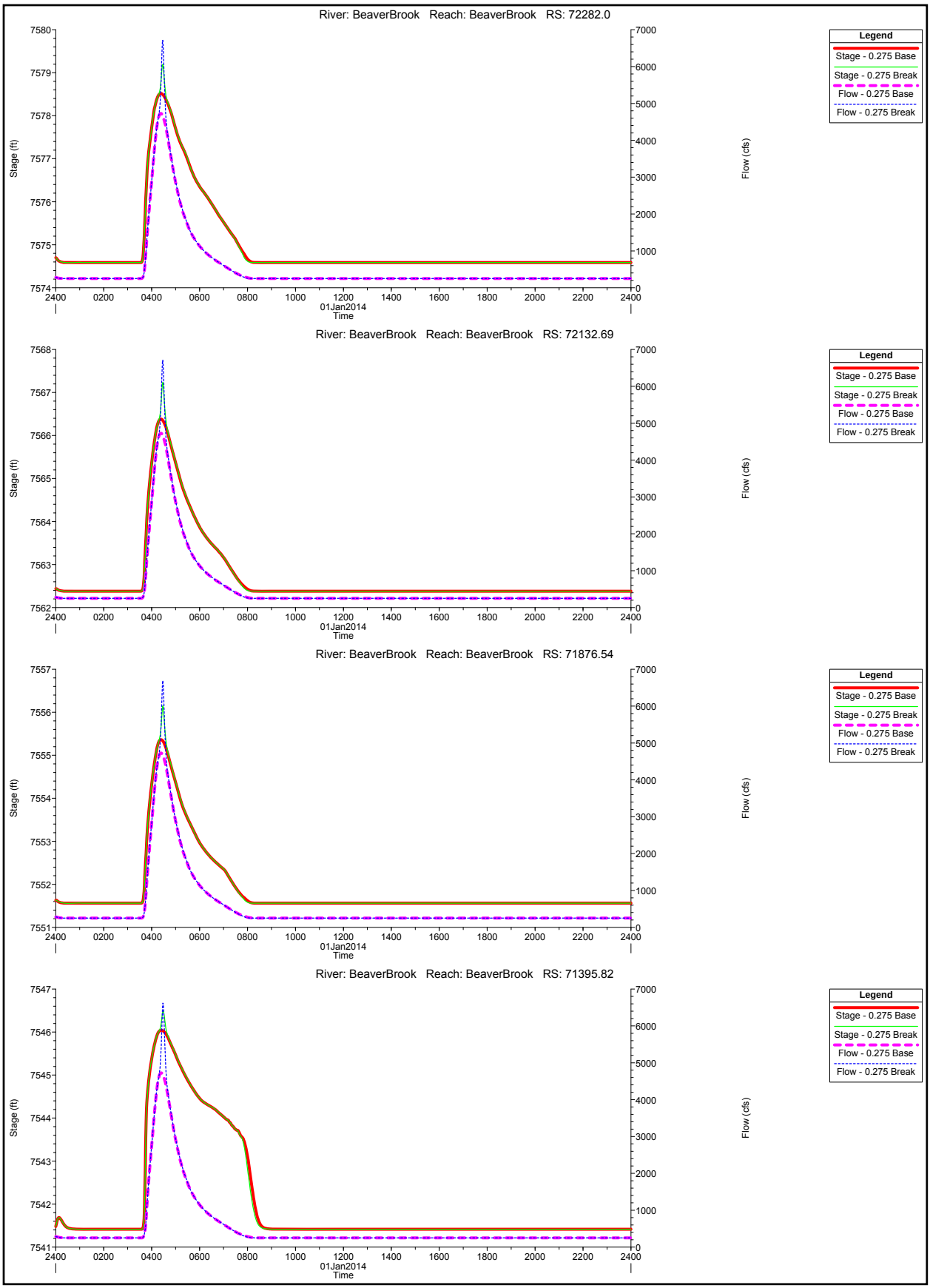

River: BeaverBrook Reach: BeaverBrook RS: 76143.17
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 76046.3
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75917.1
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75757.3
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

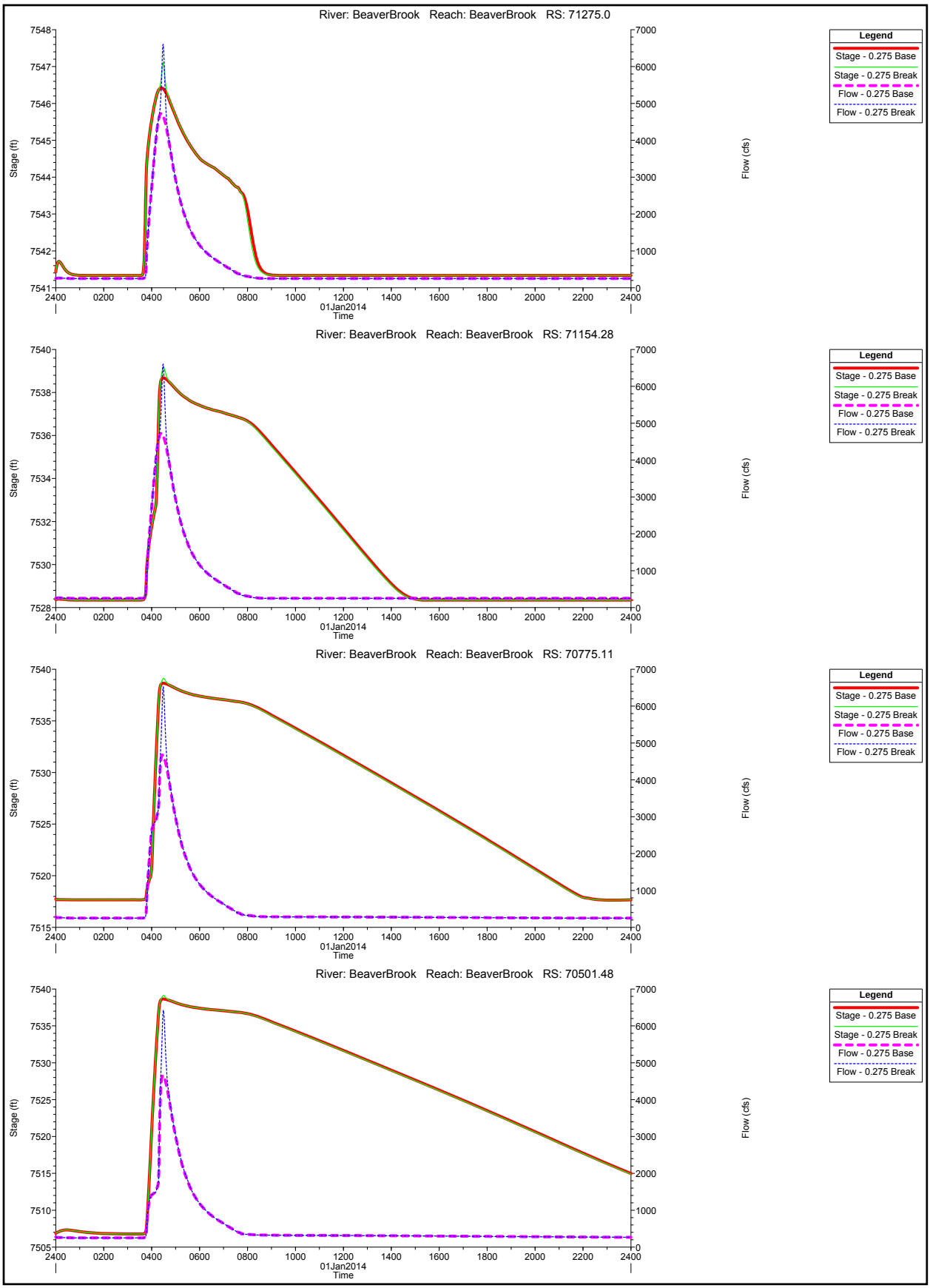

River: BeaverBrook Reach: BeaverBrook RS: 75662.1
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75630.3
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75566.91
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75538.7
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

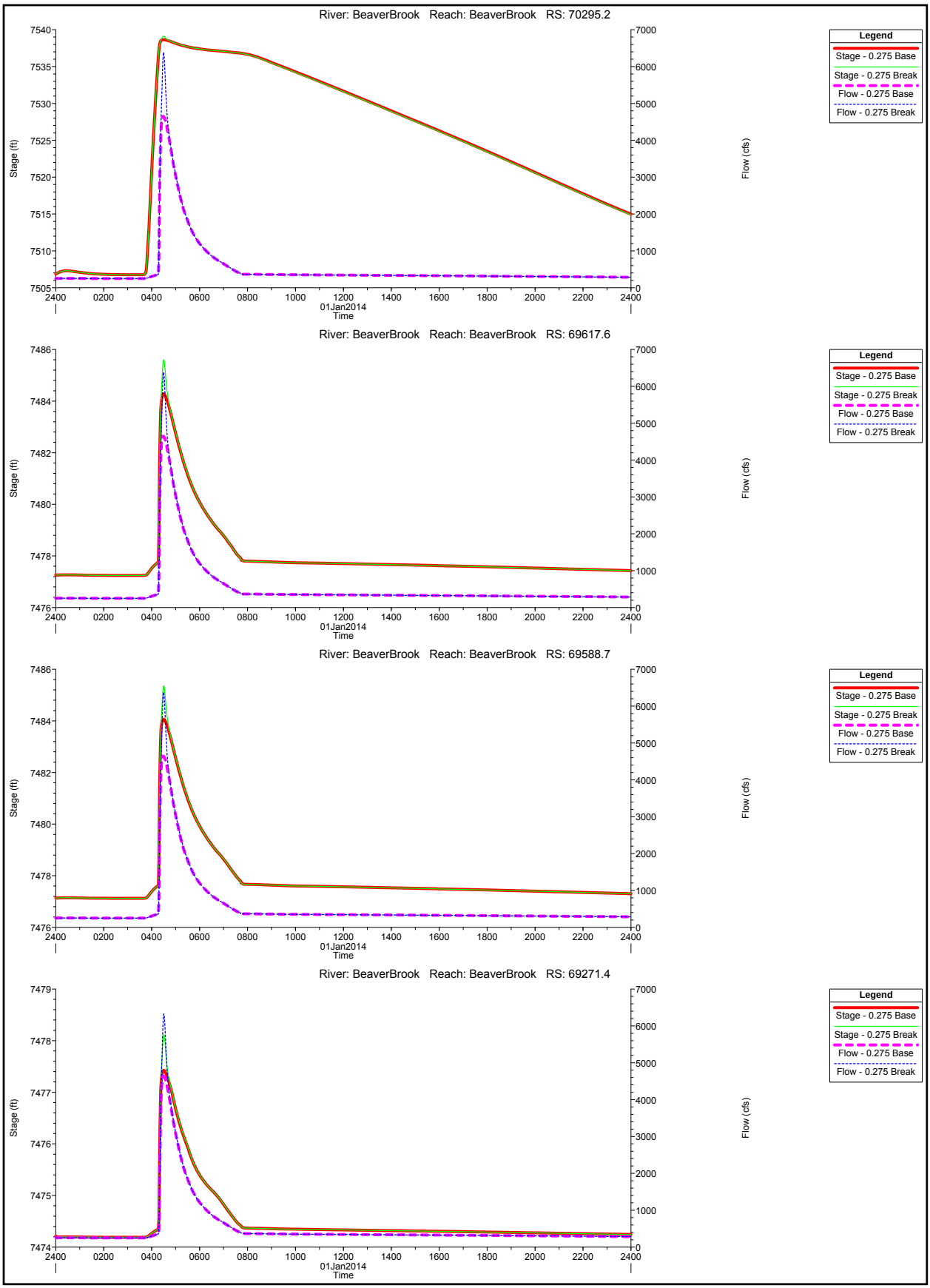

River: BeaverBrook Reach: BeaverBrook RS: 75380.8
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75313.13
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 75158.7
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 74909.5
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

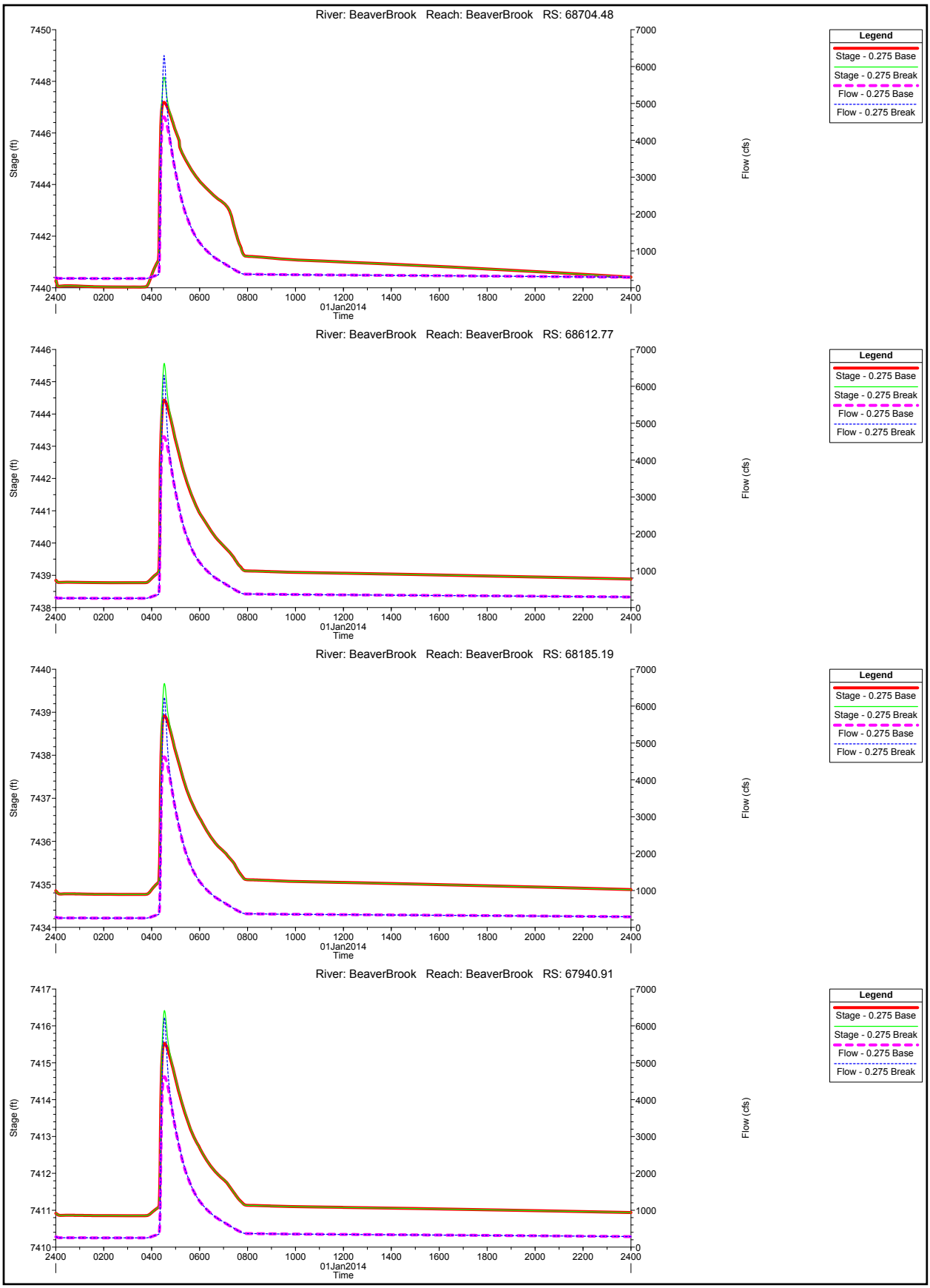

River: BeaverBrook Reach: BeaverBrook RS: 74760.0
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 74560.73
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 74095.91
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 73808.41
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

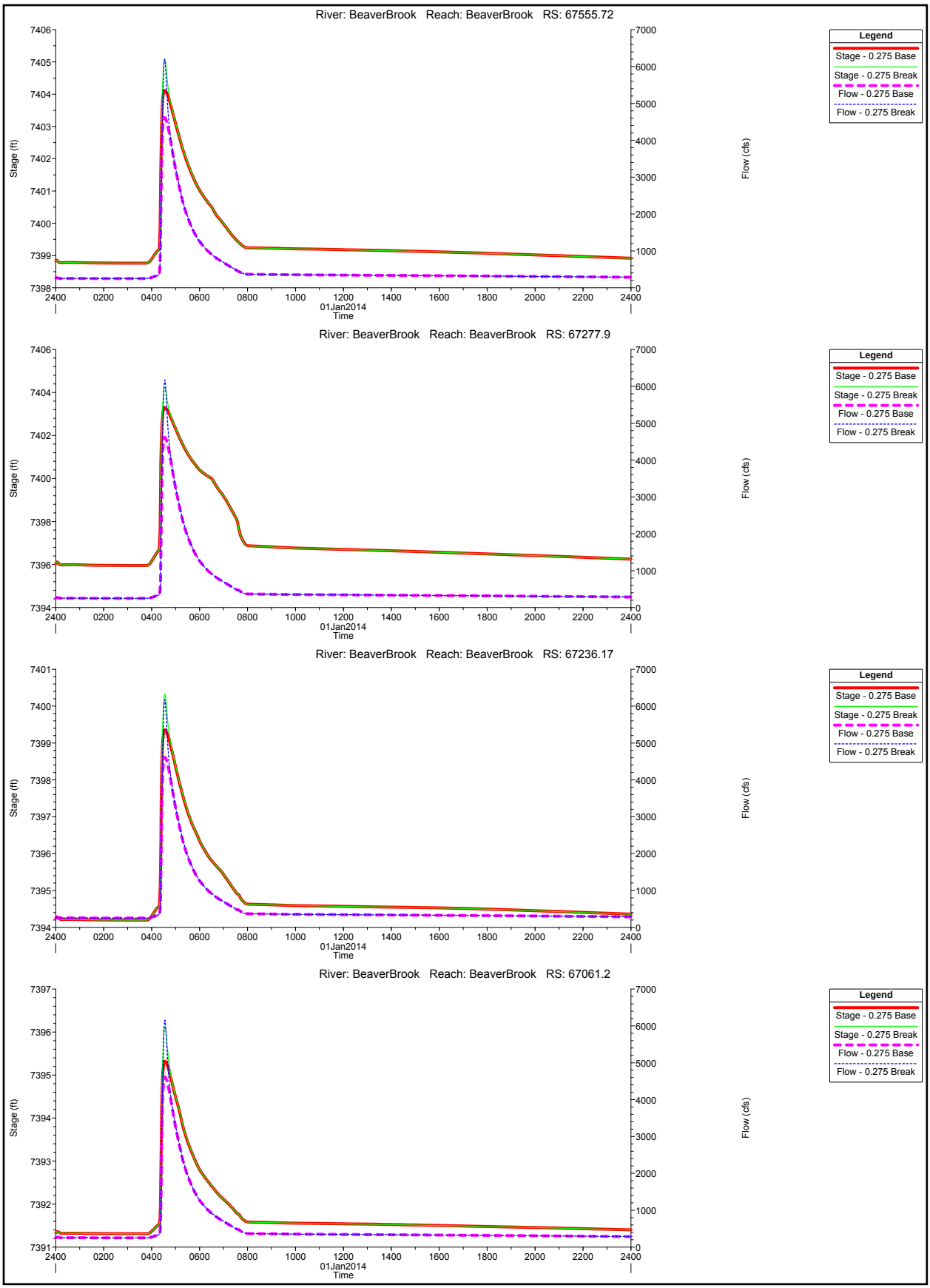

River: BeaverBrook Reach: BeaverBrook RS: 73420.61
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 73020.7
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 72935.1
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 72411.56
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 72282.0
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 72132.69
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 71876.54
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 71395.82
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 71275.0
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 71154.28
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 70775.11
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 70501.48
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 70295.2
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 69617.6
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 69588.7
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 69271.4
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 68704.48
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 68612.77
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 68185.19
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 67940.91
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 67555.72
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Flow (cfs)
Time
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Legend
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Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 67277.9
Stage (ft)
Flow (cfs)
Time
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Legend
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Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 67236.17
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 67061.2
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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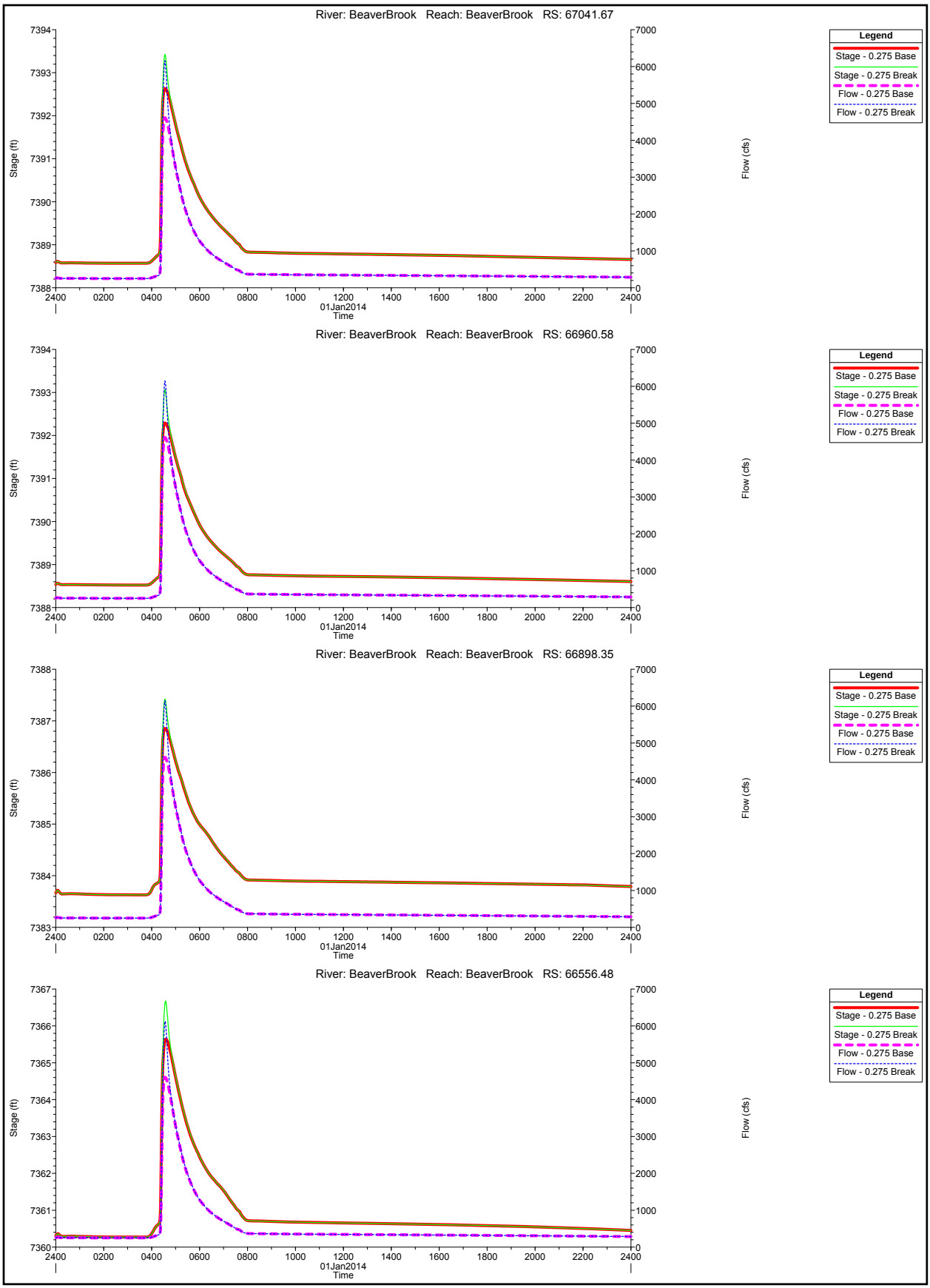
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 67041.67
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 66960.58
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 66898.35
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 66556.48
Stage (ft)
Flow (cfs)
Time
01Jan2014
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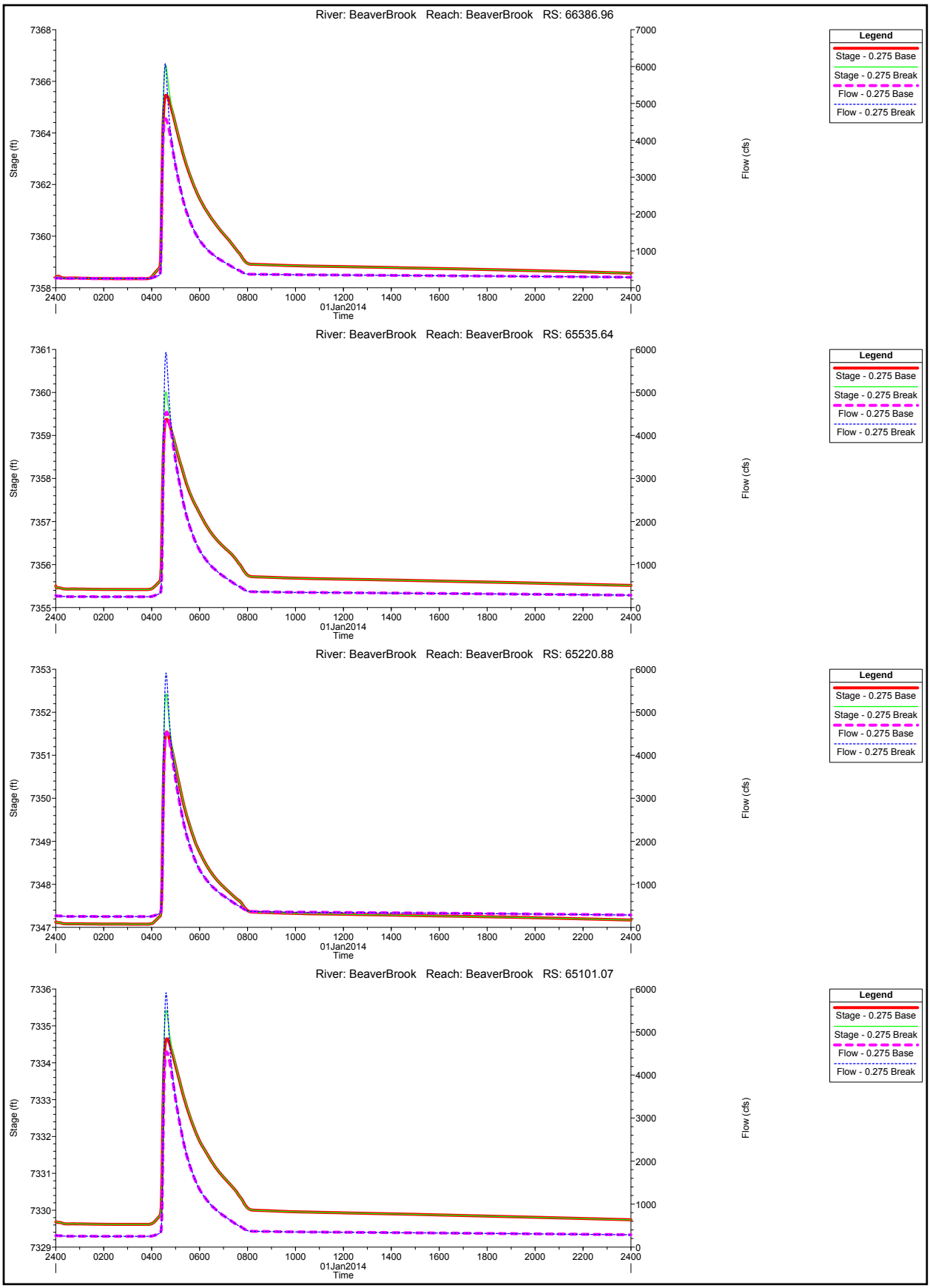
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 66386.96
Stage (ft)
Flow (cfs)
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Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 65535.64
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 65220.88
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 65101.07
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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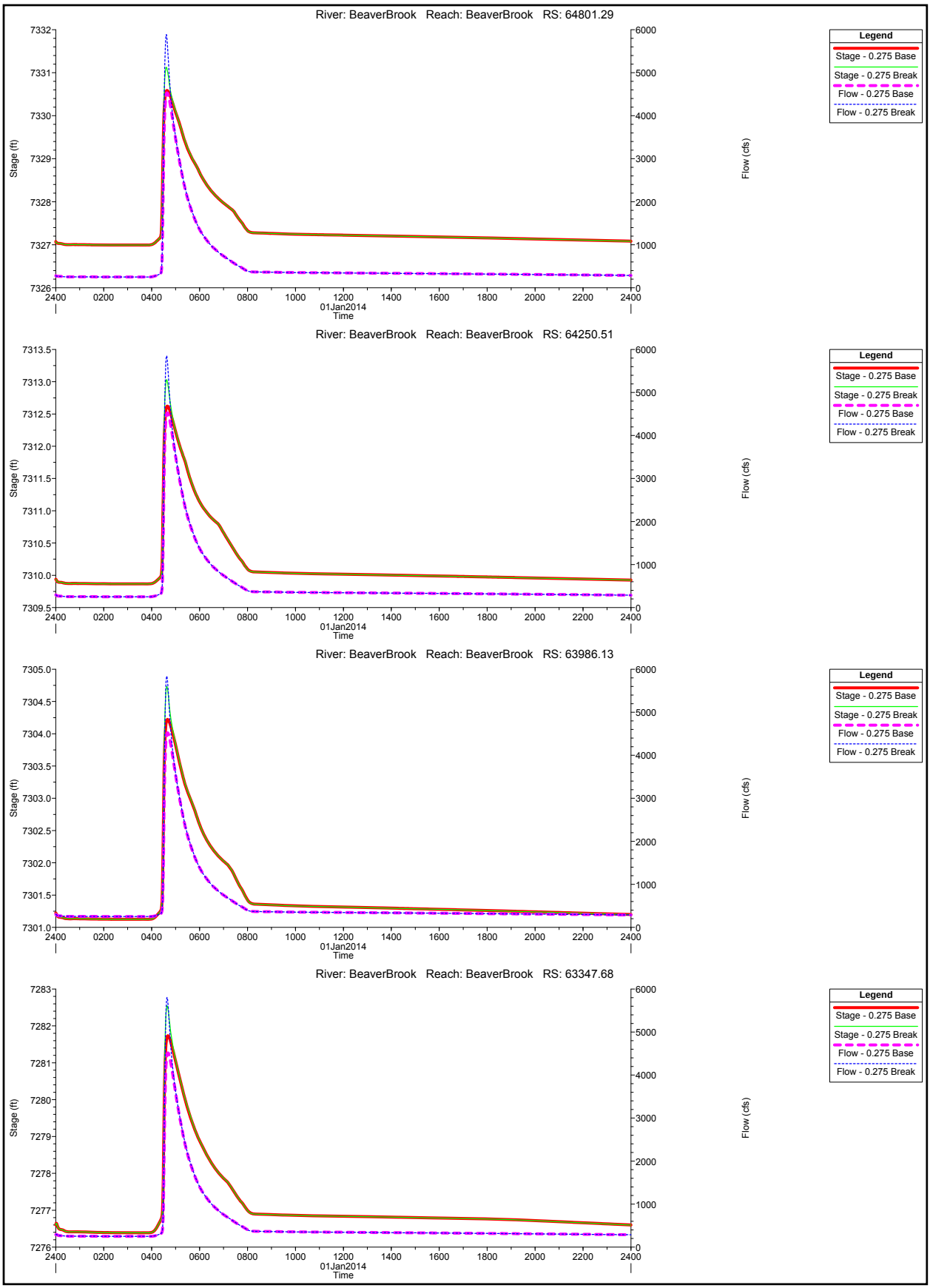
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break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Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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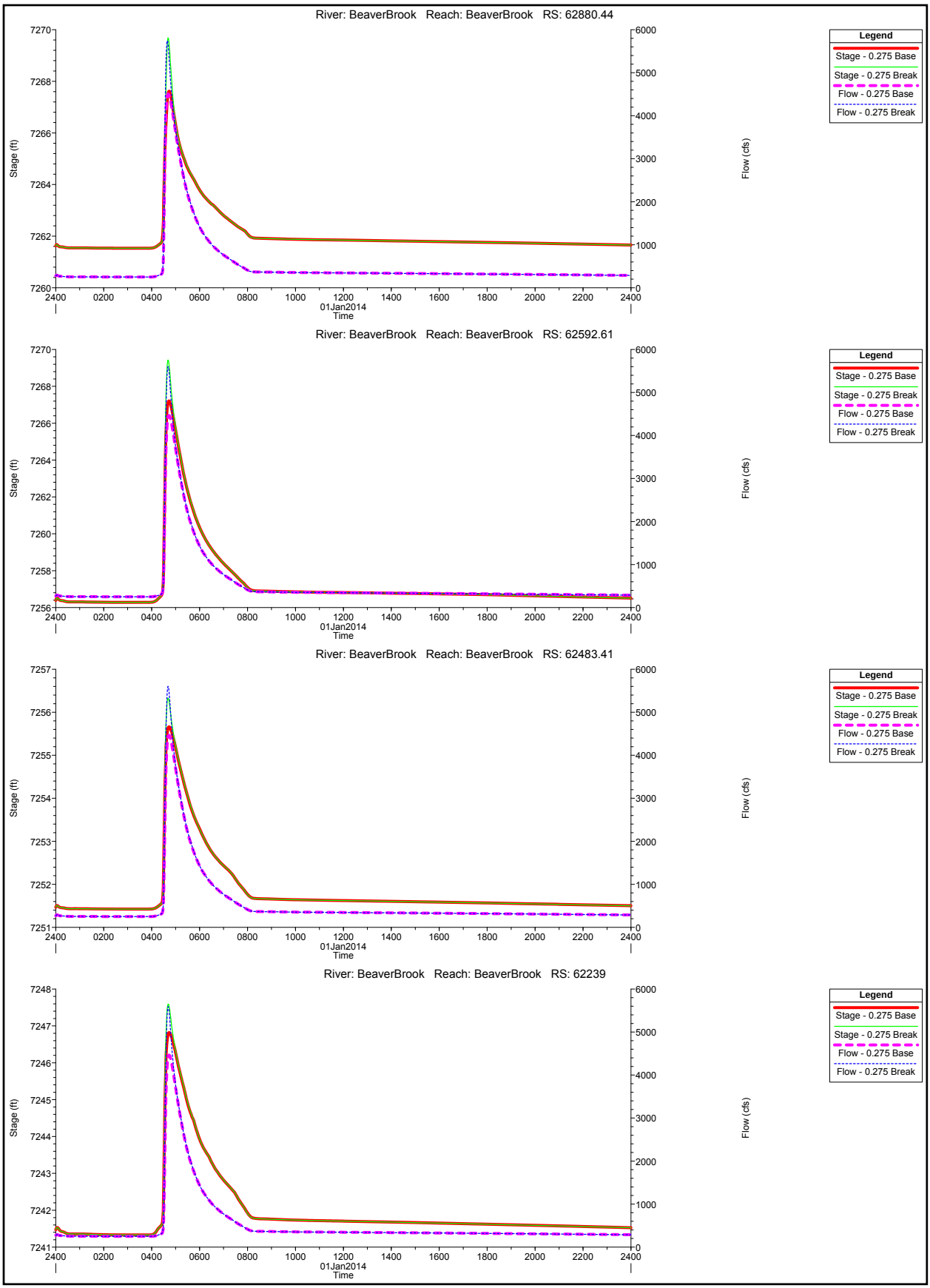
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 64250.51
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 63986.13
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 63347.68
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 62880.44
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
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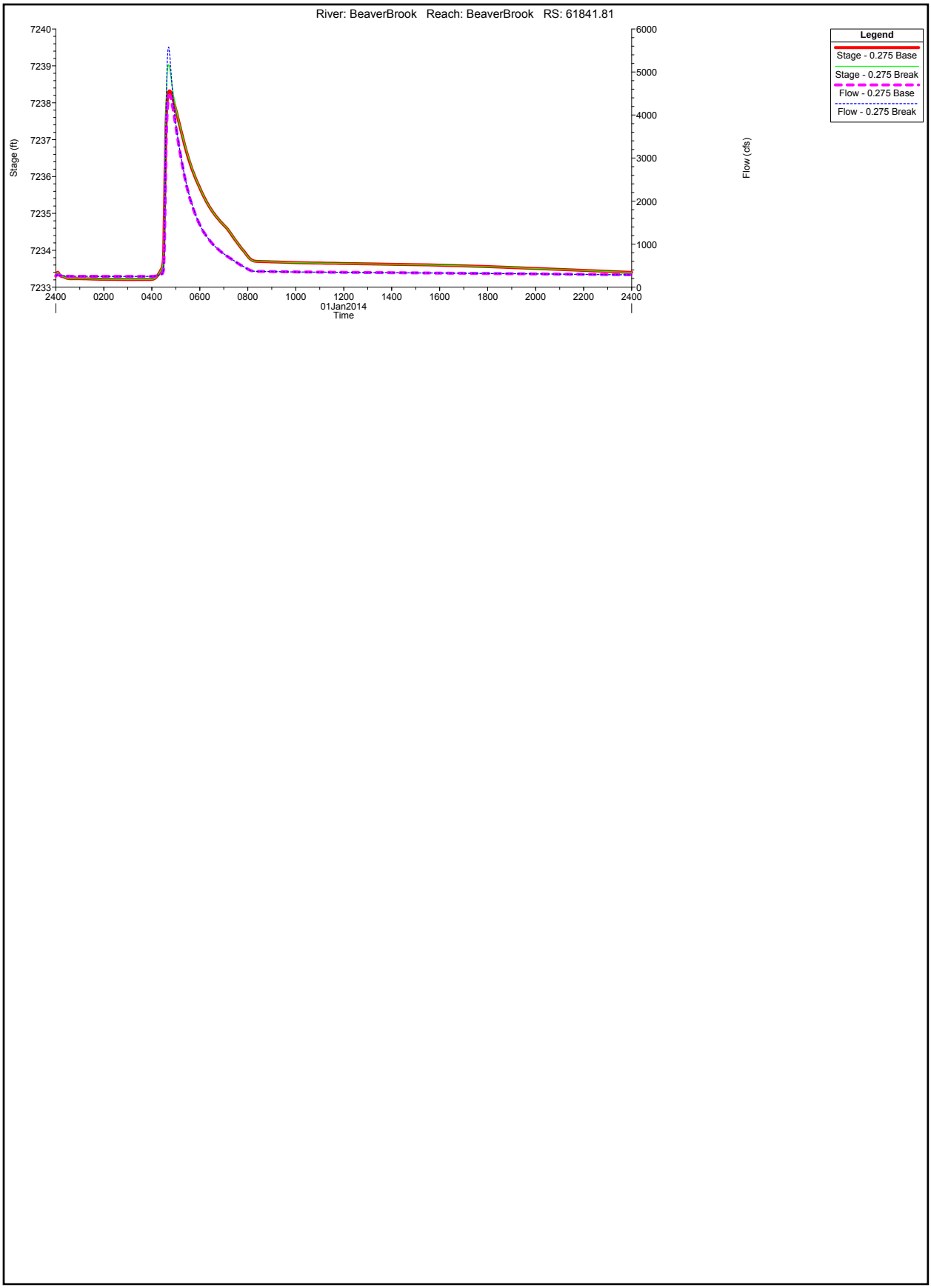
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 62592.61
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 62483.41
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break
River: BeaverBrook Reach: BeaverBrook RS: 62239
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break


River: BeaverBrook Reach: BeaverBrook RS: 61841.81
Stage (ft)
Flow (cfs)
Time
01Jan2014
Legend
Stage - 0.275 Base
Stage - 0.275 Break
Flow - 0.275 Base
Flow - 0.275 Break

# Appendix E

## Electronic Files

# Appendix F

## SEO Comment Response Memorandum

Consulting
Engineers and
Scientists

GEI Consultants

# Memo

To: Jeremy J. Franz, P.E.

From: Chad Masching, P.E., Project Manager
Nick Miller, P.E., P.H., Reviewer

CC: Bob Heine, President, LMWD

Date: December 8, 2016

**Re: Lower Beaver Brook Dam Incremental Damage Analysis Hydraulic Model Study**

## 1. Introduction

Lower Beaver Brook Dam is a 39-foot-tall, concrete-faced, rockfill dam and impounds about 30 acre-feet at the normal pool elevation (El.)[1] 7,837.7. The dam crest is at El. 7,840.0, is about 224 feet long, and has an average crest width of about 12 feet. The dam is owned and operated by Lookout Mountain Water District (LMWD).

In the Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report (Report), dated March 2015, GEI estimated the Inflow Design Flood (IDF) for Lower Beaver Brook Dam. The Report summarized hydrometeorological analyses, precipitation estimates, parameter development, inflow hydrographs, hydraulic modeling of the downstream reach and results of the Incremental Damage Analysis (IDA). The report recommended an IDF for Lower Beaver Brook Dam of 4,755 cubic feet per second (cfs). GEI submitted the Report to the Colorado State Engineer's Office (SEO) for review on April 6, 2015.

On August 6, 2015, the SEO responded with a letter summarizing their review of the Report and presenting 17 review comments. The comments are addressed in an additional memorandum submitted with this memorandum. Several of the comments in the letter addressed the hydraulic model and IDA study of the reach below the dam and required a more detailed response. Comment 11 addressed the elevation data used to develop the previous hydraulic model, and Comments 12 and 16 addressed the discrete findings presented in the Report. The purpose of this memorandum is to summarize the development of a two-dimensional (2D) hydraulic model of the reach below Lower Beaver Brook Dam to address the comments presented in the letter, dated August 6.

Comment 6 of the SEO letter, dated August 6, requested changes to the hydrologic model and adjustments to the selected breach parameters GEI developed to estimate the peak inflow, outflow and water surface elevation of Lower Beaver Brook Dam and reservoir. As a result of modifying the requested parameters, the peak inflow increased from 4,755 cfs to 5,464 cfs, the peak breach outflow decreased from 8,175 cfs to 8,129 cfs, and the peak water surface elevation

[1] Elevations in this memorandum are in feet and referenced with respect to North American Vertical Datum of 1988 (NAVD88). To convert elevations in this report to the National Geodetic Vertical Datum of 1929 (NGVD29) for the Lower Beaver Brook site, subtract 4.06 feet.

Beaver Brook hydrologic analyses. *The proposed conditions at Upper Beaver Brook Dam result in a larger peak outflow to Upper Beaver Brook, and thus a larger peak inflow to Lower Beaver Brook. This results in a larger design flood and a larger spillway at Lower Beaver Brook Dam. Therefore,* the proposed conditions at Upper Beaver Brook produce conservative results compared to the existing conditions. ~~and it is acceptable for modifications at Lower Beaver Brook to occur prior to the Upper Beaver Brook enlargement.~~"

**Comment 3:** "Section ES.3 of the report describes two field surveys performed to support the study. Please include more information about these surveys and how they were related to the topography used for the hydraulic modeling of the downstream channel."

**Response 3:** GEI will modify the referenced paragraph as follows (italics indicate changes to the report text):

"Two field surveys were conducted to identify critical structures and crossings *in the downstream reach*. The first, conducted by GEI in October 2014, identified the substantial river crossings and recording culvert/bridge dimensions. *The locations and dimensions of the river crossings were used in the hydraulic model developed by GEI to estimate the flood wave.* During this site visit, it was determined that a topographic survey identifying critical structures along the reach was necessary. LMWD mailed notifications of the survey to all property owners with property adjacent to Beaver Brook and CCS Consultants, Inc. (CCS) mobilized in December 2014. CCS surveyed 30 cross sections to determine the relative elevation of critical structures and the channel bed. The survey extended between Lower Beaver Brook Dam and the crossing of Interstate 70 (I-70), approximately 1.3 miles downstream of the dam. *The survey provided the critical first floor elevations of the buildings surrounding the study area.* The two field surveys identified 10 culverts, 2 bridges, and 42 residences/structures that might be near enough to the stream to be impacted by the flood wave."

**Comment 4:** "Section 3: We recommend including a baseflow from the downstream tributaries (e.g.: North Beaver Brook). The hydrologic event to develop the baseflows from downstream tributaries should be something significantly less than that used for the base flood in the dam basin. Please provide documentation and justification for the selected baseflow."

**Response 4:** GEI included baseflows in the two-dimensional (2D) hydraulic model for three downstream tributaries: North Beaver Brook, Soda Creek, and an unnamed tributary. Baseflow was estimated using the U.S. Geological Survey's National Streamflow Statistics (NSS) computer software, Version 6.1. NSS uses streamflow estimation regression methodologies developed by researchers for specific regions within each state. The tributaries downstream of Lower Beaver Brook Dam fall within the Mountain Region developed by Capesius and Stephens (Capesius and Stephens, 2009). The NSS software takes inputs for the tributary watershed based on parameters required for the regression methodology. The regression methodology developed by Capesius and Stephens for the Mountain Region requires drainage area, mean basin slope, and mean annual precipitation. Drainage area and mean basin slope were estimated using GIS software, and mean annual precipitation was estimated using Oregon State University's PRISM Climate Group annual precipitation estimates. The NSS software outputs estimated flows for return intervals from the 2-year peak flow to the 500-year peak flow with the associated

estimated error. GEI used the 100-year peak flow as input to the hydraulic model for the downstream tributary baseflow. Due to the estimated error in the Capesius and Stephens model, GEI rounded baseflows down to the nearest 5 cfs, which is considered to be conservative. Baseflow inputs and outputs are summarized in the table below:

| Tributary | Drainage Basin Area (sq. mi.) | Mean Basin Slope (percent) | Mean Annual Precipitation (in) | Estimated 100-Year Flow (cfs) | GEI Model Baseflow Input (cfs) |
|---|---|---|---|---|---|
| North Beaver Brook | 3.1 | 13.5 | 18 | 57.7 | 55 |
| Soda Creek | 6.1 | 9.4 | 18 | 91.2 | 90 |
| Unnamed Tributary | 1.6 | 7.6 | 18 | 32.4 | 30 |

The NSS output, which summarizes the input data and the output peak flows is provided in Attachment A.

**Comment 5:** "Section 3.3.2. We recommend also including the 500- and 1000-year frequency storms for comparison the the selected IDF. Please describe which hyetograph was used to input the frequency storms into your rainfall-runoff model. It is our understanding that NOAA Atlas 14 provides several 'mass curves' which can be used to generate hyetographs from the precipitation frequency data."

**Response 5:** GEI has supplemented the existing table with the rainfall data from NOAA for the 500- and 1,000-year frequency storms as follows (italics indicate new information):

| Precipitation (in) for Indicated Durations (hr) and Recurrence Intervals | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Duration** | **0.083** | **0.25** | **0.50** | **1** | **2** | **3** | **6** | **12** | **24** |
| 100-year | 0.59 | 1.06 | 1.46 | 1.72 | 1.98 | 2.10 | 2.55 | 3.41 | 4.51 |
| *500-year* | *0.77* | *1.37* | *1.87* | *2.17* | *2.47* | *2.60* | *3.23* | *4.54* | *6.19* |
| *1,000-year* | *0.84* | *1.51* | *2.06* | *2.37* | *2.69* | *2.82* | *3.54* | *5.08* | *7.01* |

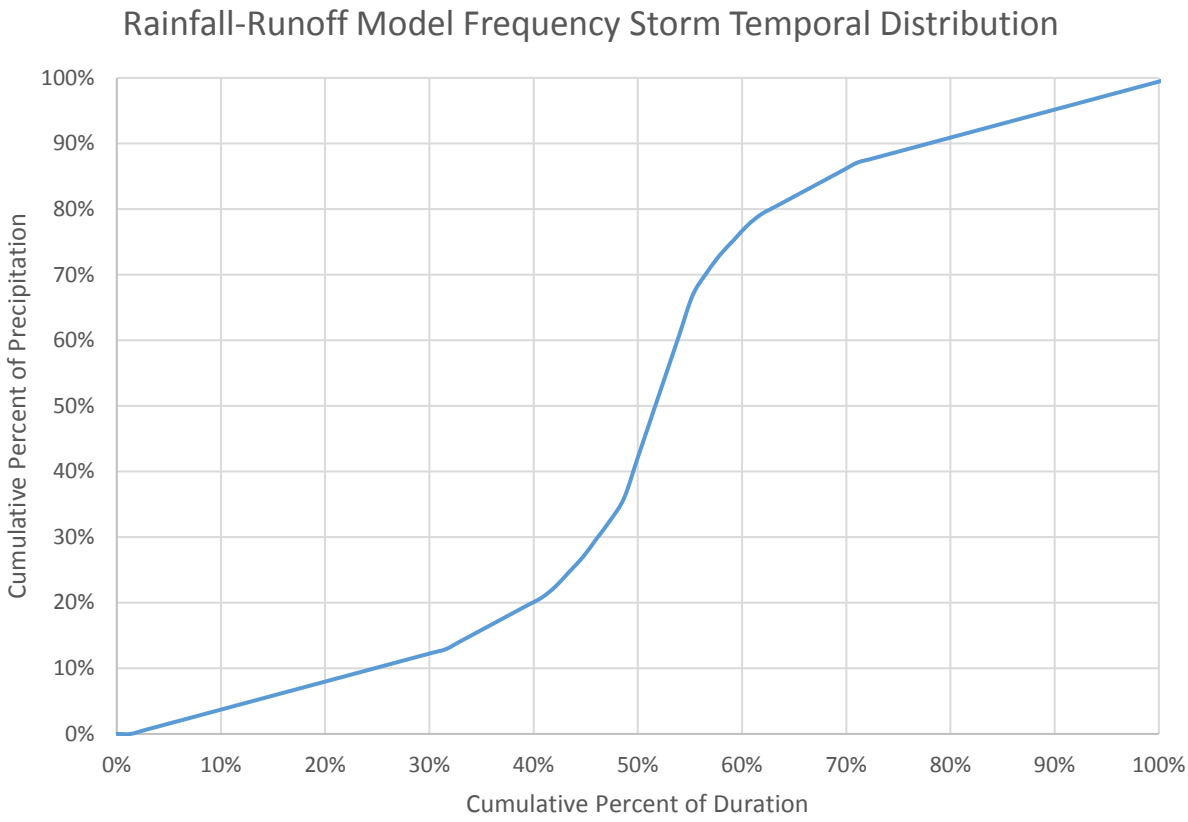
GEI has included the following tables in Section 5.2 for the 500- and 1,000-year frequency storms:

| Parameter or Modeling Result | 500-Year Storm | |
|---|---|---|
| | Upper Subbasin and Upper Beaver Brook Dam/Reservoir | Lower Subbasin and Lower Beaver Brook Dam/Reservoir |
| Subbasin Average 24-hr 500-Year Storm Depth (inches) | 6.13 | 6.13 |
| Subbasin Average 500-Year Storm Runoff (inches) | 1.66 | 1.79 |
| Subbasin Average 24-hr 500-Year Losses (inches) | 4.47 | 4.34 |
| Subbasin Average 500-Year Storm Runoff Percent (%) | 27.1 | 29.2 |
| Antecedent Moisture Condition | Saturated | Saturated |

| | | |
|---|---|---|
| Maximum Reservoir Elevation (feet) | 8,410.32 | 7,842.07 |
| Freeboard (feet) | 9.68<br>Dam Crest El. 8,420.0 | -2.07<br>Dam Crest El. 7,840.0 |
| Inflow Volume (ac-ft) | 576 | 666 |
| Peak Inflow (cfs) | 2,327 | 2,551 |
| Peak Outflow (cfs) | 2,304 | 2,549 |

| | **1,000-Year Storm** | |
|---|---|---|
| **Parameter or Modeling Result** | **Upper Subbasin and Upper Beaver Brook Dam/Reservoir** | **Lower Subbasin and Lower Beaver Brook Dam/Reservoir** |
| Subbasin Average 24-hr 1,000-Year Storm Depth (inches) | 6.94 | 6.94 |
| Subbasin Average 1,000-Year Storm Runoff (inches) | 1.85 | 1.99 |
| Subbasin Average 24-hr 1,000-Year Losses (inches) | 5.09 | 4.95 |
| Subbasin Average 1,000-Year Storm Runoff Percent (%) | 26.7 | 28.7 |
| Antecedent Moisture Condition | Saturated | Saturated |
| Maximum Reservoir Elevation (feet) | 8,410.41 | 7,842.25 |
| Freeboard (feet) | 9.59<br>Dam Crest El. 8,420.0 | -2.25<br>Dam Crest El. 7,840.0 |
| Inflow Volume (ac-ft) | 643 | 744 |
| Peak Inflow (cfs) | 2,596 | 2,847 |
| Peak Outflow (cfs) | 2,570 | 2,845 |

GEI used a center-weighted temporal distribution with an intensity position at 50 percent and an intensity duration of 5 minutes. The temporal distribution for the frequency storms is shown in the figure below:




**Comment 6:** "Table 3-7. Table 12 of HBRPEG recommends II = 0.3" for constant loss rates between 0.05-0.15 in/hr. Please review and revise your modeling as appropriate."

**Response 6:** GEI modified the HEC-HMS model to reflect II = 0.3 inches and a total initial loss of 0.7 inches. The resulting peak inflow to Lower Beaver Brook Reservoir increased from 22,485 cfs and a peak water surface El. 7,850.06 to 22,720 cfs and a peak water surface El. 7,850.13, a difference of 0.05 feet. The peak discharge increased from 22,477 cfs to 22,714 cfs.

**Comment 7:** "Section 5.3: Please note that in addition to the sensitivity analysis for the hydrology, we also strongly recommend that a sensitivity analysis be performed on the hydraulic model to determine it's sensitivity to the selected roughness coefficients."

**Response 7:** GEI developed a 2D hydraulic model in HEC-RAS using available LiDAR topographical data from the Colorado GeoData Cache. The purpose of the hydraulic model was to route the base flood and breach flood through the reach below Lower Beaver Brook Dam and evaluate the potential for incremental impacts. Early in the model development, GEI evaluated several grid cell sizes ranging from 50 feet to 300 feet. We elected to use a grid cell size of 200 feet due to conservatism, model stability, computation time efficiency, and results output. The incremental rise in all cases was less than 2 feet. GEI performed a sensitivity analysis and evaluated changes to Manning's n-values. The selected Manning's n-value for the hydraulic model was 0.06. The n-value was varied to be 0.03 and 0.12 for the sensitivity analysis. The

additional memorandum appended to these responses in Appendix B provides more information regarding the model development, results, and sensitivity analyses.

**Comment 8:** "Section 6.5: The breach parameters used to generate the breach hydrograph should be based on the impounded water storage and depth at the time of failure and the breach height should be based on the actual dam height and reservoir dimensions (Dam Height = 35 feet, Normal Storage = 30 acre-feet, Freeboard = 1.1 feet). If a smaller breach height and/or reservoir volume is used, engineering justification must be provided."

**Response 8:** The breach parameters were modified in the HEC-HMS model to reflect conditions at the time of the breach. GEI developed the maximum water surface elevation using the 27.5 percent PMF. At the request of the SEO in Comment 9, GEI developed breach parameters for Lower Beaver Brook Dam using the MLM/WA State spreadsheet for rockfill dams. Based on literature provided by the SEO, GEI reduced the breach height to 80 percent of the dam height (31.2 feet). The breach height reduction is a result of rockfill obstructing the bottom portion of the breach and preventing migration of dam particles at lower elevations. Reservoir storage and surface area were estimated using an interpolation of the existing reservoir Elevation-Area-Capacity (E-A-C) curve for the peak water surface elevation from the HEC-HMS base flood. The dam breach parameters are summarized in the table below:

| Parameter | Previous Value | Modified Value | Change | |
|---|---|---|---|---|
| | | | Value | Percent |
| Breach Parameter Estimation Method | Froehlich (2008) | MLM/WA St. | - | - |
| Top Elevation (ft) | 7840 | 7840 | 0 | - |
| Bottom Elevation (ft) | 7814 | 7808.8 | -5.2 | - |
| Height of Water of Base Elevation of Breach (ft) | 27.0 | 34.9 | 7.9 | 29.3 |
| Volume of Water in Reservoir at Time of Failure (ac-ft) | 37.4 | 46.4 | 9.0 | 24.1 |
| Reservoir Surface Area at Time of Breach (ac) | 2.2 | 3.5 | 1.3 | 59.1 |
| Height of Breach (ft) | 26.0 | 31.2 | 5.2 | 20 |
| Breach Side Slopes (xH:1V) | 1.0 | 0.5 | -0.5 | -50 |
| Bottom Width of Breach (ft) | 12.9 | 5.0 | -7.9 | 61.2 |
| Time of Development (hr) | 0.15 | 0.17 | 0.02 | 13.3 |
| Trigger Elevation (ft) | 7843.33 | 7843.69 | 0.36 | - |
| Peak Outflow (cfs) | 8,174.6 | 8,129.4 | 45.2 | 0.6 |

For Lower Beaver Brook Dam, the MLM/WA State spreadsheet estimates the breach dimensions as a bottom width of 0.1 feet with sides slopes of 0.25H:1V. Shallower side slopes produce an error in the spreadsheet and do not provide an estimated bottom width. Guidance to use the MLM/WA State breach method produced steeper side slopes than the Froehlich breach method. The MLM/WA State method takes into account the rockfill dam composition, whereas the Froehlich breach method did not. The MLM/WA State breach formation time was estimated to

be 0.17 hours, an increase from the Froehlich method. The guidance to use the MLM/WA State breach parameters allowed for the breach method to account for the rockfill composition of the dam which resulted in the increased breach formation time. GEI used a bottom width of 5 feet and side slopes of 0.5H:1V in the HEC-HMS model, which are conservative parameters compared to the MLM/WA State parameters. The peak outflow produced in HEC-HMS is considered to be conservative due to the overestimation of the breach parameters in the MLM/WA State spreadsheet. The resulting estimated peak outflow is more than two times higher than the expected peak outflow computed in the MLM/WA State spreadsheet.

GEI also examined the parameters for a 39-foot breach height, or the full dam height. For Lower Beaver Brook Dam, the MLM/WA State spreadsheet for rockfill dams estimates the largest breach dimensions as a bottom breach width of 0.5 feet with side slopes of 0.15H:1V. Shallower side slopes produce an error in the spreadsheet and do not provide an estimated bottom breach width. GEI used a bottom breach width of 5 feet and side slopes of 0.25H:1V, which are conservative compared to the MLM/WA State parameters. The breach formation time was estimated to be 0.18 hours. HEC-HMS estimated the peak breach outflow to be 8,160.8 cfs. Due to the marginal increase in peak outflow of about 30 cfs over the selected parameters, the selected breach parameters are considered to be appropriate for modeling purposes.

**Comment 9:** "Section 6.5: Although the Froehlich equation appears to be appropriate for overtopping failure modes, it appears less applicable to rockfill dams constructed with erosion resistant materials. We recommend using the MLM/WA State equations for Rockfill Dams constructed with Erosion Resistant materials to determine breach parameters for this concrete faced rockfill dam. The 'erosion resistant' breach development time may also be more applicable for rockfill dams. We have also found some literature which may justify reducing the height of breach (and corresponding height and volume of water impounded) to approximately 80% of the dam height (see previous comment). The literature is provided as an attachment to this letter. Please review and consider revising your calculations. Documentation of your justification for reducing the dimensions of the dam and reservoir at the time of breach must be provided in the report."

**Response 9:** GEI developed breach parameters using the MLM/WA State spreadsheet for rockfill dams, which are summarized in Response 8. GEI used a breach height of 31.2 feet, which is 80 percent of the height of Lower Beaver Brook Dam. This value is based on literature provided by the SEO regarding rockfill dam breach parameters. The author indicates "the eroded material is deposited immediately downstream of the dam base, restraining the breach depth development to about 80% of the dam height." Because the peak outflow for a breach height of 31.2 feet is marginally less than the peak outflow for a breach height of 39 feet, or the height of the dam, the selection of a breach height of 31.2 feet is considered to be appropriate for modeling purposes. Reservoir storage and area were developed for a water surface El. 7843.7, or an overtopping depth of 3.7 feet.

**Comment 10:** "Section 6.3: Please note that if you cannot state that ALL rises downstream of a specific point are less than 2-feet, then the model should be extended further until this statement can be made."

**Response 10:** GEI extended the 2D hydraulic model farther and has verified that all rises downstream are less than 2 feet. An additional memorandum appended to this memorandum in Attachment B provides more information regarding the model development, results, and sensitivity analysis of the 2D model.

**Comment 11:** "Section 6.4: The topography used for the modeling is based on the USGS 7.5' quadrangle contours and 10m DEM. There is much more recent and accurate data available from https://geodata.co.gov including LIDAR topography with estimated 1-foot vertical resolution that is based on an updated vertical datum (NAVD 88). We recommend using this more accurate data to better represent the base flood and breach flood inundation areas."

**Response 11:** GEI developed a 2D model in HEC-RAS with the LiDAR topographical data available on the Colorado GeoData Cache. Analyses, data, and modeling results presented in the additional memorandum were developed using the LiDAR topographical data, and exclude the 10 meter DEM topographical information.

**Comment 12:** "Section 7: It appears that incremental damages were only evaluated at discrete sections where existing houses/structures currently exist. It is our recommendation that all sections modeled be evaluated for incremental damages to support a 'global finding of no incremental damages' so that the IDA doesn't have to be revisited every time a new structure is built in the downstream floodplain. It is expected that this may necessitate increasing the fraction of PMP used for the IDF."

**Response 12:** GEI has developed a 2D model which shows the extent of the base flood and the breach flood through the reach below Lower Beaver Brook. The end of the study is about 1.6 miles above the confluence of Beaver Brook with Clear Creek. There are no structures within the reach below the end of the study, and the stream banks do not narrow below the end of the study. The selected peak breach discharge at Lower Beaver Brook Dam is less than the discharge of Clear Creek during the 100-year storm. The 100-year storm discharge of Clear Creek at the confluence with Beaver Brook is estimated to be about 9,642 cfs. GEI used FEMA FIS reports generated for Clear Creek and Jefferson Counties to interpolate the 100-year storm discharge with a regression equation developed from data provided in both reports. The 2D model supports a global finding of no incremental damages.

**Comment 13:** "Please revise Figure 7 in the report to display the minimum crest elevation which is estimated to be approximately 1.1-feet above the spillway elevation."

**Response 13:** Figure 7 has been revised and is included with this memorandum.

**Comment 14:** "Figures 14-16: The mapping of the base flood and incremental zone in the Appendix should be revised to show an aerial photograph as the background. Structures should be identified with an approximate building footprint outline instead of triangles so it can be clearly identified which lie within the base flood zone and which lie in the incremental zone. Please note that this will require a larger map scale."

**Response 14:** The maps have been modified and are included with the additional memorandum appended to this memorandum in Attachment B.

**Comment 15:** "Appendix D: Cross-section plots provided in the appendix should include RAS River Station so that they can be correlated to the hydraulic model. Structures should be included in the model as blocked obstructions."

**Response 15:** GEI developed a 2D model in HEC-RAS to route the base flood and breach flood through the downstream reach. We will provide new cross sections with identifying features. The 2D model utilized LiDAR available from the Colorado GeoData Cache. The LiDAR is sufficiently detailed to pick up obstructions.

**Comment 16:** "Appendix D: Please include a table in the hydraulic results that demonstrates the incremental depth and depth x velocity product in the incremental zone to support a global finding of no incremental damages."

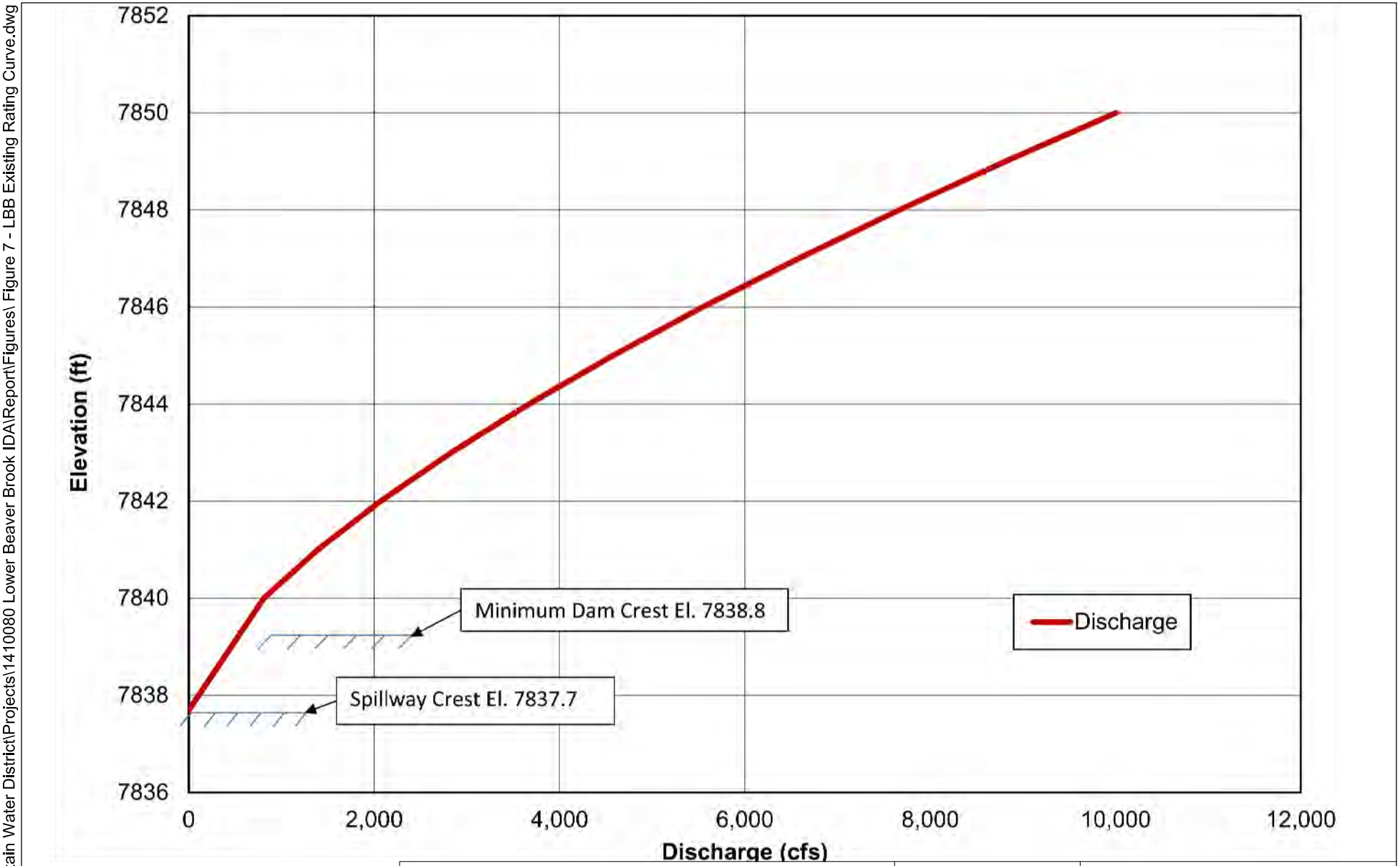
**Response 16:** GEI developed a 2D model in HEC-RAS to route the base flood and breach flood through the downstream reach. The results indicate less than 2 feet of incremental rise throughout the reach. The study ends about 1.6 miles above the confluence of Beaver Brook and Clear Creek. The reach between the end of the study and the confluence with Clear Creek does not contain any structures. The peak breach outflow from Lower Beaver Brook Dam is less than the estimated 100-year discharge of Clear Creek. After confluence with Clear Creek, the base flood and the breach flood would be attenuated to prevent incremental damages downstream.

**Comment 17:** "Modeling and mapping files (HMS, RAS, Excel, ArcGIS, etc.) should be included on a CD with the revised report."

**Response 17:** GEI will include modeling and mapping files on a CD with the final Report submittal.

# Revised Figure

V:\Lookout Mountain Water District\Projects\1410080 Lower Beaver Brook IDA\Report\Figures\ Figure 7 - LBB Existing Rating Curve.dwg Feb 2015




| | | |
|---|---|---|
| Lower Beaver Brook Dam<br>Hydrology and Incremental Damage Analysis Report<br>Clear Creek County, Colorado | GEI Consultants | LOWER BEAVER BROOK<br>EXISTING SPILLWAY RATING CURVE |
| Lookout Mountain Water District<br>Golden, Colorado | Project 1410080 | February 2015 Figure 7 |

# Attachment B

Consulting
Engineers and
Scientists

GEI Consultants

# Memo

To: Jeremy J. Franz, P.E.

From: Chad Masching, P.E., Project Manager
Nick Miller, P.E., P.H., Reviewer

CC: Bob Heine, President, LMWD

Date: September 9, 2016

**Re: Lower Beaver Brook Dam Incremental Damage Analysis Comment Response**

This memorandum provides GEI's responses to comments from the Division of Water Resources, Office of the State Engineer, Dam Safety Branch (SEO) in a letter dated August 6, 2015. The subject of the letter was regarding the Review of the Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report, which GEI submitted to the SEO on April 6, 2015. We appreciate the SEO review of the hydrology, hydraulics, and incremental damage analysis, and will identify proposed changes to address the SEO comments and provide applicable documentation for review. The SEO comments are repeated herein for clarity, followed by the response.

In response to the SEO comments, GEI developed a two-dimensional (2D) hydraulic model to analyze the reach below Lower Beaver Brook Dam. Several of the responses below refer to the new 2D model development and results. The new 2D model was developed using new elevation data available on the Colorado GeoData Cache, at the request of the SEO. The additional memorandum providing the details of the 2D model development and results is appended to this Response memorandum in Attachment B.

**Comment 1:** "The cover of the report should be revised to show DAMID: 070102, and should be signed and stamped by the responsible PE."

**Response 1:** The requested change was made. GEI has included the DAMID, signature, and stamp on the final Report submittal.

**Comment 2:** "Section ES.1 includes a statement that using the proposed condition at the Upper Beaver Brook dam (referring to the proposed labyrinth spillway which will be built when the reservoir is enlarged) is more conservative than the existing condition. We are not clear about how this is conservative. Please include additional discussion on this topic as justification for using the proposed labyrinth spillway rating curve in the modeling presented in this report."

**Response 2:** The requested change was made. GEI has modified the referenced paragraph as follows (italics indicate additions to and strikethrough indicates deletions from the report text):

"An enlargement of Upper Beaver Brook Dam/Reservoir is currently under *construction*. The proposed design is documented in GEI, 2014 and proposed conditions were used for the Lower

increased from El. 7843.3 to El. 7843.7. More information regarding the changes in dam breach parameters and modeling parameters is provided in the additional memorandum submitted to the SEO regarding responses to the comments of the letter, dated August 6.

## 2. Model Development

Hydraulic analyses of the reach below Lower Beaver Brook Dam were performed using the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center – River Analysis System (HEC-RAS), Version 5.0.1. In general the HEC-RAS model was used to route the proposed IDF and the IDF with the dam breach flood through the reach below Lower Beaver Brook Dam to evaluate incremental impacts. The hydraulic model provides estimates of the flow depths and velocities that occur downstream near structures, and in particular the Incremental zone between the two floods. The development of the model is described below.

To simulate the stream reach, a 2D model was developed using Light Detecting and Ranging (LiDAR) elevation data available from the Colorado GeoData Cache. The LiDAR elevation data was developed by FEMA after the 2013 floods along the Colorado Front Range. FEMA developed the LiDAR elevation data with 1-foot contour intervals based on the Colorado State Plane coordinate system (NAD83, Colorado Central (FIPS 502) Zone). To develop the hydraulic model, a digital terrain model of the LiDAR data was imported into HEC-RAS using RAS Mapper. A 2D Flow Area mesh was developed from the terrain model using the Geometric Data Editor. A total of 30 break lines and Storage Area/2D Area Connection (Cross Section) lines were added to align the 2D mesh faces normal to the direction of flow and to calculate flow hydrographs in the downstream reach. During early stages of model development, GEI evaluated various grid cell sizes, ranging from 50 feet to 300 feet. We elected to use a grid cell size of 200 feet due to conservatism, model stability, computation time efficiency, and results output. The incremental rises in all cases was less than 2 feet.

Manning's n-values were estimated for the downstream channels based on descriptions provided in Chow, 1959, previously assigned n-values in the Report, and engineering judgment. The mesh was assigned a Manning's n-value of 0.06, based on light brush and trees. Sensitivity analyses of the selected n-values were performed and are described in the Sensitivity Analyses section. The sensitivity analyses are in response to Comment 7 in the letter, dated August 6.

GEI included baseflow from three downstream tributaries in the hydraulic model: North Beaver Brook, Soda Creek, and an unnamed tributary of Beaver Brook. These were modeled using uniform inflow hydrograph boundary conditions at the tributary location. All of the baseflow was estimated using a regression model developed by Capesius and Stephens, 2009. Capesius and Stephens developed several regression equations for different regions within Colorado. All of the tributaries fall with the "Mountain Region." The 100-year storm event was selected from the regression results with baseflow values for each tributary shown in Table 1. More information regarding the development of baseflow values is provided in the additional memorandum submitted to the SEO regarding responses to the comments of the letter, dated August 6.

**Table 1: 100-Year Baseflow for Beaver Brook Tributaries**

| Tributary | Baseflow (cfs) |
|---|---|
| North Beaver Brook | 55 |
| Soda Creek | 90 |
| Unnamed Tributary | 30 |

The upstream boundary condition for the hydraulic model was set as a flow hydrograph. Inflow hydrographs for the hydraulic model were developed using the modified outflow results from Lower Beaver Brook Reservoir developed for the Report using the Hydraulic Engineering Center's – Hydrologic Modeling System (HEC-HMS). As discussed in the Report, GEI and the SEO decided it would be conservative to model the base flood with Lower Beaver Brook Dam in place, but with no breach as the base flood, rather than modeling the base flood with no dam in place. Hydrologic modeling parameters were modified in accordance with SEO requests in the letter, dated August 6 in HEC-HMS.

The downstream boundary condition for the hydraulic model was set as normal depth, using the estimated channel slope at the end of the study reach, which we estimated to be 0.0825 feet/feet. The hydraulic calculations were calculated using a mixed-flow regime, which allows supercritical and subcritical flows.

The model was terminated about 5.3 miles below Lower Beaver Brook Dam, or about 1.6 miles above the confluence of Beaver Brook with Clear Creek. The 100-year storm discharge for Clear Creek at the confluence with Beaver Brook is estimated to be about 9,642 cfs, which is larger than peak breach outflow at Lower Beaver Brook Dam. The 100-year storm discharge for Clear Creek was estimated using a regression equation developed from data provided in FEMA FIS reports for Jefferson and Clear Creek Counties. There are no structures between the end of the study and the confluence with Clear Creek, and the reach terrain does not change drastically in steepness or narrowness in this section of the reach. Therefore, GEI concluded that the location of the end of the study was reasonable and that there would be no incremental impacts downstream of the end of the study.

## 3. Model Results

The Lower Beaver Brook Dam IDA results are presented in Table 2. The tabulated results include the base flow and the breach flow inundation results, as well as the incremental impacts summary for the reach below Lower Beaver Brook Dam and Reservoir. The HEC-RAS input and select output corresponding to hydrograph locations, and inundation limits are included in Attachment A. The full output will be included with the submission of the final Report.

Model results indicate that the 27.5 percent PMF base flood (no dam break) significantly inundates the majority of the structures below Lower Beaver Brook Dam. Several structures are inundated by depths of about 7 to 8 feet. The base flood inundation values at the structures were determined by collecting water surface elevation and velocity values at the survey point of each structure. The peak discharge at the structure was determined using hydrographs produced at

Cross Sections in the 2D flow area mesh, and interpolated for structures between the Cross Sections.

The model results indicate the breach flood also significantly inundates the majority of the structures below Lower Beaver Brook Dam. Several structures are inundated by about 7 to 9 feet. The incremental rise values are shown in Table 2, with the incremental increase in velocity at each structure. The maximum rise at any structure downstream is 1.43 feet, and the maximum incremental depth times velocity is 3.79 feet squared per second.

As indicated in Table 2, the base flood impacts a total of 22 identified structures downstream of Lower Beaver Brook Dam, with 18 of those structures flooded by depths exceeding two feet. The breach flood impacts a total of 24 structures, with 19 of those structures flooded by depths exceeding two feet. A total of 2 additional structures are impacted by the breach flood with shallow flood depths. For the identified structures that were not already significantly flooded by the base flood (i.e. greater than two feet), or experienced impacts in the event of the breach flood but not the base flood, the incremental impacts were further evaluated. To assess if incremental damages occur at those structures, the incremental depth and velocity were determined at those structures, and incremental depth times velocity was calculated. As indicated in Table 2, all incremental depths were 1.5 feet and all incremental depth times velocity values are less than 4 feet squared per second. The base flood and breach flood inundation limits are shown in Figures 1A to 1F.

Globally, the largest expected rise is expected to be less than 1.75 feet, as shown in Figure 2. The 2D model results support a global finding of no incremental damages between the base flood and the breach flood. Inundation maps are included in Attachment B.

GEI modeled two smaller storms to verify incremental impacts would occur at these flood values. At the flood equivalent to 24 percent of the PMF, incremental impacts due to the breach flood begin to exceed the 2-foot screening threshold. At the 25 percent of the PMF flood, incremental impacts begin to minimize, but incremental rise values round up to 2 feet. GEI selected to use the 27.5 percent PMF flood to ensure incremental impacts were not present between the base flood inundation and breach flood inundation.

Variable < 1 | 1 < Variable < 2 | 2 < Variable

**Table 2: Lower Beaver Brook IDA Results**

| Terrain Data | | | | | | Base Flood | | | | | Breach Flood | | | | | Incremental Results | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| # | Survey Tag | Associated RAS Mapper ID and Section | Distance Below Dam (Miles) | Structure Elevation (NAVD88) (ft) | Min Channel El. (ft) | Peak Discharge in Section (cfs) | Max WSE at Structure (ft) | Water Depth at Structure (ft) | Velocity at Structure (ft/s) | Depth * Velocity ($ft^2/s$) | Peak Discharge in Section (cfs) | Max WSE at Structure (ft) | Water Depth at Structure (ft) | Velocity at Structure (ft/s) | Depth * Velocity ($ft^2/s$) | Incremental Rise at Structure (ft) | Incremental Velocity at Structure (ft) | Depth * Velocity ($ft^2/s$) | Incremental Impacts (Yes/No) |
| 1 | LMWD Equipment Shed | Operator House | 0.00 | 7813.94 | 7799.90 | 5461 | 0.00 | 0.00 | 0.0 | 0 | 8129 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 2 | LMWD WTP | Operator House | 0.02 | 7831.37 | 7799.90 | 5461 | 0.00 | 0.00 | 0.0 | 0 | 8086 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 3 | LMWD WRP#2 | Water Treatment Plant | 0.03 | 7813.97 | 7801.27 | 5461 | 0.00 | 0.00 | 0.0 | 0 | 8069 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 4 | Shed | House 5 | 0.17 | 7761.31 | 7759.30 | 5460 | 7769.26 | 7.95 | 10.5 | 83.2 | 7920 | 7770.27 | 8.96 | 12.0 | 107.8 | 1.01 | 1.57 | 1.6 | No |
| 5 | Cabin | House 5 | 0.17 | 7766.49 | 7759.30 | 5460 | 7768.08 | 1.59 | 10.7 | 17.1 | 7916 | 7768.93 | 2.44 | 12.2 | 29.7 | 0.85 | 1.44 | 1.2 | No |
| 6 | Bottom Foundation | House 5 | 0.17 | 7761.15 | 7759.30 | 5460 | 7767.65 | 6.50 | 11.7 | 76.1 | 7916 | 7768.54 | 7.39 | 13.4 | 99.3 | 0.89 | 1.74 | 1.5 | No |
| 7 | Finished Floor | House 5a | 0.18 | 7763.33 | 7762.21 | 5460 | 7766.21 | 2.88 | 12.9 | 37.1 | 7912 | 7767.04 | 3.71 | 14.8 | 54.8 | 0.83 | 1.89 | 1.6 | No |
| 8 | Finished Floor Shed | House 6 | 0.20 | 7755.69 | 7753.33 | 5460 | 7762.82 | 7.13 | 11.2 | 79.8 | 7904 | 7763.58 | 7.89 | 12.7 | 100.2 | 0.76 | 1.51 | 1.1 | No |
| 9 | Finished Floor Cabin | House 6 | 0.20 | 7787.68 | 7753.33 | 5460 | 0.00 | 0.00 | 0.0 | 0 | 7903 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 10 | Top Foundation | House 7 | 0.20 | 7782.60 | 7750.12 | 5460 | 0.00 | 0.00 | 0.0 | 0 | 7903 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 11 | Top Foundation | House 7 | 0.22 | 7753.67 | 7750.12 | 5460 | 7758.92 | 5.25 | 6.5 | 34.3 | 7903 | 7759.69 | 6.02 | 8.0 | 48.4 | 0.77 | 1.51 | 1.2 | No |
| 12 | Finished Floor Shed | House 7 | 0.22 | 7752.50 | 7750.12 | 5460 | 7759.18 | 6.68 | 6.4 | 42.8 | 7902 | 7759.86 | 7.36 | 7.7 | 56.7 | 0.68 | 1.31 | 0.9 | No |
| 13 | Finished Floor Cabin | House 7a | 0.22 | 7752.33 | 7748.05 | 5460 | 7757.81 | 5.48 | 5.7 | 31.2 | 7902 | 7758.29 | 5.96 | 6.8 | 40.5 | 0.48 | 1.11 | 0.5 | No |
| 14 | Finished Floor | House 8 | 0.24 | 7750.27 | 7746.13 | 5460 | 7754.44 | 4.17 | 11.1 | 46.1 | 7901 | 7754.99 | 4.72 | 11.7 | 55.0 | 0.55 | 0.61 | 0.3 | No |
| 15 | Finished Floor | House 8 | 0.24 | 7771.67 | 7746.13 | 5460 | 0.00 | 0.00 | 0.0 | 0 | 7901 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 16 | Top Foundation | House 8a | 0.24 | 7749.31 | 7744.30 | 5460 | 7751.81 | 2.50 | 10.3 | 25.8 | 7901 | 7752.53 | 3.22 | 11.9 | 38.4 | 0.72 | 1.63 | 1.2 | No |
| 17 | Top Foundation | House 9 | 0.26 | 7773.60 | 7737.22 | 5459 | 0.00 | 0.00 | 0.0 | 0 | 7900 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 18 | Finished Floor | House 9a | 0.27 | 7745.88 | 7736.90 | 5459 | 0.00 | 0.00 | 0.0 | 0 | 7900 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 19 | Finished Floor | House 9a | 0.27 | 7738.36 | 7736.90 | 5459 | 7740.09 | 1.73 | 7.9 | 13.7 | 7899 | 7740.81 | 2.45 | 9.2 | 22.5 | 0.72 | 1.27 | 0.9 | No |
| 20 | Top Foundation | House 9a | 0.28 | 7767.70 | 7736.90 | 5459 | 0.00 | 0.00 | 0.0 | 0 | 7899 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 21 | Top Foundation | House 10 | 0.29 | 7736.41 | 7728.70 | 5459 | 7736.81 | 0.40 | 12.8 | 5.1 | 7899 | 7737.70 | 1.29 | 14.8 | 19.1 | 0.89 | 2.07 | 1.8 | No |
| 22 | Top Foundation | House 10 | 0.30 | 7766.63 | 7728.70 | 5459 | 0.00 | 0.00 | 0.0 | 0 | 7898 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 23 | Top Foundation | House 10a | 0.32 | 7725.35 | 7723.46 | 5459 | 7732.40 | 7.05 | 11.9 | 83.8 | 7894 | 7733.05 | 7.70 | 13.9 | 107.3 | 0.65 | 2.06 | 1.3 | No |
| 24 | Finish Floor | House 11 | 0.34 | 7722.96 | 7718.38 | 5459 | 7726.53 | 3.57 | 13.5 | 48.3 | 7889 | 7727.14 | 4.18 | 14.9 | 62.1 | 0.61 | 1.31 | 0.8 | No |
| 25 | Finish Floor | House 11a | 0.35 | 7721.66 | 7715.40 | 5459 | 7724.29 | 2.63 | 9.4 | 24.8 | 7887 | 7725.25 | 3.59 | 11.4 | 40.7 | 0.96 | 1.91 | 1.8 | No |
| 26 | Top Foundation | House 12 | 0.40 | 7718.67 | 7708.23 | 5459 | 7718.05 | 0.00 | 7.9 | 0 | 7874 | 7718.73 | 0.06 | 8.6 | 0.5 | 0.68 | 0.71 | 0.5 | No |
| 27 | Top Foundation | House 14 | 0.62 | 7655.71 | 7649.37 | 5456 | 7655.46 | 0.00 | 9.8 | 0 | 7748 | 7656.13 | 0.42 | 10.5 | 4.4 | 0.67 | 0.71 | 0.5 | No |
| 28 | Finish Floor | House 18 | 0.83 | 7658.82 | 7609.74 | 5458 | 0.00 | 0.00 | 0.0 | 0 | 7640 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 29 | Finish Floor | House 19 | 0.95 | 7622.13 | 7584.45 | 5458 | 0.00 | 0.00 | 0.0 | 0 | 7680 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 30 | Finish Floor | House 20 | 0.99 | 7621.27 | 7582.46 | 5458 | 0.00 | 0.00 | 0.0 | 0 | 7693 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 31 | Finish Floor | House 21 | 1.04 | 7574.10 | 7570.17 | 5458 | 7574.04 | 0.00 | 10.3 | 0 | 7658 | 7574.26 | 0.16 | 11.4 | 1.8 | 0.22 | 1.07 | 0.2 | No |
| 32 | Finish Floor | House 22 | 1.17 | 7554.10 | 7544.42 | 5458 | 7555.92 | 1.82 | 3.9 | 7.1 | 7675 | 7556.39 | 2.29 | 5.1 | 11.7 | 0.47 | 1.17 | 0.5 | No |
| 33 | N/A | I-70 Approach 2 | 1.38 | 7542.08 | 7503.88 | 5448 | 7532.44 | 0.00 | 1.3 | 0 | 7311 | 7533.19 | 0.00 | 1.7 | 0.0 | 0.75 | 0.44 | 0.3 | No |
| 34 | N/A | I-70 Road Low Spot | 1.41 | 7525.13 | 7525.13 | 5417 | 7530.18 | 5.05 | 4.6 | 23.2 | 7271 | 7531.61 | 6.48 | 8.4 | 54.3 | 1.43 | 3.79 | 5.4 | No |
| 35 | N/A | House 26 | 1.62 | 7465.36 | 7456.80 | 5209 | 7467.74 | 2.38 | 8.5 | 20.2 | 6994 | 7467.89 | 2.53 | 9.4 | 23.7 | 0.15 | 0.9 | 0.1 | No |
| 36 | N/A | House 31 | 2.22 | 7393.43 | 7365.52 | 5326 | 0.00 | 0.00 | 0.0 | 0 | 7060 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 37 | N/A | House 32 | 2.49 | 7324.34 | 7321.11 | 5325 | 7325.17 | 0.83 | 8.1 | 6.7 | 7021 | 7523.43 | 1.09 | 9.4 | 10.3 | 0.26 | 0.39 | 0.4 | No |
| 38 | N/A | Highway 40 5 - Road Crossing | 2.93 | 7257.46 | 7251.25 | 5323 | 7257.52 | 0.06 | 10.5 | 0.6 | 6980 | 7258.11 | 0.65 | 12.2 | 8.0 | 0.59 | 1.73 | 1.0 | No |
| 39 | N/A | House 33 | 3.13 | 7222.77 | 7215.58 | 5322 | 7224.12 | 1.35 | 16.5 | 22.3 | 6960 | 7224.61 | 1.84 | 16.8 | 30.9 | 0.49 | 0.32 | 0.2 | No |
| 40 | N/A | House 36 | 3.30 | 7194.25 | 7186.51 | 5321 | 7194.33 | 0.08 | 8.9 | 0.7 | 6945 | 7194.90 | 0.65 | 9.4 | 6.1 | 0.57 | 0.53 | 0.3 | No |
| 41 | N/A | Highway 40 8 | 3.56 | 7190.41 | 7149.63 | 5321 | 0.00 | 0.00 | 0.0 | 0 | 6919 | 0.00 | 0.00 | 0.0 | 0.0 | 0 | 0 | 0 | No |
| 42 | N/A | Downstream Reach 7 | 4.39 | N/A | 7003.96 | 5317 | N/A | N/A | N/A | N/A | 6832 | N/A | N/A | N/A | N/A | N/A | N/A | 0 | No |
| 43 | N/A | End of Study | 5.34 | N/A | 6854.03 | 5313 | N/A | N/A | N/A | N/A | 6773 | N/A | N/A | N/A | N/A | N/A | N/A | 0 | No |

## 3.1 Sensitivity Analyses

Analyses were performed to test the sensitivity of the modeling results to changes in mesh cell size. Mesh cell size sensitivity analyses were conducted using 100-, 200-, and 300-foot mesh cell sizes to support selection for the final model. The final model was developed using a 200-foot mesh cell size. The results compared include simulation computation time, global maximum incremental rise between base flow and breach flow, and peak base and breach flows, maximum base and breach water surface elevations, and peak base and breach velocities at selected locations. The results of the mesh cell size sensitivity analyses are summarized in Table 3.

**Table 3: Lower Beaver Brook Sensitivity Analyses Results**

| Parameter | | 100-foot Mesh | 200-foot Mesh | 300-foot Mesh |
|---|---|---|---|---|
| Computation Time (simulation time = 14 hours) | | 12 mins 36 secs | 6 mins 22 secs | 3 mins 53 secs |
| Global Maximum Incremental Rise | | 1.95 feet | 1.71 feet | 1.31 feet |
| 0.58 River Miles | Peak Breach Flow (cfs) | 7805 | 7805 | 7804 |
| | Peak Base Flow (cfs) | 5514 | 5510 | 5393 |
| | Max. Breach WSE (ft) | 7674.1 | 7674.0 | 7679.4 |
| | Max. Base WSE (ft) | 7673.1 | 7673.1 | 7679.1 |
| | Incremental Rise (ft) | 1.0 | 0.9 | 0.3 |
| | Peak Breach Velocity (fps) | 13.2 | 14.2 | 13.8 |
| | Peak Base Velocity (fps) | 11.3 | 11.8 | 12.68 |
| 1.04 River Miles | Peak Breach Flow (cfs) | 7863 | 7764 | 7686 |
| | Peak Base Flow (cfs) | 5514 | 5513 | 5512 |
| | Max. Breach WSE (ft) | 7576.1 | 7577.7 | 7581.5 |
| | Max. Base WSE (ft) | 7575.8 | 7577.3 | 7580.8 |
| | Incremental Rise (ft) | 0.3 | 0.4 | 0.7 |
| | Peak Breach Velocity (fps) | 15.8 | 14.1 | 9.5 |
| | Peak Base Velocity (fps) | 14.6 | 12.3 | 8.9 |
| 1.38 River Miles | Peak Breach Flow (cfs) | 7407 | 7366 | 7205 |
| | Peak Base Flow (cfs) | 5503 | 5503 | 5483 |
| | Max. Breach WSE (ft) | 7536.2 | 7533.2 | 7530.6 |
| | Max. Base WSE (ft) | 7535.6 | 7532.5 | 7529.7 |
| | Incremental Rise (ft) | 0.6 | 0.7 | 0.9 |
| | Peak Breach Velocity (fps) | 1.8 | 5.1 | 3.0 |
| | Peak Base Velocity (fps) | 1.5 | 4.3 | 2.4 |
| 2.27 River Miles | Peak Breach Flow (cfs) | 7065 | 7112 | 6328 |
| | Peak Base Flow (cfs) | 5320 | 5381 | 4960 |
| | Max. Breach WSE (ft) | 7368.1 | 7367.8 | 7371.3 |
| | Max. Base WSE (ft) | 7367.3 | 7367.0 | 7370.6 |
| | Incremental Rise (ft) | 0.8 | 0.8 | 0.7 |
| | Peak Breach Velocity (fps) | 13.0 | 12.5 | 9.1 |
| | Peak Base Velocity (fps) | 12.6 | 11.8 | 8.6 |

| Parameter | | 100-foot Mesh | 200-foot Mesh | 300-foot Mesh |
|---|---|---|---|---|
| Computation Time (simulation time = 14 hours) | | 12 mins 36 secs | 6 mins 22 secs | 3 mins 53 secs |
| Global Maximum Incremental Rise | | 1.95 feet | 1.71 feet | 1.31 feet |
| 3.56 River Miles | Peak Breach Flow (cfs) | 7038 | 7064 | 6340 |
| | Peak Base Flow (cfs) | 5406 | 5466 | 5036 |
| | Max. Breach WSE (ft) | 7160.7 | 7159.3 | 7168.5 |
| | Max. Base WSE (ft) | 7159.5 | 7158.5 | 7167.6 |
| | Incremental Rise (ft) | 0.8 | 0.8 | 0.9 |
| | Peak Breach Velocity (fps) | 14.5 | 14.8 | 13.6 |
| | Peak Base Velocity (fps) | 11.0 | 13.7 | 12.5 |
| 4.60 River Miles | Peak Breach Flow (cfs) | 6993 | 6997 | 6331 |
| | Peak Base Flow (cfs) | 5433 | 5492 | 5056 |
| | Max. Breach WSE (ft) | 6980.1 | 6979.8 | 6982.6 |
| | Max. Base WSE (ft) | 6979.2 | 6979.0 | 6981.7 |
| | Incremental Rise (ft) | 0.9 | 0.8 | 0.9 |
| | Peak Breach Velocity (fps) | 2.3 | 9.9 | 7.1 |
| | Peak Base Velocity (fps) | 8.8 | 9.0 | 6.6 |

As indicated in Table 3, the mesh cell size has an effect on the total simulation computation time, varying from about 4 minutes to about 13 minutes, for a 14-hour simulation. The global maximum incremental rise varied slightly, between about 0.24 feet and 0.40 feet. The smaller mesh size generally produced slightly smaller incremental rises, but more peak flow attenuation. The larger mesh cell size generally produced larger incremental rise, but a smaller global incremental rise, and also more peak flow attenuation. The model with the smaller mesh cell size produced slightly unstable results, as indicated by the peak breach velocities at sections taken at 4.60 River Miles. Overall, GEI elected to use the 200-foot mesh cell size due to model accuracy and stability, conservative results, and reasonable computation time. All mesh cell size sensitivity analyses produced results with a global incremental rise of less than 2 feet. GEI considers the model results to be appropriate for IDA purposes.

Sensitivity analyses of the reach below Lower Beaver Brook Dam were performed to evaluate and compare peak outflow, water surface elevation, velocity, and depth based on Manning's n-values. The Manning's n-values were increase by 100 percent and decreased by 50 percent to evaluate the sensitivity of the selected values. The results of the sensitivity analyses at selected locations below Lower Beaver Brook Dam are presented in Table **4** for comparison purposes.

As indicated in Table 4, the adjustments to Manning's v-values results in a change in water surface elevation of about 1.0 to 3.7 feet, compared to the base case. At the selected cross sections, this resulted in a maximum increase in incremental rise from about 0.8 feet to 1.1 feet, or an increase of 0.3 feet. However, the increase in Manning's n-values produced a decrease in velocity at this section by about 8.1 feet per second (fps), or about 39 percent. While the Manning's n-values caused an increase to incremental rise of the breach flood, the incremental impacts are still less than the screening values of 2 feet for incremental rise and 7 feet squared per second for incremental depth times velocity. Additionally, the attenuation of the flood peak

flows increased from about 1,356 cfs to about 1,884 cfs with higher Manning's n-value, or an increase of about 39 percent. Breach flood attenuation at selected sections is shown in Figure 3, which is presented in Attachment B.

Overall, the model results are moderately sensitive to large changes in Manning's n-values, but the incremental results show low sensitivity to changes in Manning's n-values. For the range of flows modeled, the incremental rise and incremental velocity times depth are expected to remain below the specified threshold values.

**Table 4: Lower Beaver Brook Sensitivity Analyses Results**

| No. | Section ID (HEC-RAS 2D) | Case | Distance Below LBB Dam (mi.) | Min. Channel El. (ft) | Base Flood - 0.275 PMF | | | | Breach Flood - 80% Dam Height | | | | Incremental Changes | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Peak Flow (cfs) | Max. WSE (ft) | Max. Depth (ft) | Max. Velocity (ft) | Peak Flow (cfs) | Max. WSE (ft) | Max. Depth (ft) | Max. Velocity (ft) | Max. Rise (ft) | Incremental Velocity at Max. Rise (ft/s) | D * V ($ft^2/s$) |
| 1 | Inflow | Base Case | 0.00 | N/A | 5461 | | | | 8129 | | | | | | |
| | | High Manning's n (n = 0.12) | | | 5461 | | | | 8129 | | | | | | |
| | | Low Manning's n (n = 0.03) | | | 5461 | | | | 8129 | | | | | | |
| 2 | House 2 | Base Case | 0.06 | 7789.4 | 5461 | 7798.5 | 7.1 | 18.5 | 8010 | 7799.1 | 7.8 | 20.9 | 0.8 | 1.8 | 1.5 |
| | | High Manning's n (n = 0.12) | | | 5461 | 7799.7 | 8.5 | 11.5 | 8011 | 7800.8 | 9.5 | 12.8 | 1.1 | 1.1 | 1.1 |
| | | Low Manning's n (n = 0.03) | | | 5461 | 7797.2 | 5.8 | 30.0 | 8035 | 7797.9 | 6.5 | 34.1 | 0.7 | 3.4 | 2.3 |
| 3 | Road Crossing 1 | Base Case | 0.42 | 7703.4 | 5460 | 7710.9 | 7.4 | 12.1 | 7898 | 7712.1 | 8.6 | 13.7 | 1.3 | 1.6 | 2.1 |
| | | High Manning's n (n = 0.12) | | | 5459 | 7713.3 | 9.9 | 7.1 | 7718 | 7714.8 | 11.4 | 7.7 | 1.5 | 0.9 | 1.3 |
| | | Low Manning's n (n = 0.03) | | | 5460 | 7709.3 | 5.8 | 17.4 | 7864 | 7710.1 | 6.6 | 20.9 | 0.9 | 2.9 | 2.7 |
| 4 | House 18 | Base Case | 0.83 | 7609.7 | 5458 | 7617.1 | 5.4 | 14.6 | 7640 | 7617.5 | 6.0 | 16.4 | 0.6 | 1.4 | 0.9 |
| | | High Manning's n (n = 0.12) | | | 5455 | 7618.0 | 6.7 | 9.0 | 7566 | 7618.2 | 7.4 | 9.7 | 0.8 | 1.1 | 0.9 |
| | | Low Manning's n (n = 0.03) | | | 5459 | 7616.2 | 4.5 | 23.2 | 7719 | 7616.6 | 5.0 | 26.2 | 0.5 | 2.5 | 1.2 |
| 5 | I-70 Approach 2 | Base Case | 1.24 | 7503.9 | 5448 | 7532.5 | 28.6 | 4.2 | 7311 | 7533.2 | 29.3 | 5.0 | 0.8 | 0.8 | 0.6 |
| | | High Manning's n (n = 0.12) | | | 5428 | 7534.3 | 30.4 | 3.2 | 7049 | 7535.2 | 31.4 | 3.8 | 0.9 | 0.2 | 0.2 |
| | | Low Manning's n (n = 0.03) | | | 5510 | 7531.0 | 27.2 | 5.7 | 7565 | 7531.6 | 27.8 | 7.0 | 0.6 | 0.4 | 0.2 |
| 6 | House 31a | Base Case | 2.27 | 7356.9 | 5326 | 7365.5 | 8.5 | 11.8 | 7057 | 7366.5 | 9.5 | 12.5 | 1.0 | 0.9 | 0.9 |
| | | High Manning's n (n = 0.12) | | | 5294 | 7368.2 | 11.2 | 6.8 | 6636 | 7369.3 | 12.4 | 7.4 | 1.1 | 0.5 | 0.6 |
| | | Low Manning's n (n = 0.03) | | | 5363 | 7363.4 | 6.6 | 20.9 | 7379 | 7364.6 | 7.4 | 22.5 | 1.1 | 0.8 | 0.9 |
| 7 | Highway 40 5 - Road Crossing | Base Case | 2.93 | 7251.2 | 5323 | 7257.8 | 6.6 | 15.1 | 6981 | 7258.4 | 7.2 | 16.8 | 1.1 | 1.6 | 1.8 |
| | | High Manning's n (n = 0.12) | | | 5284 | 7261.1 | 9.8 | 9.8 | 6488 | 7262.2 | 10.9 | 10.5 | 1.1 | 1.1 | 1.2 |
| | | Low Manning's n (n = 0.03) | | | 5362 | 7256.0 | 4.7 | 23.7 | 7273 | 7256.7 | 5.4 | 26.5 | 0.7 | 1.8 | 1.3 |
| 8 | Downstream Reach 13 | Base Case | 4.88 | 6727.6 | 5316 | 6935.8 | 7.4 | 13.7 | 6798 | 6936.4 | 8.0 | 14.9 | 0.7 | 0.9 | 0.6 |
| | | High Manning's n (n = 0.12) | | | 5253 | 6937.1 | 9.1 | 8.7 | 6280 | 6937.8 | 9.8 | 9.2 | 0.7 | 0.5 | 0.3 |
| | | Low Manning's n (n = 0.03) | | | 5361 | 6934.2 | 5.8 | 21.2 | 7172 | 6934.8 | 6.4 | 23.8 | 0.6 | 1.8 | 1.1 |
| 9 | Outflow | Base Case | 5.34 | N/A | 5313 | | | | 6773 | | | | | | |
| | | High Manning's n (n = 0.12) | | | 5245 | | | | 6246 | | | | | | |
| | | Low Manning's n (n = 0.03) | | | 5360 | | | | 7157 | | | | | | |

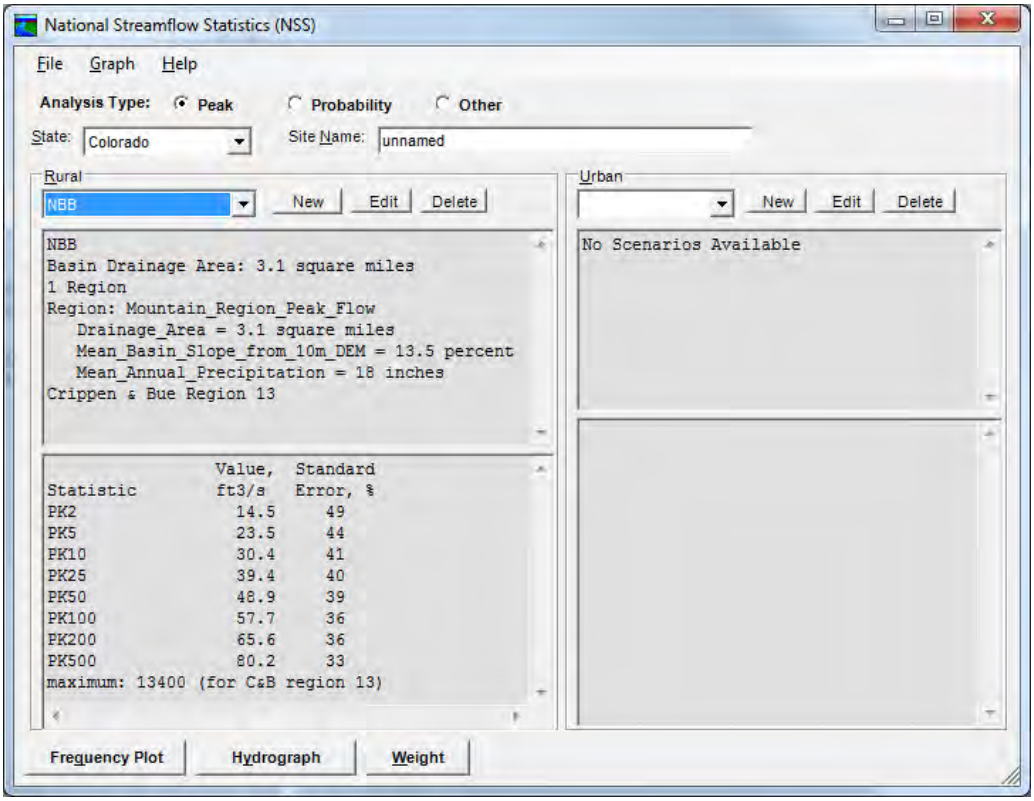
# 4. Conclusion

This memorandum summarizes the hydraulic analyses of the reach below Lower Beaver Brook Dam and Reservoir. The hydraulic model was developed at the request of the SEO in a letter response to a GEI Report submission, dated August 6. The developed 2D hydraulic model utilizes new LiDAR elevation data and provides global results of the study area, rather than discrete cross section results of the one-dimensional (1D) model.

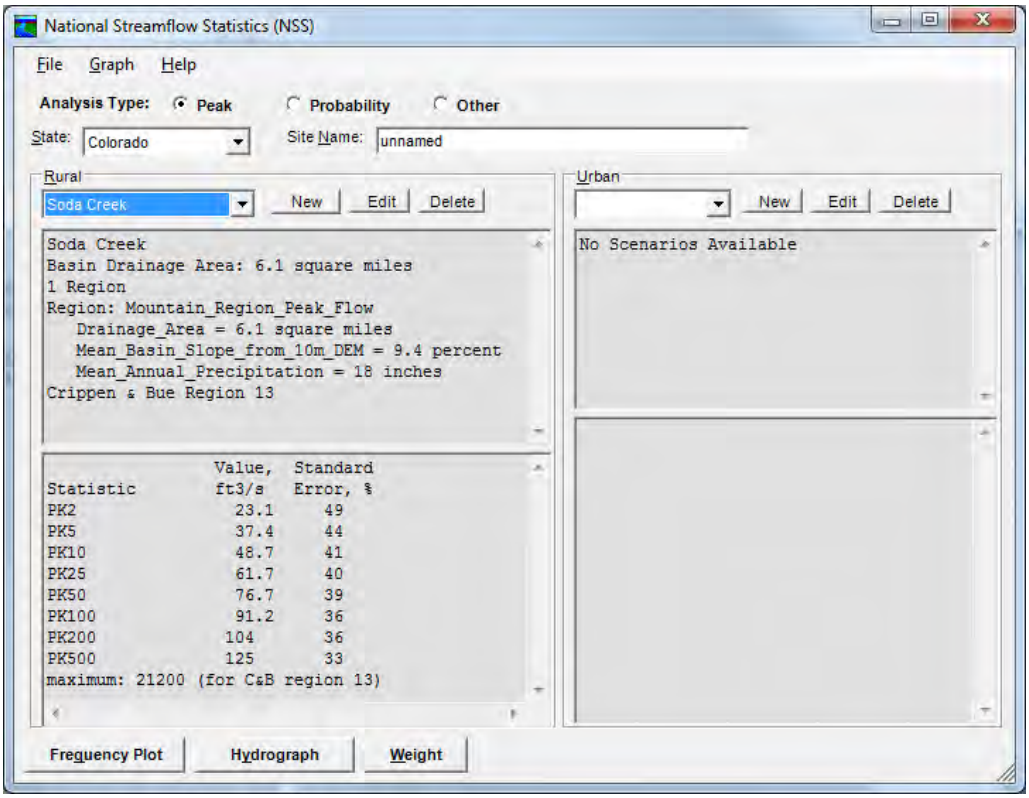
Based on the results of this study, GEI found no incremental impacts between the selected base flood and the breach flood for Lower Beaver Brook Dam. Figures 1A to 1F shows the base and breach flood inundation limits. In the previous Report, GEI found no incremental impacts. In this memorandum, GEI showed that responding to changes from the SEO increased the base flood peak outflow, and decreased the breach flood peak outflow. Thus, the results from the 2D model have less incremental impacts than the model summarized in the previous Report. All incremental rises between the base flood and the breach flood in the 2D model are less than the screening value of 2 feet, as shown in Figure 2, and all incremental depth times velocity are less than the value of 7 feet squared per second. Sensitivity analyses of the downstream reach indicate the model is relatively sensitive to changes in Manning's n-values, but that the incremental results show less sensitivity to changes in Manning's n-values. Table 4 indicates the difference in incremental rise diminishes the farther downstream, and the maximum increase in incremental rise is about 0.3 feet. Therefore, GEI recommends an IDF of 5,500 cfs for Lower Beaver Brook Dam.

# Attachment A

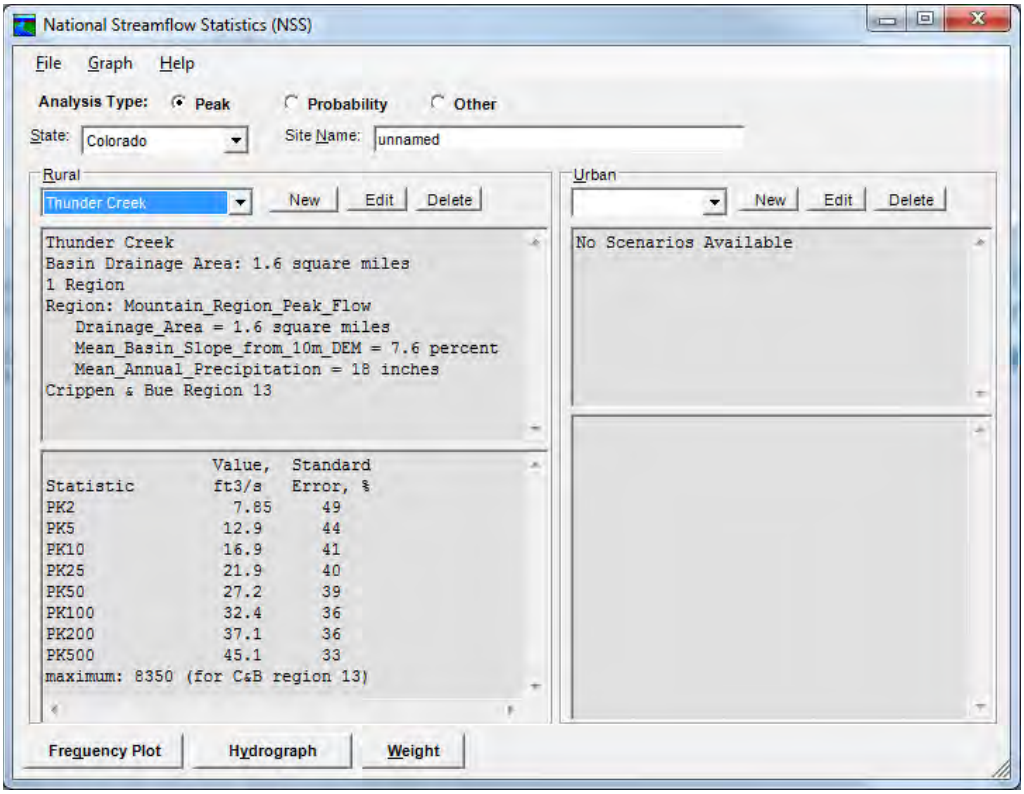
NSS Output - North Beaver Brook Baseflow Estimate




NSS Output - Soda Creek Baseflow Estimate

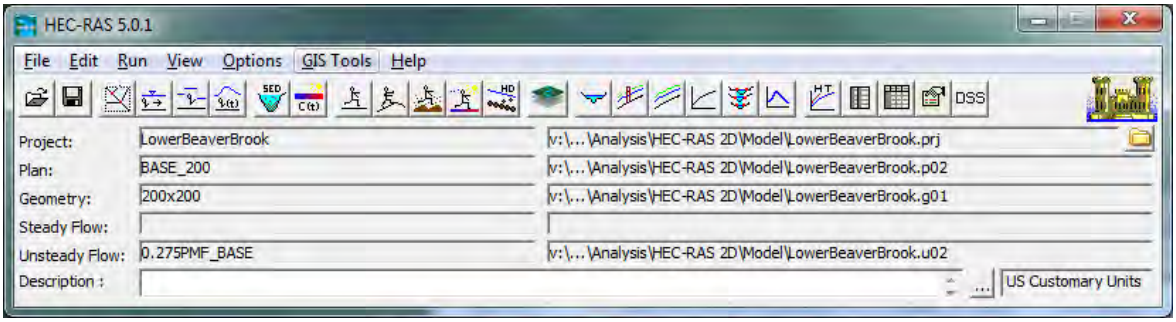


NSS Output – Unnamed Tributary, “Thunder Creek,” Baseflow Estimate

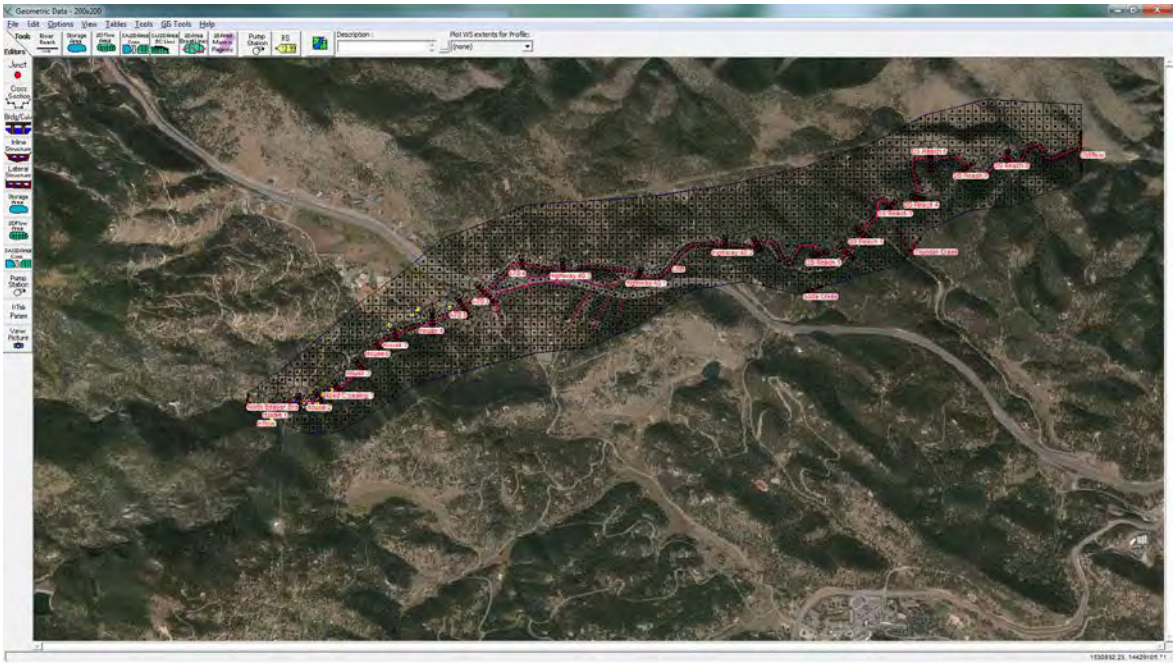


# Attachment B

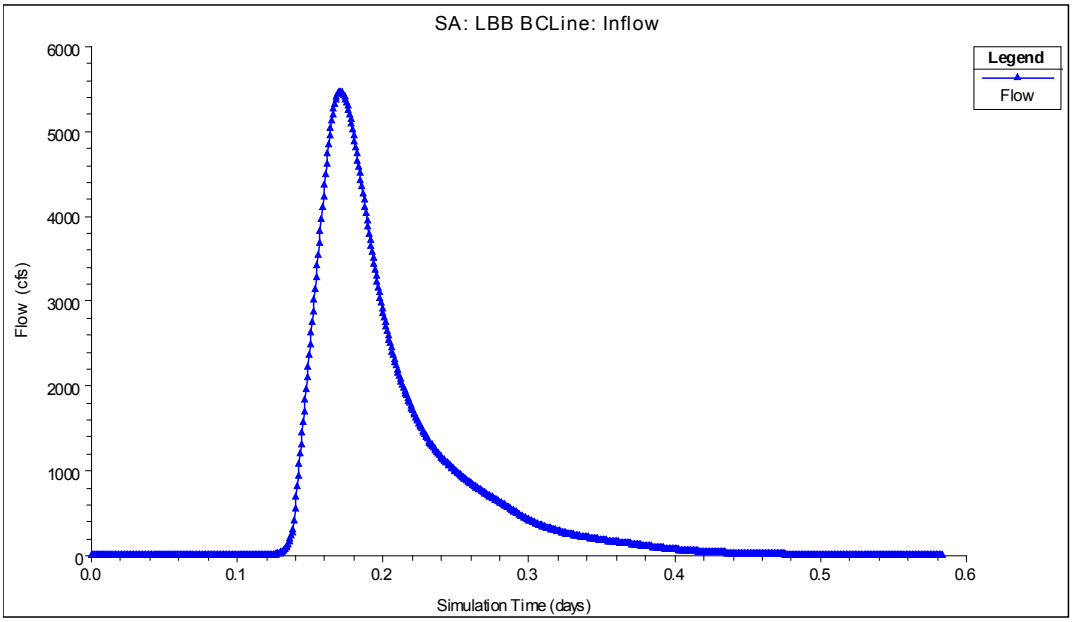
HEC-RAS Model Main Window



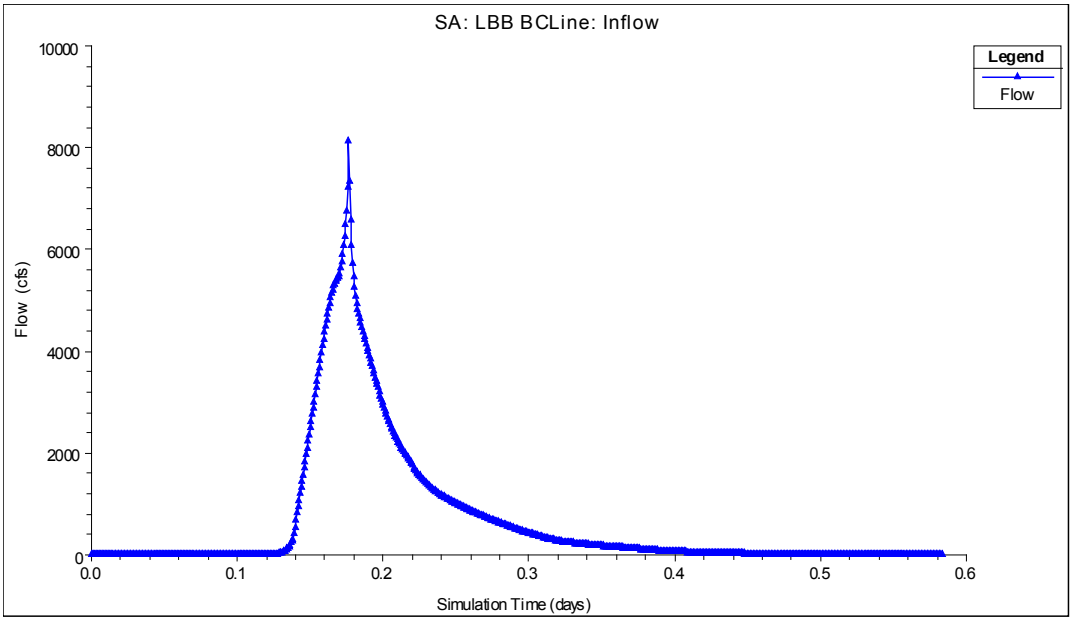

HEC-RAS Plan



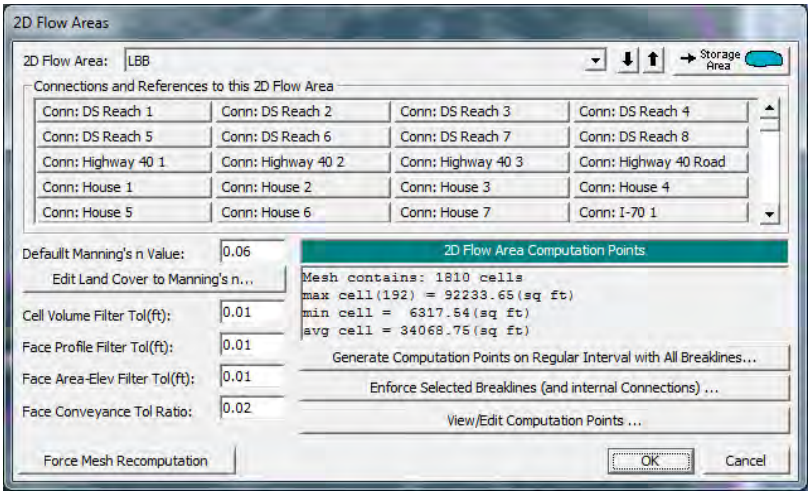
Inflow Hydrograph – BASE

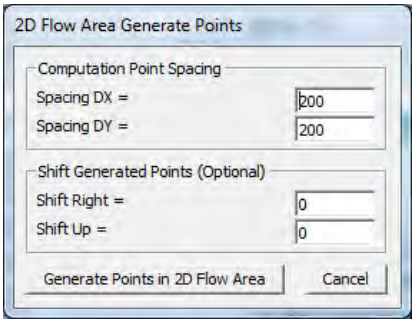



Inflow Hydrograph – BREACH

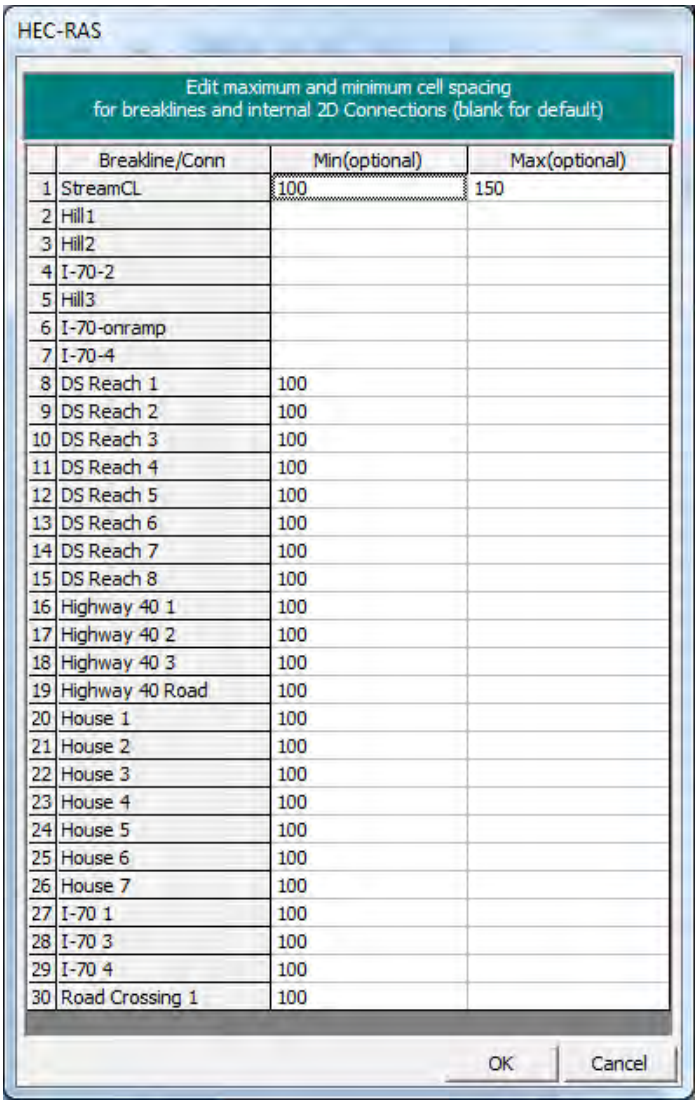


Mesh Properties



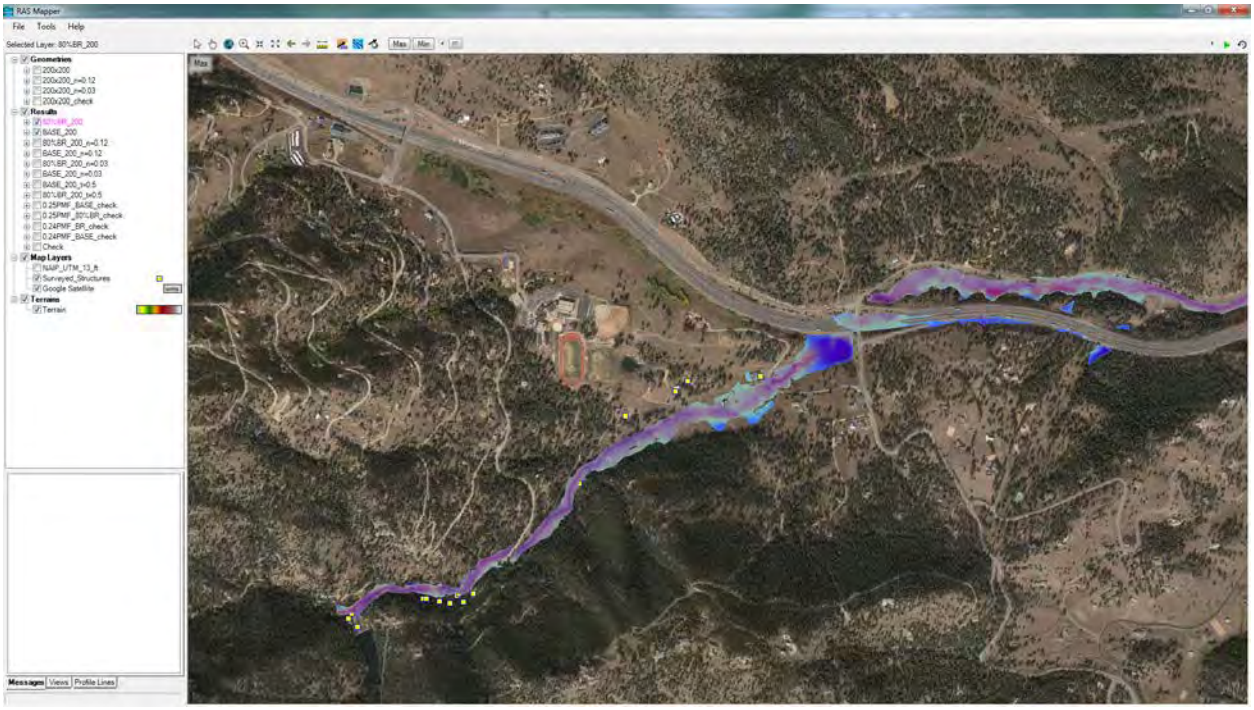




Breakline Cell Spacing Table

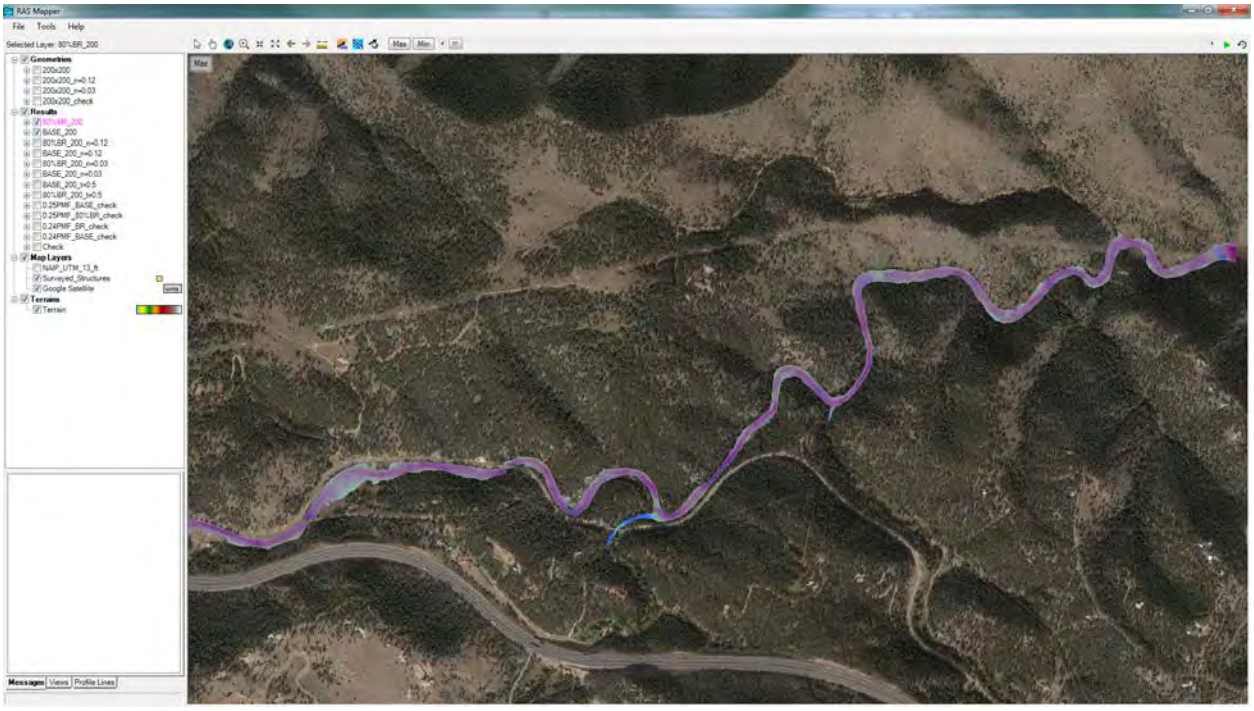



| | Breakline/Conn | Min(optional) | Max(optional) |
|---|---|---|---|
| 1 | StreamCL | 100 | 150 |
| 2 | Hill1 | | |
| 3 | Hill2 | | |
| 4 | I-70-2 | | |
| 5 | Hill3 | | |
| 6 | I-70-onramp | | |
| 7 | I-70-4 | | |
| 8 | DS Reach 1 | 100 | |
| 9 | DS Reach 2 | 100 | |
| 10 | DS Reach 3 | 100 | |
| 11 | DS Reach 4 | 100 | |
| 12 | DS Reach 5 | 100 | |
| 13 | DS Reach 6 | 100 | |
| 14 | DS Reach 7 | 100 | |
| 15 | DS Reach 8 | 100 | |
| 16 | Highway 40 1 | 100 | |
| 17 | Highway 40 2 | 100 | |
| 18 | Highway 40 3 | 100 | |
| 19 | Highway 40 Road | 100 | |
| 20 | House 1 | 100 | |
| 21 | House 2 | 100 | |
| 22 | House 3 | 100 | |
| 23 | House 4 | 100 | |
| 24 | House 5 | 100 | |
| 25 | House 6 | 100 | |
| 26 | House 7 | 100 | |
| 27 | I-70 1 | 100 | |
| 28 | I-70 3 | 100 | |
| 29 | I-70 4 | 100 | |
| 30 | Road Crossing 1 | 100 | |

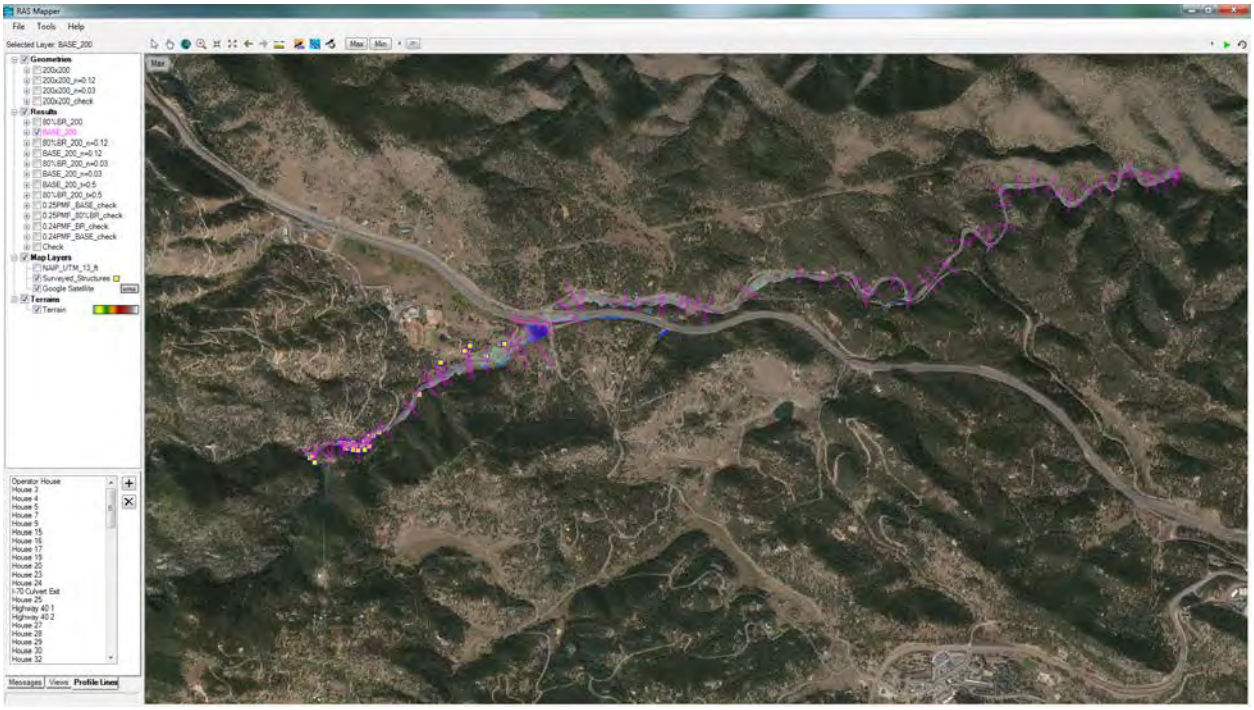
2D Results Output – RAS Mapper (1 of 2)



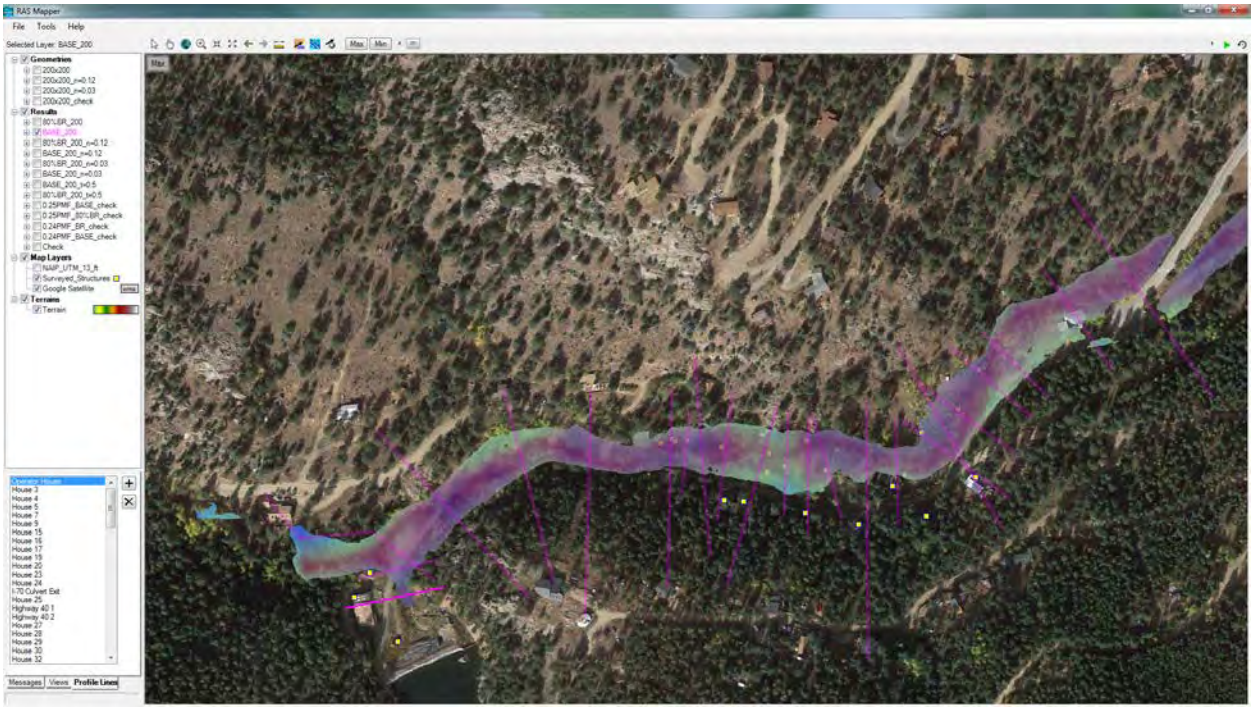

2D Results Output – RAS Mapper (2 of 2)



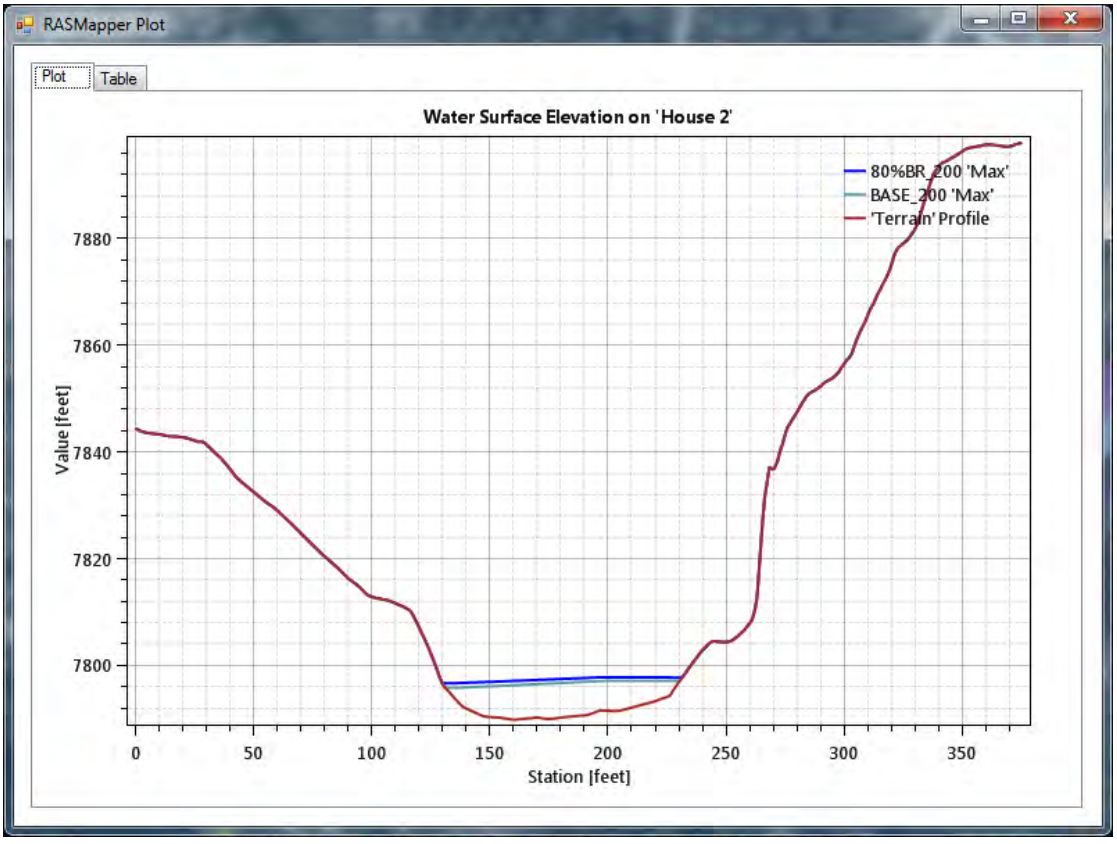
Profile Lines for Viewing Results



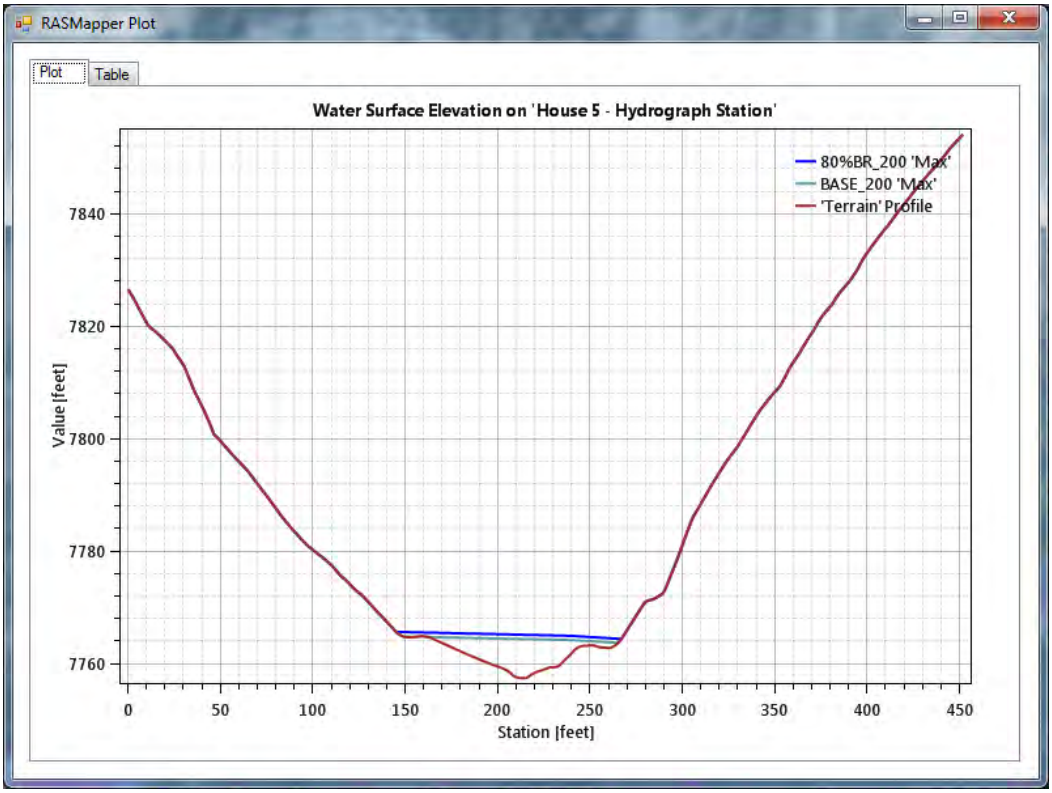
Profile Lines for Viewing Results – Close-up View



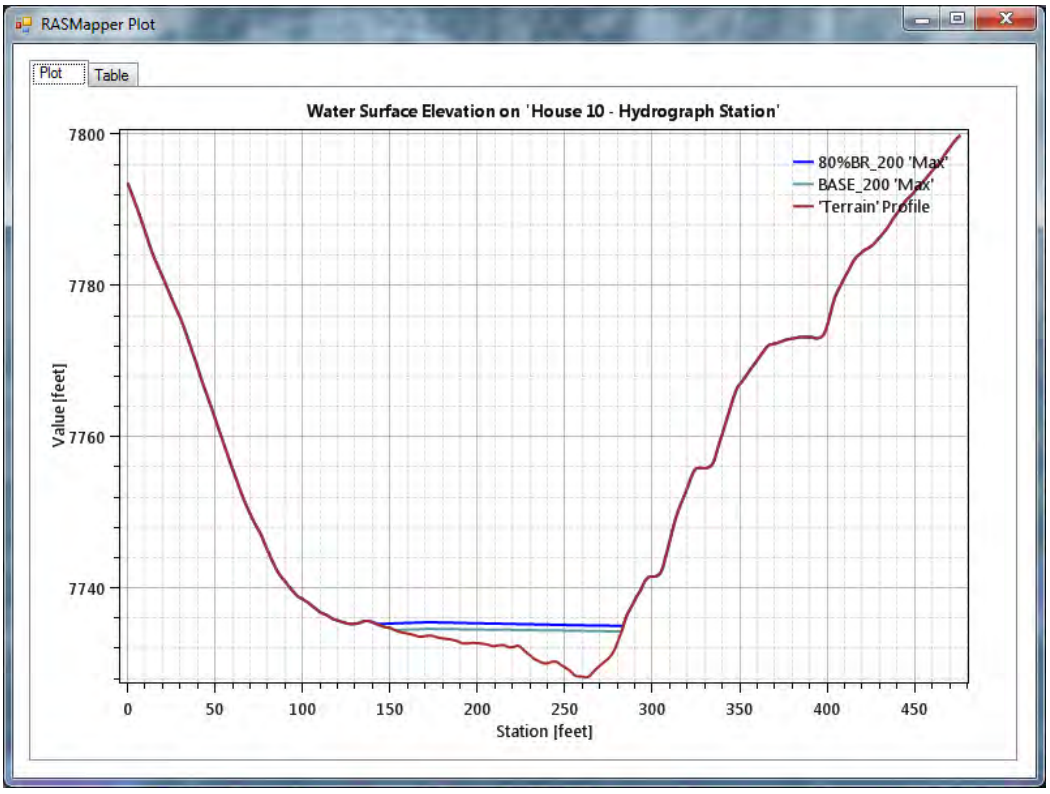
Water Surface Elevation Results – “House 2”



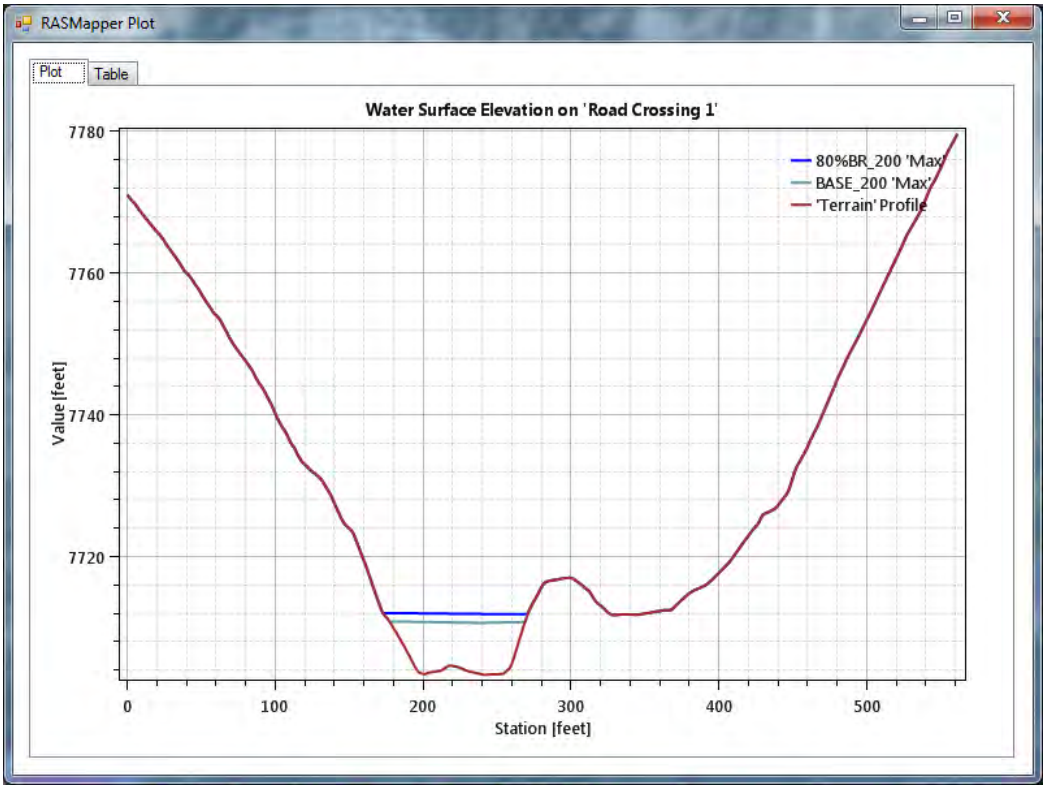
Water Surface Elevation Results – “House 5 – Hydrograph Station”



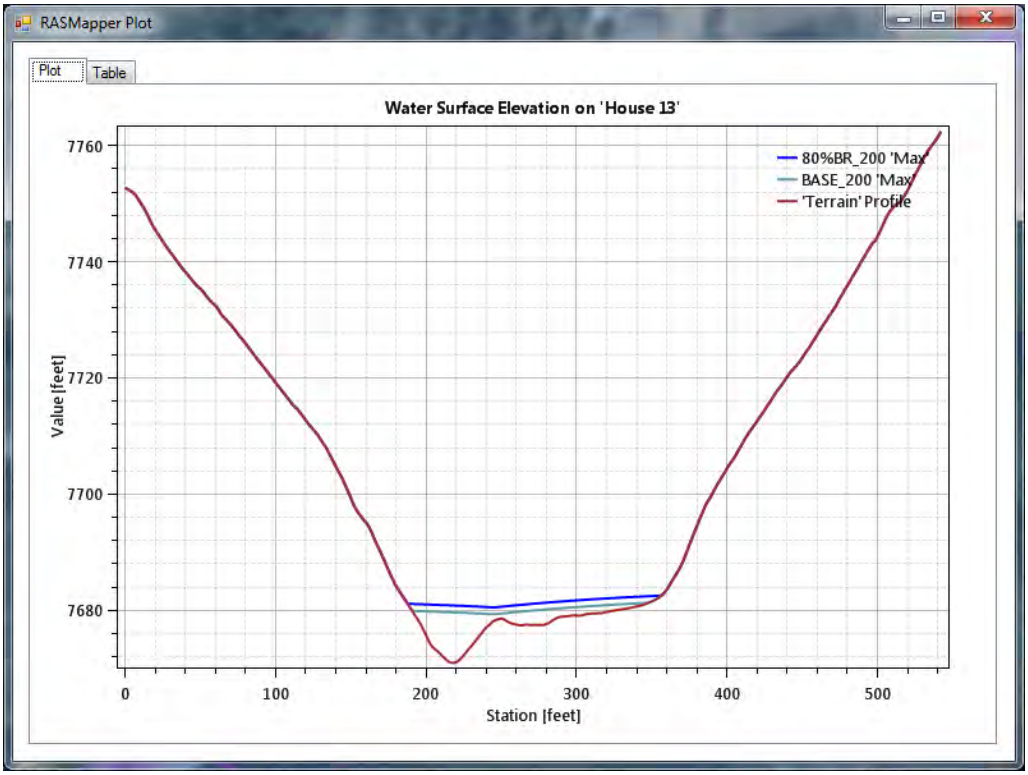

Water Surface Elevation Results – “House 10 – Hydrograph Station”



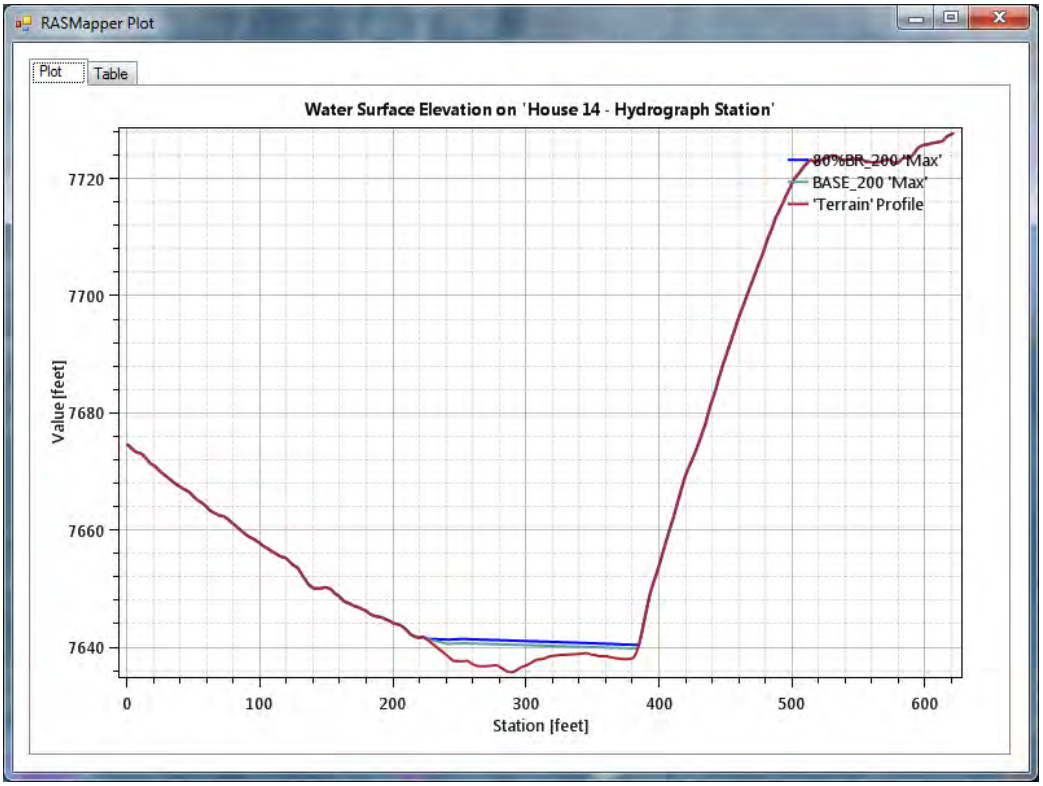
Water Surface Elevation Results – “Road Crossing 1”



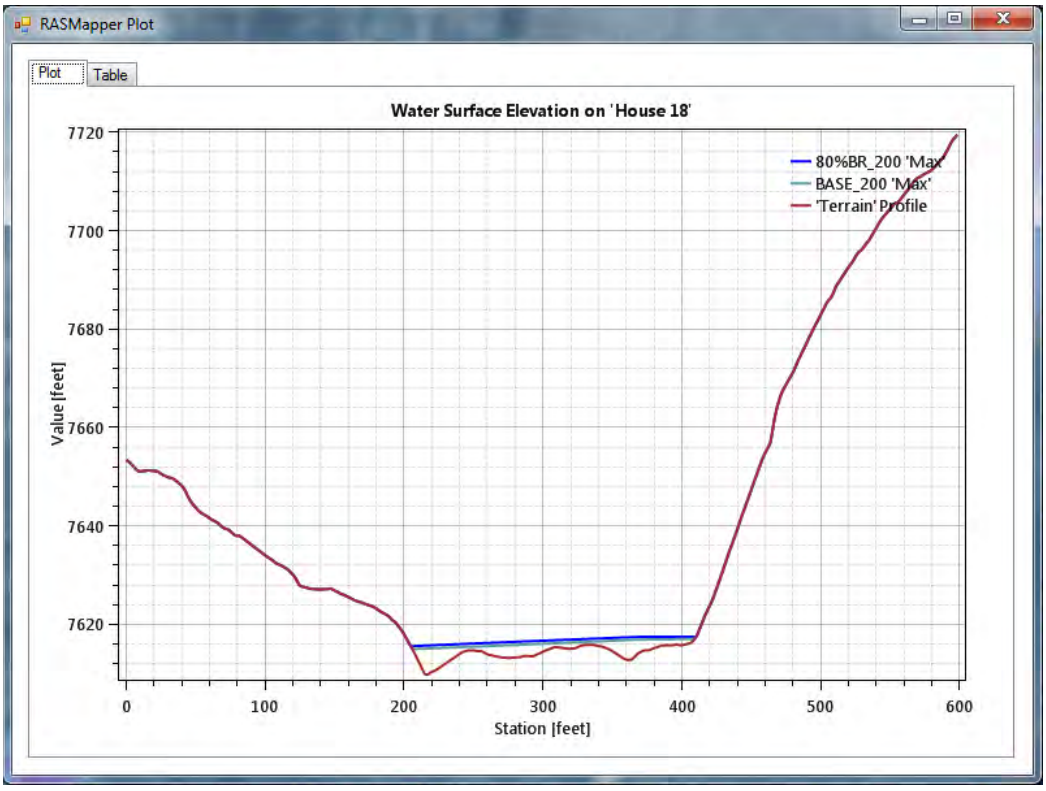

Water Surface Elevation Results – “House 13”



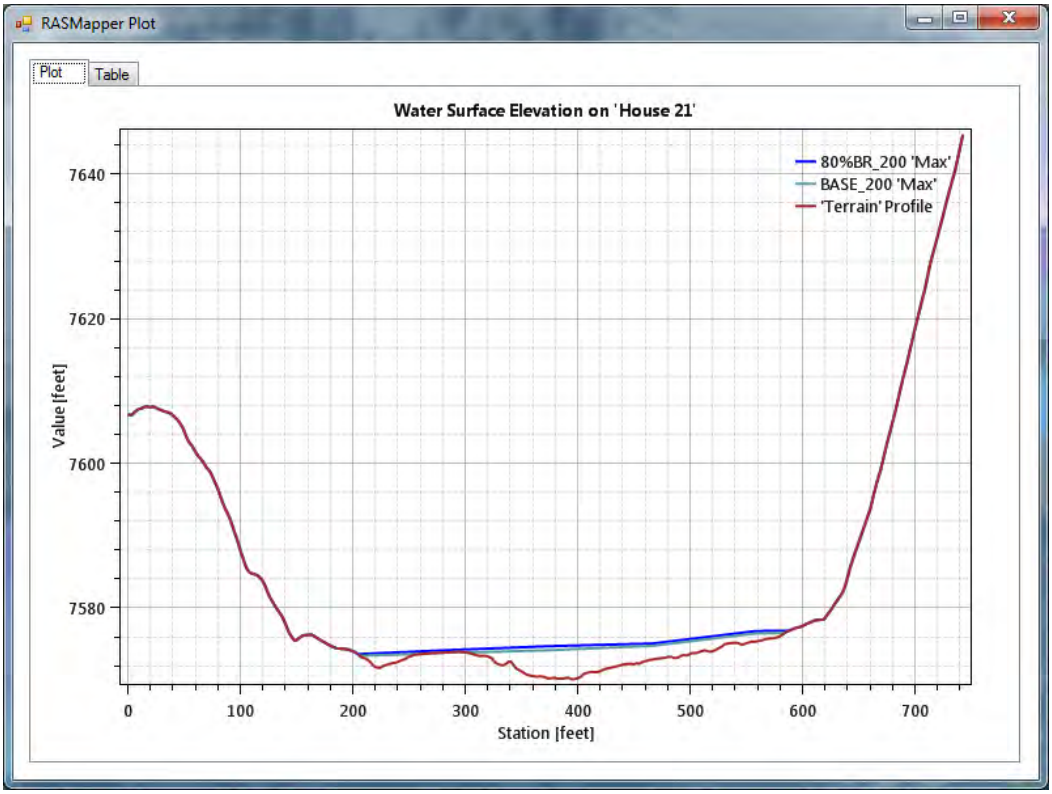
Water Surface Elevation Results – “House 14 – Hydrograph Station”



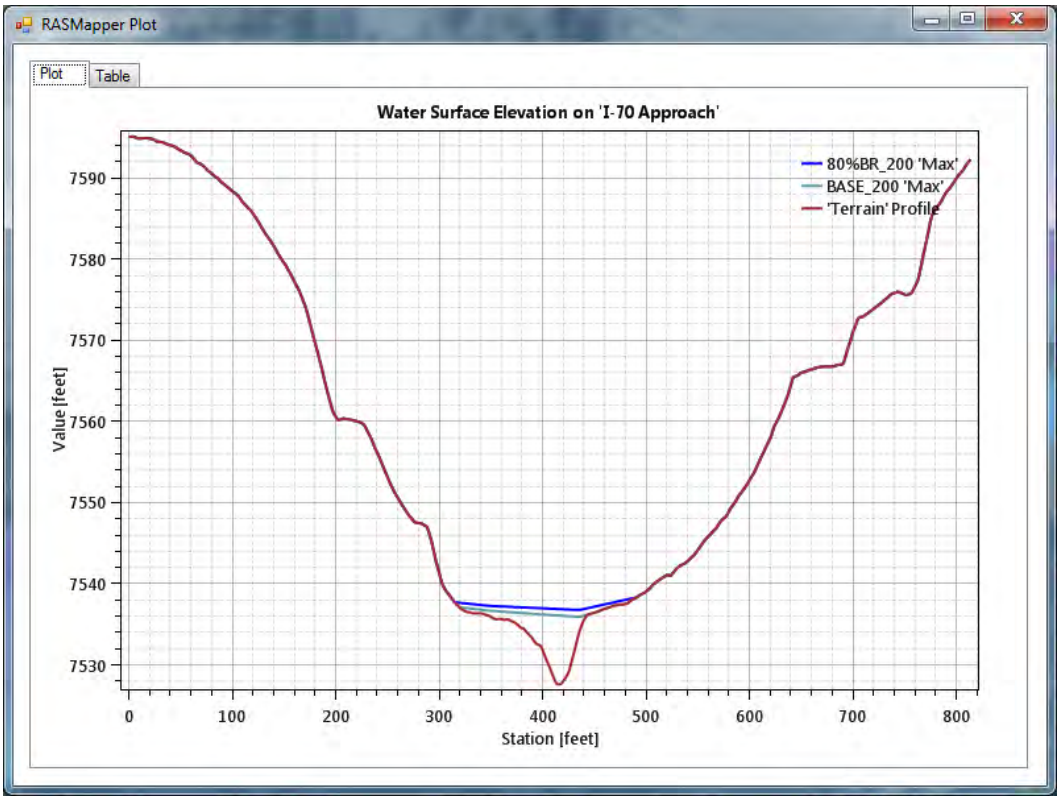

Water Surface Elevation Results – “House 18”



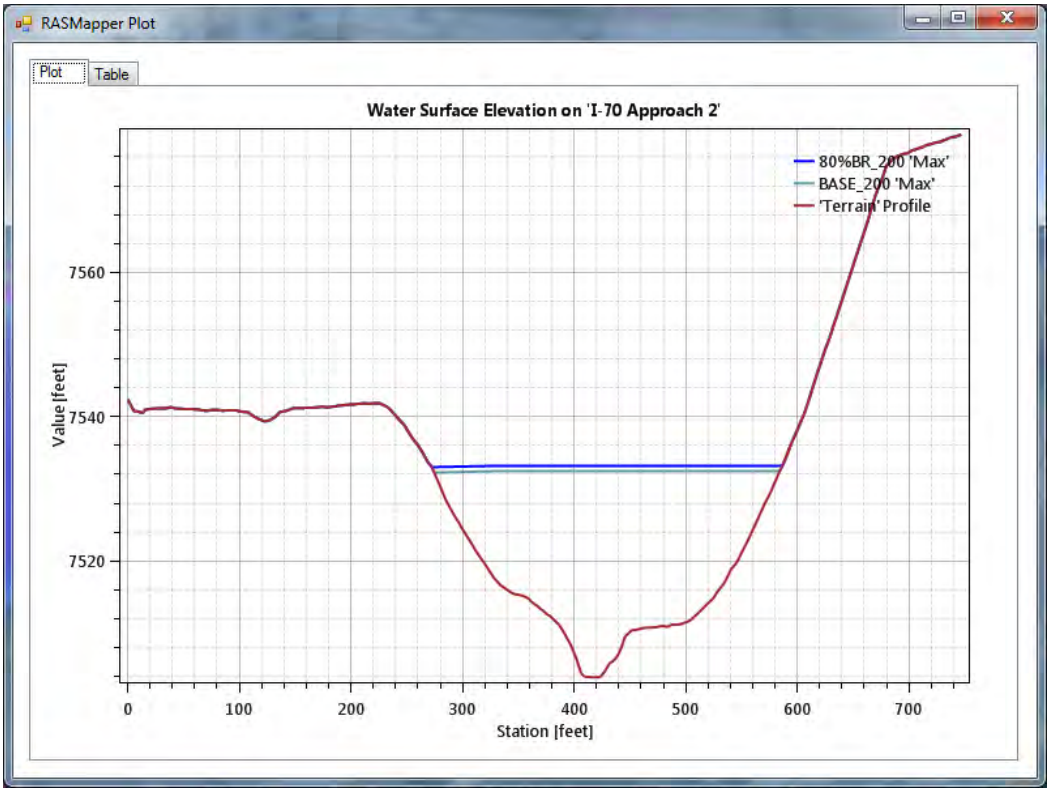
Water Surface Elevation Results – “House 21”



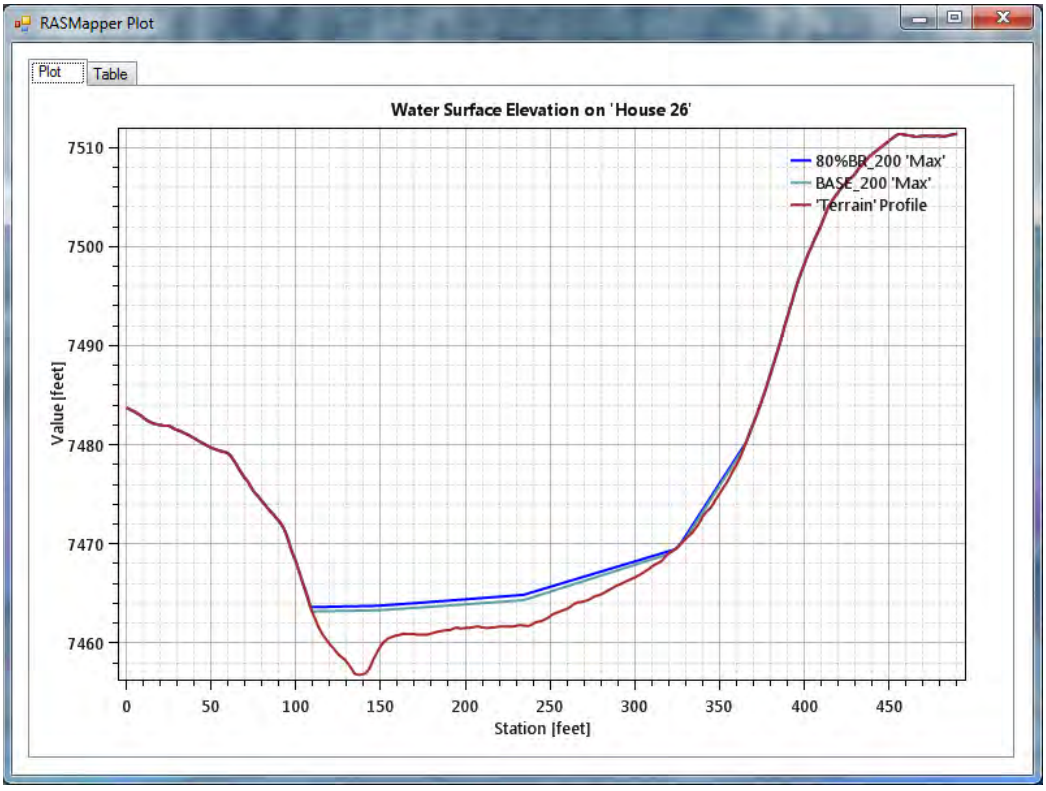

Water Surface Elevation Results – “I-70 Approach”



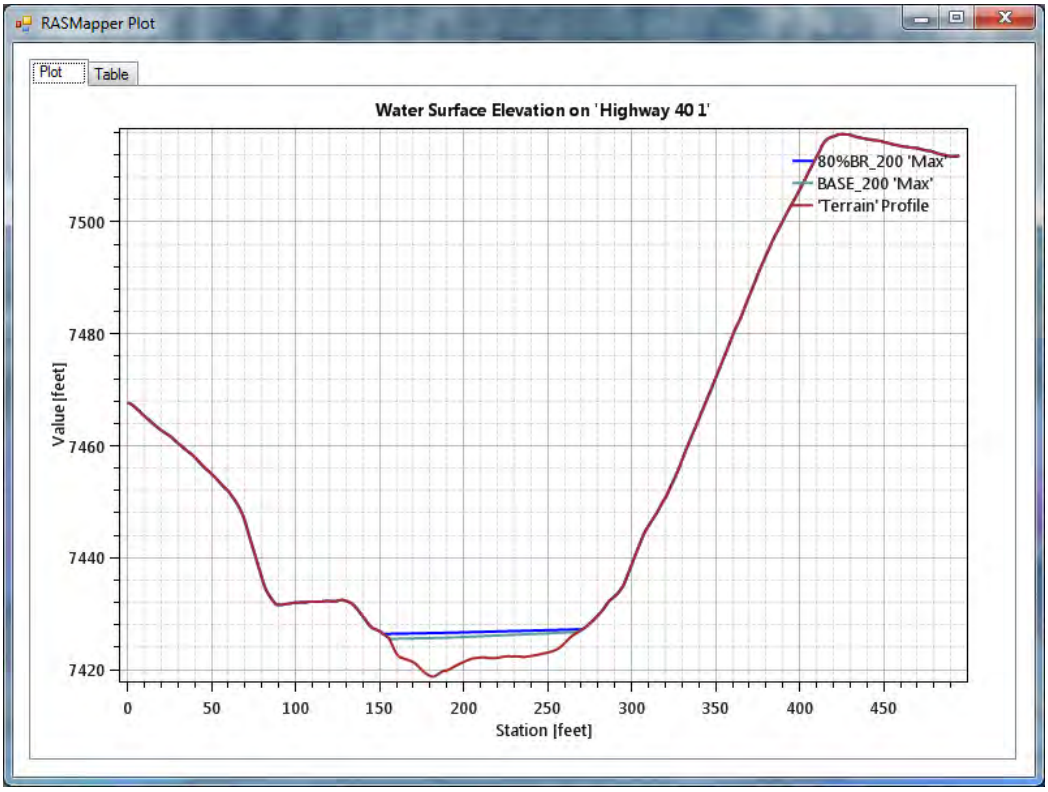
Water Surface Elevation Results – “I-70 Approach 2”



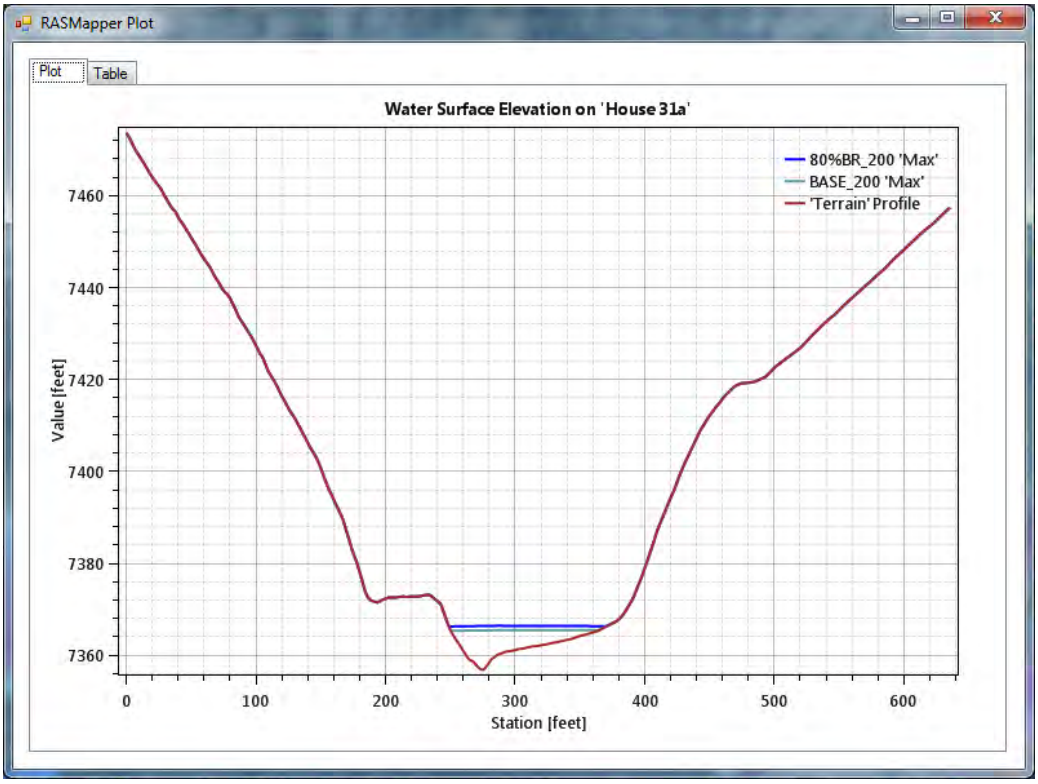

Water Surface Elevation Results – “House 26”



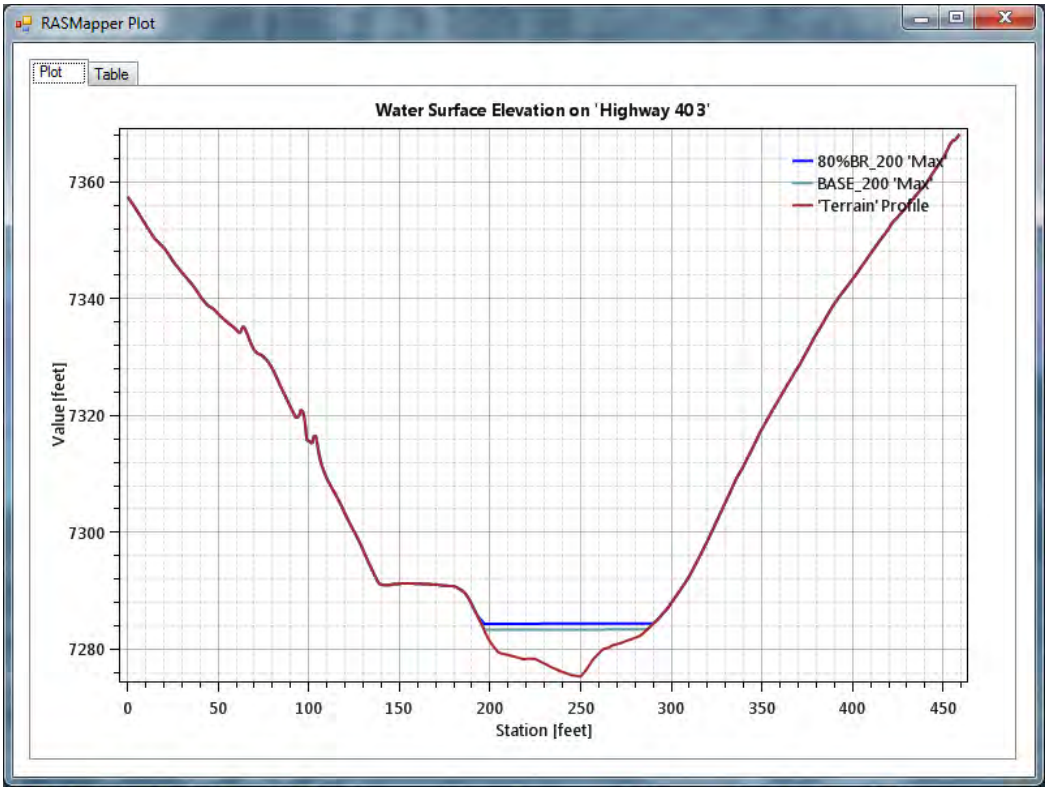
Water Surface Elevation Results – “Highway 40 1”



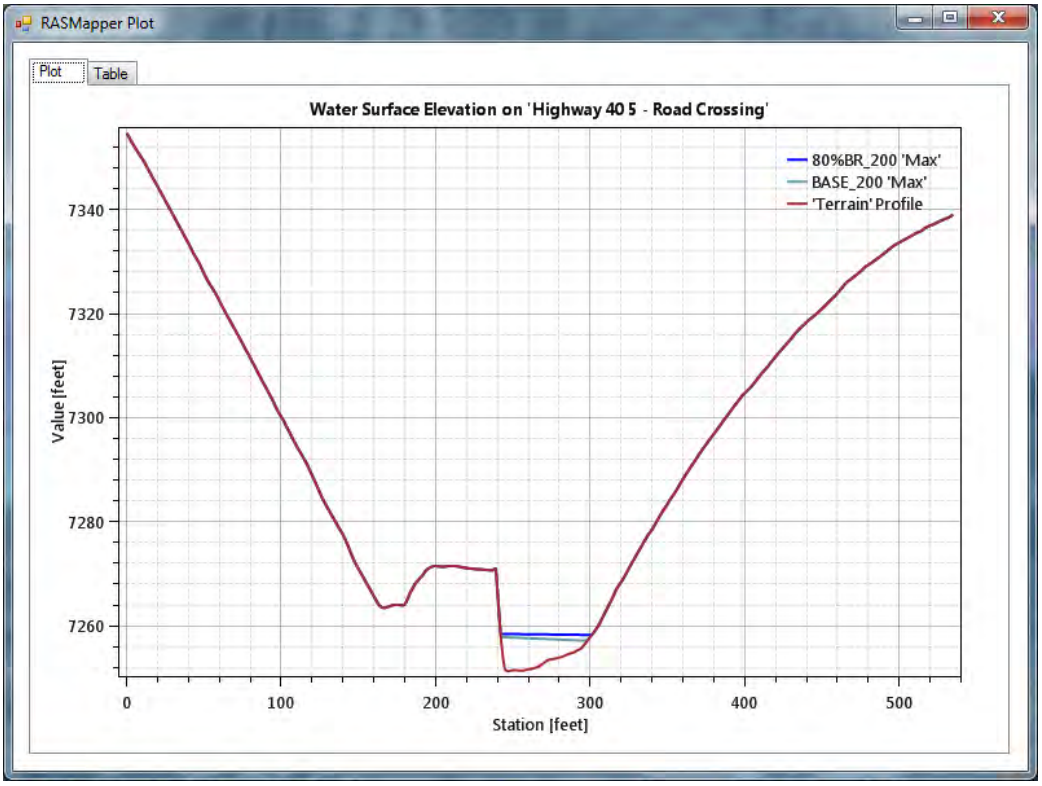

Water Surface Elevation Results – “House 31a”



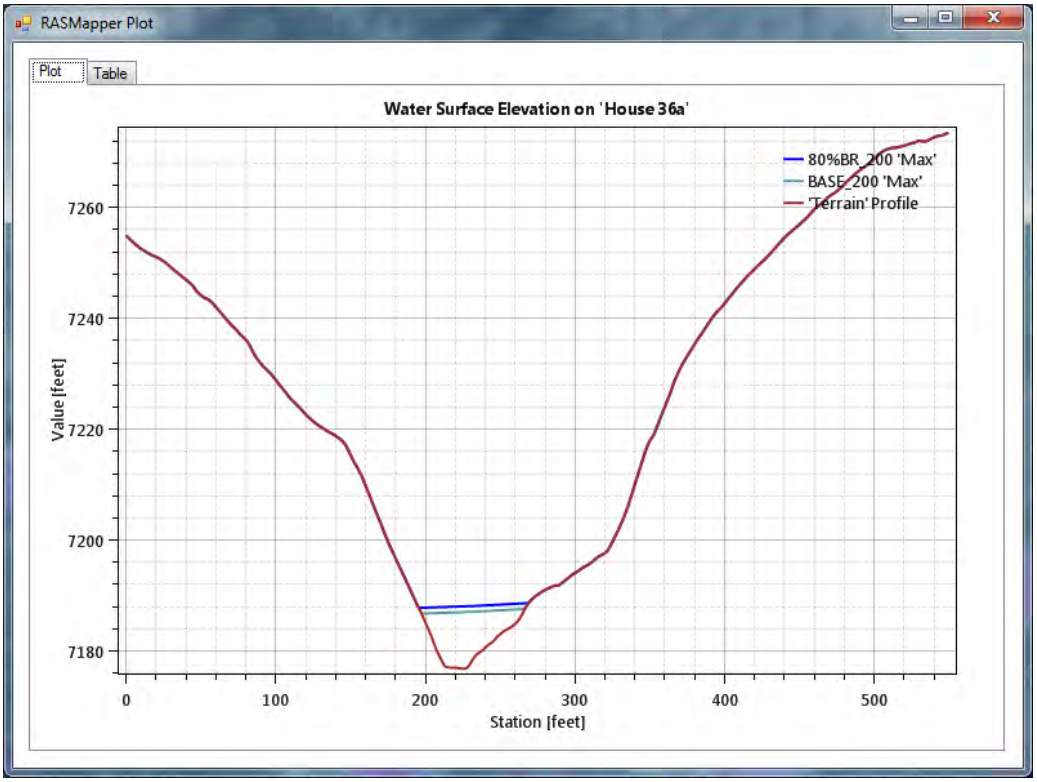
Water Surface Elevation Results – “Highway 40 3”



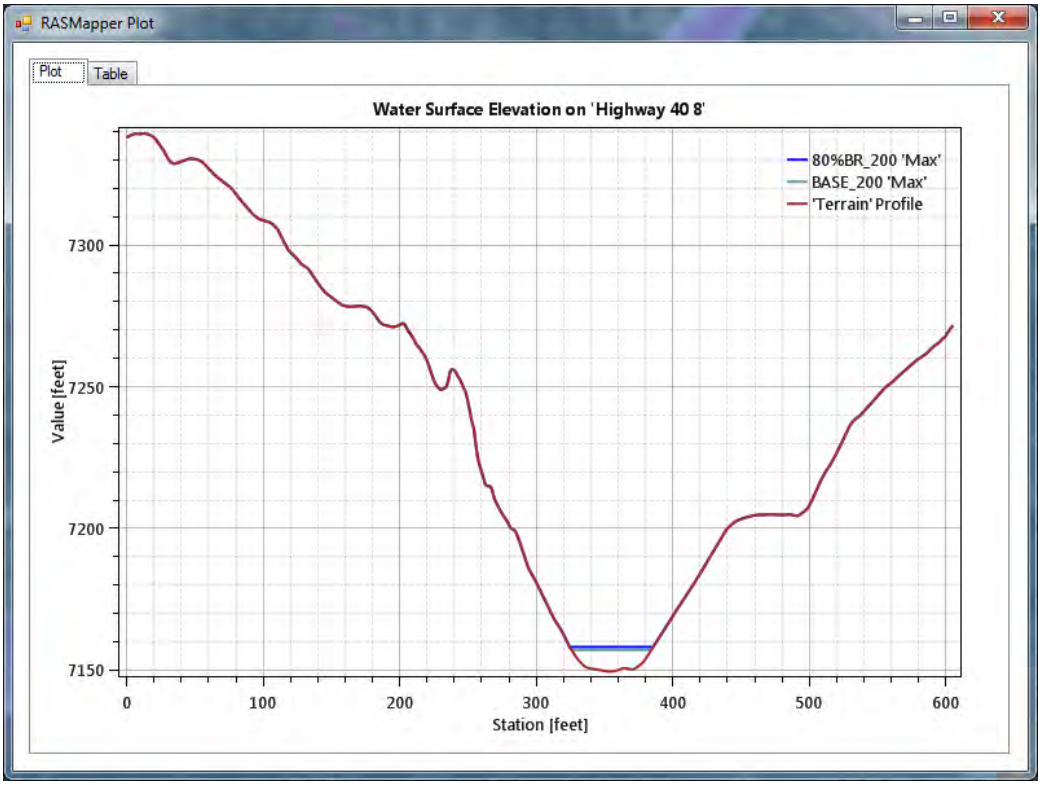

Water Surface Elevation Results – “Highway 40 5 – Road Crossing”



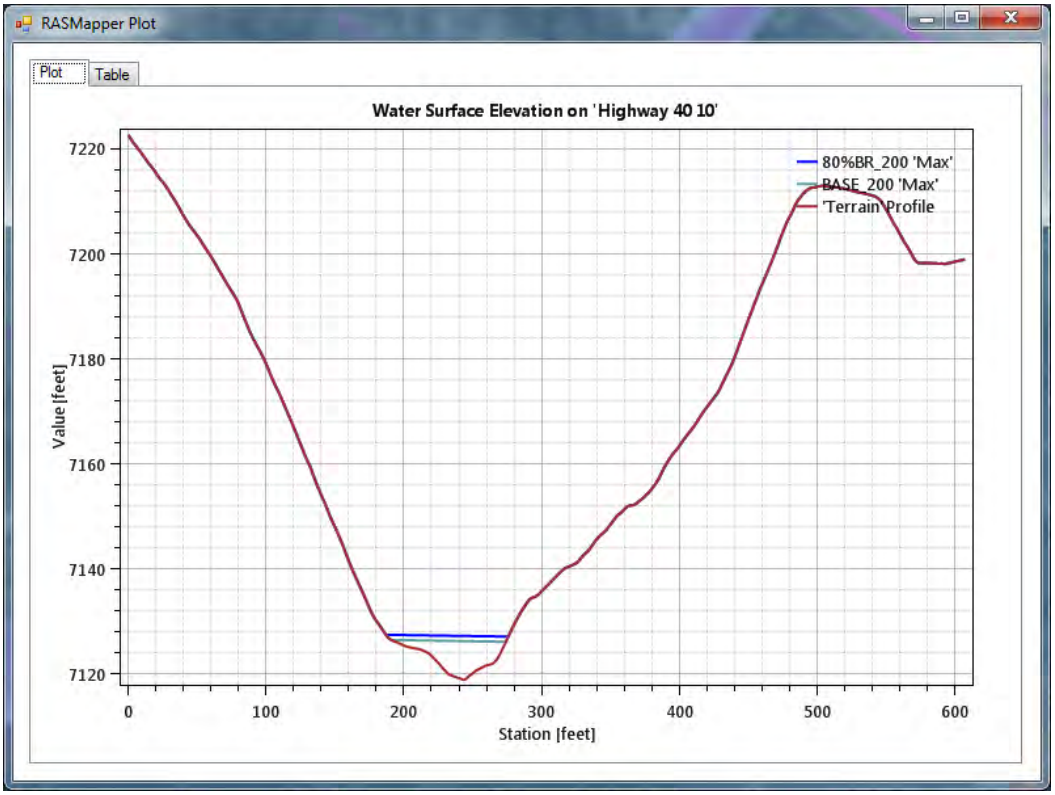
Water Surface Elevation Results – “House 36a”



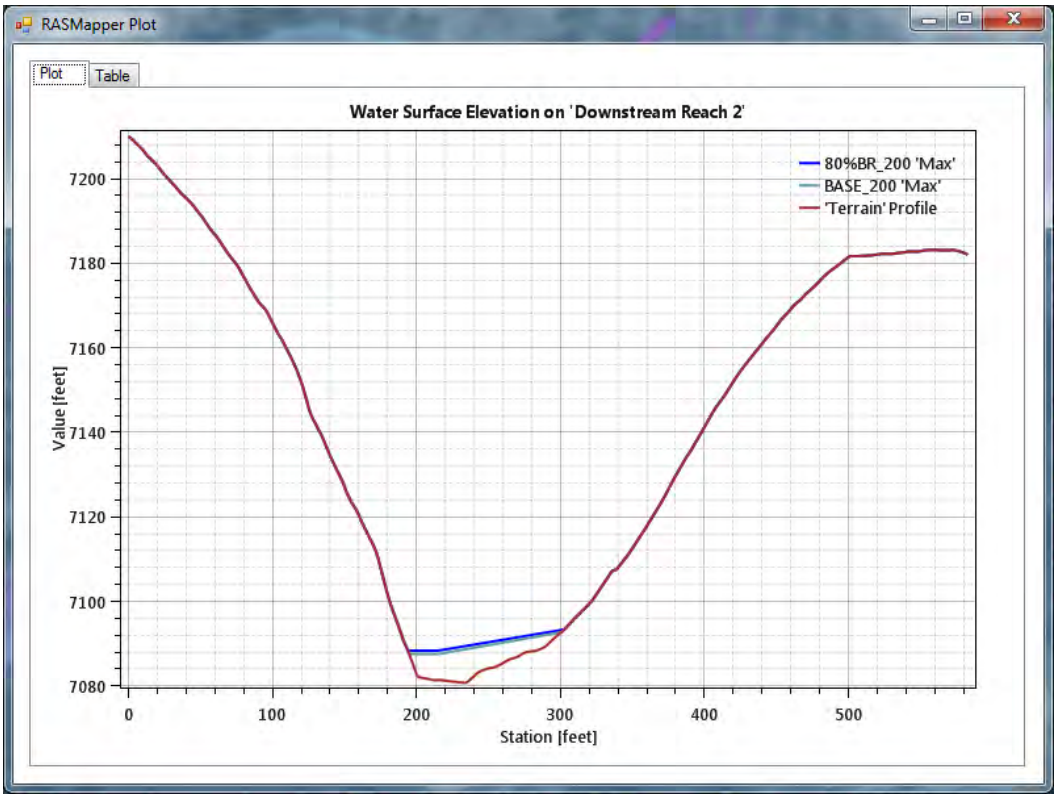

Water Surface Elevation Results – “Highway 40 8”



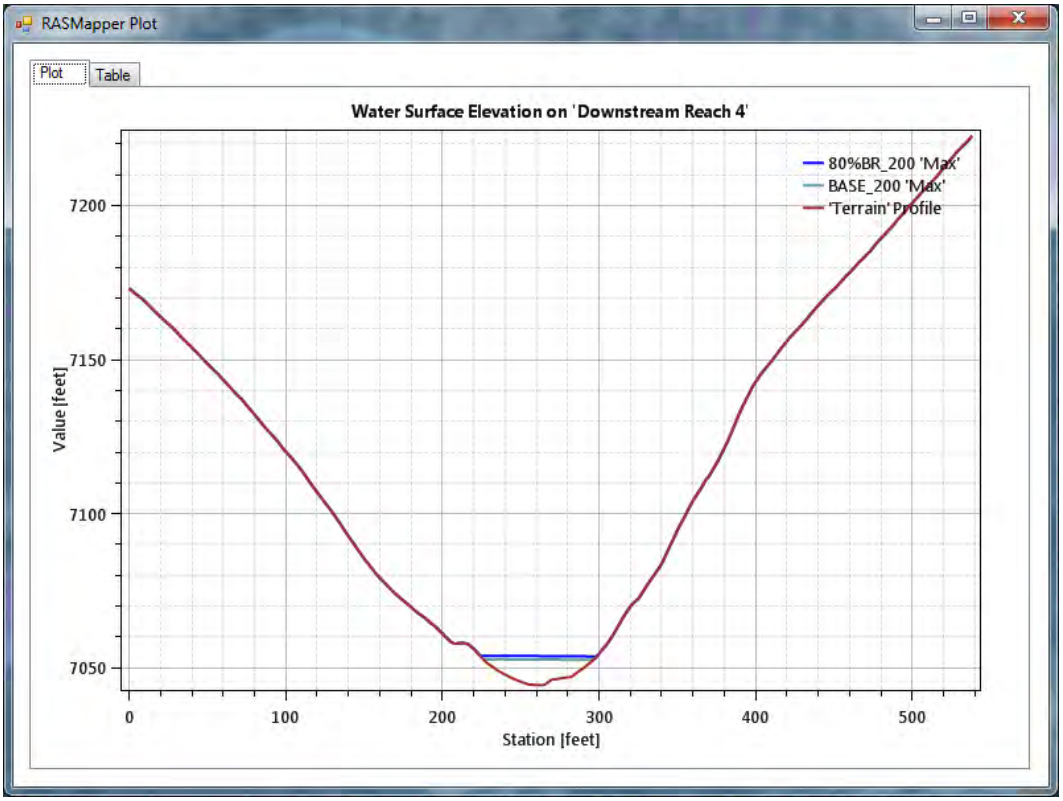
Water Surface Elevation Results – “Highway 40 10”



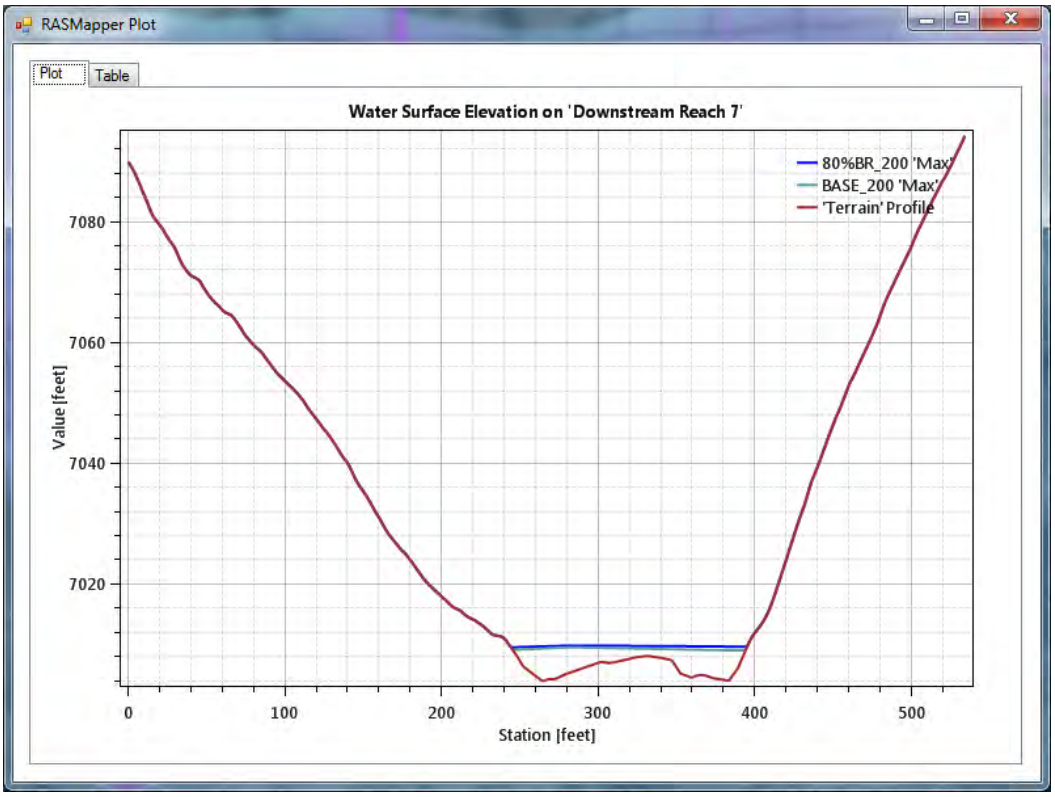

Water Surface Elevation – “Downstream Reach 2”



Water Surface Elevation – “Downstream Reach 4”




Water Surface Elevation – “Downstream Reach 7”



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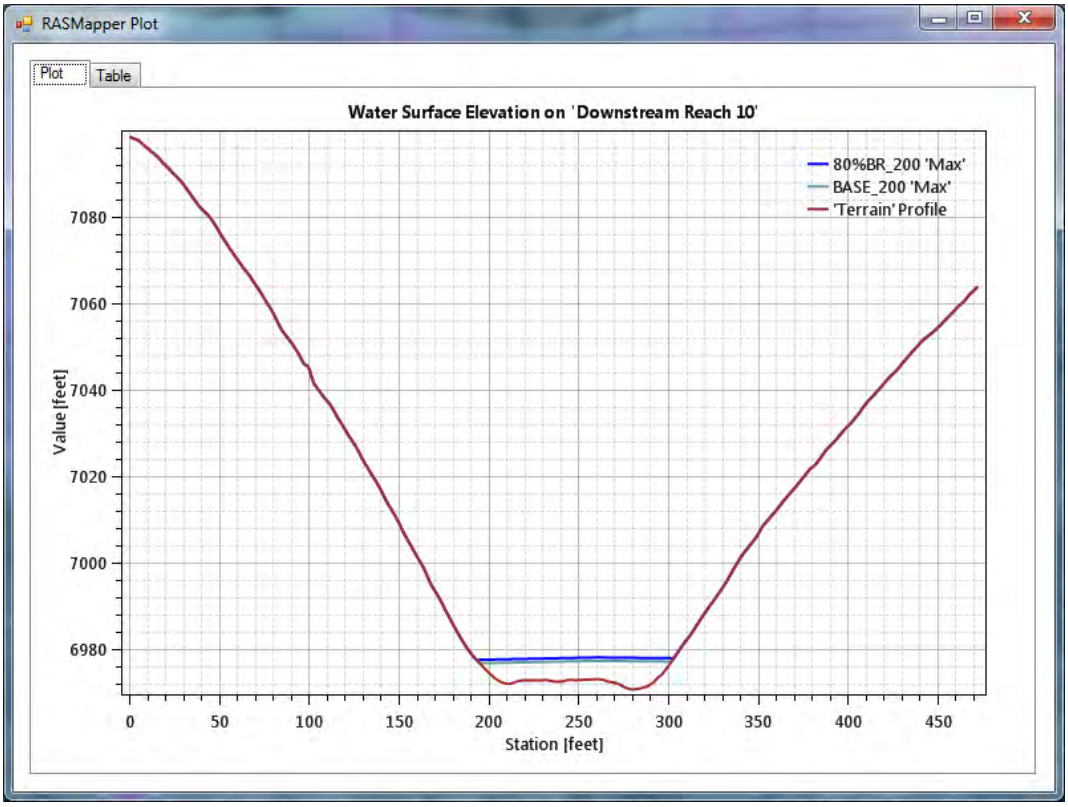
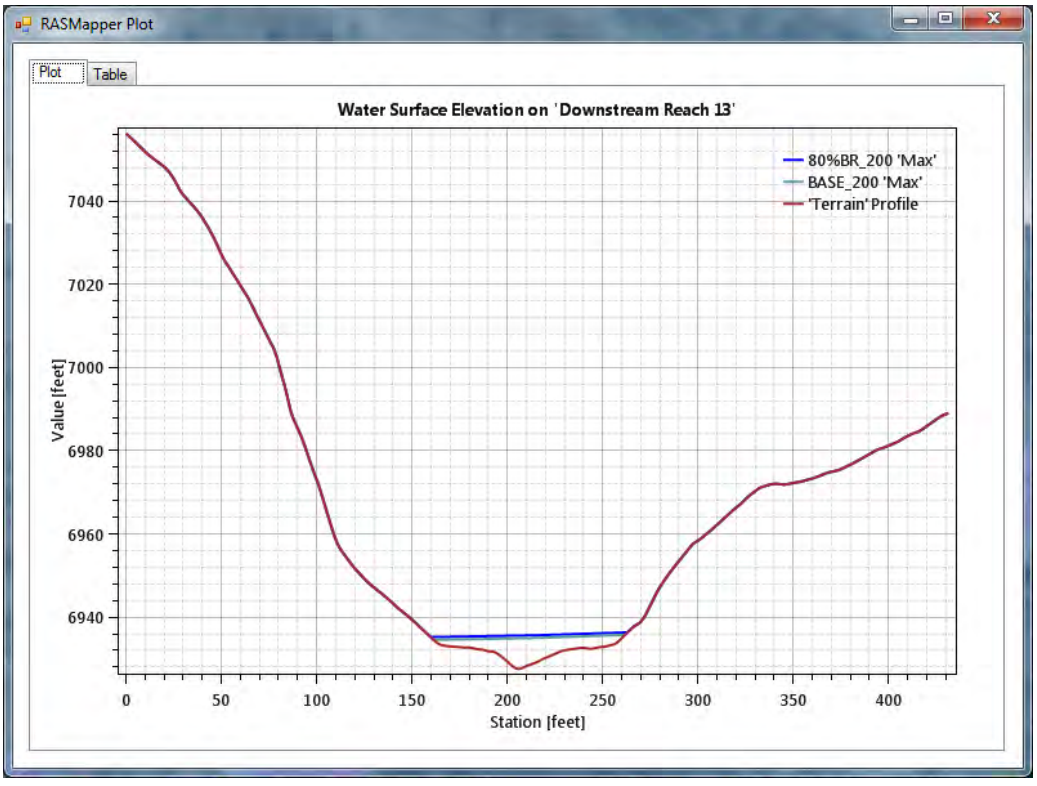
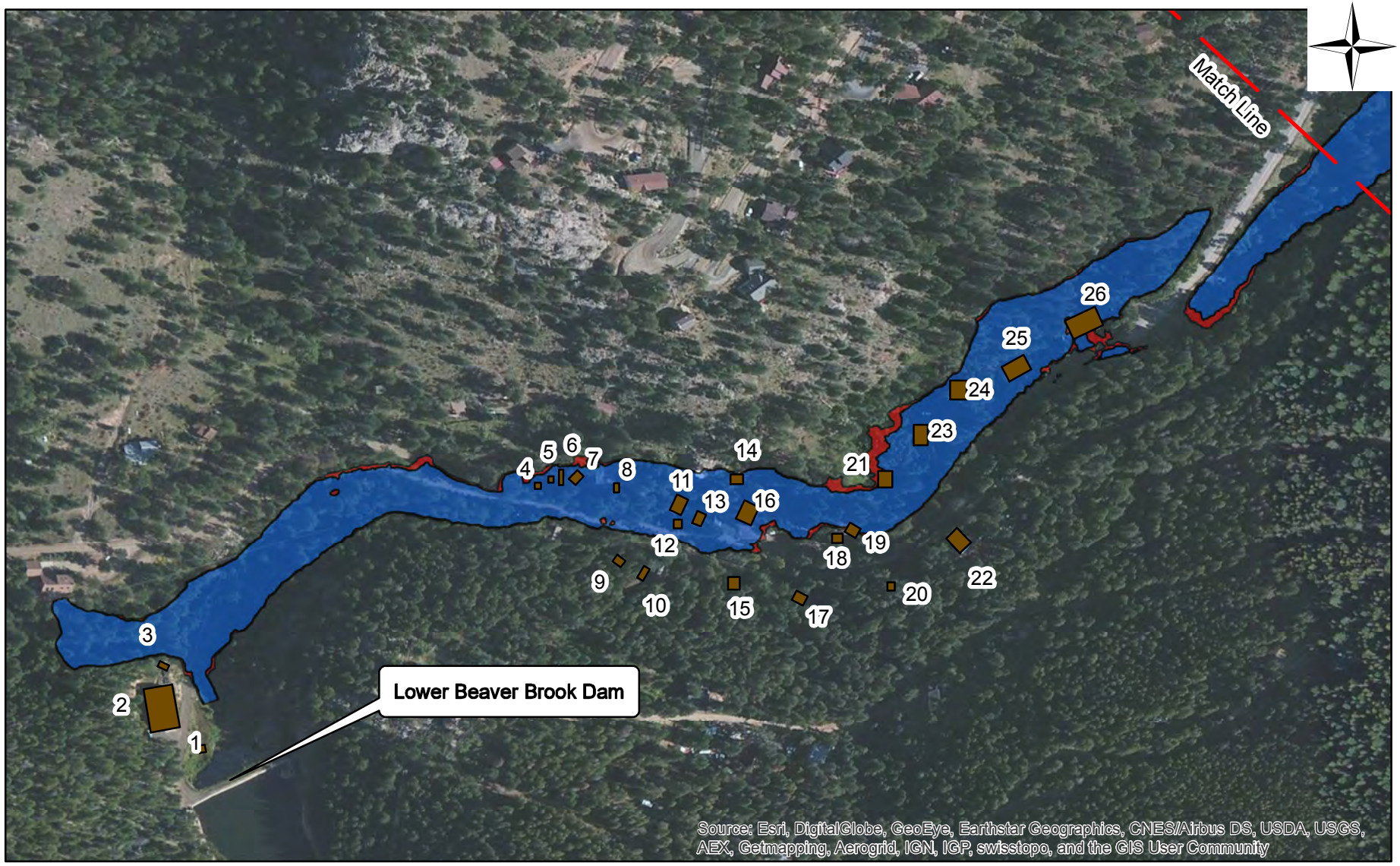



Water Surface Elevation – “Downstream Reach 13”



# Attachment B




**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

0 80 160 320 480 640 Feet

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

GEI Consultants

Project 1410080

LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1A

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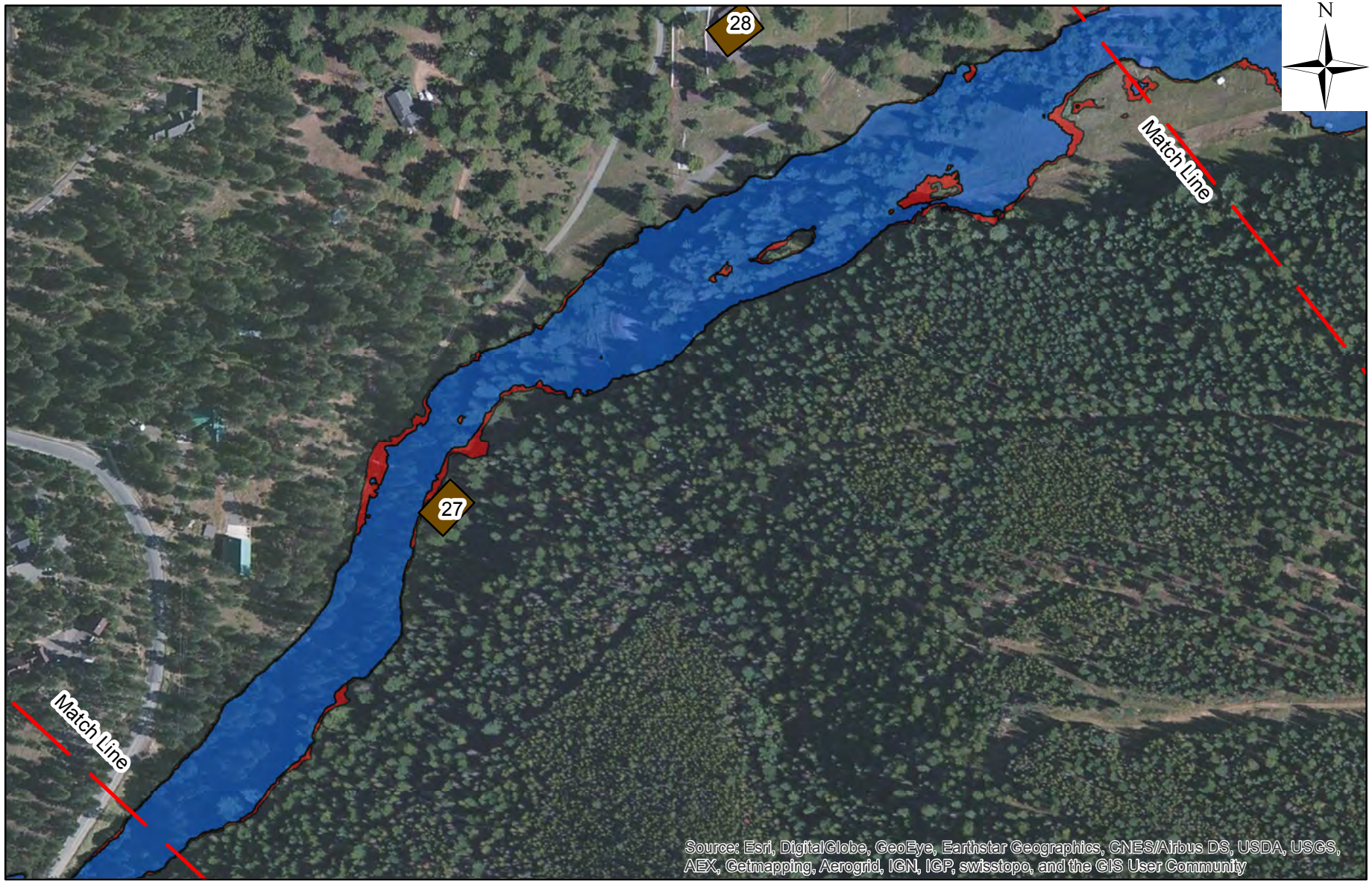


0 80 160 320 480 640 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
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LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1B

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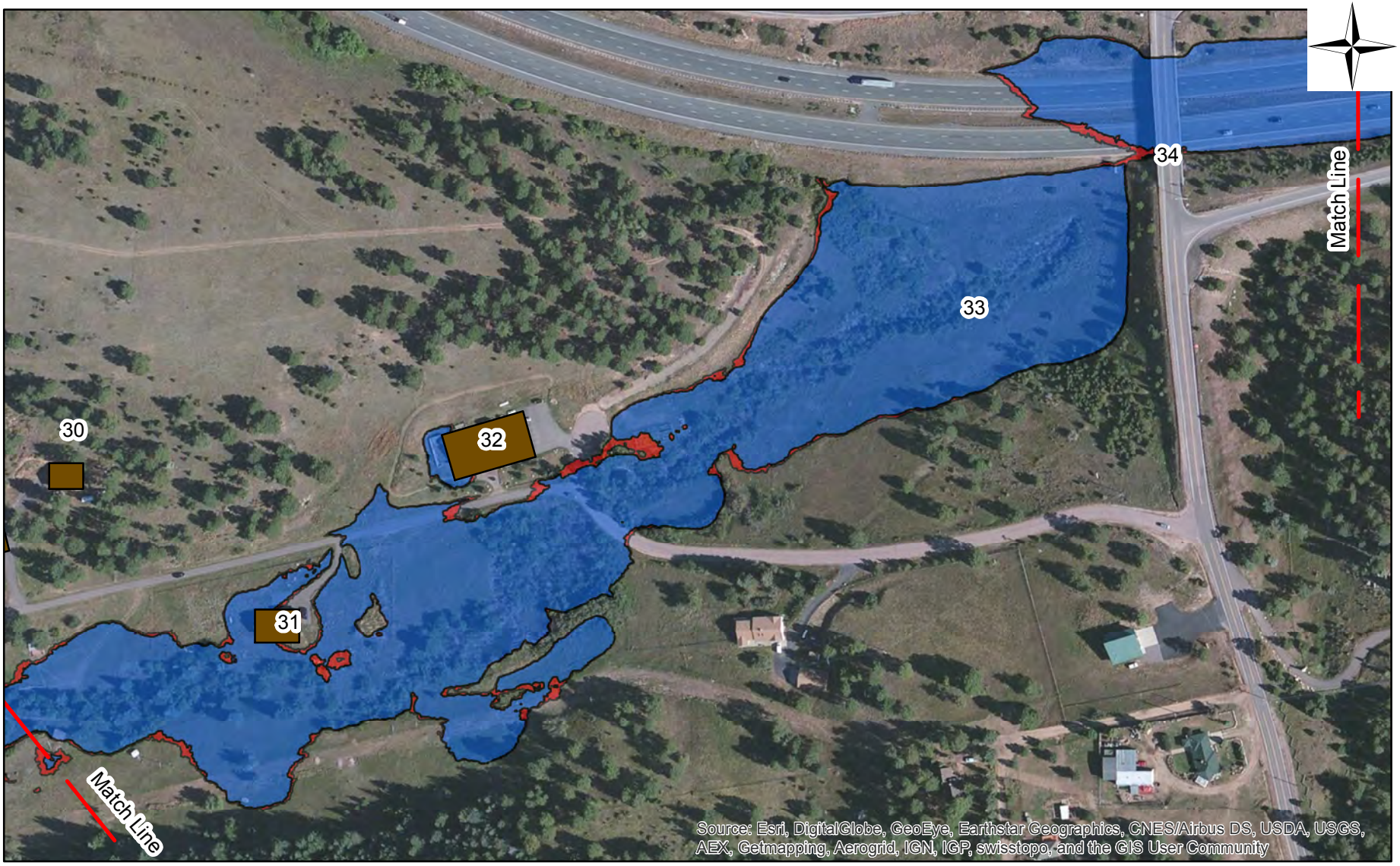


0 80 160 320 480 640 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1C

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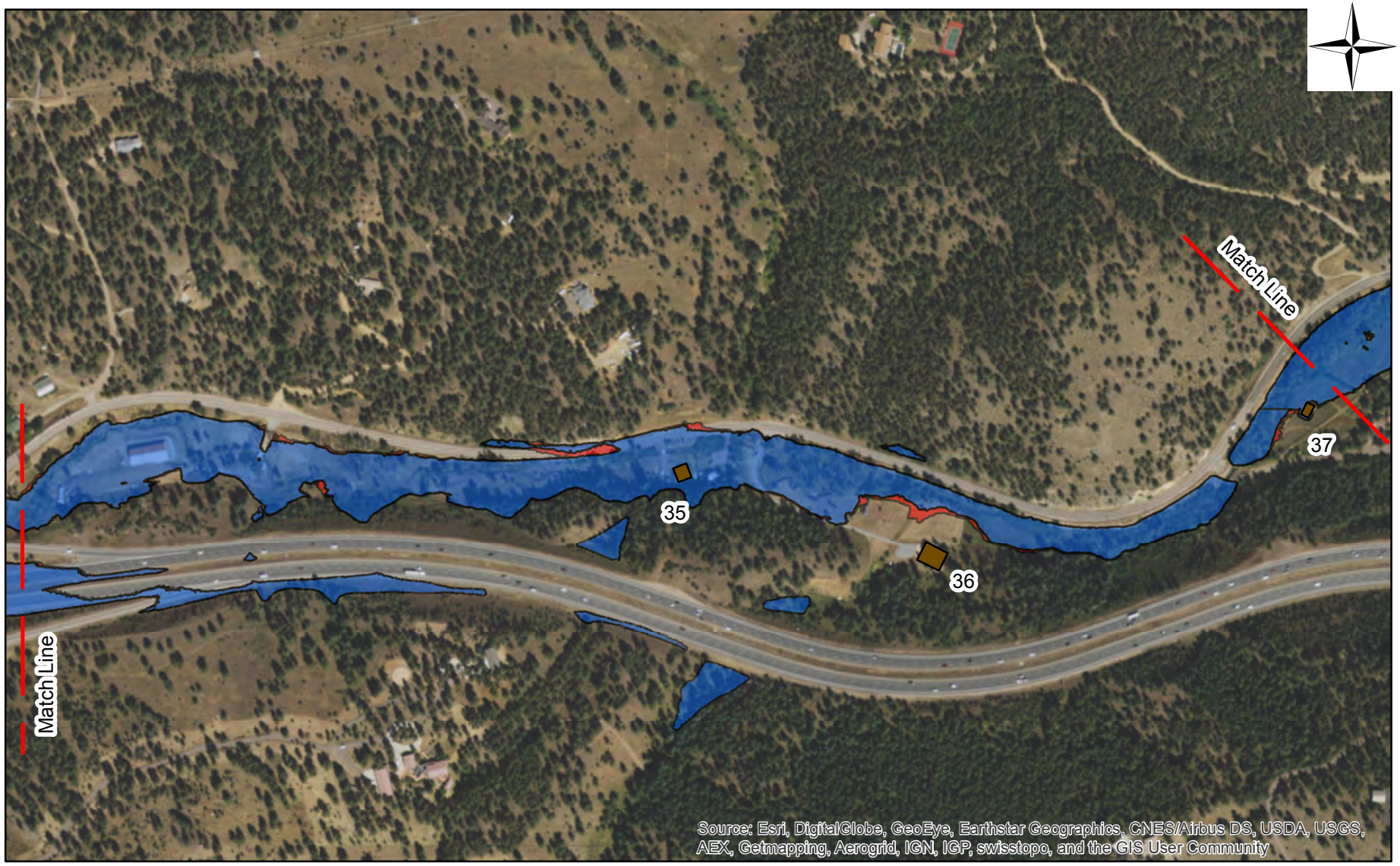


0 165 330 660 990 1,320 Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1D

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0 220 440 880 1,320 1,760
Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
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LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1E

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0 220 440 880 1,320 1,760
Feet

**Legend**

- Approximate Structure Outlines
- Base Flood Inundation Boundary
- Break Flood Inundation Boundary

Lower Beaver Brook Dam
Hydrology and Incremental Damage Analysis Report
Clear Creek County, Colorado

Lookout Mountain Water District
Golden, Colorado

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LOWER BEAVER BROOK
INUNDATION LIMITS

September 2016 Figure 1F

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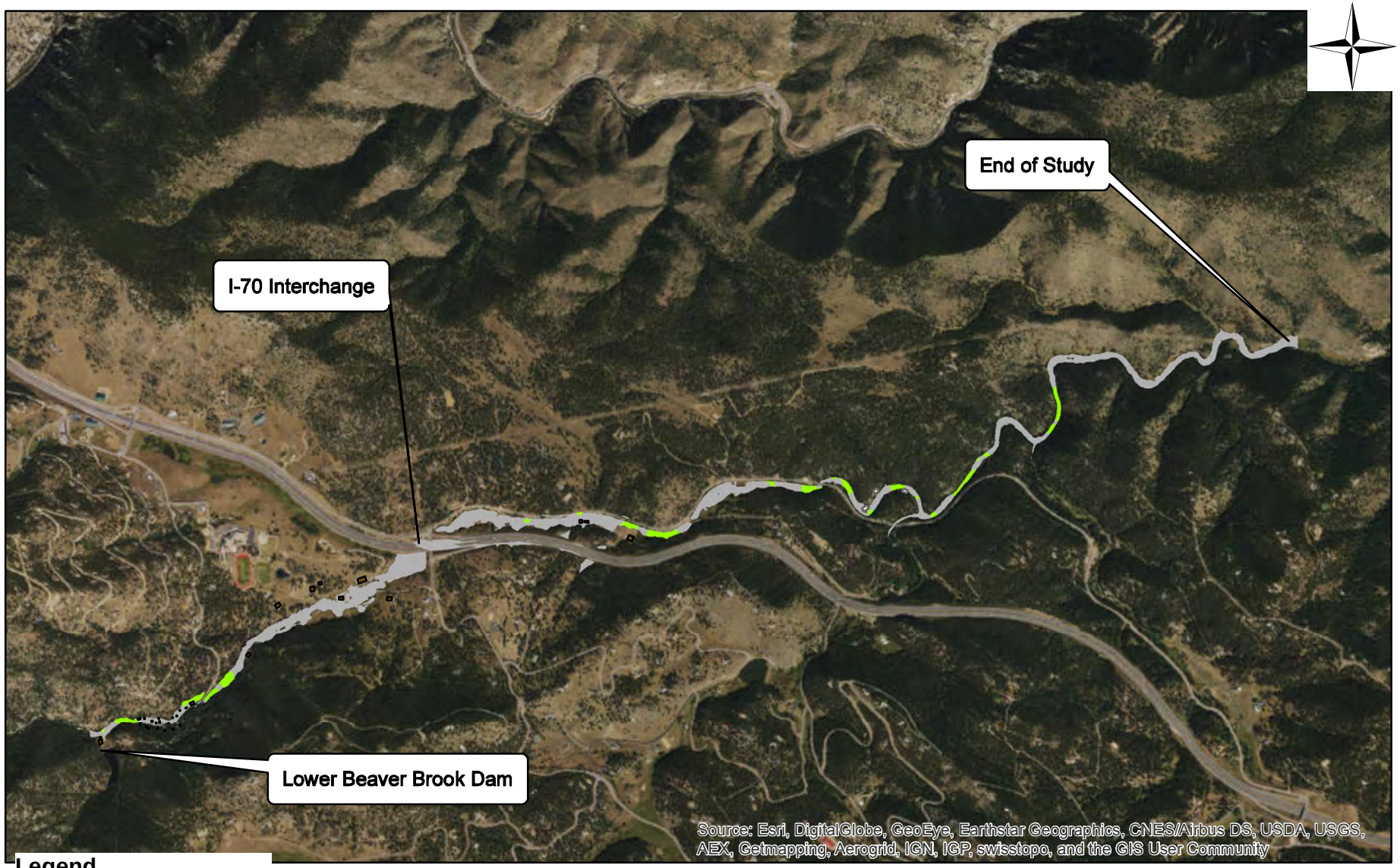


**Legend**

House Outlines

**Incrememntal Inundation**

- 0 - 1
- 1 - 1.99
- 2+

0 800 1,600 3,200 4,800 6,400 Feet

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Clear Creek County, Colorado

Lookout Mountain Water District
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LOWER BEAVER BROOK
INCREMENTAL
INUNDATION DEPTHS

September 2016 Figure 2

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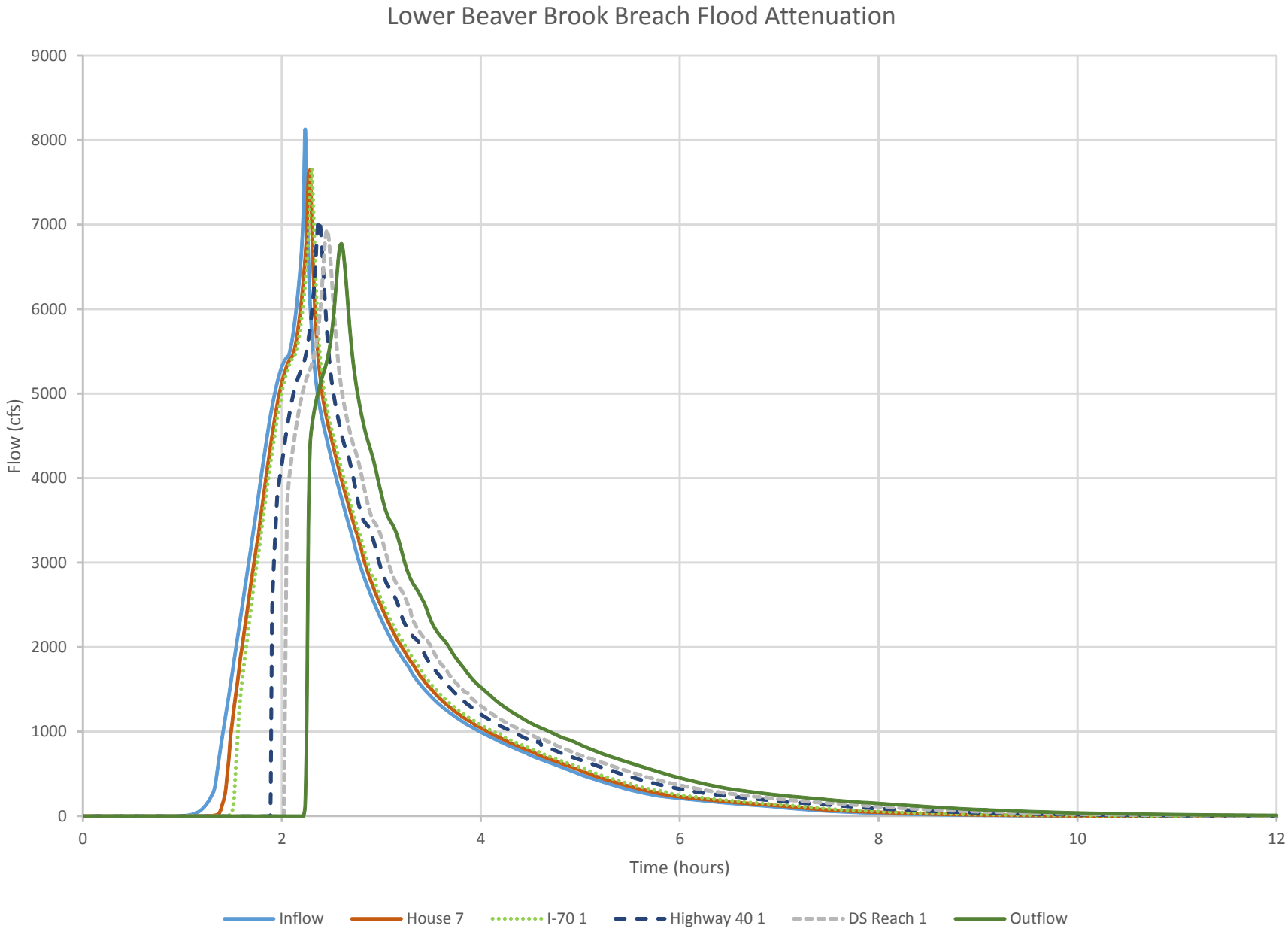


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Clear Creek County, Colorado

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LOWER BEAVER BROOK BREACH FLOOD ATTENUATION

Project 1410080 | September 2016 | Figure 3

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# APPENDIX B-2

## TECHNICAL MEMORANDUM - LOWER BEAVER BROOK IDF MODIFICATIONS – CONCEPTUAL DESIGN ALTERNATIVES (GEI, 2015)

# Technical Memorandum

## Lower Beaver Brook IDF Modifications - Conceptual Design Alternatives

Previous studies have determined the existing spillway at Lower Beaver Brook Dam is inadequate to pass the Inflow Design Flood (IDF) without overtopping the dam. This Conceptual Design Technical Memorandum (TM) presents potential alternatives to the Lookout Mountain Water District (LMWD) for modifying Lower Beaver Brook Dam to meet State dam safety regulatory criteria. This TM focusses on three conceptual level designs for a spillway enlargement at Lower Beaver Brook and presents an additional alternative which would allow the dam to be safely overtopped. A complete reconstruction of the dam as a Roller Compacted Concrete (RCC) structure was also considered. However, due to the cost of this other construction alternative, the design concepts and costs were not explored beyond order of magnitude costs.

GEI Consultants, Inc. (GEI) was tasked with developing alternatives and associated cost estimates for modifying the spillway capacity at Lower Beaver Brook Dam to meet regulatory flood routing criteria. This information is to be used as a planning tool for LMWD to develop long term budgets for capital improvements of their water storage facilities, including Upper Beaver Brook Dam and Lookout Mountain Dam.

### Existing Conditions

Lower Beaver Brook Dam is located approximately 7.1 miles northwest of Evergreen, Colorado in Clear Creek County in the NE ¼ of Section 14, Township 4 South, Range 72 West of the 6th Principal Meridian. The dam is located on Beaver Brook, a tributary to Clear Creek and the South Platte River, upstream of Golden, Colorado. The dam is classified as a High Hazard dam by the Colorado Office of the State Engineer (SEO) because loss of life is anticipated in the event that there is a failure of the dam. Lower Beaver Brook Dam is classified as a “Small Dam”.

Lower Beaver Brook Dam is a concrete faced rockfill dam with a structural height of 39 feet and impounds approximately 30 acre-feet (AF) at the normal pool elevation (El.) 7,837.7. The original Lower Beaver Brook Dam was originally constructed around 1903 and was modified to the current configuration in 1935. The dam crest is at El. 7,840.0, is about 224 feet long and has an average crest width of 12 feet. The upstream slope is approximately 0.7H:1V (Horizontal to Vertical) and the downstream slope is about 1.25H:1V.

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The spillway is located at the right side of the dam crest. The spillway is an ungated overflow channel with a crest width of approximately 29 feet at El. 7,837.7 with a maximum capacity of about 313 cubic feet per second (cfs). The concrete control sill is approximately 2 feet long with near vertical side slopes. The discharge channel between the spillway sill and the dam toe consists of short, steep sections of channel between vertical drops. There is a concrete drop structure approximately halfway between the spillway and dam toe. The drop structure consists of a 1 foot-wide concrete sill between vertical sidewalls. The sill is approximately 8 feet wide with about a 3 foot vertical drop immediately downstream.

The existing outlet works consists of two 14-inch steel pipes through a rock tunnel. The outlet works conduits have upstream control and are operated from the dam crest. The approximately downstream invert of the outlet conduits is El. 7,801. According to design drawings, the outlet pipe is about 122 feet long and is sloped at 0.02 feet/feet. The calculated upstream invert is El. 7,803.44. The outlet works discharges to the spillway discharge channel near the toe of the dam.

The existing site configuration is shown on Figure 1.

## Previous Studies

GEI performed an Incremental Damage Analysis (IDA) to evaluate the Inflow Design Flood (IDF) estimate for Lower Beaver Brook Dam (DAMID 070102) in Clear Creek County, Colorado. The analysis was performed in accordance with the Colorado State Engineer's Office *Rules and Regulations for Dam Safety and Construction* (SEO, 2007) and *Guidelines for Dam Breach Analysis* (SEO, 2010) and is documented in *Lower Beaver Brook Dam Hydrology and Incremental Damage Analysis Report* (GEI, 2015).

As part of the IDA, GEI developed estimates of the base flood, dam breach parameters, breach flood and downstream incremental impacts. GEI estimated the base flood to be equivalent to a storm with a peak inflow rate of 4,755 cfs, with a dam failure event triggering when the base flood reaches maximum overtopping of the dam crest. The hypothetical failure of the Lower Beaver Brook Dam due to dam crest overtopping from the base flood resulted in a breach flood with a peak breach discharge of about 8,175 cfs. Routing the base flood and the breach flood downstream showed that the breach flood does not produce incremental damages at the identified structures; therefore there are no incremental impacts in the zone between the base flood and the breach flood. Based on these results, the existing Lower Beaver Brook Dam meets the SEO IDA criteria to allow an IDF equal to the base flood. Therefore, the IDF for the existing Lower Beaver Brook Dam could be considered as the flood produced by base flood (27.5 percent of the HMR 55 PMP). The SEO has reviewed this report and has provided comments to LMWD and GEI. Results of the IDA study and the recommended IDF is summarized in Table 1. The IDF peak inflow of 4,755 cfs has not been approved yet and will be potentially changed based on discussions with the SEO.


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**Table 1: Lower Beaver Brook Dam Inflow Design Flood**

| Parameter | Base Flood Modeling Results |
|---|---|
| HMR-55 Local-Storm Average 6-hr PMP Depth, No SEO Reductions | 9.91 inches |
| Base Flood Percent of HMR-55 Local-Storm 6-hr PMP | 27.5% |
| Base Flood Basin Average 6-hr PMP Depth | 2.55 inches |
| Base Flood Basin Average PMP Runoff | 1.66 inches |
| Base Flood Basin Average 72-hr Losses | 0.89 inches |
| Base Flood Basin Average PMP Runoff Percent | 65.1% |
| Maximum Reservoir Elevation | 7,843.3 feet |
| Residual Freeboard | -3.3 feet |
| Inflow Volume | 657 acre-feet |
| Peak Inflow | 4,755 cfs |

## Conceptual Spillway Alternatives

The proposed dam and spillway modification alternatives consist of the following:

1. Maintain the dam crest elevation, lower the spillway to El. 7,833.25, and extend the spillway 71 feet to the right (east);
2. Raise the dam crest with a 3-foot-high parapet wall on the crest of the dam, lower the spillway to El. 7,833.25, and extend the spillway 31 feet to the right; and
3. Raise the dam crest with a 5-foot-high mechanically stabilized earth (MSE) wall on the crest of the dam, lower the spillway to El. 7,833.25, and extend the spillway 16 feet to the right.

Two additional dam alternatives were considered and are summarized as follows:

1. Replace the existing rockfill dam with a new RCC dam.
2. Modify the existing dam with an RCC crest, downstream RCC overtopping protection, and a new RCC stilling basin. The dam crest would be raised by 3 feet.

Replacing the existing dam with a similarly sized RCC dam was estimated to cost between $7M and $9.5M based on similar constructed projects in the vicinity. The RCC overtopping option was estimated to cost between $2.25M and $3M. This alternative is still feasible if LMWD wishes to pursue an overtopping alternative.

## Spillway Modification Design Assumptions

Although the SEO has not yet approved the IDA, for this study, the conceptual spillway alternatives were designed based on routing the IDA (4,755 cfs). Due to the small reservoir size, there will be a negligible reduction in required outflow compared to inflow for flood routing.

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Therefore, the three spillway alternatives were designed based on the peak IDF inflow without routing the flood hydrographs. It was assumed that the SEO will allow a freeboard variance to allow no residual freeboard during flood routing.

All alternatives will include maintaining the reservoir operating level at least 5 feet above the existing intake for the water treatment plant. Treatment Technologies indicated the minimum water level where raw water intake is possible is 11'-3" below the lowest point on the dam crest (El. 7,839.50). The minimum intake elevation is El. 7,828.25 and the spillway crest elevation for all alternatives spillway modifications was set at El. 7,833.25. Spillway capacity was calculated assuming the spillway acts as a broad-crested weir with discharge coefficient of 2.8. The spillway invert for the RCC overtopping alternative was maintained at the current elevation of 3837.7 feet.

Major cost items were developed and quantified based on an Association for the Advancement of Cost Engineering (AACE) Level 3 degree of accuracy. Rock excavation assumes a mixture of controlled blasting and percussive excavations with a pneumatic hammer and assume a 0.5H:1V excavation slope. Rock excavation costs were based in part on the costs developed for the Upper Beaver Brook spillway project. Other improvements to the dam, including outlet works trashracks and concrete lining improvements were not detailed during this study. However, a contingency was placed in the recommended design costs for these improvements.

### Alternative 1 – No dam raise and 100-foot-long spillway

Alternative 1 maintains the dam crest elevation and lowers the spillway crest to El. 7,833.25. The spillway, currently 29-feet-long, would be extended to the right (east) by 71 feet for a total length of 100 feet. The spillway extension will require a rock excavation of about 22,600 CY with maximum excavation depths of over 80 feet (assumes a 0.5H:1V excavation slope).

An entrance channel transitions water from the reservoir over the spillway and into a narrowing chute with a 2 percent slope. The chute narrows to 30-feet-wide and then transitions down at a 24 percent slope. Water is discharged into a stilling basin and then into the natural drainage. Alternative 1 is shown in Figures 2, 3, and 4.

### Alternative 2 – Dam raise with 3-foot-high parapet and 60-foot-long spillway

Alternative 2 raises the dam crest to El. 7,843.0 and lowers the spillway crest to El. 7,833.25. The spillway, currently 29-feet-long, would be extended to the right (east) by 31 feet for a total length of 60 feet. The spillway extension will require a rock excavation of about 8,700 CY with maximum excavation depths of about 55 feet (assumes a 0.5H:1V excavation slope).

An entrance channel transitions water from the reservoir over the spillway and into a narrowing chute with 2 percent slope. The chute narrows to 30-feet-wide and then transitions down at a 22 percent slope. Water is discharged into a stilling basin and then into the natural drainage. Alternative 2 is shown in Figures 5, 6, and 7.

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### Alternative 3 – Dam raise with 5-foot-high MSE wall and 45-foot-long spillway

Alternative 3 raises the dam crest to El. 7,845.0 and lowers the spillway crest to El. 7,833.25. The spillway, currently 29-feet-long, would be extended to the right (east) by 16 feet for a total length of 45 feet. The spillway extension will require a rock excavation of about 5,700 CY with maximum excavation depths of about 40 feet (assumes a 0.5H:1V excavation slope).

An entrance channel transitions water from the reservoir over the spillway and into a narrowing chute with 2 percent slope. The chute narrows to 30-feet-wide and then transitions down at a 20 percent slope. Water is discharged into a stilling basin and then into the natural drainage. Alternative 3 is shown in Figures 8, 9, and 10. A MSE wall schematic is shown in Figure 11.

### Alternative 4 – Dam Raise with RCC Overtopping Protection

Alternative 4 consists of modifying the existing dam to allow the dam to be safely overtopped during extreme flooding events. A new RCC crest would be constructed on top of the existing crest, which would add approximately 3 feet of height to the dam. A stair-stepped RCC downstream facing would be constructed. We have assumed a step width of 12 feet for constructability. Normal operational spillway flows would be routed through the existing spillway. It is anticipated that an RCC overtopping section between 100 and 125 feet wide would be sufficient to route the IDF along with the service spillway. A downstream RCC stilling basin would be constructed to help dissipate energy from the flowing water.

The maximum section for Alternative 4 is shown in Figure 11.

### Construction Cost Estimates

Cost estimates for the alternatives are based on the conceptual-level design concepts and estimated quantities of major construction items. The lump sum item prices are based on qualitative estimates of the work required and the corresponding cost. Estimated unit prices and costs for the listed work items were derived from the following sources: 1) Upper Beaver Brook spillway construction cost estimates; 2) published and non-published bid price data for similar work from similar projects; 3) R.S. Means Heavy Construction Cost Data for 2014; 4) GEI's experience on related construction work; and 5) price quotes from material suppliers and contractors.

The sum of the listed items for each category is defined for this study as the "Base Construction Subtotal" (BCS)", which includes a an allowance for unlisted construction items. The Opinion of Probable Project Cost (OPPC) is the sum of the BCS, construction contingencies, mobilization and demobilization, permitting, engineering final design services, and construction engineering and administration and QA/QC. For this project, the OPPC for Alternatives 1, 2, and 3 includes:

- 10 percent of the Alternative 2 BCS for mobilization and demobilization;
- 15 percent of the Alternative 2 BCS + mobilization/demobilization for contingencies;

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- Relative cost placeholder for permitting, engineering final design services, and construction engineering and administration and QA/QC

The OPPC for Alternative 4 includes:

- 10 percent of the Alternative 4 BCS for mobilization and demobilization;
- 15 percent of the Alternative 4 BCS + mobilization/demobilization for contingencies;
- Relative cost placeholder for permitting, engineering final design services, and construction engineering and administration and QA/QC

Summaries of our OPPCs for each alternative are presented in Tables 2 and 3. All costs are presented in 2015 dollars.

Estimates of OPPC presented in this report are based on our professional opinion of the cost to construct the alternatives as described in this TM. The estimated costs are based on the conceptual design concepts and layouts, the sources of information described above, and our knowledge of current construction cost conditions in the locality of the project. Actual project construction costs are affected by a number of factors beyond our control, such as supply and demand for the types of construction required at the time of bidding and in the project vicinity; changes in material supplier costs; changes in labor rates; the competitiveness of contractors and suppliers; changes in applicable regulatory requirements; and changes in design standards. Therefore, conditions and factors that arise as project development proceeds through design and construction may result in costs that differ from the estimates documented in this TM.

### Design and Construction Funding

The District's Rate Study provides for a build-up in reserves to provide for capital improvement expenditures starting in 2020. If the reserve study recommendations are implemented and found to be accurate, by 2020, without additional rate increases, the District will have $1,086,000 in reserve (general fund $550,000 and enterprise $536,000). In 2020, after a retirement of debt service in 2019, an additional $132,000 annually will become available. The combination of the reserves and newly available annual cash flow in and after 2020 will provide flexibility for the District to go forward with a modification to the Lower Beaver Brook dam and spillway in subsequent years while only taking on a modest debt burden.


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**TABLE 2 - CONCEPTUAL DESIGN COST BREAKDOWN**
**LOWER BEAVER BROOK SPILLWAY MODIFICATIONS**
**GEI PROJECT NO. 1507260**
**17-Nov-15**

| No. | Construction Item | Estimated Quantity | Units | Unit Cost (Bid Price) | Estimated Total Cost |
|---|---|---|---|---|---|
| **1** | **Site Work** | | | | |
| | Access Improvements | 1.0 | LS | $ 5,000.00 | $ 5,000 |
| | Reclamation and Revegatation | 0.50 | AC | $ 3,500.00 | $ 1,750 |
| | ***Subtotal*** | | | | **$ 6,750** |
| **2** | **Water Control** | | | | |
| | Dewatering and Unwatering | 1 | LS | $ 5,000.00 | $ 5,000 |
| | Cofferdam | 1 | LS | $ 20,000.00 | $ 20,000 |
| | ***Subtotal*** | | | | **$ 25,000** |
| **3** | **Erosion and Sediment Control** | | | | |
| | Silt Fence | 1,200 | LF | $ 6.00 | $ 7,200 |
| | Erosion and Sediment Control/SWPPP | 1 | LS | $ 7,500.00 | $ 7,500 |
| | ***Subtotal*** | | | | **$ 14,700** |
| **4A** | **Alt 1 Spillway Construction (ALL CUT, NO RAISE)** | | | | |
| | Removal of Existing Weir | 1 | LS | $ 5,000.00 | $ 5,000 |
| | Unclassified Excavation | 22,600 | CY | $ 70.00 | $ 1,582,000 |
| | Shape and Place DS Left Channel | 800 | CY | $ 6.00 | $ 4,800 |
| | Grout DS Left Channel | 1 | LS | $ 20,000.00 | $ 20,000 |
| | Excavation Disposal on Site | 1,500 | CY | $ 6.00 | $ 9,000 |
| | Excavation Disposal Off Site | 20,300 | CY | $ 20.00 | $ 406,000 |
| | Foundation Preparation | 200 | SY | $ 25.00 | $ 5,000 |
| | Reinforced Concrete Walls (6000 psi) | 20 | CY | $ 800.00 | $ 16,000 |
| | Stilling Basin | 1 | LS | $ 50,000.00 | $ 50,000 |
| | Control Section | 1 | LS | $ 22,000.00 | $ 22,000 |
| | ***Subtotal*** | | | | **$ 2,119,800** |
| **4A** | **Alt 2 Spillway Construction (60' CUT WITH 3' PARAPET)** | | | | |
| | Removal of Existing Weir | 1 | LS | $ 5,000.00 | $ 5,000 |
| | Unclassified Excavation | 8,700 | CY | $ 70.00 | $ 609,000 |
| | Shape and Place DS Left Channel | 800 | CY | $ 6.00 | $ 4,800 |
| | Grout DS Left Channel | 1 | LS | $ 20,000.00 | $ 20,000 |
| | Excavation Disposal on Site | 1,500 | CY | $ 6.00 | $ 9,000 |
| | Excavation Disposal Off Site | 6,400 | CY | $ 20.00 | $ 128,000 |
| | Foundation Preparation | 300 | SY | $ 25.00 | $ 7,500 |
| | Concrete Parapet Wall | 250 | CY | $ 650.00 | $ 162,500 |
| | Reinforced Concrete Walls (6000 psi) | 25 | CY | $ 800.00 | $ 20,000 |
| | Stilling Basin | 1 | LS | $ 50,000.00 | $ 50,000 |
| | Control Section | 1 | LS | $ 18,000.00 | $ 18,000 |
| | ***Subtotal*** | | | | **$ 1,033,800** |
| **4C** | **Alt 3 Spillway Construction** | | | | |
| | Removal of Existing Weir | 1 | LS | $ 5,000.00 | $ 5,000 |
| | Unclassified Excavation | 5,700 | CY | $ 70.00 | $ 399,000 |
| | Shape and Place DS Left Channel | 800 | CY | $ 6.00 | $ 4,800 |
| | Grout DS Left Channel | 1 | LS | $ 20,000.00 | $ 20,000 |
| | Excavation Disposal on Site | 1,500 | CY | $ 6.00 | $ 9,000 |
| | Excavation Disposal Off Site | 3,400 | CY | $ 20.00 | $ 68,000 |
| | MSE Walls | 4,000 | SF | $ 50.00 | $ 200,000 |
| | MSE Wall Fill (15 foot crest) | 1,100 | CY | $ 30.00 | $ 33,000 |
| | Foundation Preparation | 600 | SY | $ 25.00 | $ 15,000 |
| | Reinforced Concrete Walls (6000 psi) | 30 | CY | $ 800.00 | $ 24,000 |
| | Stilling Basin | 1 | LS | $ 50,000.00 | $ 50,000 |
| | Control Section | 1 | LS | $ 10,000.00 | $ 10,000 |
| | ***Subtotal*** | | | | **$ 837,800** |

| | | Spillway Alt. 1 | Spillway Alt. 2 | Spillway Alt. 3 |
|---|---|---|---|---|
| | Subtotal | **$ 2,166,250** | **$ 1,080,250** | **$ 884,250** |
| | Unlisted Items | $ 100,000 | $ 100,000 | $ 100,000 |
| **BASE CONSTRUCTION SUBTOTAL** | | **Spillway Alt. 1** | **Spillway Alt. 2** | **Spillway Alt. 3** |
| | | $ 2,266,250.0 | $ 1,180,250 | $ 984,250 |
| | Mobilization and Demobilization @ 10% of Alt 2 | $ 120,000 | $ 120,000 | $ 120,000 |
| | Contingencies (15% of BCS + Mob) of Alt 2 | $ 200,000 | $ 200,000 | $ 200,000 |
| | Permitting | $ 40,000 | $ 40,000 | $ 40,000 |
| | Final Design | $ 60,000 | $ 80,000 | $ 100,000 |
| | Construction Management and QA/QC | $ 80,000 | $ 120,000 | $ 120,000 |
| **OPINION OF PROBABLE CONSTRUCTION COSTS (OPCC)** | | **$ 2,767,000** | **$ 1,741,000** | **$ 1,565,000** |

## TABLE 3 - CONCEPTUAL DESIGN COST BREAKDOWN
## LOWER BEAVER BROOK RCC OVERTOPPING PROTECTION
## GEI PROJECT NO. 1507260

**17-Nov-15**

| No. | Construction Item | Estimated Quantity | Units | Unit Cost (Bid Price) | Estimated Total Cost |
|---|---|---|---|---|---|
| **1** | **Site Work** | | | | |
| | Access Improvements | 1.0 | LS | $ 5,000.00 | $ 5,000 |
| | Reclamation and Revegatation | 0.50 | AC | $ 4,000.00 | $ 2,000 |
| | ***Subtotal*** | | | | **$ 7,000** |
| **2** | **Water Control** | | | | |
| | Dewatering and Unwatering | 1 | LS | $ 25,000.00 | $ 25,000 |
| | ***Subtotal*** | | | | **$ 25,000** |
| **3** | **Erosion and Sediment Control** | | | | |
| | Silt Fence | 500 | LF | $ 6.00 | $ 3,000 |
| | Erosion and Sediment Control/SWPPP | 1 | LS | $ 10,000.00 | $ 10,000 |
| | ***Subtotal*** | | | | **$ 13,000** |
| **4A** | **Alt 4 RCC Overtopping Section** | | | | |
| | Roller Compacted Concrete | 4,400 | CY | $ 275.00 | $ 1,210,000 |
| | (unit cost includes all ancillaries, drainage, etc) | | | | |
| | Reinforced Concrete Training Walls | 250 | CY | $ 1,200.00 | $ 300,000 |
| | ***Subtotal*** | | | | **$ 1,510,000** |
| | | | | | **RCC Alternative** |
| | Subtotal | | | | **$ 1,555,000** |
| | Unlisted Items | | | | $ 250,000 |
| **BASE CONSTRUCTION SUBTOTAL** | | | | | **Spillway Alt. 1** |
| | | | | | $ 1,805,000 |
| | Mobilization and Demobilization @ 10% | | | | $ 120,000 |
| | Contingencies (15% of BCS + Mob) | | | | $ 271,000 |
| | Permitting | | | | $ 40,000 |
| | Final Design | | | | $ 180,000 |
| | Construction Management and QA/QC | | | | $ 125,000 |
| **OPINION OF PROBABLE CONSTRUCTION COSTS (OPCC)** | | | | | **$ 2,541,000** |

CONCEPTUAL DESIGN

N

0 20 40
SCALE, FEET

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

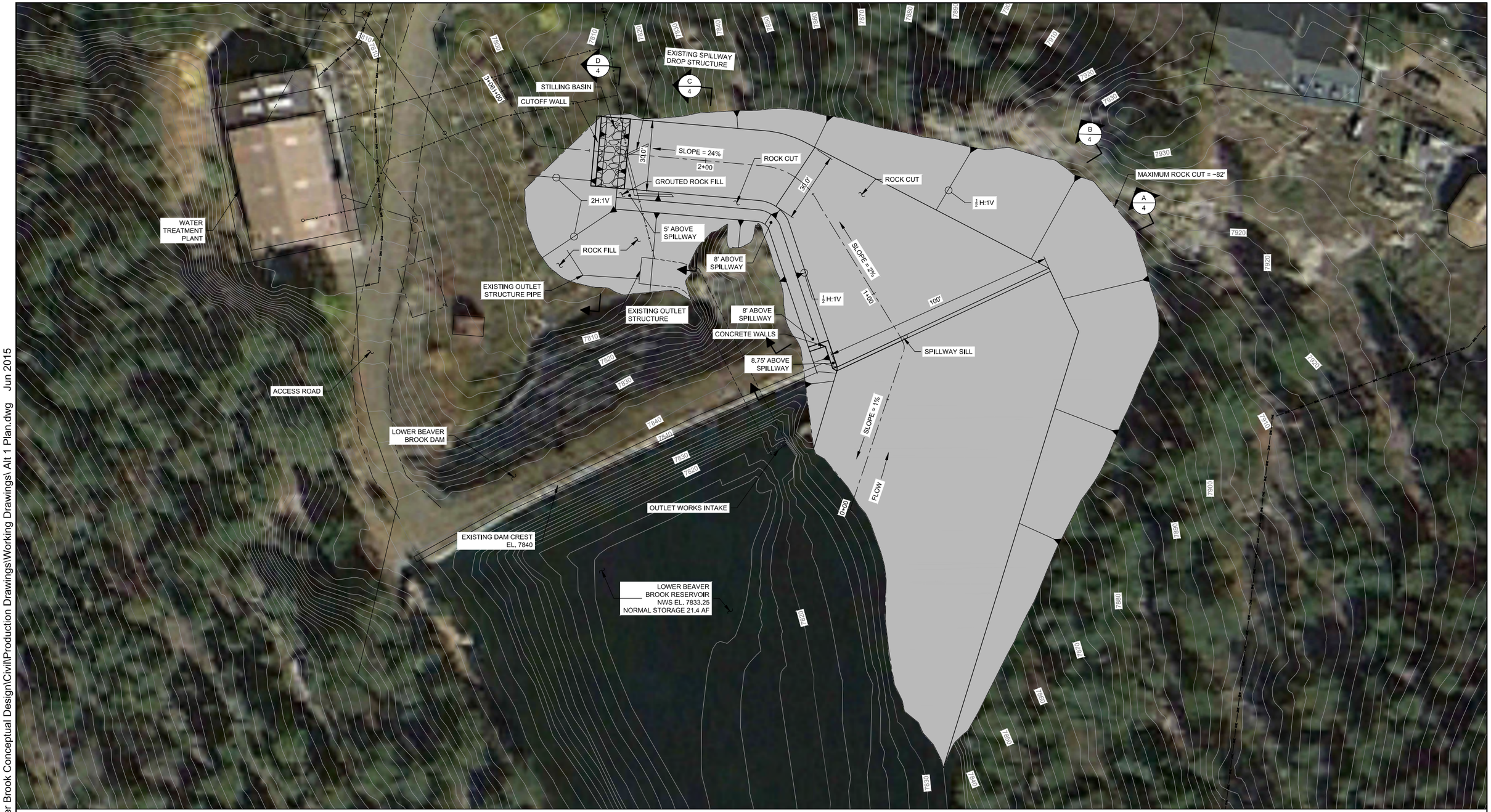
Lookout Mountain Water District, Golden, Colorado

GEI Consultants

PLAN OF EXISTING CONDITIONS

Project 1507260 | November 2015 | Figure 1

P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Existing Plan.dwg Jun 2015




P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 1 Plan.dwg Jun 2015

N

0 20 40
SCALE, FEET

CONCEPTUAL DESIGN

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

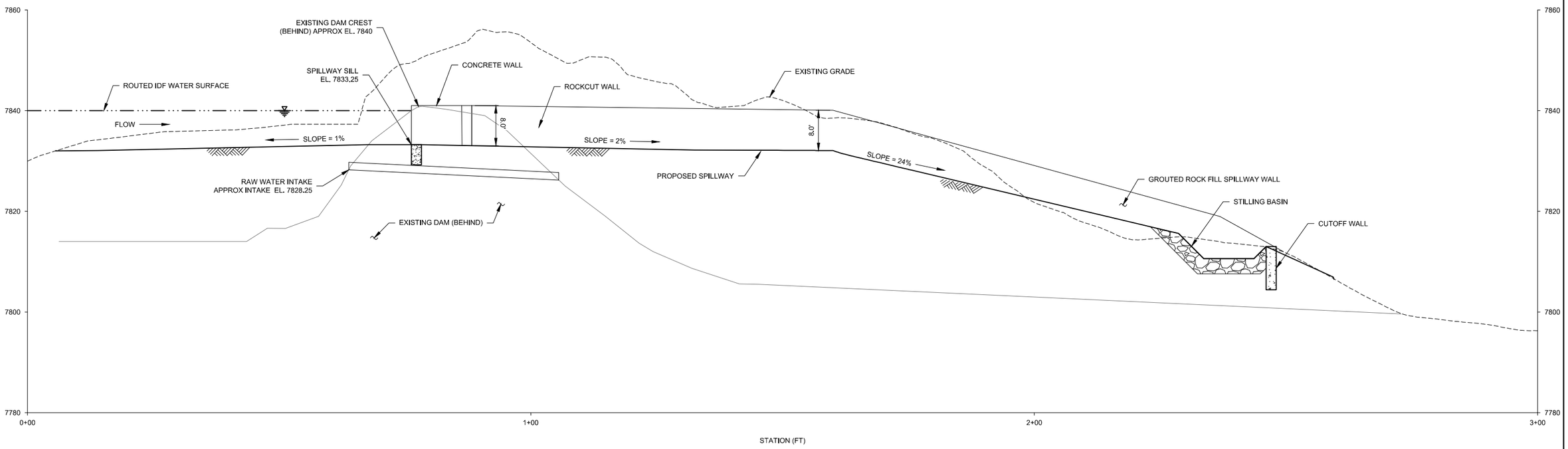
Lookout Mountain Water District, Golden, Colorado

GEI Consultants

Project 1507260

ALTERNATIVE 1 PLAN

November 2015 Figure 2




P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 1 Profile.dwg Jun 2015

N

0 20 40
SCALE, FEET

*CONCEPTUAL DESIGN*

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

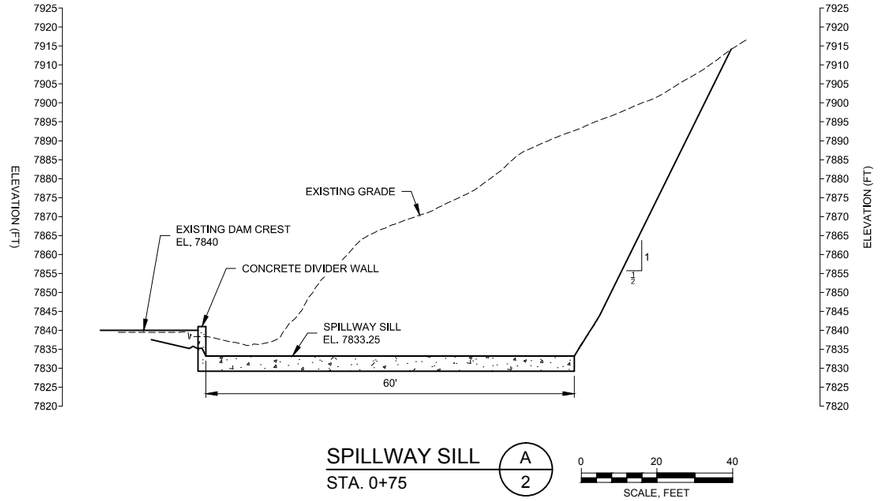
Lookout Mountain Water District, Golden, Colorado

GEI Consultants

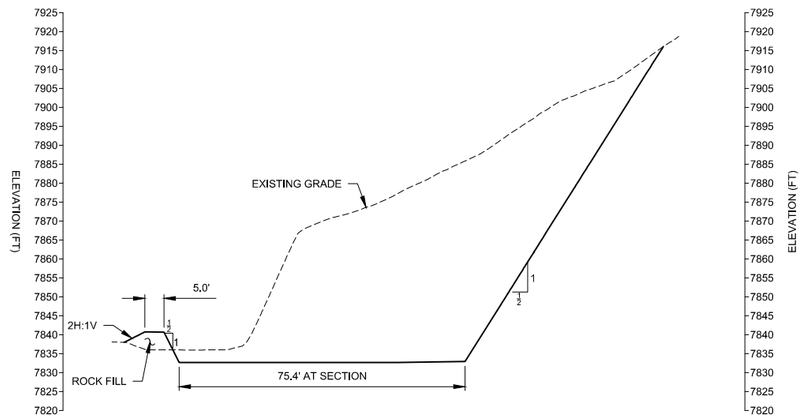
Project 1507260

ALTERNATIVE 1
PROFILE

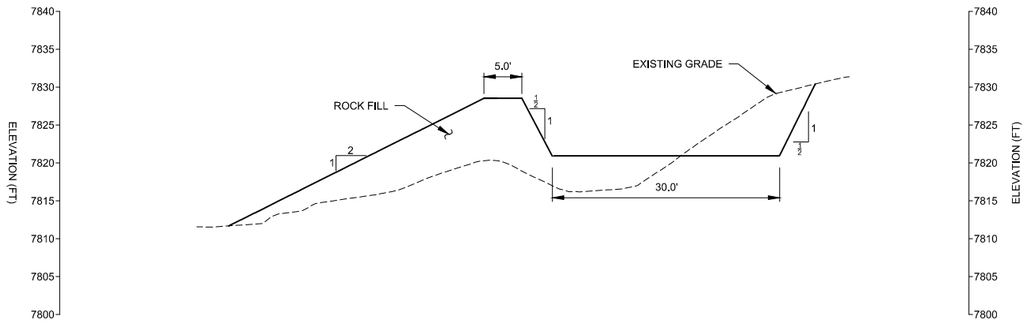
November 2015 Figure 3



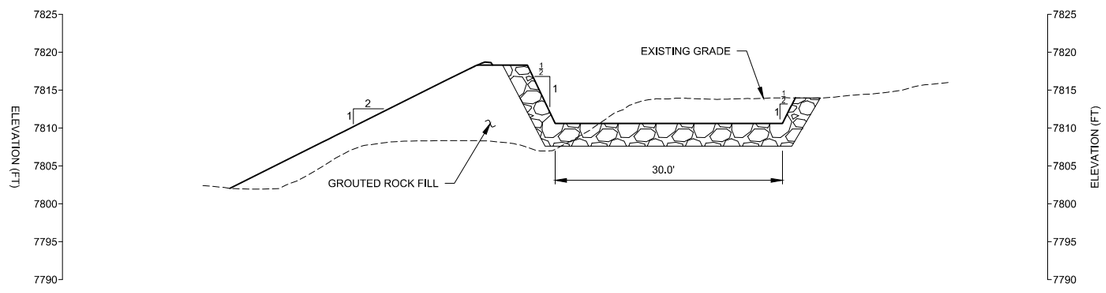

SPILLWAY SILL
STA. 0+75
A
2




SECTION
STA. 1+00
B
2




SECTION
STA. 2+00
C
2




STILLING BASIN
STA. 2+31
D
2

CONCEPTUAL DESIGN

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

GEI Consultants

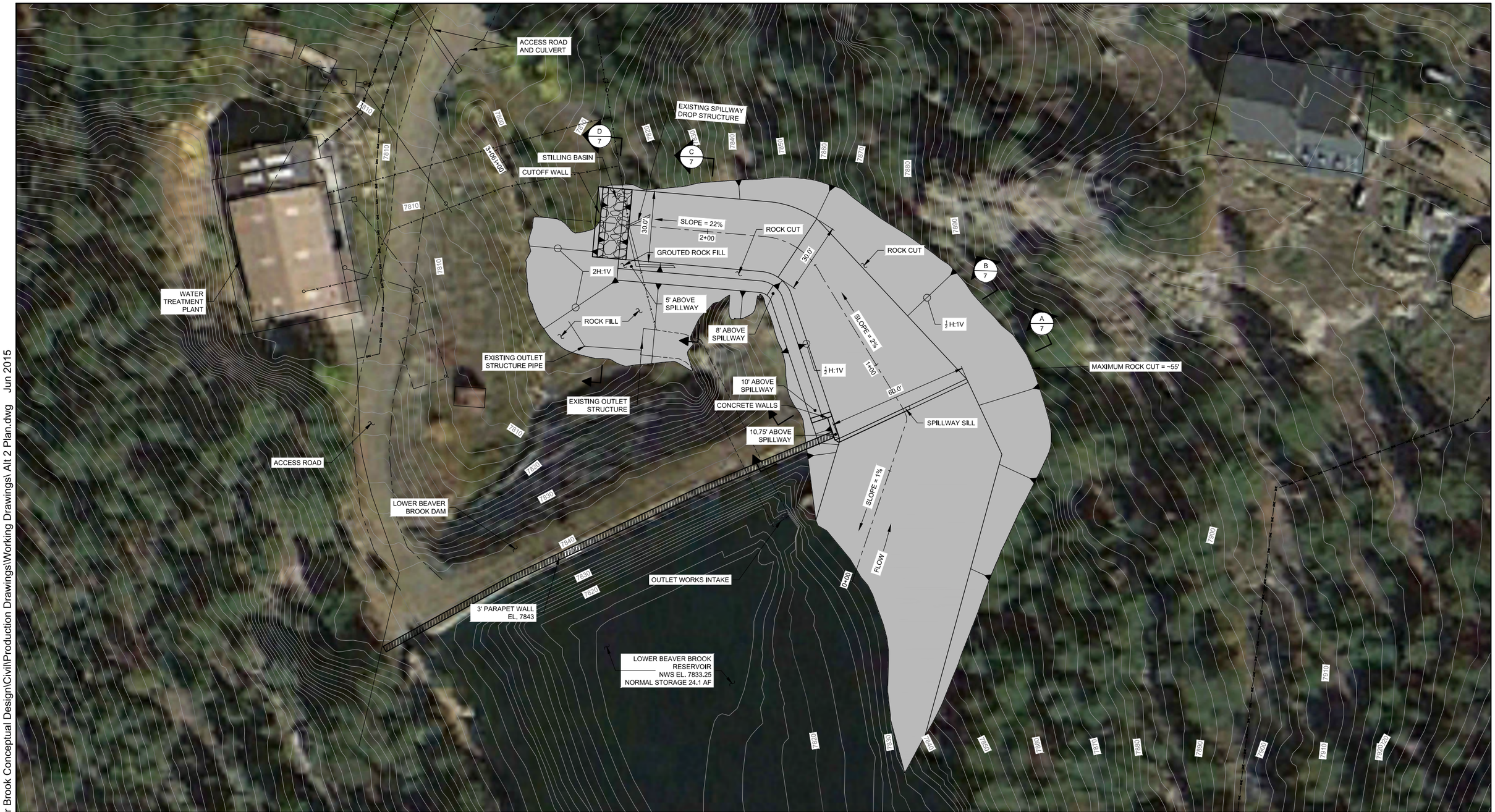
ALTERNATIVE 1
SECTIONS

Project 1507260

November 2015

Figure 4

P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 1 Sections.dwg Jun 2015




P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 2 Plan.dwg Jun 2015

*CONCEPTUAL DESIGN*

N

0 20 40
SCALE, FEET

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

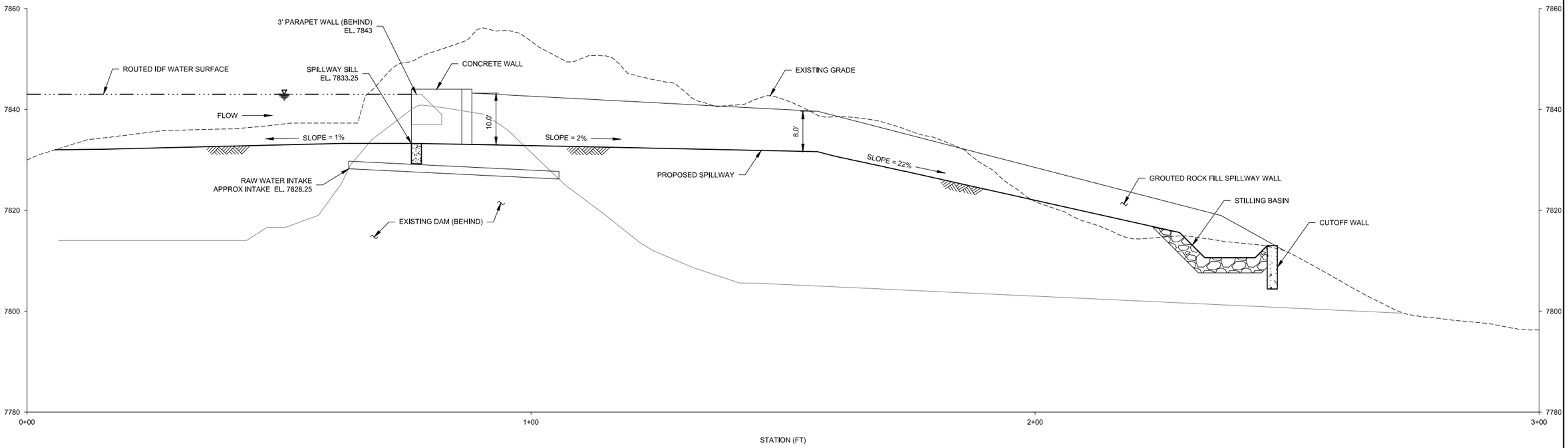
Lookout Mountain Water District, Golden, Colorado

GEI Consultants

Project 1507260

ALTERNATIVE 2
PLAN

November 2015 Figure 5




P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 2 Profile.dwg Jun 2015

N

0 20 40
SCALE, FEET

*CONCEPTUAL DESIGN*

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

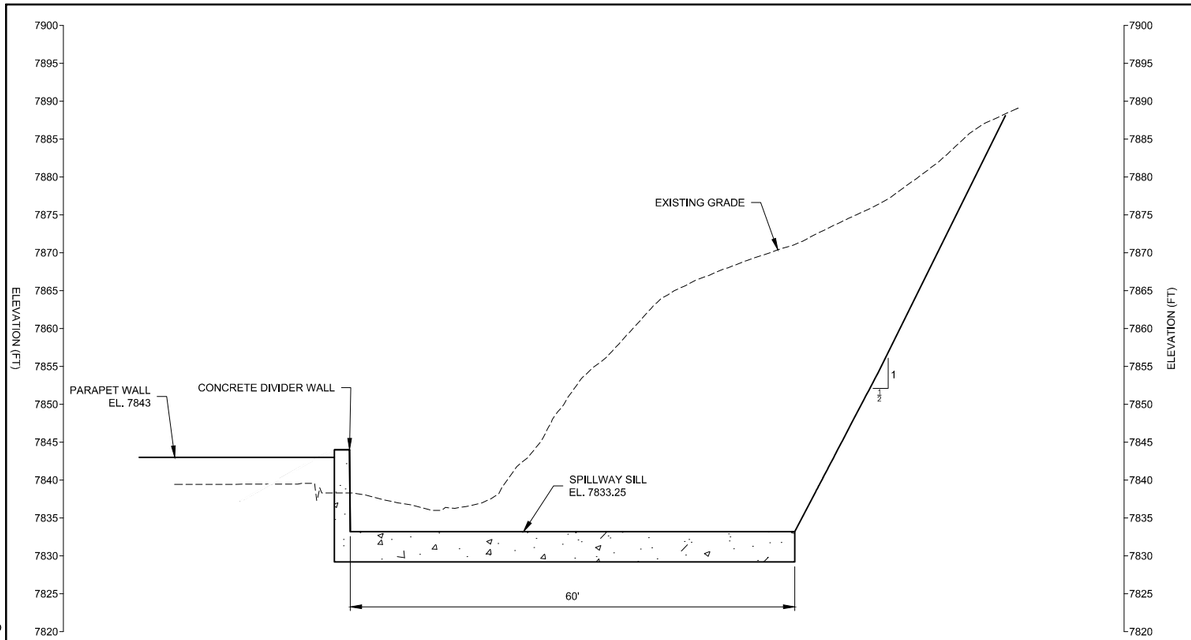
Lookout Mountain Water District, Golden, Colorado

GEI Consultants

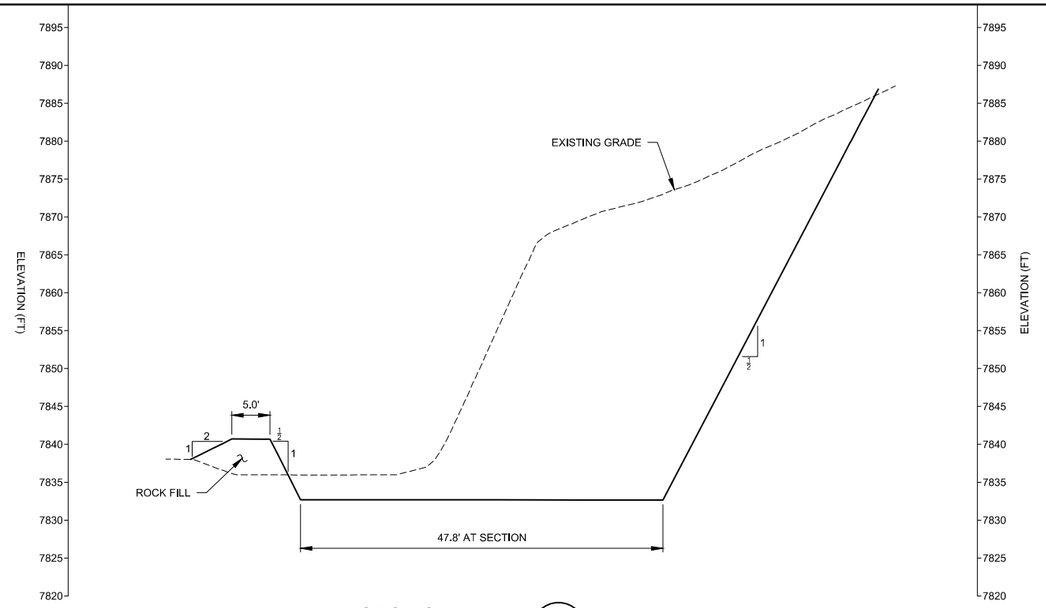
Project 1507260

ALTERNATIVE 2
PROFILE

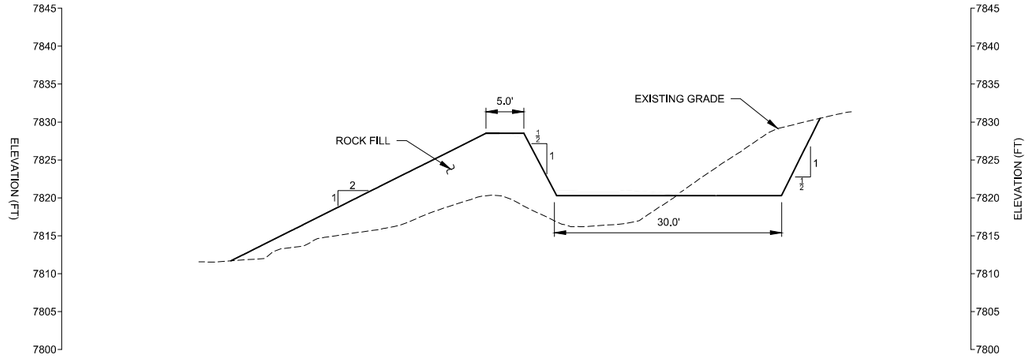
November 2015 Figure 6



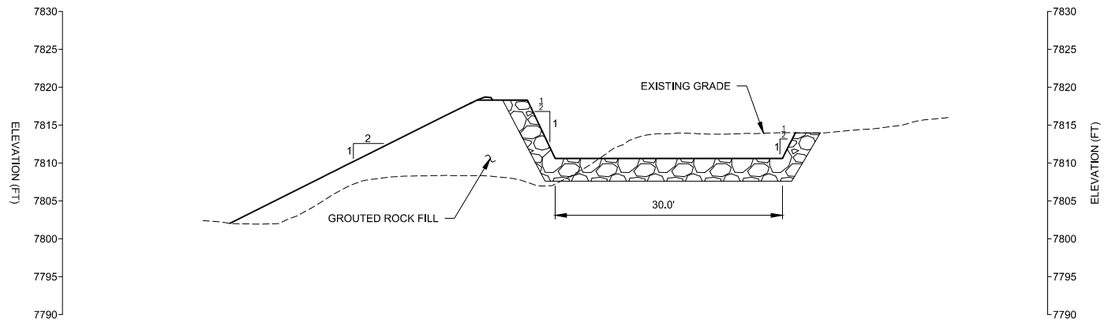

SPILLWAY SILL — A / 5
STA. 0+75




SECTION — B / 5
STA. 1+00




SECTION — C / 5
STA. 2+00




STILLING BASIN — D / 5
STA. 2+31

CONCEPTUAL DESIGN

N

0 10 20
SCALE, FEET

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

GEI Consultants

ALTERNATIVE 2 SECTIONS

Project 1507260 | November 2015 | Figure 7

P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 2 Sections.dwg Jun 2015

ACCESS ROAD
EXISTING SPILLWAY DROP STRUCTURE
D 10
C 10
STILLING BASIN
CUTOFF WALL
SLOPE = 20%
2+00
30.0'
GROUTED ROCK FILL
ROCK CUT
2H:1V
5' ABOVE SPILLWAY
ROCK FILL
8' ABOVE SPILLWAY
EXISTING OUTLET STRUCTURE PIPE
10' ABOVE SPILLWAY
CONCRETE WALLS
EXISTING OUTLET STRUCTURE
WATER TREATMENT PLANT
ROCK CUT
MAXIMUM ROCK CUT = ~40'
B 10
A 10
30.0'
SLOPE = 2%
1+40
½ H:1V
½ H:1V
45.0'
SPILLWAY SILL
12.75' ABOVE SPILLWAY
SLOPE = 1%
FLOW
0+00
ACCESS ROAD
LOWER BEAVER BROOK DAM
OUTLET WORKS INTAKE
5' PARAPET WALL
LOWER BEAVER BROOK RESERVOIR
NWS EL. 7833.25
NORMAL STORAGE
24.1 AF
7810
7820
7830
7840
7850
7860
7870
7880

*CONCEPTUAL DESIGN*

N

0 20 40
SCALE, FEET

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

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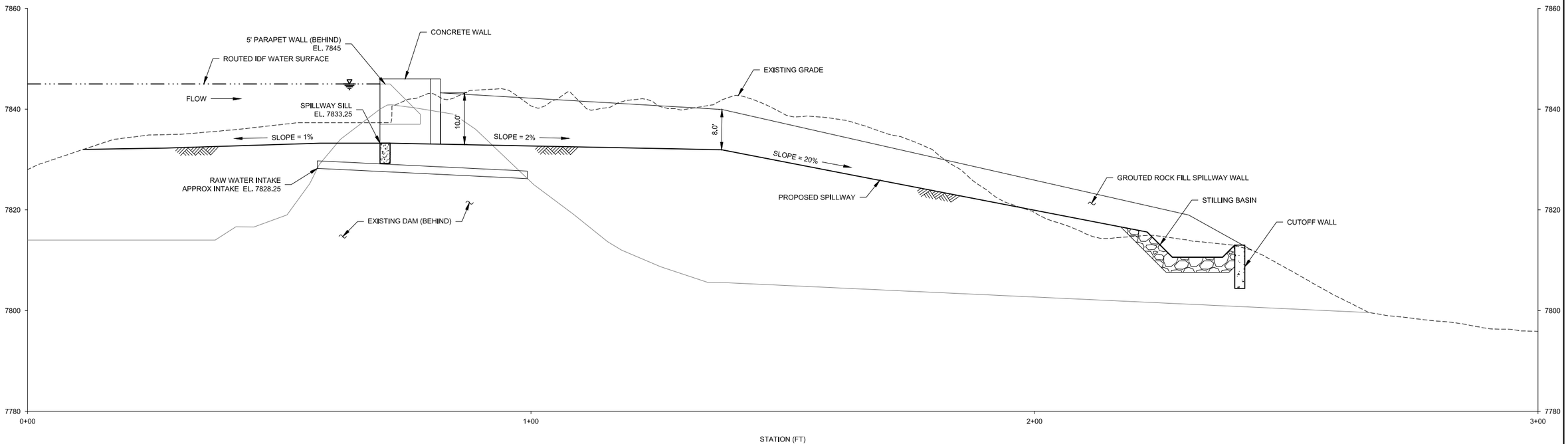
Project 1507260

ALTERNATIVE 3 PLAN

November 2015 Figure 8

P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 3 Plan.dwg Jun 2015




N

0 10 20
SCALE, FEET

*CONCEPTUAL DESIGN*

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

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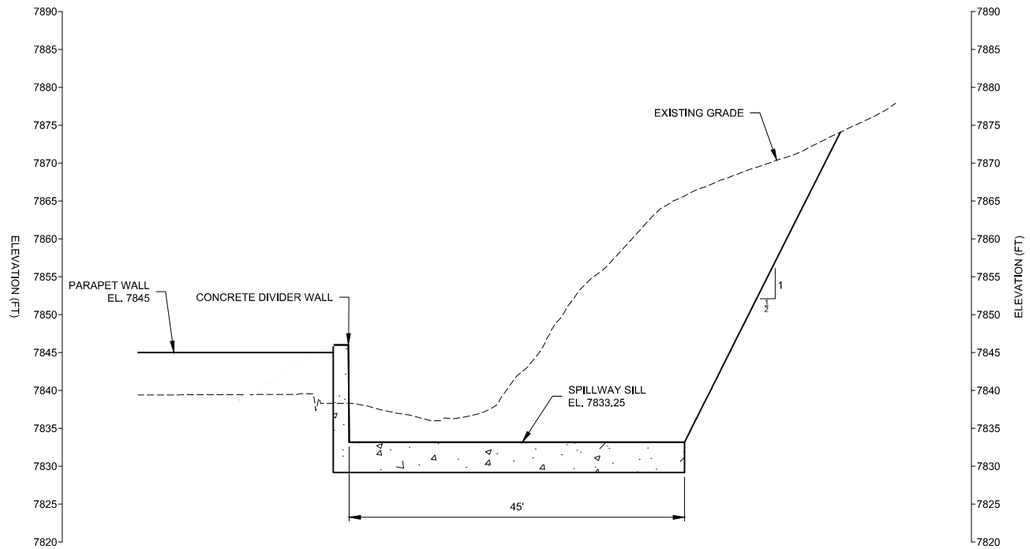
ALTERNATIVE 3
PROFILE

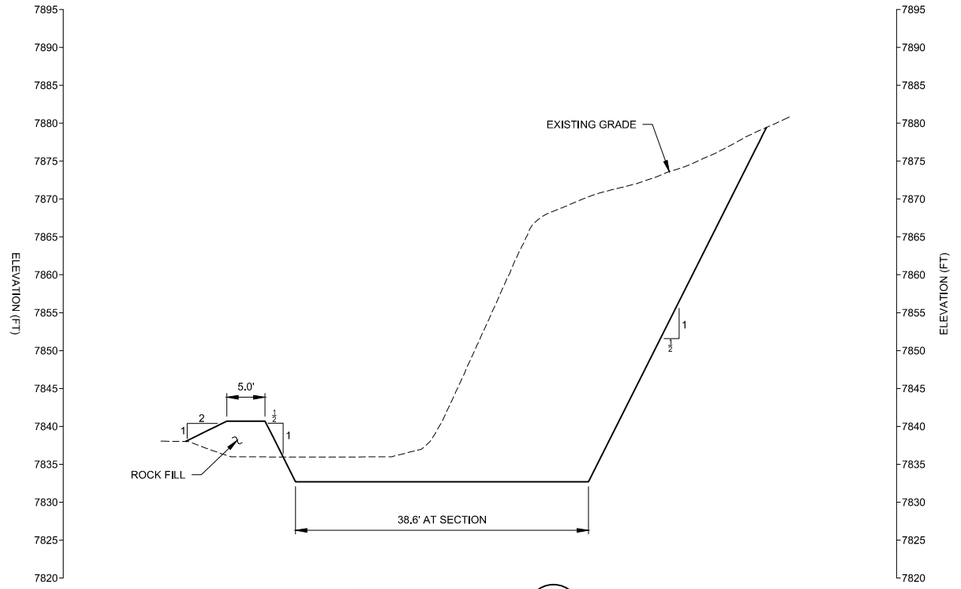
Project 1507260

November 2015 Figure 9

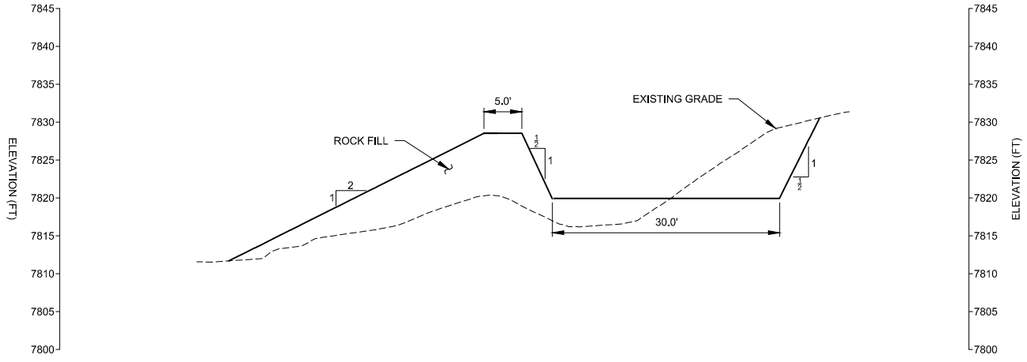
P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 3 Profile.dwg Jun 2015



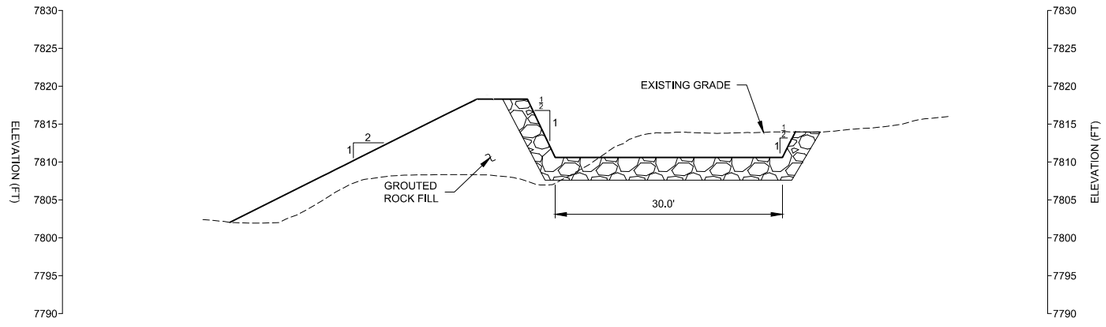

SPILLWAY SILL — A/8
STA. 0+75




SECTION — B/8
STA. 1+00

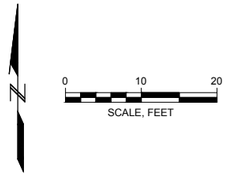



SECTION — C/8
STA. 2+00




STILLING BASIN — D/8
STA. 2+31

*CONCEPTUAL DESIGN*




Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

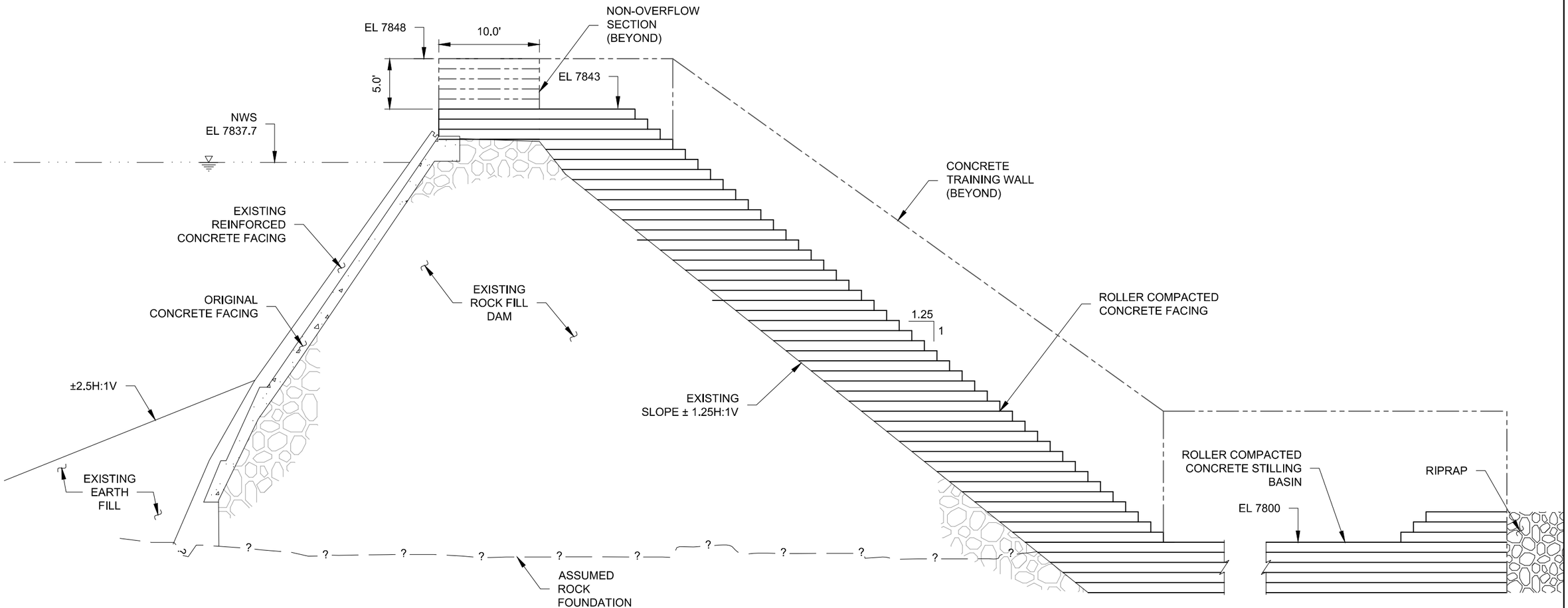
GEI Consultants

ALTERNATIVE 3 SECTIONS

Project 1507260

November 2015 Figure 10

P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Alt 3 Sections.dwg Jun 2015




## MAXIMUM SECTION

*CONCEPTUAL DESIGN*

0 10 20

SCALE, FEET

Lookout Mountain Water District

Lower Beaver Brook Conceptual Spillway Design

Lookout Mountain Water District, Golden, Colorado

GEI Consultants

Project 1507260

ROLLER COMPACTED CONCRETE OVERTOPPING PROTECTION

November 2015 Figure 11

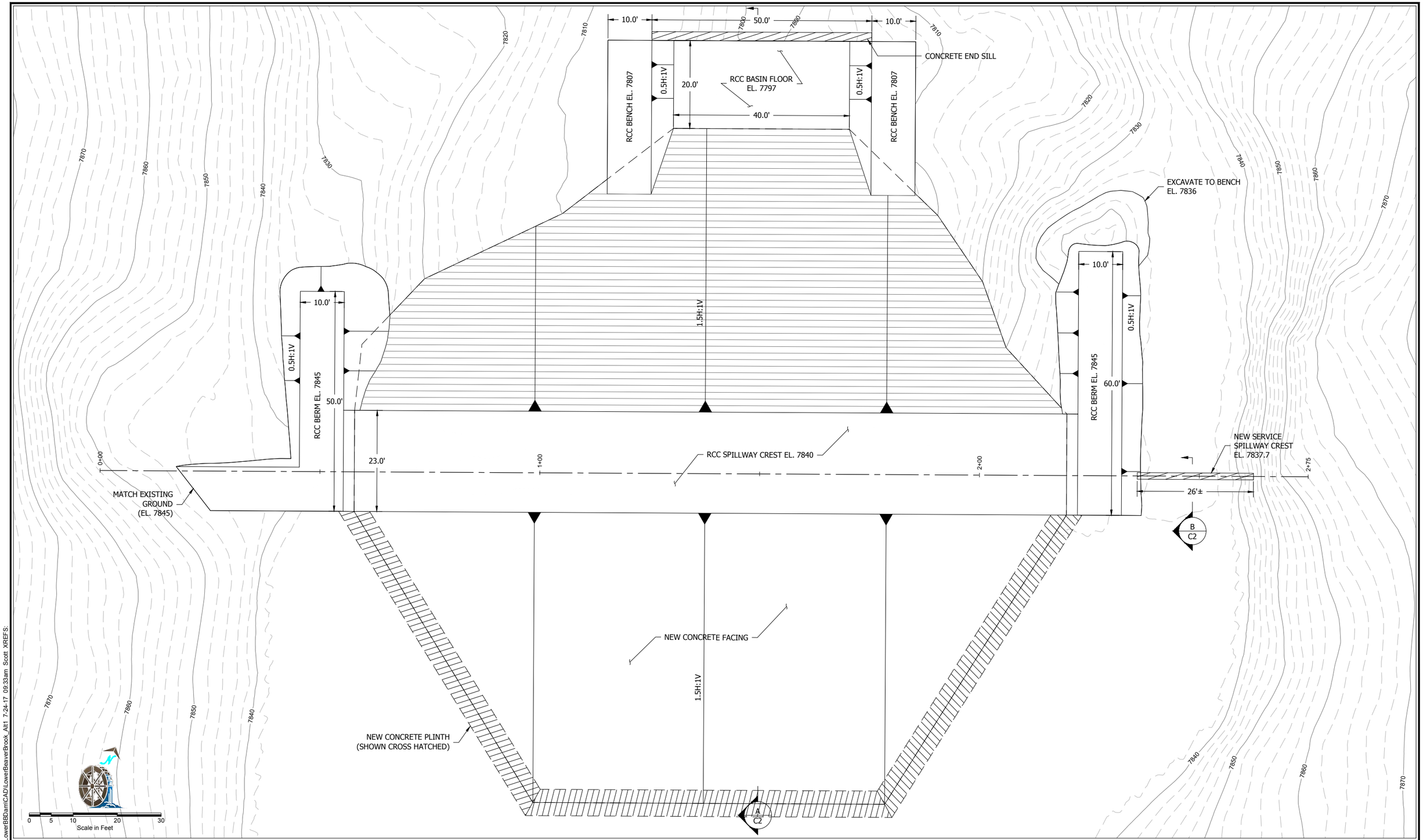
P:\1507260 - Lower Beaver Brook Conceptual Design\Civil\Production Drawings\Working Drawings\ Figure 11 - RCC Overtopping Protection.dwg Nov 2015

# APPENDIX C

## CONCEPTUAL DESIGN DRAWINGS FOR

## ALTERNATIVE NO. 4

## DAM REHABILITATION WITH RCC OVERTOPPING

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| Revisions | No. | Date | Made | Checked | Remarks |
|---|---|---|---|---|---|
| | 0 | 07/01/17 | YKC | DTH | PRELIMINARY CONCEPTUAL DRAWING |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| Reference | Sheet No. | Drawing No. | Title |
|---|---|---|---|
| | | | |
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| | | | |
| | | | |

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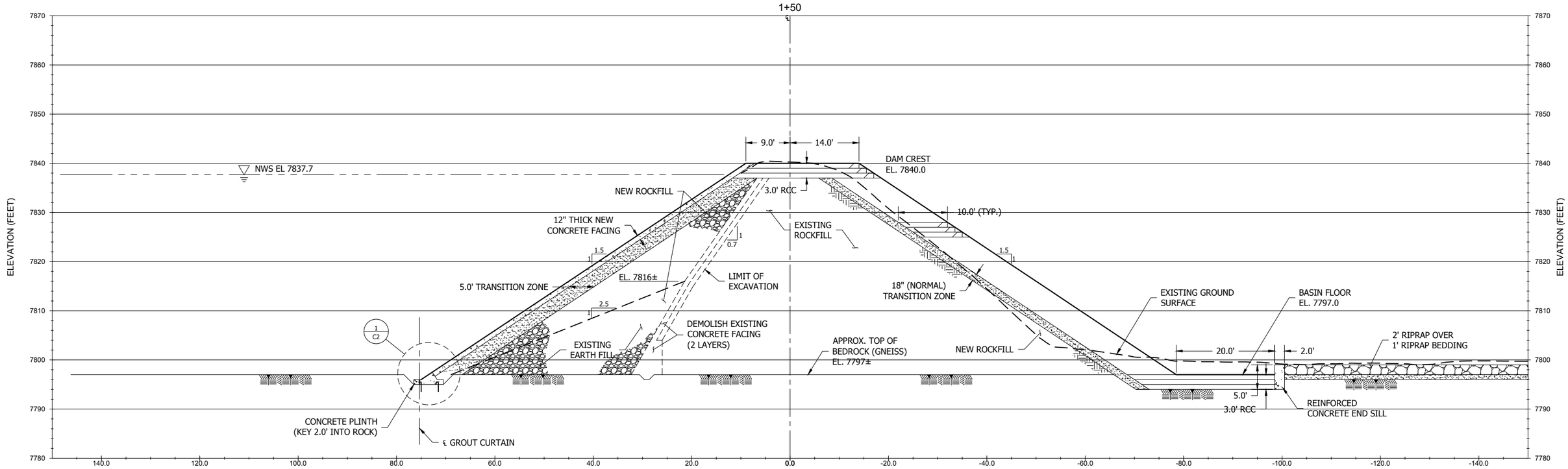
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405
303-761-4130 | fax 303-761-2802

# LOWER BEAVER BROOK DAM

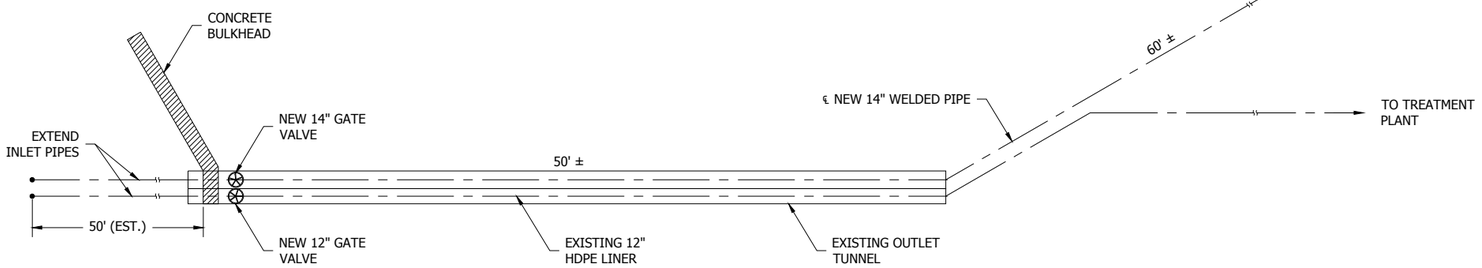
ALTERNATIVE 4 - DAM REABILITATION
RCC OVER TOPPING PROTECTION
PLAN OF MODIFICATIONS

| | |
|---|---|
| Client | LOOKOUT MOUNTAIN WATER DISTRICT |
| Design | YKC |
| Drawn | SAA |
| Check | DTH |
| Plot Date | 07/24/2017 |
| Wheeler No. | 1867.01 |
| Sheet No. | 1 of 2 |
| Drawing No. | C1 |
| | 0 |



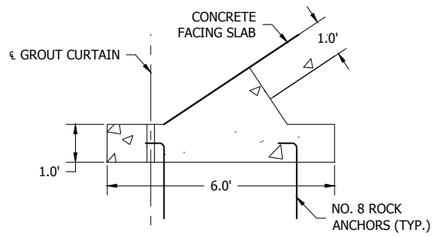

## LOWER BEAVER BROOK DAM
MAXIMUM SECTION

A / C1




## OUTLET WORKS MODIFICATIONS
SCHEMATIC PLAN (N.T.S.)

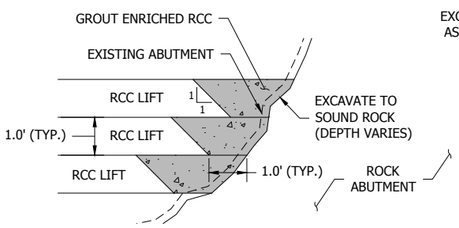
2




## CONCRETE PLINTH
TYPICAL DETAIL

1 / C2

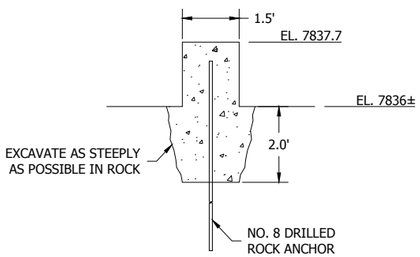
0 1 2 4 6
Scale in Feet




## RCC/ABUTMENT CONTACT
TYPICAL DETAIL

3

0 1 2 4 6
Scale in Feet




## SERVICE SPILLWAY CREST
TYPICAL SECTION

B / C1

0 1 2 4 6
Scale in Feet

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| Revisions No. | Date | Made | Checked | Remarks |
|---|---|---|---|---|
| 0 | 07/01/17 | YKC | DTH | PRELIMINARY CONCEPTUAL DRAWING |
| | | | | |
| | | | | |
| | | | | |
| | | | | |

| Reference | Sheet No. | Drawing No. | Title |
|---|---|---|---|
| | | | |
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Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405
303-761-4130 | Fax 303-761-2802

# LOWER BEAVER BROOK DAM

ALTERNATIVE 4 - DAM REHABILITATION
RCC OVERTOPPING PROTECTION
MAXIMUM SECTION AND DETAILS

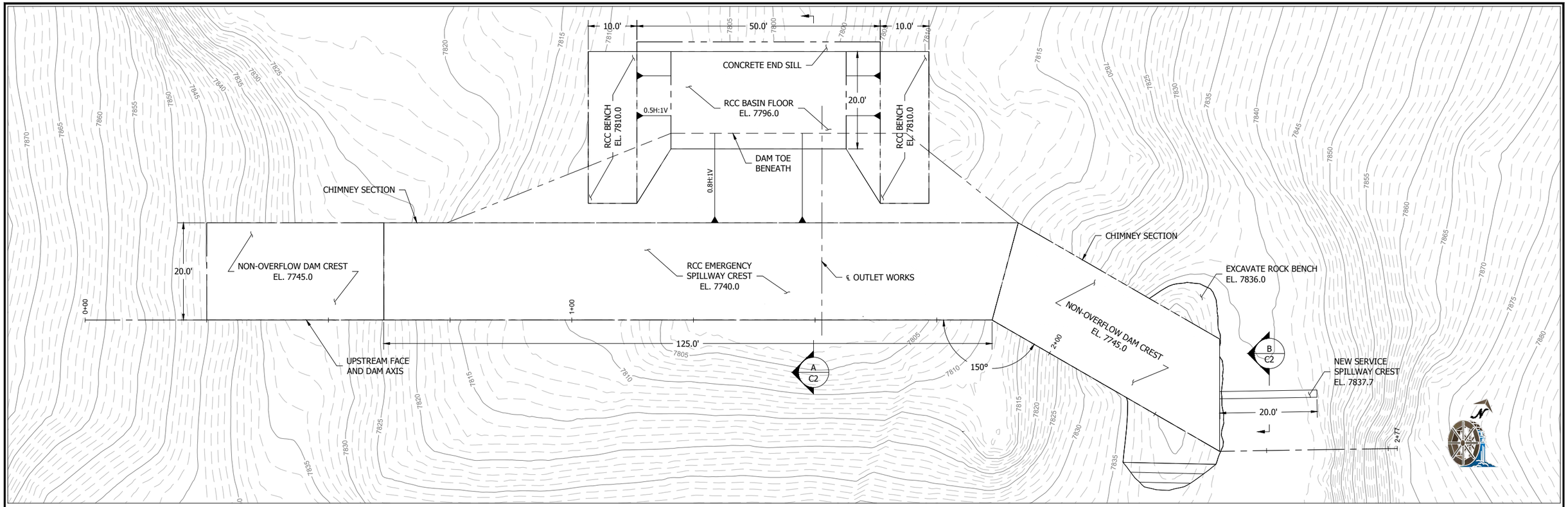
| | |
|---|---|
| Client | LOOKOUT MOUNTAIN WATER DISTRICT |
| Design | YKC |
| Drawn | SAA |
| Check | DTH |
| Plot Date | 07/24/2017 |
| Wheeler No. | 1867.01 |
| Sheet No. | 2 of 2 |
| Drawing No. | C2 |
| Revision | 0 |

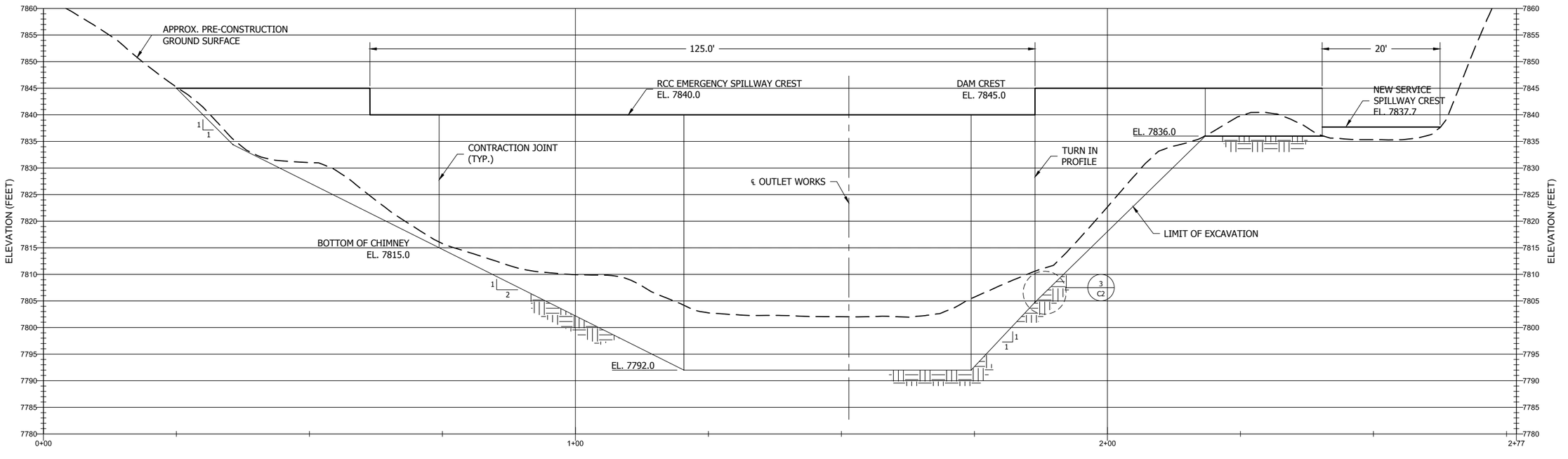
# APPENDIX D

## CONCEPTUAL DESIGN DRAWINGS FOR

## ALTERNATIVE NO. 5

## NEW CONCRETE DAM

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| Reference Sheet No. | Drawing No. | Title |
|---|---|---|

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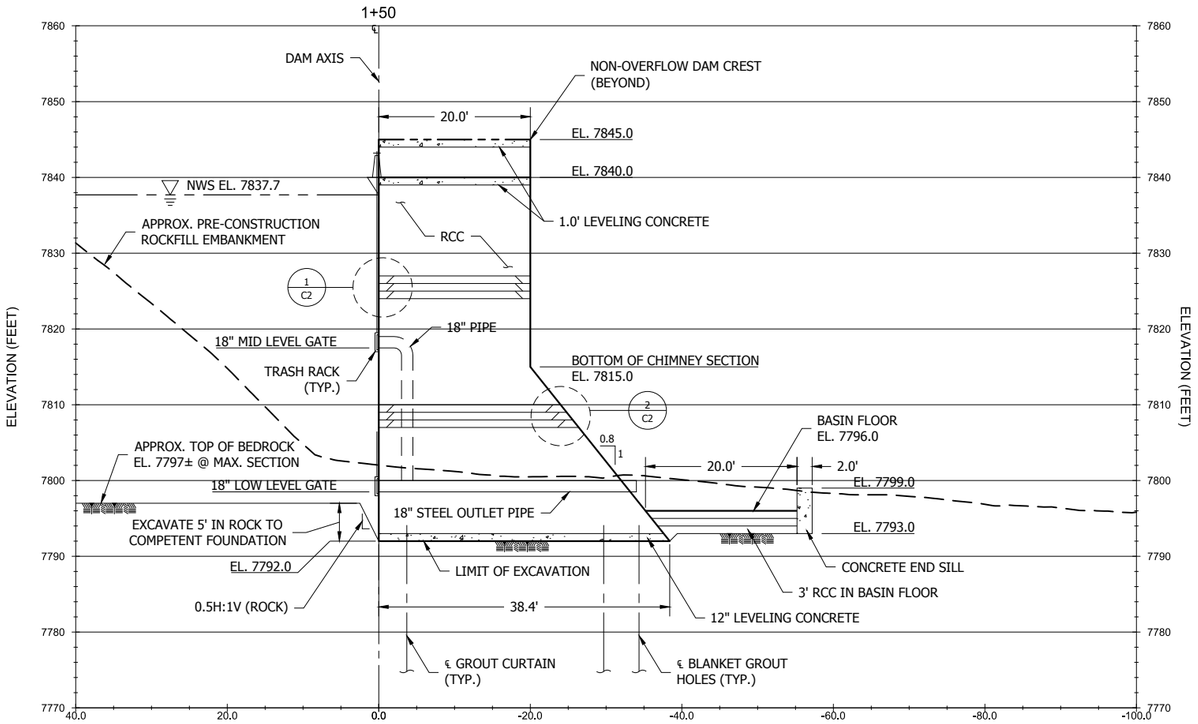
W. W. WHEELER & ASSOCIATES, INC
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405
303-761-4130 | fax 303-761-2802

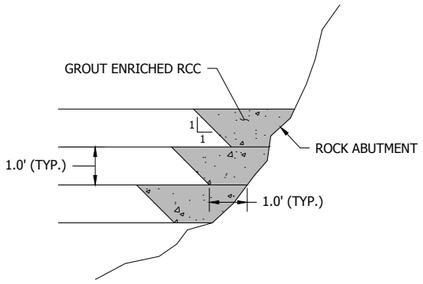
# LOWER BEAVER BROOK DAM

ALTERNATIVE 5 - NEW RCC DAM
CONCEPTUAL PLAN AND PROFILE

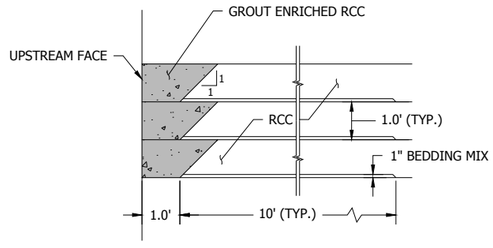
| | | | |
|---|---|---|---|
| Client | LOOKOUT MOUNTAIN WATER DISTRICT | | |
| Design | YKC | Wheeler No. | 1867.01 |
| Drawn | SAA | Sheet No. | 1 of 3 |
| Check | DTH | | |
| Plot Date | 07/24/2017 | Drawing No. | C1 |
| | 0 | | |



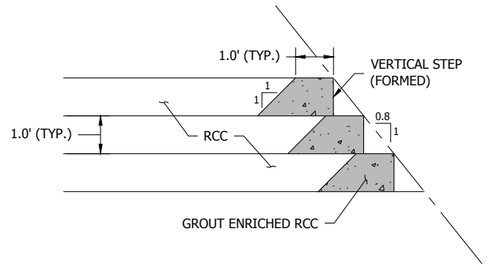

## NEW CONCRETE DAM
MAXIMUM SECTION — A / C1



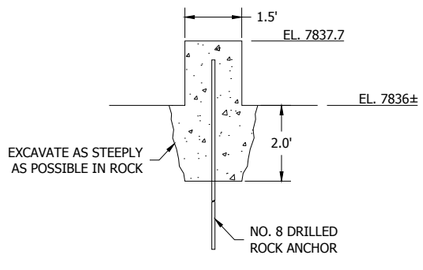

## RCC/ABUTMENT
TYPICAL DETAIL — 3




## UPSTREAM FACING
TYPICAL DETAIL — 1 / C2




## DOWNSTREAM FACING
TYPICAL DETAIL — 2 / C2




## SERVICE SPILLWAY CREST
TYPICAL SECTION — B / C1

R:\1800\1867\1867.01_LowerBBDam\CAD\LowerBeaverBrook_Alt2 7-24-17 09:33am Scott XREFS:

| Revisions | No. | Date | Made | Checked | Remarks |
|---|---|---|---|---|---|
| | 0 | 07/01/17 | YKC | DTH | PRELIMINARY CONCEPTUAL DRAWING |
| | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| Reference | Sheet No. | Drawing No. | Title |
|---|---|---|---|
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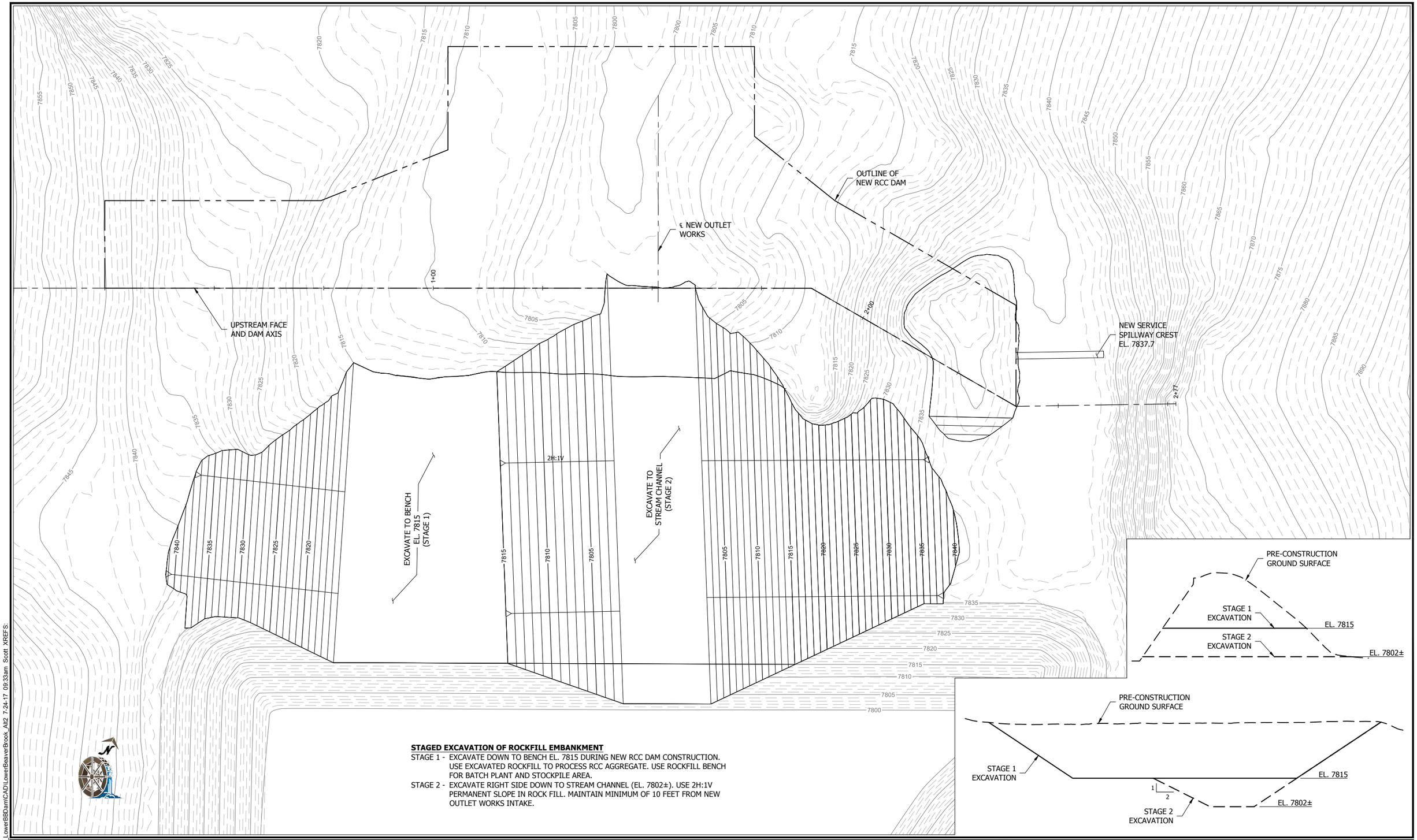
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405
303-761-4130 | fax 303-761-2802

LOWER BEAVER BROOK DAM
DAM REHABILITATION
ALTERNATIVE 5 - NEW RCC DAM
DAM SECTIONS AND DETAILS

| | |
|---|---|
| Client | LOOKOUT MOUNTAIN WATER DISTRICT |
| Design | YKC |
| Drawn | SAA |
| Check | DTH |
| Plot Date | 07/24/2017 |
| Wheeler No. | 1867.01 |
| Sheet No. | 2 of 3 |
| Drawing No. | C2 |
| | 0 |










**STAGED EXCAVATION OF ROCKFILL EMBANKMENT**

STAGE 1 - EXCAVATE DOWN TO BENCH EL. 7815 DURING NEW RCC DAM CONSTRUCTION. USE EXCAVATED ROCKFILL TO PROCESS RCC AGGREGATE. USE ROCKFILL BENCH FOR BATCH PLANT AND STOCKPILE AREA.

STAGE 2 - EXCAVATE RIGHT SIDE DOWN TO STREAM CHANNEL (EL. 7802±). USE 2H:1V PERMANENT SLOPE IN ROCK FILL. MAINTAIN MINIMUM OF 10 FEET FROM NEW OUTLET WORKS INTAKE.

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| Revisions | No. | Date | Made | Checked | Remarks |
|---|---|---|---|---|---|
| | 0 | 07/01/17 | YKC | DTH | PRELIMINARY CONCEPTUAL DRAWING |

| Reference | Sheet No. | Drawing No. | Title |
|---|---|---|---|

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& ASSOCIATES, INC
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405
303-761-4130 | fax 303-761-2802

# LOWER BEAVER BROOK DAM

DAM REHABILITATION

ALTERNATIVE 5 - NEW RCC DAM

STAGED EXCAVATION

| | |
|---|---|
| Client | LOOKOUT MOUNTAIN WATER DISTRICT |
| Design | YKC |
| Drawn | SAA |
| Check | DTH |
| Wheeler No. | 1867.01 |
| Sheet No. | 3 of 3 |
| Plot Date | 07/24/2017 |
| Drawing No. | 0 C3 |

# APPENDIX E

## FEASIBILITY-LEVEL COST OPINIONS FOR ALTERNATIVE NOS. 4 AND 5

# FEASIBILITY-LEVEL OPINION OF PROBABLE COSTS
# LOWER BEAVER BROOK DAM
## ALTERNATIVE 4 - DAM REHABILITATION WITH RCC OVERTOPPING PROTECTION

| Item No. | Item Description | Quantity | Unit | Unit Price | Total Cost |
|---|---|---|---|---|---|
| | | | | | |
| 1 | Mobilization and Preparatory Work | 1 | Lump Sum | $296,000.00 | $ 296,000 |
| 2 | Stream Diversion and Reservoir Control | 1 | Lump Sum | $33,000.00 | $ 33,000 |
| 3 | Foundation Dewatering | 1 | Lump Sum | $22,000.00 | $ 22,000 |
| 4 | Soil and Rockfill Excavation | 3500 | Cubic Yard | $10.29 | $ 36,000 |
| 5 | Rock Excavation | 600 | Cubic Yard | $30.00 | $ 18,000 |
| 6 | Site Demolition | 1 | Lump Sum | $139,000.00 | $ 139,000 |
| 7 | Foundation Grouting | 1 | Lump Sum | $52,000.00 | $ 52,000 |
| 8 | Rock Anchors | 70 | Each | $1,485.71 | $ 104,000 |
| 9 | Furnishing and Placing New Rockfill | 4200 | Cubic Yard | $44.29 | $ 186,000 |
| 10 | Furnishing and Placing Transition Zone | 1500 | Cubic Yard | $133.33 | $ 200,000 |
| 11 | Furnishing and Placing New Concrete Facing | 350 | Cubic Yard | $1,480.00 | $ 518,000 |
| 12 | Furnishing and Placing Concrete Plinth | 80 | Cubic Yard | $1,475.00 | $ 118,000 |
| 13 | Furnishing and Placing Concrete End Sill | 20 | Cubic Yard | $1,350.00 | $ 27,000 |
| 14 | Furnishing and Placing Service Spillway Crest | 5 | Cubic Yard | $1,200.00 | $ 6,000 |
| 15 | Furnishing and Placing Riprap | 80 | Cubic Yard | $175.00 | $ 14,000 |
| 16 | Furnishing and Placing Riprap Bedding | 40 | Cubic Yard | $175.00 | $ 7,000 |
| 17 | RCC Test Section | 1 | Lump Sum | $124,000.00 | $ 124,000 |
| 18 | Furnishing and Placing RCC | 2500 | Cubic Yard | $444.00 | $ 1,110,000 |
| 19 | Furnishing Cement for RCC | 500 | Tons | $266.00 | $ 133,000 |
| 20 | Furnishing and Placing Grout-Enriched RCC | 20 | Cubic Yard | $750.00 | $ 15,000 |
| 21 | 12-inch Steel Pipe | 50 | Linear Feet | $160.00 | $ 8,000 |
| 22 | 14-inch Steel Pipe | 160 | Linear Feet | $175.00 | $ 28,000 |
| 23 | 12-inch Gate Valve | 1 | Lump Sum | $15,000.00 | $ 15,000 |
| 24 | 14-inch Gate Valve | 1 | Lump Sum | $21,000.00 | $ 21,000 |
| 25 | Reclamation of Disturbed Areas | 1 | Lump Sum | $15,000.00 | $ 15,000 |
| | | | | | |
| | **Listed Items Subtotal** | | | | $ 3,245,000 |
| | | | | | |
| **Base Construction Subtotal (BCS)** | | | | | **$ 3,245,000** |
| | | | | | |
| **Direct Construction Subtotal (DCS)** | | | | | **$ 3,245,000** |
| | Final Design Field Investigations | | | | $ 108,000 |
| | Final Design Engineering (8% of DCS) | | | | $ 218,000 |
| | Permitting and Mitigation (5% of DCS) | | | | $ 136,000 |
| | Legal and Administrative Costs (2% of DCS) | | | | $ 54,000 |
| | Construction Administration and Engineering (10% of DCS) | | | | $ 272,000 |
| **TOTAL ESTIMATED PROJECT COST** | | | | | **$ 4,033,000** |

****** Costs are in 2020 dollars (Planned construction year)***



**W. W. Wheeler and Associates, Inc.**
3700 S Inca Street + Englewood, CO 80110 + 303-761-4130 + wwwheeler.com

# FEASIBILITY-LEVEL OPINION OF PROBABLE COSTS
# LOWER BEAVER BROOK DAM
# ALTERNATIVE 5 - NEW CONCRETE DAM

| Item No. | Item Description | Quantity | Unit | Unit Price | Total Cost |
|---|---|---|---|---|---|
| | | | | | |
| 1 | Mobilization and Preparatory Work | 1 | Lump Sum | $388,000.00 | $ 388,000 |
| 2 | Stream Diversion and Reservoir Control | 1 | Lump Sum | $6,000.00 | $ 6,000 |
| 3 | Foundation Dewatering | 1 | Lump Sum | $56,000.00 | $ 56,000 |
| 4 | Stage 1 Rockfill Excavation | 4500 | Cubic Yard | $10.44 | $ 47,000 |
| 5 | Stage 2 Rockfill Excavation | 2500 | Cubic Yard | $10.40 | $ 26,000 |
| 6 | Rock Excavation | 1500 | Cubic Yard | $36.67 | $ 55,000 |
| 7 | Site Demolition | 1 | Lump Sum | $139,000.00 | $ 139,000 |
| 8 | Foundation Curtain Grouting | 1 | Lump Sum | $128,000.00 | $ 128,000 |
| 9 | Foundation Blanket Grouting | 1 | Lump Sum | $41,000.00 | $ 41,000 |
| 10 | Furnishing and Placing Leveling Concrete | 230 | Cubic Yard | $960.87 | $ 221,000 |
| 11 | Furnishing and Placing Grout-Enriched RCC | 1000 | Cubic Yard | $769.00 | $ 769,000 |
| 12 | Furnishing and Placing Bedding Mix | 200 | Cubic Yard | $295.00 | $ 59,000 |
| 13 | Furnishing and Placing Concrete End Sill | 23 | Cubic Yard | $1,347.83 | $ 31,000 |
| 14 | Furnishing and Placing Service Spillway Crest | 5 | Cubic Yard | $1,200.00 | $ 6,000 |
| 15 | RCC Test Section | 1 | Lump Sum | $124,000.00 | $ 124,000 |
| 16 | Furnishing and Placing RCC | 4500 | Cubic Yard | $399.33 | $ 1,797,000 |
| 17 | Furnishing and Placing Fly Ash for RCC | 430 | Tons | $267.44 | $ 115,000 |
| 18 | Furnishing Cement for RCC | 430 | Tons | $267.44 | $ 115,000 |
| 19 | Contraction Joints | 3100 | Linear Feet | $18.39 | $ 57,000 |
| 20 | 18-inch Steel Pipe | 60 | Linear Feet | $200.00 | $ 12,000 |
| 21 | 18-inch Cast-iron Sluice Gates | 2 | Each | $20,000.00 | $ 40,000 |
| 22 | Miscellaneous Metals | 1 | Lump Sum | $15,000.00 | $ 15,000 |
| 23 | Reclamation of Disturbed Areas | 1 | Lump Sum | $15,000.00 | $ 15,000 |
| | | | | | |
| | **Listed Items Subtotal** | | | | $ 4,262,000 |
| | | | | | |
| **Base Construction Subtotal (BCS)** | | | | | **$ 4,262,000** |
| | | | | | |
| **Direct Construction Subtotal (DCS)** | | | | | **$ 4,262,000** |
| | Final Design Field Investigations | | | | $ 162,000 |
| | Final Design Engineering | | | | $ 286,000 |
| | Permitting and Mitigation | | | | $ 179,000 |
| | Legal and Administrative Costs | | | | $ 71,000 |
| | Construction Administration and Engineering | | | | $ 357,000 |
| **TOTAL ESTIMATED PROJECT COST** | | | | | **$ 5,317,000** |

****** Costs are in 2020 dollars (Planned construction year)***



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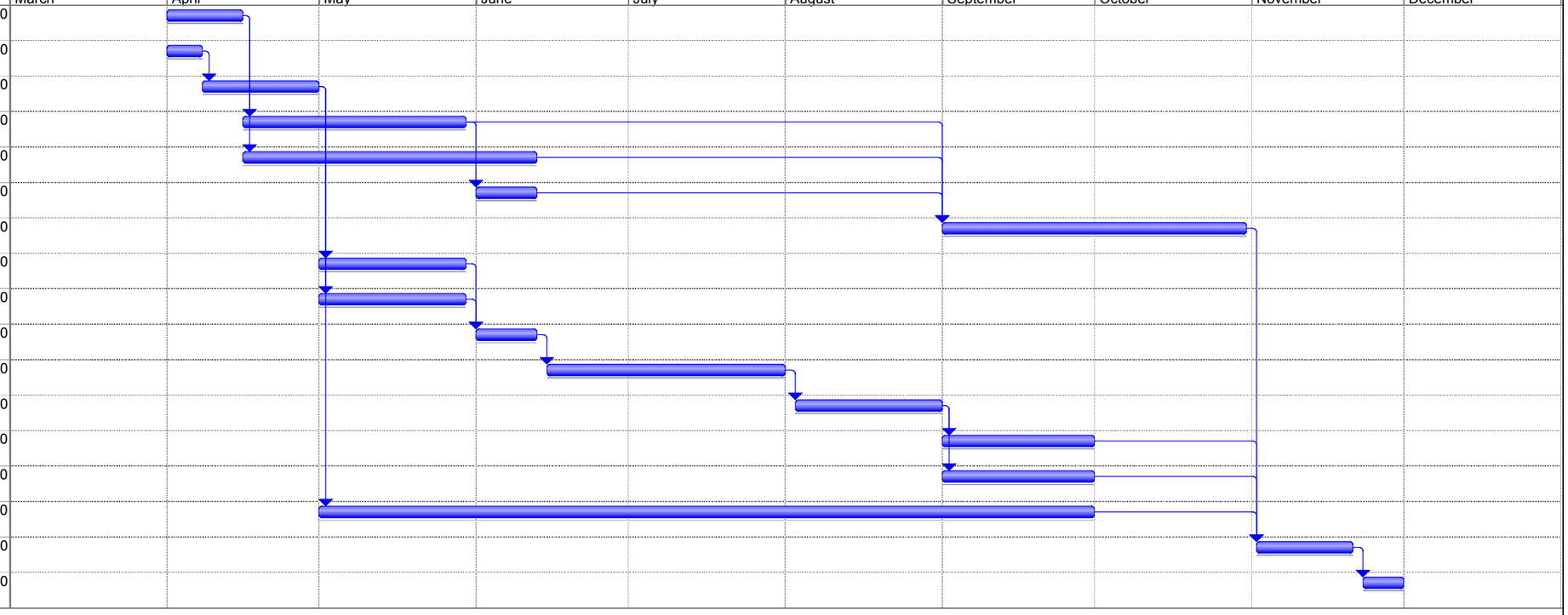
# APPENDIX F

## PRELIMINARY CONSTRUCTION SCHEDULE FOR ALTERNATIVE NOS. 4 AND 5

# W.W. Wheeler & Associates, Inc.
# Lower Beaver Brook Dam
# Estimated Construction Schedule
# Alternate 4 - Dam Rehabilitation with RCC Overtopping Protection

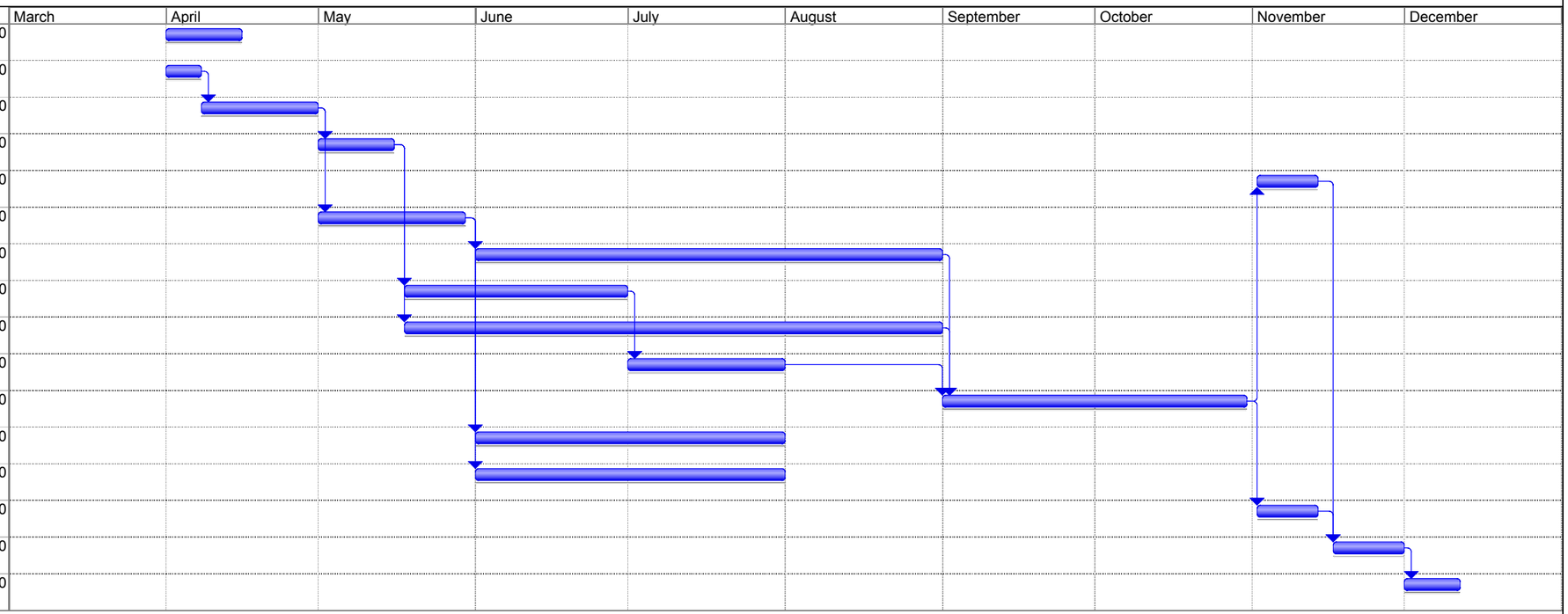
| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | Mobilization/Site Preparation | Wed 4/1/20 | Wed 4/15/20 |
| 2 | Drain Reservoir | Wed 4/1/20 | Tue 4/7/20 |
| 3 | Stream Diversion/Cofferdam | Wed 4/8/20 | Thu 4/30/20 |
| 4 | RCC Batch Plant Setup | Thu 4/16/20 | Fri 5/29/20 |
| 5 | Stockpile RCC Aggregate | Thu 4/16/20 | Fri 6/12/20 |
| 6 | RCC Test Section | Mon 6/1/20 | Fri 6/12/20 |
| 7 | RCC Production Placement | Tue 9/1/20 | Fri 10/30/20 |
| 8 | Excavation in Embankment | Fri 5/1/20 | Fri 5/29/20 |
| 9 | Site Demolition | Fri 5/1/20 | Fri 5/29/20 |
| 10 | New Concrete Plinth | Mon 6/1/20 | Fri 6/12/20 |
| 11 | Foundation Grouting | Mon 6/15/20 | Fri 7/31/20 |
| 12 | New Embankment Fill | Mon 8/3/20 | Mon 8/31/20 |
| 13 | New Concrete Facing | Tue 9/1/20 | Wed 9/30/20 |
| 14 | New Service Spillway Crest | Tue 9/1/20 | Wed 9/30/20 |
| 15 | Outlet Works Gates & Pipes | Fri 5/1/20 | Wed 9/30/20 |
| 16 | Reclamation/Cleanup | Mon 11/2/20 | Fri 11/20/20 |
| 17 | Demobilization | Mon 11/23/20 | Mon 11/30/20 |




W. W. WHEELER & ASSOCIATES, INC.
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405

# W.W. Wheeler & Associates, Inc.
# Lower Beaver Brook Dam
# Estimated Construction Schedule
# Alternate 5 - New Concrete Dam

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 1 | Mobilization/Site Preparation | Wed 4/1/20 | Wed 4/15/20 |
| 2 | Drain Reservoir | Wed 4/1/20 | Tue 4/7/20 |
| 3 | Stream Diversion | Wed 4/8/20 | Thu 4/30/20 |
| 4 | Stage 1 Rockfill Excavation | Fri 5/1/20 | Fri 5/15/20 |
| 5 | Stage 2 Rockfill Excavation | Mon 11/2/20 | Fri 11/13/20 |
| 6 | Dam Foundation Excavation | Fri 5/1/20 | Fri 5/29/20 |
| 7 | Foundation Grouting | Mon 6/1/20 | Mon 8/31/20 |
| 8 | RCC Batch Plant Setup | Mon 5/18/20 | Tue 6/30/20 |
| 9 | Process/Stockpile RCC Aggregate | Mon 5/18/20 | Mon 8/31/20 |
| 10 | RCC Test Section | Wed 7/1/20 | Fri 7/31/20 |
| 11 | RCC Production Placement | Tue 9/1/20 | Fri 10/30/20 |
| 12 | Outlet Works Gate Tower & Conduit | Mon 6/1/20 | Fri 7/31/20 |
| 13 | New Service Spillway Crest | Mon 6/1/20 | Fri 7/31/20 |
| 14 | Outlet Works Gates | Mon 11/2/20 | Fri 11/13/20 |
| 15 | Reclamation/Cleanup | Tue 11/17/20 | Mon 11/30/20 |
| 16 | Demobilization | Tue 12/1/20 | Fri 12/11/20 |




W. W. WHEELER
& ASSOCIATES, INC.
Water Resources Engineers
3700 S. Inca Street | Englewood, CO 80110-3405

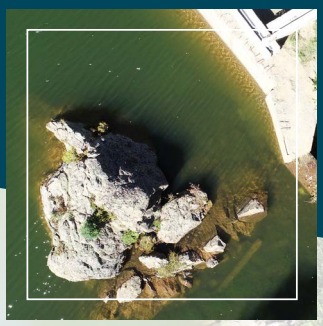
GEI Consultants

# Lower Beaver Brook Dam Project

## Consulting and Engineering Services: Design and Construction Management

Prepared for: Lookout Mountain Water District

August 28, 2019



# Cover Letter

August 28, 2019

Bob Heine, President
Lookout Mountain Water District
1202 Bergen Parkway, Suite 215
Evergreen, CO 80439

**Re: Consulting and Engineering Services for the Design and Construction Management of Lower Beaver Brook Dam**

Dear Mr. Heine:

GEI Consultants, Inc. (GEI) is submitting this proposal for design and construction management for replacement of the Lower Beaver Brook Dam in response to your Request for Proposals (RFP) issued on July 31, 2019. The Lookout Mountain Water District (District) has an incredible opportunity to reconstruct Lower Beaver Brook Dam with significant funding through your FEMA grant. GEI understands that even with this 75% Federal contribution, the District is financially stretching to fund this match and that there is no room for budget exceedances.

We have reviewed the conceptual designs and cost estimates developed for the grant application and have identified some significant risk items that must be addressed during design, permitting, bidding, and construction to reduce the potential for project costs that are higher than anticipated.

## *Risk During Design*

This project is driven by an aggressive schedule due to the FEMA funding stipulations. GEI commits to developing an efficient design from concept through construction. Any fatal flaws, including anticipated exceedance of the identified construction budget, will be provided to the District as they are identified. The Incremental Damage Analysis that GEI completed to reduce the dam's design flood by nearly 80% may not be valid with this dam type and could be significantly higher, up to the full flood that the Upper Beaver Brook Dam is designed for. An early task will be to reconcile the hydrology so that a refined dam cross section can be used. During our 30% design workshop, we will incorporate a risk-based approach to this design so that the District understands where the greatest risk potential lies, what the greatest drivers for cost will be, and how this project can be constructed for the allotted money available from the District and the FEMA grant.

## *Permitting Risk*

Any identified issue that could trigger re-evaluation of the Finding of No Significant Impact (FONSI) will be identified and mitigated if possible. Sarah Skigen-Caird will work directly with the District to facilitate issuance of the U.S. Army Corps of Engineers (Section 401 and 404) and FEMA (Record of Environmental Consideration) permits required for construction. The State Engineer's Office (SEO) will be integrated into the design process from the project kick off through submission of final documents to reduce risk of late design re-work which could affect schedule. We have successfully used this collaborative process on past projects to expedite regulatory review time.

## *Bid Selection Risk*

Developing appropriate scoring criteria, properly evaluating and qualifying each contractor, and understanding how unit cost items are loaded into the bid schedule will be key to contractor selection. GEI will work closely with the Board selection committee throughout the bidding process to mitigate this risk.

GEI will work closely with the Board selection committee throughout the bidding process to mitigate this risk.

### *Construction Risk*

The construction window is very small for this project. Our plan entails considering early construction activities, such as major construction of water treatment plant diversions and site access before the 2021 construction season. In addition to providing a head start for the 2021 construction, this would allow testing to demonstrate that water supplies will not be interrupted once the reservoir is drawn down. Stormwater management, protection of deliveries to downstream water users, and protection of the District's facilities and contractor's work and equipment are essential to the successful completion of this project.

Selecting and involving a construction contractor early in the design process is a direction many owners are moving towards in order to reduce overall construction costs and schedule impacts. GEI can assist the District if this approach is chosen.

### *Operational Risk*

The downstream conceptual dam layout may not have an adequately sized stilling basin to dissipate energy from overtopping flows. Proper design and modeling of the stilling basin will help protect the water treatment plant from damage and potential washout during large runoff events. While we believe the existing replacement dam concept is constructible, we have also considered a dam replacement concept centered near the existing dam alignment that would provide better energy dissipation.

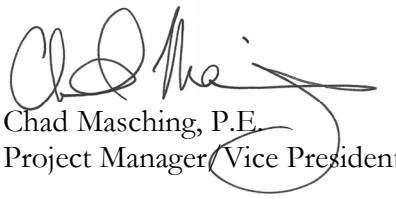
The existing flume has been susceptible to washout during higher spillway discharges. We recommend incorporating outlet works discharges and a small auxiliary overflow spillway into the main dam so that flow measurement can be constructed in a protected area.

GEI is committed to working with the District, FEMA, and the SEO through design workshops, Board Meeting attendance, and weekly updates with the District's project representative. Our team includes RIZZO International, CCS Surveying, and Dan Johnson (Roller Compacted Concrete [RCC] expert), all specifically chosen to provide exceptional value to the District.

GEI has the necessary qualifications, experience, and resources to successfully deliver this work to the District, and we affirm that these resources will be efficiently utilized on this project. We have read the terms and conditions, requirements, and instructions in this RFP. Please review our attached proposal and call me at 303.264.1088 or email at cmasching@geiconsultants.com if you have any questions or require additional information. We would be happy to discuss our proposal personally with the District's selection committee and provide additional details about our concepts. We look forward to delivering another successful construction project to the District.

Sincerely,

GEI CONSULTANTS, INC.



Chad Masching, P.E.
Project Manager / Vice President

Paul Eggers, P.E., PMP
Engineering Division Manager

**GEI Consultants, Inc.**
4601 DTC Boulevard, Suite 900
Denver, CO 80237
T: 303-264-1001
F: 303-662-8757

# Summary

GEI Consultants, Inc. is an employee-owned engineering, environmental, and water resources firm that provides civil and geotechnical engineering and geologic services for dams and levees, power plants, and pipelines and tunnels. **GEI is one of the top dam engineering firms in the U.S. and the recipient of many top awards for project innovation. Additionally, GEI is a leading provider of dam safety and inspection services.** Since its inception in 1970, GEI has provided engineering services on more than 35,000 projects, including thousands of dam, water resource, and flood control projects throughout the U.S.

GEI has designed and/or inspected over 1,000 dams ranging in heights from 10 feet to over 250 feet. We have been performing dam alternative studies, rehabilitation designs, and safety inspections and evaluations for almost 50 years. These have included RCC gravity dams, earthfill and rockfill embankments, masonry dams, arch dams, buttress dams, timber crib, and conventional concrete dams. Our dam designs and evaluations are led by licensed professional engineers and geologists.

While our project portfolio includes large private, state, and federal clients such as U.S. Bureau of Reclamation and Xcel Energy, some of our most challenging and rewarding projects include small private and municipal clients such as the Lookout Mountain Water District. These clients are typically financially constrained and require innovative solutions to save construction costs while meeting project objectives. A local client example is the Big Elk Meadows Association, near Lyons, Colorado, which provides treated water for its 166 taps. The 2013 flooding caused failures of all five of their water storage dams. Reconstruction of these facilities was made possible with FEMA grant funding, similar to that provided for the Lower Beaver Brook Dam project.

**GEI has developed alternatives and/or final designs for 30 RCC dams, spillways, and overtopping protection projects**. GEI is one of the most technically capable dam engineering firms in the nation, ranked #11 in ENR's top dam designers in the United States, and we bring that depth of expertise to the District. **Our team includes Dan Johnson, a former GEI dams practice leader with 45 years of experience and a history of 35 RCC projects**. Additionally, our team includes RIZZO International, a Woman's Business Enterprise (WBE) global engineering firm that has provided RCC mix design, dam design, and testing services on over 15 RCC projects.

**Photo 1: New Big Cherry RCC Dam**

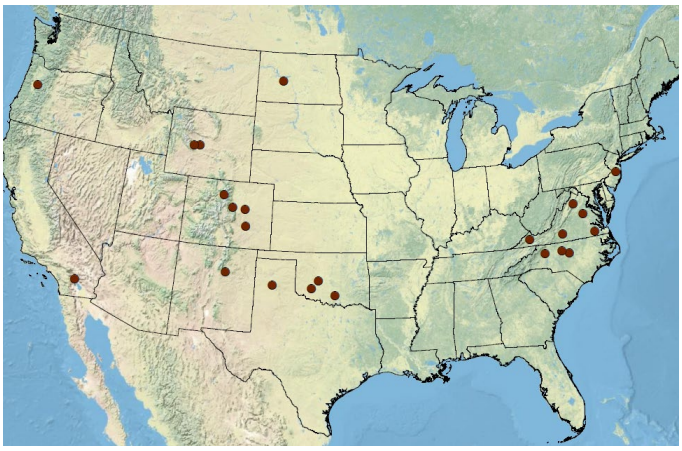
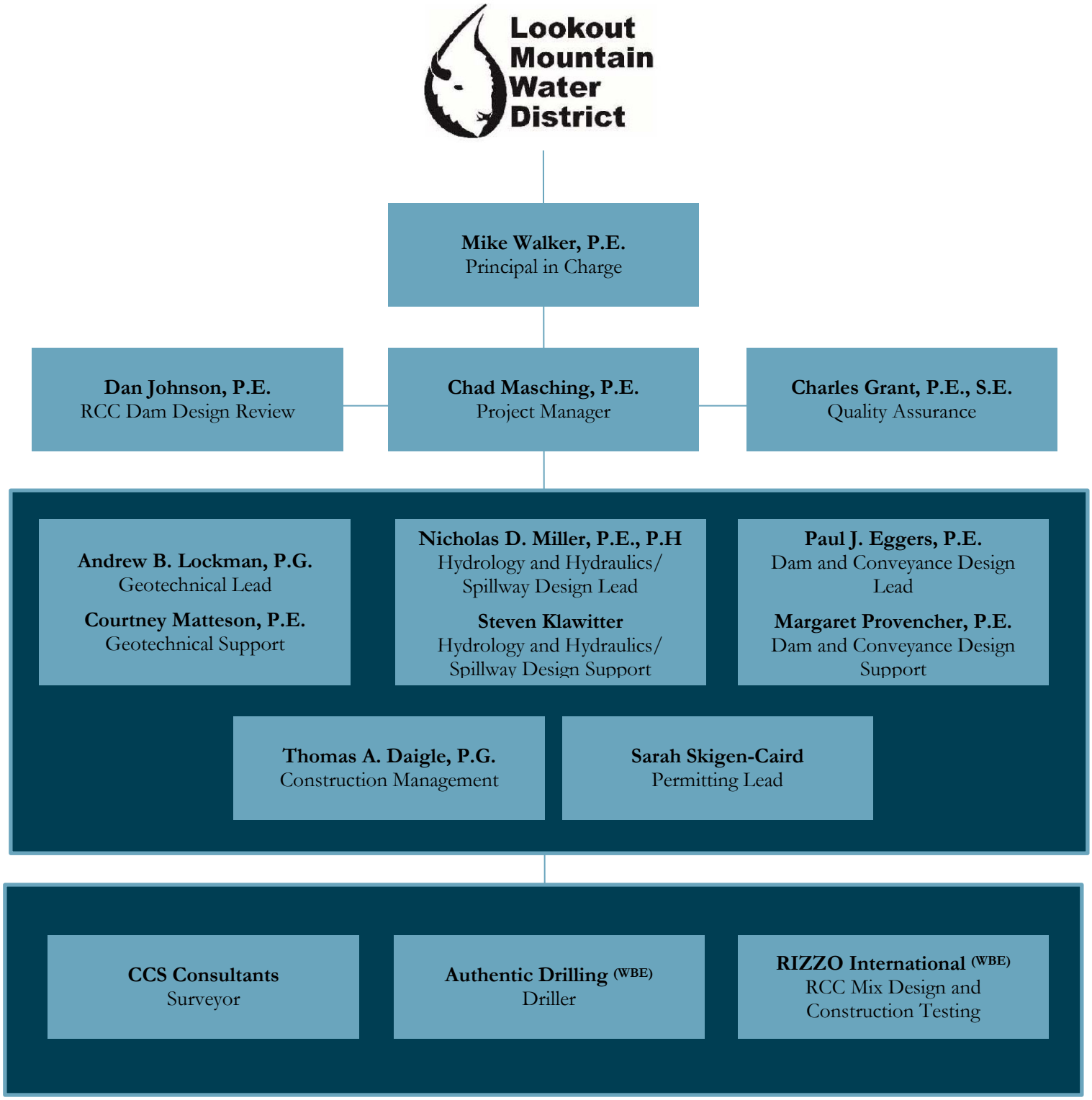


**Figure 1: GEI RCC Dam and Spillway Project Locations**

CCS Consultants, our project surveyor, has a long history with the District's dam monitoring. Authentic Drilling is a WBE drilling company based in Kiowa that has provided services on a number of GEI's dam investigation projects and will bring the necessary skill and professionalism required during drilling at the project site. Nearly 100% of this work will be completed out of GEI's Denver office, and we are able to meet with the District in person at a moment's notice.


Lookout Mountain Water District
Mike Walker, P.E.
Principal in Charge
Dan Johnson, P.E.
RCC Dam Design Review
Chad Masching, P.E.
Project Manager
Charles Grant, P.E., S.E.
Quality Assurance
Andrew B. Lockman, P.G.
Geotechnical Lead
Courtney Matteson, P.E.
Geotechnical Support
Nicholas D. Miller, P.E., P.H
Hydrology and Hydraulics/ Spillway Design Lead
Steven Klawitter
Hydrology and Hydraulics/ Spillway Design Support
Paul J. Eggers, P.E.
Dam and Conveyance Design Lead
Margaret Provencher, P.E.
Dam and Conveyance Design Support
Thomas A. Daigle, P.G.
Construction Management
Sarah Skigen-Caird
Permitting Lead
CCS Consultants
Surveyor
Authentic Drilling (WBE)
Driller
RIZZO International (WBE)
RCC Mix Design and Construction Testing

# Background and Government-wide SAM Requirement

## RESPONDENT BACKGROUND

GEI Consultants, Inc. is a consulting engineering firm that delivers value-laden professional services that improve our world's built environment. With more than 900 staff and 40 offices across the U.S. and Canada, GEI is a leader in providing multidisciplined engineering and technical services to a range of private and public sector clients, both domestically and abroad. The lead office for this project will be the Denver, Colorado, branch of GEI, supported by the whole of GEI's staff and services in the company.

| | |
|---|---|
| Company Names | GEI Consultants, Inc., a Massachusetts Corporation<br>GEI Consultants, Inc., a Delaware Corporation<br>GEI Consultants, Inc. P.C.<br>GEI Consultants of North Carolina, P.C.<br>GEI Consultants of Michigan, P.C.<br>Inland Seas Engineering (Wholly-Owned Subsidiary)<br>Hayden Consultants (Wholly-Owned Subsidiary)<br>GEI Designers of MA (Wholly-Owned Subsidiary)<br>GEI Consultants Corporation (Wholly-Owned Canadian Subsidiary) |
| Project Lead Branch | GEI Denver Office:<br>4601 DTC Boulevard<br>Suite 900<br>Denver, CO 80237<br>303.662.0100 phone<br>303.662.8757 fax |
| State of Incorporation | Massachusetts |
| Ownership | Employee Owned |
| GEI Headquarters | Woburn, Massachusetts<br>400 Unicorn Park Drive<br>Woburn, MA 01801<br>781.721.4000 phone<br>781.721.4073 fax |
| Licensed to do business in Colorado | GEI has a certificate of "good standing" and is licensed to do business in the State of Colorado. |

As an employee-owned firm, we foster personal relationships with our clients and support our staff in a partnership model, which is underpinned by continuous learning and sharing of knowledge. We retain proven, recognized experts and attract the best young minds to deliver to our clients a refreshing blend of technical expertise, collaborative spirit, and innovation that is rare in our profession.

## SAM.GOV VERIFICATION

GEI Consultants has no exclusions in SAM.gov. Confirmation of our registration is below. No person assigned to this project is excluded from working on federal contracts.

GEI Consultants, Inc.
DUNS: 057824526 CAGE Code: 4P724
Status: Active
Expiration Date: 04/07/2020
Purpose of Registration: All Awards

400 Unicorn Park Dr
Woburn, MA, 01801-3365,
UNITED STATES

**Entity Overview**
**Entity Registration Summary**
**Name:** GEI Consultants, Inc.
**Business Type:** Business or Organization
**Last Updated By:** Kelly Cohane
**Registration Status:** Active
**Activation Date:** 04/08/2019
**Expiration Date:** 04/07/2020

**Exclusion Summary**
**Active Exclusion Records?** No

# Project Experience

GEI has designed and built dams of all types and sizes across the U.S., and although our corporate resume is extensive and speaks to the breadth and depth of our background and resources, the real source of pride for our team lies in the trusted relationships we have built with our local clients in Colorado and the West. Our experience and the positive client relationships we enjoy are based not just on delivering technical excellence but in working directly with our client's unique problems and concerns. To that end, we consider our legacy and reputation to be founded on providing solutions to difficult problems as well as establishing long-term and trusted client partnerships.

Recently, our team completed geotechnical investigations and provided design recommendations for foundation grouting, groundwater cutoff, and bearing capacity at Chimney Hollow Dam near Loveland, Colorado. One key challenge of that project was addressing foundation concerns at the main dam, which included placing a large concrete plinth to connect the water barrier in the dam to the underlying bedrock. The bedrock in this location is highly variable in terms of compressibility, ultimate bearing capacity, and permeability. To meet these challenges, our Denver-based team reached out to our in-house industry experts from specialized fields that include grouting in highly karstic limestone bedrock to developing foundation designs for some of the largest high-rise buildings in the world. These contributions made the project a success and provided our client with the confidence that their project challenges were being addressed by some of the brightest minds in the industry, with a constant focus on costs and long-term risks.

Our background and recent experience in hydrologic evaluations includes hydrology and hydraulic (H&H) analyses for Upper Beaver Brook and Lower Beaver Brook Dams, as well as spillway modification designs and construction oversight at Upper Beaver Brook Dam. We stay at the forefront of industry changes by attending and actively participating in conferences to advance the state of knowledge in our H&H practice. A key aspect of our hydrologic evaluations includes following the latest advancements in the science as well as staying up to date with changes in regulations, such as the recent changes to the SEO's requirements for developing precipitation as they relate to inflow design floods. One example includes the Upper Black Creek Dam evaluation in Summit County, which includes spillway capacity assessments and flood routing evaluations in support of dam safety. That project is currently being performed using state of the art modeling methods and is in full conformance with the latest SEO requirements.

Our extensive experience in H&H design, construction, and evaluation includes work on outlet works conduits, inlet and outlet structures, and spillways. Recent and extensive work evaluating spillways in California after the failure of the spillway at Oroville Dam has highlighted the importance the designer plays during construction for safe and reliable spillway operation. Our skills, knowledge, and experience in designing, constructing, and evaluating the performance of spillways and other hydraulic structures are unmatched, and we are excited about bringing this experience to the Lower Beaver Brook project.

We also understand that a critical aspect for success at Lower Beaver Brook is meeting the project schedule due to grant funding requirements. A major challenge to this requirement will be to facilitate rapid regulatory reviews of project deliverables. We have maintained a long lasting and positive relationship with individual members of the SEO and will leverage these relationships extensively to facilitate reviews of design documents. This will be accomplished by fostering clear and frequent communications with the Dam Safety Officers in advance of project deliverables and providing them with complete and quality deliverables. Our approach to communication, our positive working history, and trust with the SEO are built on a history of quality, integrity, and mutual respect between individuals and the organizations.

The following pages highlight our RCC experience and include information on client contacts.

Between the combined experience of GEI Consultants, RIZZO International, and Dan Johnson, we have provided engineering services on over 80 RCC projects. Table 1 below highlights GEI's RCC dam related portfolio as well as the types of design services provided for each project. We will draw from this combined experience to streamline the design process for Lower Beaver Brook Dam.

**Table 1: GEI RCC Dam Related Projects**

| | | Type of Experience | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Project** | **Application** | **RCC Quantity (C.Y.)** | **Dam height (ft)** | **Mix Design** | **Feas. Design** | **Conc. Design** | **Final Design** | **Const. Oversight** |
| Aetna Lakes Dam No. 1 and Dam No. 2, NJ | New Dams | 10,000 each | 20 | ■ | ■ | ■ | ■ | ■ |
| Bass Lake Dam, NC | Overtopping | 6,000 | 20 | | | ■ | | |
| Cedar Run Dam, VA | New Dam | 100,000 | 90 | ■ | | | ■ | |
| Clear Lake Dam, CO | Overtopping | 3,150 | 19 | | | ■ | ■ | ■ |
| Comanche Dam, OK | Raise/Buttress | 7,200 | 50 | | | ■ | | |
| Emergency Storage Project, CA | New Dams | 170,000-6,000,000 | 100-550 | | ■ | | | |
| Fountain Creek Improvement, CO | Slope Protection | not avail. | -- | ■ | ■ | | ■ | |
| Grama Dam, OK | Overtopping | 12,900 | 43 | | | ■ | | |
| Greybull Valley Dam, WY | New Dam | | | | ■ | | | |
| Harrison Lake Dam, VA | Overtopping | 5,250 | 10 | ■ | | ■ | ■ | |
| Hungry Mother Dam, VA | Overtopping | 13,300 | 44 | ■ | | | ■ | |
| Lake Ilo Dam, ND | Emergency Spillway | 3,850 | 38 | ■ | | ■ | ■ | ■ |
| Lake Raleigh Dam, NC | Overtopping | 5,000 | 22 | | | ■ | | |
| Milltown Hill Dam, OR | New Dam | 225,000 | 190 | ■ | | | ■ | |
| New Big Cherry Dam, VA | New Dam | 13,000 | 70 | ■ | ■ | ■ | ■ | ■ |
| New Elmer Thomas Dam, OK | New Dam | 38,000 | 113 | ■ | | ■ | ■ | ■ |
| Pardee Dam, CA | Raise/Buttress | 1,400,000 | 400 | | | ■ | | |
| Price Lake Dam, NC | Overtopping | 2,700 | 30 | ■ | | | ■ | |
| Randleman Dam, NC | New Dam | 160,000 | 100 | | | | ■ | |
| Ray Lake Dam, WY | Upstream Facing | 17,000 | 30 | | ■ | | | |
| San Vicente Dam, CA | Dam Raise | 600,000 | 337 | | ■ | ■ | | |
| Sheriff Reservoir, CO | Overtopping | 5,600 | 45 | | ■ | | | |
| Standley Lake Dam, CO | Spillway Chute | | NA | ■ | ■ | ■ | ■ | ■ |
| Storrie Lake Dam, NM | Upstream Facing | 11,000 | 80 | ■ | | | ■ | ■ |
| Trout Creek Dam, CO | New Dam | 25,000 | 60 | ■ | | | ■ | |
| Trout Lake Dam, NC | Overtopping | 3,400 | 28 | ■ | | | ■ | |
| Umbarger Dam, TX | Overtopping | 28,500 | 43 | ■ | | ■ | ■ | ■ |
| Washakie Dam, WY | New Dam | 86,000-150,000 | 165-205 | | ■ | | | |
| Western Branch Dam, VA | Emergency Spillway | 7,500 | 41 | | ■ | ■ | ■ | |

We have provided several representative projects on the following page to highlight our relevant experience which include RCC projects, FEMA grants/reconstruction projects for small associations, and our past design work with the District. Additional projects and client contacts can be provided upon request.

# Representative Projects within Last 15 Years

## AETNA DAMS

*Dewberry-Goodkind, Alaimo Group, Borough of Medford Lakes*
*Burlington County, New Jersey*

Upper and Lower Aetna Dams were two earth embankment dams destroyed by flooding caused by 12 inches of rain that fell in a 14-hour period. The flooding in Medford Lakes was precipitated by a series of dam failures upstream, which ultimately led to the overtopping of both dams.

State guidelines suggest that the construction or rehabilitation of dams not alter the existing upstream or downstream flow characteristics. Therefore, spillway capacity or reservoir storage could not be increased to allow the design storm to be passed safely, and the dams had to be designed to allow overtopping when the spillway discharge capacity was exceeded.

The work involved the simultaneous construction of two 300-foot-long by 40-foot-wide RCC dams with reinforced concrete facing elements and precast concrete spillways.

GEI provided design and construction support for the geotechnical and structural components, including conceptual cofferdam and excavation support design, evaluation of foundation soils, RCC mix design, RCC construction sequencing, and aggregate filter design.

Issues that affected the design and construction were:

- Presence of a sand foundation
- Areas of poor foundation soils
- Absence of appropriate RCC aggregate on-site
- Off-site RCC batching
- Construction in a heavily populated area
- Construction within existing reservoirs
- Accelerated construction schedule

**Reference**
Peter Black, PE, Dewberry Project Manager
973.576.9677, pblack@dewberry.com
**Key Team Members:** Mike Walker, Charles Grant, Dan Johnson
**Project Type:** RCC Dam Design and Construction
**Size/Capacity:** two 10,000 CY RCC Dams
**Fees:** Contracted: $235K/Final: $333K (w construction add-on)
**Dates**: June 2005 – January 2008

## TAUM SAUK UPPER RESERVOIR REBUILD

*Ameren Missouri*
*Lesterville, Missouri*

In December 2005, an overtopping failure of the Upper Reservoir at the Taum Sauk Pump Storage facility resulted in over $1B in damage. Ameren Missouri elected to reconstruct the dam as an RCC ring dam, using materials from the failed embankment dam. The award winning reconstruction included a gravity dam up to 125 feet high and 6,800 feet long and supports a hydropower capacity of 450 MW. As this is a pump storage project, water is piped from the Upper Reservoir through the powerhouse turbines to the Lower Reservoir, which is approximately 860 feet lower in elevation during peak power demand when power is more expensive. The water is then pumped back up to the Upper Reservoir at night when the price of electricity is lower.

RIZZO was the Engineer of Record and Construction Manager for the reconstruction of the hydropower storage reservoir. RIZZO also performed the Phase 1 mix design of the RCC and testing of aggregates, which were derived from on-site materials.

GEI provided review of the RIZZO design, including foundation treatment, internal drainage provisions, quantities, cost estimates, RCC dam sections and RCC mix design.

Key Elements

- RCC Dam Design
- RCC Mix Design
- Construction QA testing
- Construction Cost Estimating

**Reference**
Matt Frerking, Chief Dam Safety Engineer
314.957.3426, mfrerking@ameren.com
**Key Team Members:** Dan Johnson, Chad Masching
**Project Type:** Hydropower Generation
**Size/Capacity:** 4,350 acre-feet
**Fees:** RIZZO Contracted: $45.5M
GEI Contracted and Final: $75K
**Dates:** 2006 - 2010

## BIG ELK MEADOWS DAM RECONSTRUCTIONS

*Big Elk Meadows Association*
*Lyons, Colorado*

GEI provided the Big Elk Meadows Association (BEMA) near Lyons, Colorado, with final design and construction engineering services to reconstruct five small, low-hazard embankment dams that were destroyed during the Colorado September 2013 flooding. In addition to recreation, these dams provided BEMA with their drinking water supply.

BEMA owns and operates the raw and treated water storage facilities serving 166 homes and received FEMA funding to reconstruct four of the facilities. GEI was originally contracted to reconstruct one dam but ended up designing replacements for all five facilities, with dam heights ranging from 16 to 26 feet high and reservoir storage capacities ranging from 8 to 32 acre-feet. The final design of the five new dams were approved by the SEO and also included spillways, outlet works, and flow measurement flumes.

Project challenges for the reconstruction of the dams included construction with limited site access at an elevation over 7,500 feet, providing a continuous water supply for the water treatment plant, and difficult site access for equipment and construction materials. During construction, GEI provided engineering services for field support and testing.

Key Elements

- FEMA funded project for small water provider
- WTP supply during construction and active stream channel
- Hydrologic and geotechnical investigations and reporting
- Design Alternatives
- Slope stability and seepage analysis
- Final design and engineering
- Plans, specifications, and construction costs estimate
- Bidding support and construction oversight

**Reference**
Glenn Christensen, Project Manager
303.823.5328, glenn.christensen@att.net
**Key Team Members:** Nick Miller, Paul Eggers, Chad Masching, Nate Jorgensen, Courtney Mattson
**Project Type:** Raw Water Supply and Recreation
**Size/Capacity:** 5 reservoirs between 8 and 32 acre-feet, total capacity 108 acre-feet
**Fees:** Contracted: $545,000/Final: $500,000
**Dates:** 2014 - current

## UPPER BEAVER BROOK DAM

*Evergreen, Colorado*
*Lookout Mountain Water District*

Upper Beaver Brook Reservoir is LMWD's primary raw water storage facility. Prior to the spillway improvements, the reservoir impounded 257 acre-feet at the spillway crest. GEI designed a new 3-cycle labyrinth spillway which provided an additional 10 feet of reservoir storage to increase the total stored volume by over 50%. Additionally, GEI designed modifications to replace the existing 90-year-old outlet works stems with new stainless-steel stems encased in a food grade oil filled pipe assembly to allow winter operation of the control valves.

GEI provided construction oversite of the work, which included blast monitoring to increase the width of the spillway excavation by 10 feet with a full reservoir. The reinforced concrete labyrinth structure was constructed and spillway rundown modifications were made to accommodate the design flood discharges. Rock generated from the spillway excavation was utilized to provide a slope stabilization berm on the downstream side of the dam so that export hauling of blast rock was not required.

GEI provided permitting support with the U.S. Army Corps of Engineers and Forest Service and coordinated closely with the SEO and owner during design and construction to manage change conditions that were encountered. The project was completed on schedule and within the District's construction budget.

Key Elements

- Probable Maximum Flood and Inflow Design Flood
- Spillway Analysis
- Geotechnical analysis and investigation
- Grout Curtain Design
- Seepage and slope stability modeling
- Preparation of design and construction schedules, project plans, construction costs
- Construction observation, inspection, and review

**Reference**
Dean Snyder, LMWD Project Designee
303.910.7311, dsnyder6@comcast.net
**Key Team Members:** Chad Masching, Andrew Lockman, Paul Eggers, Tom Daigle, Sarah Skigen-Caird
**Project Type:** Reservoir raise with new spillway
**Size/Capacity:** 20000 cfs spillway/10 foot water level raise
**Fees:** Contracted: $390K/Final: $450K (longer construction)
**Dates:** August 2013 - February 2017

# Key Personnel

The following pages contain our project lead and subject matter experts. This core team will be supported by staff engineers, geologists, and administrative/drafting personnel as needed to meet the project deliverable milestones. Additional resumes of support staff are available upon request.

**Chad Masching, P.E.**
Project Manager
Denver, CO
(main project office)
Colorado PE 39806

Chad has worked on over 70 dam projects during his 18 years with GEI. He brings a common-sense attitude to dam design and will use his diverse background in civil, geotechnical, structural, and hydraulic engineering to develop cost effective construction strategies which limit the District's risks during the project. He is keenly aware of the District's financial constraints and will work to maintain open communication with the Board, SEO and funding agencies from preliminary design through completion of construction.

**Chad was the Project Manager and Engineer of Record for the Upper Beaver Brook Spillway Improvement project.**

**Paul J. Eggers, P.E.**
Dam Design
Denver, CO
Colorado PE 41671

Paul has been a project engineer, lead dam designer, or project manager for over 30 dams within Colorado and the Western United States. His expertise is in preparing clear, consistent, well-detailed construction document packages that minimize client risk and improve the quality of work from the contractor. Paul has used his extensive background in field engineering to understand how a project is built from the perspective of both the engineer and the contractor, which has led to successful outcomes for all parties. As Dam Design Lead for Lower Beaver Brook, Paul will use his experience in RCC and embankment dam design to deliver high quality construction documents.

**Paul was the Upper Beaver Brook Dam Project Design Lead.**

**Nicholas D. Miller, P.E., P.H**
Hydrology and Hydraulics/Spillway Design Lead
Denver, CO
Colorado PE 42743

As the project manager for the Big Elk Meadows Association dam replacements, Nick was able to provide SEO approved designs for 5 replacement dams for the Association with FEMA grants similar to the Lower Beaver Brook Dam funding. Nick is a professional civil engineer with 15 years of experience in hydrologic and hydraulic engineering. He has completed numerous hydrologic and hydraulic studies for dams in Colorado and throughout the United States. He has a solid understanding of the Colorado SEO Rules and Regulations. Based on Mr. Miller's comprehensive project experience he has achieved Professional Hydrologist (P.H.) recognition by American Institute of Hydrology.

**Sarah Skigen-Caird**
Permitting Lead
Denver, CO

Sarah Skigen-Caird is the Ecology Division Manager for GEI's Denver ecology practice and an environmental scientist with over 16 years of professional experience within both the public and private sector. Sarah has worked extensively with aquatic and terrestrial ecosystems, vegetation and wildlife surveys, wetland delineations, CWA 404 permitting and NEPA/CEQA compliance, restoration of disturbed systems, and biomonitoring study design.

**Sarah's permitting efforts at Upper Beaver Brook allowed construction under a simple Nationwide 404 permit, saving the District $150K to $250K in wetland mitigation costs.**

**Andrew B. Lockman, P.G.**
Geotechnical Lead
Denver, CO

Andrew is a geological engineer with expertise in coordinating and executing geotechnical investigations for dams, subsurface characterization, developing criteria for foundation grouting and preparation. His background includes geotechnical analysis, geologic mapping and interpretation, instrumentation design and installation, seepage and stability analyses, and developing designs for new dams and rehabilitating aging structures. He applies his diverse skill set with enthusiasm and brings a team oriented, collaborative approach to each project he works on.

**Andrew was the Project Geologic Engineer for the Upper Beaver Brook Spillway Replacement project.**

**Thomas A. Daigle, P.G.**
Construction Management
Denver, CO

Tom is professional geologist with a proven background in construction management. He brings a collaborative philosophy to the project site, able to help bring owners, contractors, and regulators into agreement to keep projects moving forward. He is experienced in foundation preparation, geologic mapping, earthworks, piping, and concrete construction.

**Tom managed the construction and oversight of the new 3-cycle concrete labyrinth weir spillway constructed at the Upper Beaver Brook Dam.**

**Mike Walker, P.E.**
Principal in Charge
Boston, MA

Michael Walker is GEI's RCC Practice Leader and has experience as a contractor, designer, and consultant for a wide variety of geotechnical, civil, and structural projects. His pragmatic engineering style is focused on providing safe and economical solutions to engineering issues. He is committed to providing refinement to GEI's RCC dam solution in order to meet the District's objectives.

**Charles Grant, P.E., S.E.**
Structural Review/QA
Boston, MA

Charles is a structural engineer specializing in dams and appurtenant structures, water resources facilities, earth retention systems, foundations, and temporary structural shoring. His areas of expertise include stability analysis of dams and hydraulic structures; design of reinforced concrete, structural steel, and timber structures; structural and geotechnical finite element analysis; seismic analysis and design; and construction management. Mr. Grant served on active duty in the U.S. Army Corps of Engineers (USACE) from 1996 to 2004.

**Dan Johnson**
RCC Dam Subject Matter Expert
Boulder, CO
Colorado PE 0013365

Mr. Johnson brings 45 years of experience supporting multi-disciplinary water supply and storage projects, particularly in dam design and geotechnical engineering. Dan has been a key participant on more than 220 water supply projects in the U.S. and abroad. His project portfolio includes embankment and concrete dam and reservoir projects, and he is a recognized international expert in RCC dam technology with about 35 RCC dam projects completed. In addition to dam design, recent dam industry involvement has focused on developing a shared risk strategy for cofferdam sizing.

# Approach

The design concept presented as Alternative 5 in the report by W.W. Wheeler & Associates assumes the new dam will be constructed downstream of the existing rockfill dam. Although this appears feasible, the lack of staging area for contractors presents a serious challenge during construction, and we have concerns that this could result in schedule delays or cost overruns that the District cannot afford. Furthermore, the option leaves minimal area for a stilling basin to dissipate the energy of the floods, which could be a long-term risk item for the water treatment plant (WTP).

A preferred alternative for consideration would be to construct the new dam along or just upstream of the existing dam alignment and use the area within the dewatered reservoir for construction staging. This proposed alternative would provide the same reservoir storage capacity and include a spillway apron capable of efficiently dissipating flood flows and removing some of the potential risk to the WTP. The key benefit of this alternative is that it provides contractors with more area for staging, stockpiling, equipment laydowns, and supply deliveries, which greatly facilitates workflow during construction and reduces impacts to surrounding areas. The significance of having this additional area for use during construction is highlighted by considering that the available on-site staging area below the dam is about a half-acre from the dam centerline to the gated entrance of the WTP. To construct an RCC or concrete dam of this size, a total staging area of 3 acres is ideal, and as the work area shrinks, the price for construction increases. Constructing the new dam downstream of the existing dam effectively cuts the available staging area to a quarter acre.

Our alternative includes early dewatering of the reservoir and utilizing the area within the reservoir footprint as the contractor's staging area. This would provide ample space for stockpiling and processing materials as well as an adequate footprint for an efficient RCC batch plant and facilitate site traffic. Of equal importance is providing water to the WTP during construction of the new dam. We understand that an operational flow of 250 to 300-gpm is required for the duration of construction. Our approach includes providing flow to the WTP from water stored by a coffer dam or diversion structure at the upper end of the reservoir to the plant via piping along the western edge of the reservoir. The existing outlet tunnel below the right abutment of the dam would be a bypass for storms during construction.

If this alternative is selected and supported by the District, we highly recommend having the infrastructure ready, in place, and tested prior to drawing down the reservoir for construction. We recommend construction of the upstream diversion dam and piping be performed in the fall of 2020 so that draining of the reservoir can begin in early 2021.

GEI's design process will focus on meeting the schedule milestones identified in the RFP and finding opportunities to compress the construction schedule or identify early construction items which can be completed prior to a 2021 mobilization. We understand that the District's property includes an access corridor west of the WTP. Developing this access road could be considered to maintain access to the WTP during construction and having a second site access route would increase resiliency during a large flood event. GEI will address the Board and its operators with the pros and cons of this development.

Significant value could be added by early contractor selection and involvement in the project. Depending on stipulations with the FEMA grant, a contractor could be selected and engaged between the 30% and 60% design level to collaborate and work with the District, GEI, and SEO to finalize the designs. This process is becoming common in dam construction with several contracting methods available to make sure that the District has a feasible project within the allotted project budget prior to the end of 2020.

Per the RFP, agendas and meeting minutes will be prepared for each of the required workshops summarizing the events, discussions, and District direction. We will provide timely invoicing with written progress reports for District reimbursement through the EMGrants system. We have developed a general sequence of construction events that we believe reduces risk and completes the construction by the end of 2021 and have presented these concepts on the following page.

We have reviewed the general sequence of work required to complete this project within the allotted timeframe. Early contractor involvement can be utilized to streamline the process.

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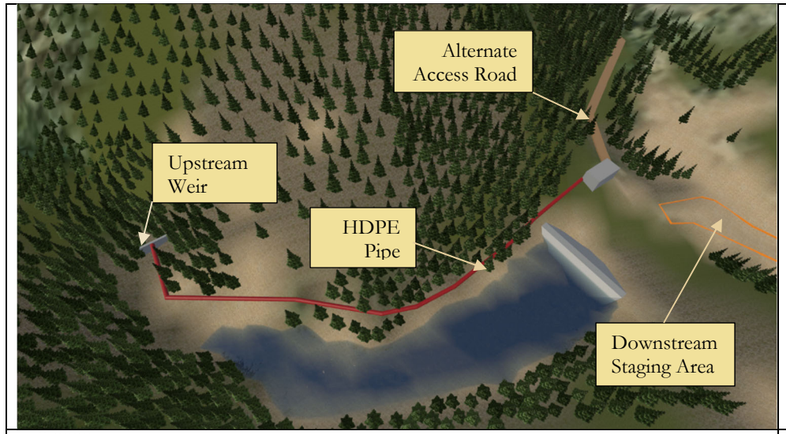
<td> 
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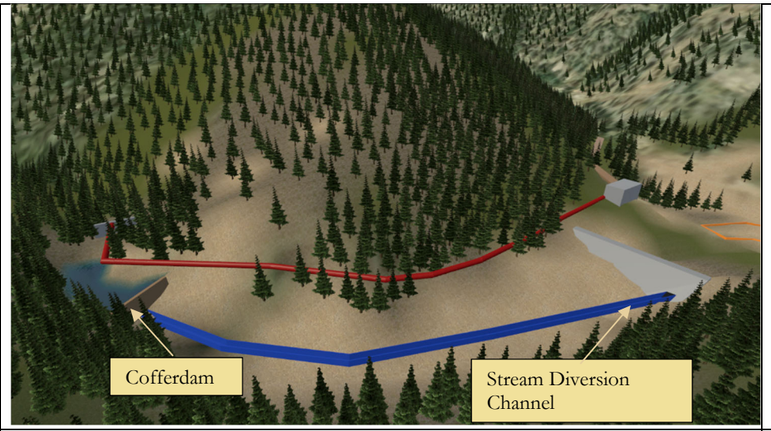
<td> 
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<tr>
<td>Fall 2020<ul><li>Develop alternate site access (if selected) and downstream staging area</li><li>Construct upstream diversion (18” HDPE) and test capacity</li><li>Move high pressure natural gas pipeline out of the construction footprint</li></ul></td>
<td>March/April 2021<ul><li>Lower reservoir, construct temporary cofferdam and develop upstream staging/stockpile area</li><li>Begin WTP diversion through HDPE pipeline and stream diversions through the existing dam tunnel</li><li>The stored water behind the cofferdam may be pumped up into the diversion pipe for peak demand flows.</li></ul></td>
<td>May 2021<ul><li>Excavate existing dam and begin crushing operations for RCC aggregate</li><li>Begin foundation grouting, starting at the left abutment.</li></ul></td>
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<tr>
<td>June 2021<ul><li>Complete foundation grouting and begin final preparation of new dam foundation.</li><li>Construct RCC test section at stilling basin and incorporate into the final work</li></ul></td>
<td>July/November 2021<ul><li>Continue construction of RCC dam and appurtenant facilities. The key to low cost construction is providing the contractor with adequate work space to construct the RCC project elements.</li><li>The existing tunnel will be backfilled, and stream diversions will occur through the new outlet works.</li></ul></td>
<td>December 2021<ul><li>Completion of dam and contractor demobilization.</li><li>Begin Completion Documents and project closeout.</li></ul></td>
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</table>

# Scope of Work

## Review of Background Information

GEI is familiar with the dam performance history, existing documentation, and dam safety inspections of Lower Beaver Brook Dam. We will apply this knowledge along with any additional information from the District or SEO to the design development and documentation. A 2-hour workshop with site visit will be held after initial data review.

## Geotechnical Investigation

Three drill holes will be advanced along the centerline of the dam to meet requirements by the SEO for a geotechnical investigation of a new dam. Two of these holes will be angled to intercept preferential jointing so that foundation grouting characteristics can be established, and low pressure water testing (Packer) will be completed in each hole at varying elevations to establish how water tight the rock formation is. These holes are critical for determining the cost and quantity of grout to be anticipated for foundation treatment as well as determining foundation characteristics for design. A combined total of 250 lineal feet is assumed for these three holes. A 30-foot-deep drill hole will be executed downstream of the dam in the area of the proposed stilling basin to help characterize the erodibility and excavatability of the rock. A laboratory testing program will be completed to determine the engineering properties of the rock. Additionally, rocks from the existing dam will be extracted, crushed, and tested for suitability of use with RCC.

*Deliverables:* Geotechnical investigation plan and Draft/Final Geotechnical Investigation Reports

## Site Survey

CCS Consultants will develop the project basemap using the District's existing local horizontal and vertical datum to the required extent beyond the normal high-water line. Our survey will also cover the alternate access road alignment. Additionally, two permanent control points will be established on site to be used for construction of the dam facility. A sealed 24x36-inch hard copy, PDF, and AutoCAD files will be provided to the District. A bathymetric survey to calculate actual storage volume can be added, at the District's request.

## Hydrology Update

In 2016, GEI completed an Incremental Damage Assessment (IDA) for the Lower Beaver Brook Dam which allowed the design flood to be reduced from 22,714 cfs down to 4,755 cfs. This reduction provided the District with options to modify the existing dam spillway to pass the design flood without overtopping the dam. Because a new dam type has been attached to the FEMA funding, the flood reduction values used in GEI's previous analysis may not be recognized by the SEO due to different breach parameters for an RCC dam. Additionally, the SEO published new guidance and precipitation values this year which will need to be used for a new dam design. GEI proposes to complete an addendum to our Hydrology and Incremental Damage Analysis Report which utilizes the new precipitation data and will make the case for accepting the previous IDA values. We have already completed a screening level analysis of the new rainfall data and there will be a negligible impact to the previous flood estimates, therefore, the IDA is preferred flood.

*Deliverables:* Draft and Final Addenda to GEI's Hydrology and Incremental Damage Analysis Report

## Preliminary Designs (30%, 60% and 90%)

GEI will complete the preliminary design phases of the project per the requirements of the RFP. The 30% phase will focus on developing the overall design footprint and layout of the dam and conveyance facilities, developing a feasible construction plan and schedule (including phased construction and development of staging/stockpile/batch plant areas), identifying permitting requirements, and an AACE Class 3 cost estimate (-20% to +30% of construction cost). A focus of this early design phase will be to develop plans for maintaining reliable water deliveries to the WTP during construction. General construction drawings will be

at 80% complete, plans and sections will be at 50% complete, and structural outlines will be provided. A Technical Specification list will be generated.

At 60% design, GEI will advance general construction drawings to 90%, plans and sections to 75%, and structural and piping details to 50%. Technical Specifications will be completed to a 60% level, and a draft Design report will be developed with supporting calculations and assumptions for design. The construction schedule and cost estimate will be updated, as will permitting and regulatory requirements.

At 90% design, drawing and specification packages will be at an overall 90% or greater level and the design report will be updated to reflect changes since the previous submission. GEI is anticipating that the front end documents that we developed for Upper Beaver Brook with language specific to the FEMA grant included will be appropriate for this project. We will provide a draft of these upfront specifications, an update to the permitting status, and refine the cost estimate to a AACE Class 2 (-15% to +20% of construction cost).

*Deliverables:* As described above. Four-hour workshops with site visits will be held after each submittal.

### Final Design and Construction Documents

The preliminary documents (drawings, front end and technical specifications, and design report) will be advanced to the 100% level, sealed, and will be submitted to the SEO for approval. A permitting update, construction staging flow diversion measures, AACE Class 1 (-10% to +15% of construction cost) estimate, and updated construction schedule will be provided in the design report. SEO comments will be summarized and responded to and a sealed Issued for Bid set of drawings and specifications will be provided to the District for Bid advertisement.

*Deliverables:* 100% and Issued for Bid construction documents and comment log.

### Permitting and Regulatory Reviews

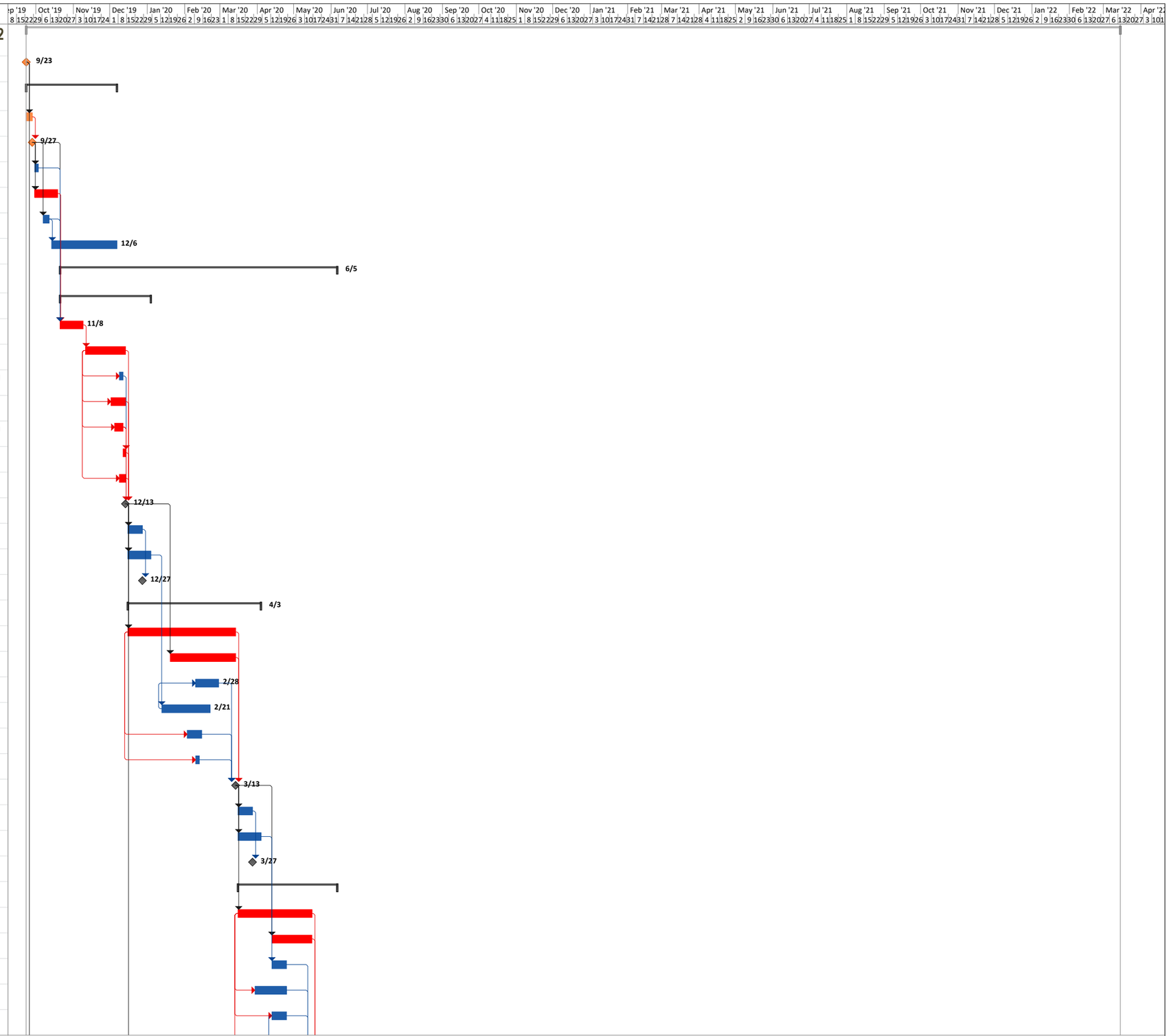
GEI's permitting specialists will lead the effort for final acquisition of necessary environmental permits for construction. Essential to the submittal of permit applications is the ability to discuss advanced designs with the U.S. Army Corps of Engineers, Omaha District, Denver Regulatory Office (USACE) as well as any agencies that may require ongoing coordination (e.g., USFWS, USEPA, FEMA). Pre-application meetings with relevant agencies will occur as early in the design process as practical with final applications submitted upon reaching 60% design with a preferred alternative. GEI will review all previously completed surveys and associated reporting for incorporation into the permit report to accompany the submittal to the USACE. Based on the Environmental Assessment's (EA) finding of no significant impacts, it is anticipated that this work can be permitted by the USACE under a Nationwide Permit, therefore no 401 Certification from the Colorado Department of Public Health and Environment will be required. GEI assumes that the final EA addresses all mitigating measures required by FEMA. GEI will verify that these measures are carried forward and final project closeout compliance documents are submitted to regulatory agencies post-construction.

### Construction Engineering and Management

Similar to the Upper Beaver Brook Spillway project, we will assist the District with development of the RFP for the construction. Mr. Masching will attend the pre-bid meeting and assist the District with bid selection and response to contractor questions. During construction, GEI will attend the pre-construction meeting, coordinate submittal reviews, respond to requests for information, proactively manage contractor change requests (both contractual and those requiring SEO approval) during construction, and review and approve contractor pay requests. GEI's on-site project representative will observe and document daily progress and participate in weekly construction progress meetings, along with Mr. Masching. Monthly progress reports will be submitted to the SEO. GEI will prepare all documentation required to meet the project closeout requirements with the SEO and FEMA including SEO Rule 9, 10, and 16 requirements.

*Deliverables:* As-constructed documents and redlines, daily/monthly, reports, Final Completion Report, Construction Observation Plan, and Emergency Action Plan in the formats required in the RFP.

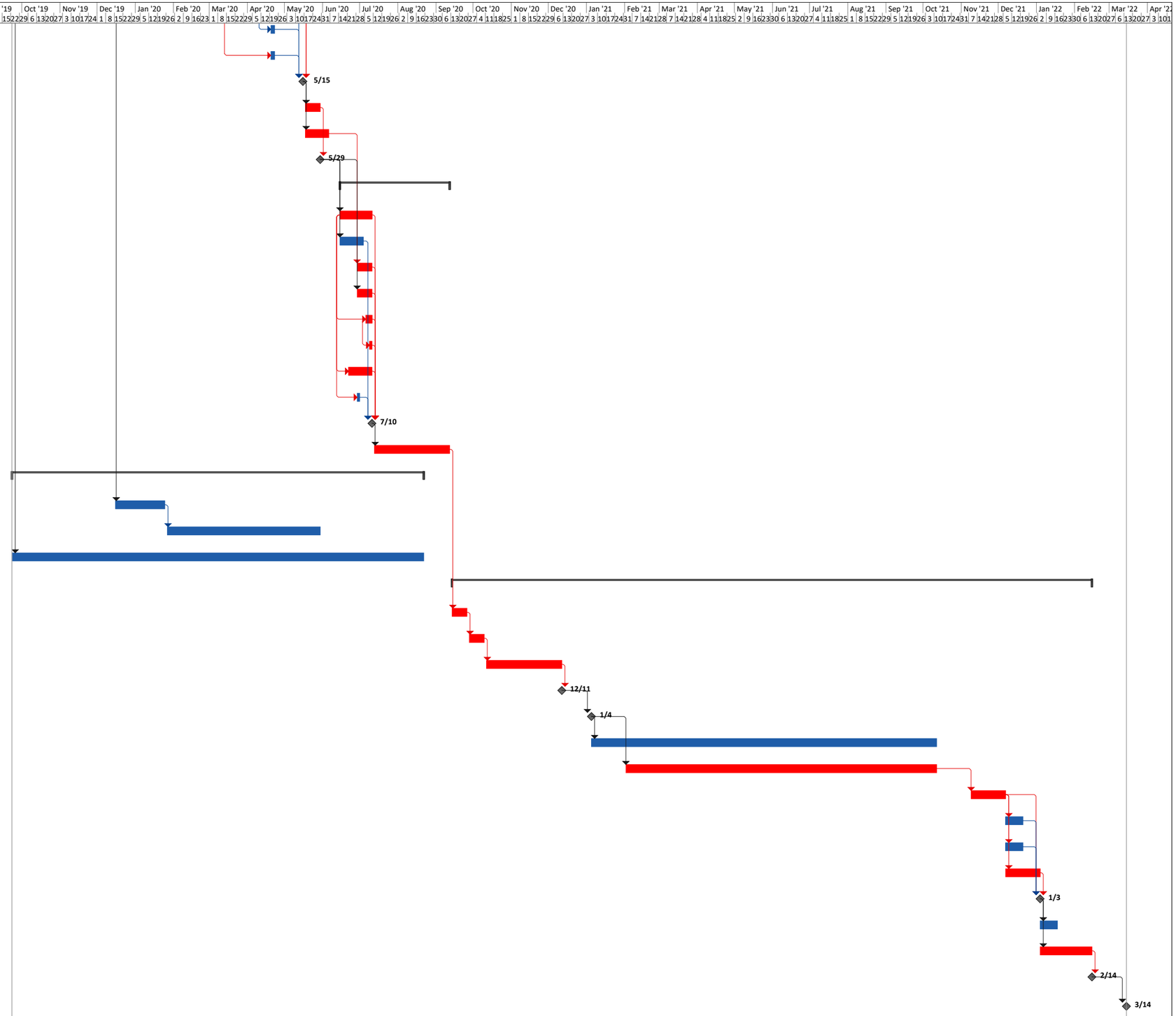
| ID | Task Name | Start | Finish |
|---|---|---|---|
| 0 | **Lower Beaver Brook Dam Schedule** | **Mon 9/23/19** | **Mon 3/14/22** |
| 1 | **Notice to Proceed** | **Mon 9/23/19** | **Mon 9/23/19** |
| 2 | **Task 5.4.1: Site Investigations** | **Mon 9/23/19** | **Fri 12/6/19** |
| 3 | Review Background Information | Mon 9/23/19 | Fri 9/27/19 |
| 4 | Kickoff Meeting with District and SEO | Fri 9/27/19 | Fri 9/27/19 |
| 5 | Site Topographic Survey | Mon 9/30/19 | Wed 10/2/19 |
| 6 | Review and Update Hydrology Report | Mon 9/30/19 | Fri 10/18/19 |
| 7 | Conduct Subsurface Investigation | Mon 10/7/19 | Fri 10/11/19 |
| 8 | Prepare Geotechnical Data Report | Mon 10/14/19 | Fri 12/6/19 |
| 9 | **Task 5.4.2: Preliminary Designs** | **Mon 10/21/19** | **Fri 6/5/20** |
| 10 | **30% Design** | **Mon 10/21/19** | **Fri 1/3/20** |
| 11 | Perform Preliminary Analyses | Mon 10/21/19 | Fri 11/8/19 |
| 12 | Prepare 30% Design Drawings | Mon 11/11/19 | Fri 12/13/19 |
| 13 | Prepare Technical Specification Table of Contents | Mon 12/9/19 | Wed 12/11/19 |
| 14 | Prepare Draft Constructability TM | Mon 12/2/19 | Fri 12/13/19 |
| 15 | Prepare 30% Engineer's Cost Estimate (Class 3) | Thu 12/5/19 | Wed 12/11/19 |
| 16 | Prepare 30% Construction Schedule | Thu 12/12/19 | Fri 12/13/19 |
| 17 | Identify permitting and regulatory requirements | Mon 12/9/19 | Fri 12/13/19 |
| 18 | Submit 30% Design Package | Fri 12/13/19 | Fri 12/13/19 |
| 19 | LMWD Review | Mon 12/16/19 | Fri 12/27/19 |
| 20 | SEO Review | Mon 12/16/19 | Fri 1/3/20 |
| 21 | Attend 30% Design Review Workshop and Site Visit | Fri 12/27/19 | Fri 12/27/19 |
| 22 | **60% Design** | **Mon 12/16/19** | **Fri 4/3/20** |
| 23 | Prepare 60% Drawings | Mon 12/16/19 | Fri 3/13/20 |
| 24 | Prepare Draft Technical Specifications | Mon 1/20/20 | Fri 3/13/20 |
| 25 | Prepare 60% Design Report | Mon 2/10/20 | Fri 2/28/20 |
| 26 | Complete Final Analyses | Mon 1/13/20 | Fri 2/21/20 |
| 27 | Prepare 60% Engineer's Cost Estimate (Class 3) | Mon 2/3/20 | Fri 2/14/20 |
| 28 | Prepare permitting status memo | Mon 2/10/20 | Wed 2/12/20 |
| 29 | Submit 60% Design Package | Fri 3/13/20 | Fri 3/13/20 |
| 30 | LMWD Review | Mon 3/16/20 | Fri 3/27/20 |
| 31 | SEO Review | Mon 3/16/20 | Fri 4/3/20 |
| 32 | Attend 60% Design Review Workshop and Site Visit | Fri 3/27/20 | Fri 3/27/20 |
| 33 | **90% Design** | **Mon 3/16/20** | **Fri 6/5/20** |
| 34 | Prepare 90% Drawings | Mon 3/16/20 | Fri 5/15/20 |
| 35 | Prepare Draft Final Technical Specifications | Mon 4/13/20 | Fri 5/15/20 |
| 36 | Prepare 90% Design Report | Mon 4/13/20 | Fri 4/24/20 |
| 37 | Prepare Draft Front-End Documents | Mon 3/30/20 | Fri 4/24/20 |
| 38 | Prepare 90% Engineer's Cost Estimate (Class 2) | Mon 4/13/20 | Fri 4/24/20 |




Proposed Schedule

Task | Summary | External Milestone | Inactive Summary | Manual Summary Rollup | Finish-only | Critical Split | Path Driving Predecessor Normal Task
Split | Project Summary | Inactive Task | Manual Task | Manual Summary | Deadline | Path Driving Predecessor Milestone Task | Progress
Milestone | External Tasks | Inactive Milestone | Duration-only | Start-only | Critical | Path Driving Predecessor Summary Task

| ID | Task Name | Start | Finish |
|---|---|---|---|
| 39 | Prepare 90% Construction Schedule | Mon 4/20/20 | Wed 4/22/20 |
| 40 | Prepare permitting status memo | Mon 4/20/20 | Wed 4/22/20 |
| 41 | Submit 90% Design Package | Fri 5/15/20 | Fri 5/15/20 |
| 42 | LMWD Review | Mon 5/18/20 | Fri 5/29/20 |
| 43 | SEO Review | Mon 5/18/20 | Fri 6/5/20 |
| 44 | Attend 90% Design Review Workshop and Site Visit | Fri 5/29/20 | Fri 5/29/20 |
| 45 | **Task 5.4.3: Final Design and Construction Documents** | **Mon 6/15/20** | **Fri 9/11/20** |
| 46 | Prepare 100% Drawings | Mon 6/15/20 | Fri 7/10/20 |
| 47 | Prepare Final Technical Specifications | Mon 6/15/20 | Fri 7/3/20 |
| 48 | Prepare 100% Design Report | Mon 6/29/20 | Fri 7/10/20 |
| 49 | Prepare Final Front-End Documents | Mon 6/29/20 | Fri 7/10/20 |
| 50 | Prepare 100% Engineer's Cost Estimate (Class 1) | Mon 7/6/20 | Fri 7/10/20 |
| 51 | Prepare 100% Construction Schedule | Thu 7/9/20 | Fri 7/10/20 |
| 52 | Prepare Final Constructability TM | Mon 6/22/20 | Fri 7/10/20 |
| 53 | Prepare permitting status memo | Mon 6/29/20 | Tue 6/30/20 |
| 54 | Submit 100% Design Package | Fri 7/10/20 | Fri 7/10/20 |
| 55 | SEO Approval | Mon 7/13/20 | Fri 9/11/20 |
| 56 | **Task 5.4.4: Permitting and Regulatory Reviews** | **Mon 9/23/19** | **Fri 8/21/20** |
| 57 | 404 Nationwide Permit Application | Mon 12/16/19 | Fri 1/24/20 |
| 58 | USACE Review & Approval | Mon 1/27/20 | Fri 5/29/20 |
| 59 | Coordinate with Agencies | Mon 9/23/19 | Fri 8/21/20 |
| 60 | **Task 5.4.5: Construction Engineering & Management** | **Mon 9/14/20** | **Mon 2/14/22** |
| 61 | Prepare Issued for Bid Construction Documents | Mon 9/14/20 | Fri 9/25/20 |
| 62 | Develop Construction RFP | Mon 9/28/20 | Fri 10/9/20 |
| 63 | Conduct Bidding Services | Mon 10/12/20 | Fri 12/11/20 |
| 64 | Notice to Proceed (Construction) | Fri 12/11/20 | Fri 12/11/20 |
| 65 | Attend and Participate in Pre-Construction Meeting | Mon 1/4/21 | Mon 1/4/21 |
| 66 | Construction Office Engineering | Tue 1/5/21 | Mon 10/11/21 |
| 67 | Construction Resident Engineering | Tue 2/2/21 | Mon 10/11/21 |
| 68 | Prepare Record Drawings | Tue 11/9/21 | Mon 12/6/21 |
| 69 | Prepare Construction Completion Report | Tue 12/7/21 | Mon 12/20/21 |
| 70 | Prepare Instrumentation and Monitoring Plan | Tue 12/7/21 | Mon 12/20/21 |
| 71 | Prepare Emergency Action Plan | Tue 12/7/21 | Mon 1/3/22 |
| 72 | Submit Construction Completion Documents | Mon 1/3/22 | Mon 1/3/22 |
| 73 | LMWD Review | Tue 1/4/22 | Mon 1/17/22 |
| 74 | SEO Review | Tue 1/4/22 | Mon 2/14/22 |
| 75 | **Project Acceptance** | **Mon 2/14/22** | **Mon 2/14/22** |
| 76 | **Project Close Out** | **Mon 3/14/22** | **Mon 3/14/22** |




Proposed Schedule

Task | Summary | External Milestone | Inactive Summary | Manual Summary Rollup | Finish-only | Critical Split | Path Driving Predecessor Normal Task
Split | Project Summary | Inactive Task | Manual Task | Manual Summary | Deadline | Path Driving Predecessor Milestone Task | Progress
Milestone | External Tasks | Inactive Milestone | Duration-only | Start-only | Critical | Path Driving Predecessor Summary Task

# Price Proposal

GEI's experience with similar sized water storage projects will provide exceptional value in meeting the District's objectives for this project. Based on our proposed approach as presented in the previous sections of this proposal and the assumptions below, our Not to Exceed Fixed Fee budget for the project is $599,351.

Table 2 presents a summary of the proposed fixed fee project cost breakdown by task and estimated total labor hours. A more detailed cost summary, including labor category and expenses, is included at the end of this Section.

The following assumptions were used when developing this price proposal:

- The geotechnical investigation will be completed during one mobilization, and no drilling through the existing rockfill dam will be required.
- The construction costs provided by the District's consultant for Alternative 5 are reasonable, and the project can be constructed within the allowable budget.
- The construction schedule provided by the District's consultant for Alternative 5 will match the selected Contractor's schedule. Based on this construction schedule we will have a part time or full time resident engineer based on the schedule below.
    - April 2021 — 10 hours per week for 4 weeks
    - May 2021 — 20 hours per week for 4 weeks
    - June – October 2021 — 50 hours per week for 22 weeks
    - November – December 2021 — 20 hours per week for 5 weeks
- An RCC mix design will be completed during the design engineering phase. We have included this to bring value to the District so that Contractor bids will be more competitive and to expedite the construction schedule. However, approximately 2 cubic yards of rock from the dam will be required to be selectively removed and crushed to perform the mix design. The cost for RIZZO to complete the mix design in $15,000. At the District's request, this task can be put onto the construction contract.
- A $30,000 allotment for owner Quality Assurance testing has been included. The majority of testing will be completed by the Contractor's Quality Control testing agency.
- The Contractor will provide final survey for the completed work.
- The work can be permitted by the USACE under a Nationwide Permit and no 401 Certification from the Colorado Department of Public Health and Environment will be required. No floodplain related permitting will be required.

**Table 2: Fixed Fix Project Cost Breakdown**

| | | GEI Consultants | | | Subcontractors | | | Subconsultants | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Task Code | STAFF | Total Hours | Labor Cost | Other Direct Costs | Authentic Drilling | ATT - Laboratory | CCS Consultants - Survey | Dan Johnson RCC | RIZZO - Mix Design & Field QA | Subs Subtotal | Total Cost |
| 5.4.1 | Site Investigations | 248 | $26,142 | | $22,000 | $5,000 | $11,000 | | | $38,000 | $ 64,142 |
| 5.4.2 | Preliminary Designs | 1854 | $194,233 | 3250 | | | | $20,000 | $15,000 | $35,000 | $ 232,483 |
| | 30% Design | 469 | $50,712 | $450 | | | | $15,000 | $15,000 | $30,000 | $ 81,162 |
| | 60% Design | 883 | $89,097 | $1,350 | | | | $5,000 | | $5,000 | $ 95,447 |
| | 90% Design | 502 | $54,424 | $1,450 | | | | | | | $ 55,874 |
| 5.4.3 | Final Design and Construction Documents | 218 | $23,844 | $1,300 | | | | | | | $ 25,144 |
| 5.4.4 | Permitting and Regulatory Reviews | 90 | $11,110 | | | | | | | | $ 11,110 |
| 5.4.5 | Construction Engineering & Management | 2106 | $231,672 | $4,800 | | | | | $30,000 | $30,000 | $ 266,472 |
| | Total | 4516 | $ 487,001 | $ 9,350 | $ 22,000 | $ 5,000 | $ 11,000 | $ 20,000 | $ 45,000 | $ 103,000 | $ 599,351 |

## FEE SCHEDULE

| | *Hourly Billing Rate* |
|---|---|
| **PERSONNEL CATEGORY** | **$ PER HOUR** |
| Staff Professional – Grade 1 | $ 85 |
| Staff Professional – Grade 2 | $ 90 |
| Project Professional – Grade 3 | $ 95 |
| Project Professional – Grade 4 | $ 102 |
| Senior Professional – Grade 5 | $ 130 |
| Senior Professional – Grade 6 | $ 150 |
| Senior Professional – Grade 7 | $ 175 |
| Senior Consultant – Grade 8 | $ 240 |
| Permitting Specialist | $ 135 |
| Dan Johnson, P.E. (no mark-up) | $ 275 |
| CADD Drafter / Designer and Senior Technician | $ 85 |
| Residential Engineer | $ 102 |
| Technician, Word Processor, Administrative Staff | $ 65 |
| Office Aide | $ 65 |

These rates are billed for both regular and overtime hours in all categories. Rates will increase up to 5% annually, at GEI's option, if the contract extends beyond March 2022.

### OTHER PROJECT COSTS

**Subconsultants, Subcontractors and Other Project Expenses -** All costs for subconsultants, subcontractors and other project expenses will be billed at cost plus a 10% service charge.

**Field and Laboratory Equipment Billing Rates** – GEI-owned field and laboratory equipment such as pumps, sampling equipment, monitoring instrumentation, field density equipment, portable gas chromatographs, etc. will be billed at a daily, weekly, or monthly rate, as needed for the project. Expendable supplies are billed at a unit rate.

**Transportation and Subsistence** - Automobile expenses for GEI or employee owned cars will be charged at the rate per mile set by the Internal Revenue Service for tax purposes plus tolls and parking charges or at a day rate negotiated for each project. When required for a project, four-wheel drive vehicles owned by GEI or the employees will be billed at a daily rate appropriate for those vehicles.

## *PAYMENT TERMS*

Invoices will be submitted monthly or upon completion of a specified scope of service.

Payment is due per the terms outlined in the Contract attached to the Request for Proposal. Interest will accrue at the rate of 1% of the invoice amount per month, for amounts that remain unpaid more than 30 days after the 30th of the month following the month in which the request for payment was received by Lookout Mountain Water district. All payments will be made by either check or electronic transfer to the address specified by GEI and will include reference to GEI's invoice number.

# Resumes and Subconsultants Profiles

**CCS Consultants, Inc. | Surveyor**
*4860 Robb Street, Suite 206, Wheat Ridge, CO 80033*

CCS Consultants, Inc. is a Colorado land surveying firm whose land surveyors have worked along the Front Range and Western Slope since 1978.

Their land surveyors understand the value of accurate data since land surveying is the precursor to development, planning and initial design of a project. They have extensive experience in subdividing and platting land, section breakdowns, topographic and utility mapping, ALTA surveys, annexation maps, legal descriptions, flight control/aerial mapping, condominium maps, and gathering field data for civil or architectural design.

Their assigned personnel are involved throughout all aspects of the job, eliminating the time it takes to familiarize additional personnel with the client and project needs. This also reduces the possibility of errors and duplicating work. Their key personnel have years of experience in land surveying and civil engineering which allows them to better understand the information needed by engineers and architects for project design.

CCS' computer workstations communicate directly with its data collection and GPS systems. The state-of-the-art system reduces time and the possibility of errors and eliminates the need for note reduction. The field data is downloaded directly into their computers and calculated automatically. This system saves crew time because the information needed for a project can be contained within a data collector so crews spend less time on calculations in the field.

**Authentic Drilling, Inc. (WBE) | Driller**
*33555 County Road 37, Kiowa, CO 80117*

Authentic Drilling mobilizes new and reliable drilling equipment to projects anywhere West of the Mississippi.

Their specialty is difficult access drilling coring and odex drilling. Services include anything from geotechnical drilling, exploration drilling, environmental drilling, well installations, development and rehab, packer testing, pressuremeter testing to grouting.

They have built their reputation by utilizing new equipment, using highly skilled drillers and offer a very extensive variety and quantity of all drill tooling sizes.

**RIZZO International, Inc. (WBE) | RCC Mix Design and Construction Testing**
*3538 Peoria Street, Unit 511, Aurora, CO 80010*

Through its Material Testing Laboratory, RIZZO International, Inc., (RIZZO) offers high-quality construction materials testing and inspection services. RIZZO understands its responsibility to provide the technical test data its clients depend on to evaluate the quality of the materials that are being incorporated into their projects. Their hands-on experience and acute attention to detail enables its staff to provide timely, reliable test data required by the most demanding civil projects in today's industry. Their staff is trained in Roller-Compacted Concrete (RCC) testing in the United States and abroad. Their business is based upon providing the best construction materials testing services when and where our clients need them.

Resumes for the key project staff and the subconsultant proposal follow.

**Chad M. Masching, P.E.**
Project Manager

resume

Chad Masching has a diverse background in civil, geotechnical, structural, and hydraulic design with an emphasis on water storage projects and raw water conveyance. Project experience includes embankment and concrete dams, spillways, augmentation reservoirs, fish passage, dam facing design and inspections, outlet works and conveyance piping, surface water management and groundwater relief systems, deep foundations, and environmental projects. Mr. Masching is a collaborative leader with significant experience in design, inspection, and assessment of dams and hydraulic structures.

EDUCATION
B.S., Civil Engineering, University of Illinois at Urbana-Champaign

EXPERIENCE IN THE INDUSTRY
19 years

EXPERIENCE WITH GEI
18 years

REGISTRATIONS AND LICENSES
Professional Engineer, CO No. 39806
Professional Engineer, HI No. 15888
Professional Engineer, MT No. 18297
Professional Engineer, ND No. PE9686
Professional Engineer, WY No. 14574
P. Eng – British Columbia No. 179987

CERTIFICATIONS
SPRAT Rope 1 Rope Access Technician

PROFESSIONAL ASSOCIATIONS
United States Society on Dams

PROJECT EXPERIENCE

**Upper Beaver Brook Spillway Improvements, Lookout Mountain Water District, Evergreen, CO.** Project Manager/Engineer of Record. Project consisted of increasing the normal pool storage of Upper Beaver Brook Reservoir by 10 feet by removing the existing spillway control section and constructing a new 3 cycle labyrinth spillway. The work included controlled rock blasting with a full reservoir to widen the existing spillway and construction of a shallow grout curtain. Additional improvements included replacement of the two 100-year old outlet works gate stems with stainless steel stems encased in oil filled pipes which will allow year-round gate operation.

**Long Hollow Dam and Reservoir, La Plata Water Conservancy District/Colorado Water Resources and Power Development Authority, Hesperus, CO.** Project Civil Engineer and Engineer-of-Record. Responsible for outlet works design for a 120-foot-tall, 5,300 acre-foot zoned earth embankment dam. The project provides releases to comply with the requirements of the La Plata River Compact between Colorado and New Mexico. Outlet facilities include 600 feet of concrete encased steel pipe, a hydraulically operated gated intake structure, two fixed cone valves for providing operational and emergency outlet releases, a valve house and stilling basin, and an 80-cfs downstream conduit for conveying releases around sensitive wetlands.

**Taum Sauk Storage Facility, Clausen Miller, Pineville, MO.** Staff Engineer. Evaluated RCC dam design with respect to industry practice and identified betterment in the proposed design relative to the requirements of the project and the performance objectives of the original dam. Evaluated construction cost estimates for reasonableness of major component costs and of the construction costs that can be attributed to betterment.

**Chimney Hollow Dam, Northern Colorado Water Conservancy District – Municipal Subdistrict, Berthoud, CO.** Lead Geotechnical Engineer. GEI is the geotechnical engineer for the Chimney Hollow Dam, a 350-foot tall rockfill structure to be constructed with a thin asphaltic concrete core. The dam will impound a reservoir which provides approximately 90,000 acre-feet of storage. As lead geotechnical engineer, developed drilling, sampling, and lab testing program. Drafted geotechnical data report which summarized results from the investigation. GEI also developed recommendations for foundation excavation depths, cutoff and grout curtain design criteria, and rock quarry development.

**Rueter-Hess Dam and Reservoir, Parker Water and Sanitation District; Parker, CO.** Staff Civil/Geotechnical Engineer. Mr. Masching assisted during design implementation of Phase I dam and reservoir construction. Performed borrow evaluation and construction material quantity determinations for the dam as well as concrete and backfill construction observations for the outlet works and tower facilities. GEI designed the Phase I 135-foot-high zoned-earth embankment dam with provisions to facilitate a future raise of up to 60 feet. The raise was implemented immediately after the initial project was started. The site involved many technical challenges, specifically the weak sedimentary foundation.

**Red Lake Dam Rehabilitation, Bureau of Indian Affairs, Navajo Nation, NM.** Project Manager/Engineer of Record. Responsible for delivery of a value engineered solution to a dam threatened with excessive seepage. Along with BIA and the Navajo Nation, GEI completed a potential failure mode analysis and value engineering alternative session, reducing construction cost by over $6 million over a previous design. Dam modifications included excavation of the downstream face of the dam and construction of an inclined chimney filter, downstream filter trench, and filter protected drain pipe envelope. A new outlet works consisting of three discharge conduits with individual, hydraulically operated gate controls was also constructed. The gates have local and remote (SCADA) controls.

**Davis Dam Construction Management Services, Bureau of Indian Affairs, Fort Apache Indian Reservation, AZ.** Project Manager. Responsible for management of construction activities and ensuring compliance with Bureau of Reclamation generated Construction Documents. Project role involved advising and assisting Tribal construction staff and coordinating with the Bureau of Indian Affairs and Reclamation. The construction project consisted of downstream slope improvements, including a downstream chimney filter and collection drain system, realignment of the emergency spillway, construction of a new siphon, and armoring the upstream slope of the dam. During the construction project, a previously abandoned outlet works was discovered with a nearly full reservoir. The outlet conduit was not concrete filled, as previous documentation indicated, and a level 2 emergency action plan was initiated. GEI contracted to drain the lake by continuous pumping.

**Dam and Reservoir Maintenance and Remediation Improvements on Kauai, State of Hawaii, Honolulu, HI.** Project Manager. GEI evaluated the existing condition of five state-owned dams on the island of Kauai and performed design and construction work to mitigate the identified deficiencies or remove the dam from state jurisdiction in accordance with the Hawaii Dam and Reservoir Safety Act of 2007. Responsible for implementation during construction of modifications to four embankment dam storage facilities. Tasks include construction design support, submittal review, responses to contractor questions, and construction observation.

**Marston Dam South Embankment Investigation, Denver Water, Denver, CO.** Project Manager. Responsible for evaluation of seepage along a previously abandoned south outlet works conduit alignment. Conducted field investigations, ROV pipe inspection, and currently developing feasibility study alternatives for proper outlet works abandonment. Based on the investigation, GEI prepared designs for in-place abandonment of the outlet works conduits using drill and intercept methods.

**Montgomery Dam Improvements Project, Colorado Springs Utilities, Fairplay, CO.** Project Civil Engineer. Responsible for dam rehabilitation design, contract documents, and construction management. Project objectives included providing upstream control for the 60-inch diameter outlet works as well as repairing and resealing the asphaltic concrete face of this 105-foot-tall rockfill dam at 10,800 feet in elevation. The outlet works modifications were completed in the wet with divers and included installing a pipe insert and gate mounting plate, gate vent piping, a 48-inch by 48-inch hydraulically operated sluice gate, hydraulic operating unit, and a permanent access manway into the outlet works conduit for future inspection and maintenance.

**New Exchequer Dam Inspection, Merced Irrigation District, Merced County, CA.** Civil/Structural Engineer. Conducted analysis of upstream concrete facing, of 490-foot high rockfill dam. Rope access (rappelling) techniques were required to access the steep-sloping concrete dam face. Used field observations in conjunction with xyz data acquired from an unmanned aerial vehicle (UAV) to assess the kinematics of the deformation to the dam. The point cloud data set containing approximately 20 million xyz data points proved instrumental to characterize the extent and locations of the deformations. Inspection observations were used to develop a repair program for the concrete dam face.

**Guntersville Dam Stability Analysis, Tennessee Valley Authority (TVA), Guntersville, AL.** Project Lead. Lead for investigation of structural and foundation elements of the concrete structures and related stability analysis. This 94-foot dam located on the Tennessee River in Northeast Alabama impounds 67,900-AF serving hydropower generation, navigation, and recreation. The facilities extend 3,979 feet across the Tennessee River and include two earth embankments, a 4-unit powerhouse/intake, an 18-bay gated spillway, and two navigation locks. The project is located in an area with a highly karstic bedrock environment and includes a 2-mile-long dike that protects the City of Guntersville from flooding.

**Paul J. Eggers, P.E., P.M.P.**
Dam Design Lead

resume

Paul J. Eggers is a civil engineer with experience in project management, dam engineering, quality control and assurance, and field engineering on a wide variety of water resources and geostructural projects, including gravel pit reclamation, dams and reservoirs, pipelines, irrigation and drainage systems, earth retention, and ground anchoring. His experience has included slurry trench construction, master planning, seepage analysis, dam rehabilitation design, conceptual level design studies, subsurface exploration, report preparation, reinforced concrete and structural steel design, specification preparation, design drawing preparation, and field engineering.

Mr. Eggers stakes his reputation on superior service to his clients and their projects. As a certified Project Management Professional and Professional Engineer, he has used his skills to successfully deliver technically challenging projects to clients along the Front Range, within the State of Colorado, and the greater Western United States. He is an excellent communicator and seeks to maintain strong, collaborative relationships with everyone he works with – whether they are clients, teaming partners, subcontractors, GEI employees, or other interested stakeholders. In addition, he is proficient in the use of AutoCAD Civil3D, SAP2000, GeoSlope, Microsoft Excel, Microsoft Word, and Microsoft Project.

EDUCATION
M.B.A., University of Colorado Denver
B.S., Civil Engineering, Florida Tech

EXPERIENCE IN THE INDUSTRY
16 years

EXPERIENCE WITH GEI
15 years

REGISTRATIONS AND LICENSES
Professional Engineer, CO No. 41671
Professional Engineer, CA No. C 88704
Professional Engineer, KS No. 23155
Professional Engineer, MO No. PE-2013025020
Project Management Professional

CERTIFICATIONS
Adult First Aid-CPR-AED

PROFESSIONAL ASSOCIATIONS
United States Society on Dams
American Institute of Steel Construction
American Concrete Institute
American Water Works Association
Deep Foundations Institute

PROJECT EXPERIENCE

**Upper Beaver Brook Spillway Improvements, Lookout Mountain Water District, Evergreen, CO.** Lead Design Engineer. Project consisted of increasing the normal pool storage of Upper Beaver Brook Reservoir by 10 feet by removing the existing spillway control section and constructing a new 3 cycle labyrinth spillway. Additional improvements included replacement of the two 100-year old outlet works gate stems with stainless steel stems encased in oil filled pipes which will allow year-round gate operation. Responsible for design development of the outlet works improvements and labyrinth spillway and review of geotechnical and structural analyses for the spillway.

**New Bullards Bar Dam Secondary Spillway Project, Yuba Water Agency, Yuba County, CA.** Lead Design Engineer and Deputy Project Manager. Project consists of design of new secondary spillway through the left abutment of the dam to increase capacity and allow reservoir operational flexibility and forecasting capabilities. The secondary spillway consists of a reinforced concrete intake structure with roller gates, approach channel and training walls, large diameter horseshoe-shaped tunnel, and flip bucket outlet structure. The entire project must be constructed without impacting reservoir operations, requiring cofferdams, braced excavations, grout curtains, and other features to protect the constructed works. As Lead Design Engineer, responsible for design of roller compacted concrete (RCC) cofferdams, support of excavation systems, and the other components of the secondary spillway. Responsible for day-to-day coordination of multiple subconsultants and internal team members, report preparation, technical specifications, design drawings, and project controls and monitoring. The 30% design is scheduled to be complete in October 2019.

**Cucharas Dam Rehabilitation, HCIC Holdings Corp, Huerfano County, CO.** Project Engineer. Cucharas Dam, located near Walsenburg, Colorado, is an aging rockfill dam constructed on a poor foundation with many other dam safety deficiencies. Responsible for developing several alternatives for dam reconstruction or replacement, including a 10% design of an RCC option with central spillway. Developed several preliminary design drawings, developed quantities, and performed preliminary stability analysis for RCC options of various

heights. Because of the poor foundation conditions discovered after subsurface investigations were completed, the RCC option was abandoned and the dam was rehabilitated as an interim measure.

**Long Hollow Dam and Reservoir - Phase II Final Design, Colorado Water Resources & Power, Hesperus, CO.** Project Engineer. During early phases of the project, developed several RCC alternatives and performed preliminary stability analyses for a new dam in Southwest Colorado with a height of up to 130 feet. The RCC option was determined to be less cost effective than the embankment option, which was ultimately selected by the client. During final design, responsible for developing design drawings, specifications, cost estimates, and reports for the new 130-foot-tall embankment dam. Analyzed and designed several reinforced concrete hydraulic structures, including outlet works intake structure, valve and meter vaults, and outlet structure.

**Western Branch Dam Safety Modifications, City of Norfolk, Suffolk, VA.** Project Engineer. Project consisted of dam safety rehabilitation design for a new RCC-lined emergency spillway and retrofit of the existing ogee service spillway. Responsible for design drawings and quantity estimates using Civil3D for the emergency spillway RCC steps. Assisted the Owner and Construction management team with submittal reviews, RFI responses and design changes and clarifications during the construction phase.

**Big Elk Meadows Dam Reconstruction, Big Elk Meadows Association, Lyons, CO.** Project Engineer. Prepared final design drawings and technical specifications for Mirror Lake and Rainbow Lake Dams within the Big Elk Meadows subdivision. These small dams, which stored water for the subdivision's treatment plant, were destroyed during the 2013 Colorado flood events. The dams were reconstructed to safely convey the inflow design flood and were modified to provide state-of-the-practice dam safety measures.

**Busk-Ivanhoe Dam Rehabilitation, Busk-Ivanhoe Water System Authority, Pitkin County, CO.** Project Engineer. Developed design drawings and specifications for repairs to the existing dam. Repairs include modifications to the existing emergency spillway, construction of downstream stability berm and chimney drain, replacement of downstream flume, and slip-lining the CMP low-level outlet pipeline with new steel pipe.

**Guadalupe Dam Seismic Retrofit Project Final Design, Santa Clara Valley Water District, San Jose, CA.** Engineering Manager and Outlet Works Design Lead. The project consists of upgrading Guadalupe Dam near San Jose to meet current standards for embankment seismic stability, spillway capacity and scour protection, and outlet works capacity and operational requirements. Design components of the outlet works will include a reinforced concrete sloping intake structure, tunneled outlet works conduit, and downstream release facilities. Responsible for overseeing analysis and design of the sloping intake structure, which will require manned entry with hydraulic loads of up to 100 feet of head and the ability to withstand the MCE for the site, as well as the coordination between multiple disciplines and subconsultants as it relates to the outlet works and appurtenances. As Engineering Manager, responsible for coordination between client, subconsultants, and GEI internal project team to ensure design milestones are met on time. Recently completed 60% design submittal, which included 183 design drawings, general and special provisions, technical specifications, a Basis of Design Report, several technical memoranda, and cost estimate.

**Red Lake Dam Rehabilitation, Bureau of Indian Affairs, Navajo Nation, NM.** Project Engineer. Performed the rehabilitation design of this embankment dam, outlet works, and spillway for the Navajo Nation. Rehabilitation design included new downstream shell, chimney and blanket drain, toe drain pipeline and appurtenances, complete replacement of the existing outlet works facilities, and new access roads. Primarily responsible for developing Civil 3D objects, including excavation surface, final embankment surface, and access road layouts. Trained several staff level engineers in the use of AutoCAD Civil 3D and also reviewed drawings, specifications, and cost estimates.

**Hodgson-Harris Dam Rehabilitation; Boulder County Parks and Open Space; Superior, CO.** Project Engineer. Hodgson-Harris Dam is a homogeneous earthfill dam which was placed on a zero-pool restriction due to excessive seepage and development of sinkholes from loss of materials through defects in the outlet works conduit. Developed construction drawings and specifications for construction of a downstream filter blanket and drain, spillway improvements, and replacement of the existing CMP outlet works. Performed structural design and analysis for all reinforced concrete hydraulic structures at the site.

**Nicholas D. Miller, P.E., P.H.**
Hydrology and Hydraulics/Spillway Design Lead

resume

Nick Miller is a professional civil engineer with 15 years of experience in project management and hydrologic and hydraulic engineering. Mr. Miller's primary expertise is in the area of hydrology and hydraulics relating to dams, including the planning and design of dams, feasibility and economic studies of dam projects, spillways design and analysis, inlet and outlet works design, analysis of conduit and open channel flow, and probable maximum flood (PMF) studies. He also has extensive experience in 1D and 2D hydraulic computer modeling for hydraulic structures including final design of spillways, channels, and numerous dam break studies. Several of his projects have required coordination with state regulatory agencies, and many have required coordination with FERC and FEMA. Nick's experience also includes dam inspections, PFMA workshops/reports, preparation of Supporting Technical Information Documents (STID), and preparation of Emergency Action Plans. Based on Mr. Miller's comprehensive project experience, he has achieved Professional Hydrologist (P.H.) recognition by American Institute of Hydrology.

EDUCATION
M.S., Civil Engineering, Colorado State University
B.S., Civil Engineering, Colorado State University

EXPERIENCE IN THE INDUSTRY
15 years

EXPERIENCE WITH GEI
14 years

REGISTRATIONS AND LICENSES
Professional Engineer, CO No. 42743

CERTIFICATIONS
Professional Hydrologist-American Institute of Hydrology

PROFESSIONAL ASSOCIATIONS
American Society of Civil Engineers, Member
Association of State Dam Safety Officials, Member

AWARDS
2013 Technical Paper of the Year, "*Dam Safety Alternatives Analysis Using Optimized Hydropower Simulations*", HydroVision 2013 Conference.

PROJECT EXPERIENCE

**Big Elk Meadows Dams Reconstruction Project, Big Elk Meadows Association, Lyons, CO.** Project Manager and Design Engineer. Mr. Miller was responsible for managing the preparation of final design plans and specifications for five low hazard dams that were destroyed in the Colorado September 2013 flood event. Necessary tasks included developing designs for the embankments ranging in height from 16 to 26 feet high, concrete overflow spillways, riprap lined spillways, and outlet works systems. In support of the designs, he prepared hydrologic and hydraulic studies, geotechnical investigations, environmental 404 permitting, and developed construction cost estimates. All final designs were prepared for and approved by the Colorado State Engineer's Office, Dam Safety Branch. Four of the five have been constructed with GEI performing the construction observation and documentation to meet SEO and FEMA funding requirements.

**Stanley Canyon Dam, Colorado Springs Utilities, Colorado Springs, CO.** Project Manager. Mr. Miller was project manager for a conceptual-level dam safety alternatives evaluation to minimize risk for Stanley Canyon Dam, a small, low-hazard earthfill embankment. Alternatives included dam breach, dam rehabilitation, and dam reconstruction, which ranged from about $1.1 million to $4.4 million. GEI performed hydrologic, hydraulic, and geotechnical analyses to support the development of the dam safety alternatives. Based on the results of the study, Utilities awarded the final design plans, technical specifications, permitting, and construction oversight for the Stanley Canyon Dam Interim Risk Reduction breach project to GEI. The Interim Risk reduction breach project included excavating the existing embankment and outlet works and installation of riprap-lining and a sedimentation basin.

**Ivanhoe Dam Repairs, Busk-Ivanhoe Water System Authority, Pitkin County, CO.** Project Manager and Design Engineer. Mr. Miller was responsible for managing the final design plans and specifications, as well as construction oversight, for the significant hazard Ivanhoe Dam located at 11,000 feet near Leadville, Colorado. Necessary tasks included developing designs for the 16-foot high, 270-foot long earthfill embankment, 42-foot wide concrete overflow spillway, and 36-inch diameter outlet works system integrated wet well and slide gate. In support of the designs, he prepared hydrologic and hydraulic studies, geotechnical investigations, environmental 404 permitting, and developed construction cost estimates. All final designs were prepared for and approved by the Colorado State Engineer's Office, Dam Safety Branch, and constructed following construction observation and documentation requirements.

**Clear Creek Dam Reservoir Enlargement Study, Board of Water Works of Pueblo, CO.** Project Manager and Design Engineer. Mr. Miller prepared a Reservoir Enlargement Study that included developing conceptual level designs for repairs to the existing 80-foot-high, high hazard dam and also four separate reservoir enlargement alternatives. The conceptual designs for the repairs to the existing dam included slip-lining the existing outlet conduit, adding a new upper outlet works facility, repair of the chimney and blanket drain, and adding a downstream filter blanket. The conceptual designs for the enlargement alternatives ranged from modifying the existing spillways to achieve additional storage, to three embankment raise alternatives from 10 feet up to 36 feet. To support the conceptual designs, he prepared estimates of the inflow design flood (IDF) for the dam and performed geological mapping and a limited geotechnical exploration of areas of concern. He developed opinions of probable construction costs for the repairs and each alternative, which ranged $8.5 million up to $75 million.

**Upper Black Creek Reservoir Hydrology, Blue Lake Reservoir Company, Summit County, CO.** Project Hydrology and Hydraulics Engineer. Mr. Miller was responsible for performing all hydrology and hydraulic calculations and computer modeling for the development of the IDF at Upper Black Creek Dam located in Northern Summit County Colorado. Necessary tasks included subbasin delineation of a 14.3-square-mile watershed, development of PMP and precipitation frequency estimates using CO-NM Regional Extreme Precipitation Study (REPS), estimating basin loss rates, developing unit hydrographs, creating reservoir and spillway routing parameters, developing the IDF of 1,940 cfs, performing hydraulic model calculations to support the design of the new spillway, and preparing the final report and figures.

**Long Hollow Dam and Reservoir - Phase II Final Design, Colorado Water Resources & Power, Hesperus, CO.** Project Hydrology and Hydraulics Engineer. Mr. Miller was responsible for performing all hydrology and hydraulic calculations and computer modeling for the development of the Long Hollow Dam PMF estimate. Necessary tasks included watershed and subbasin delineation, development of Probable Maximum Precipitation (PMP) using HMR 55A, estimating basin loss rates, determining drainage baseflows, developing unit hydrographs, developing spillway rating curve, creating channel and reservoir routing parameters, and preparing the final report and figures.

**Long Lakes Hydrology and Hydraulics Study and Alternatives Analysis, Denver Water, CO.** Project Manager and Subject Mater Expert: Prepared estimates of the IDF for Upper and Lower Long Lake Dams. The IDF estimates were developed using the PMP estimates from HMR 55A methods and also included frequency storms estimates. The IDF study was developed to provide an evaluation of the existing Upper and Lower Long Lake Dams to safely pass the SEO-required IDF. Based on the study results, developed conceptual layouts that included spillway modifications and dam raises to increasing spillway capacity. Prepared cost estimates for the alternatives and provided a recommended alternative for both dams.

**Santa Felicia Dam Spillway Improvements Project, United Water Conservation District, Santa Paula, CA.** Project Design Engineer. Mr. Miller was responsible for performing and managing hydraulic analyses and final design documents to mitigate dam safety concerns related to the inadequate spillway capacity to pass the IDF. Necessary tasks included developing eight spillway alternative configurations; 2D hydraulic modeling of all spillway alternatives; developing a spillway alternatives evaluation report including conceptual designs and cost estimates; evaluating structural stability of existing walls, slabs, and ogee structure; developing dam raise conceptual designs and costs estimates; performing erosion evaluations of the downstream channel; preparing Basis of Design Report, construction plans and specifications; and preparing reports and a presentation for the Board of Consultants, FERC, and California DSOD.

**Hydrology Study, Dam Breach Analysis, and EAP Update, White Mountain Apache Tribe, Whiteriver, AZ.** Senior Hydraulic Engineer and Reviewer. The project consisted of preparing hydrology studies including frequency storms and PMF estimates for five high hazard dams and preparing dam failure analyses and flood routing for the Sunny Day, IDF, and advisory flood (non-dam break) conditions for nine high hazard dams. Emergency Action Plans were updated for nine dams on the Fort Apache Indian Reservation. Watershed basin parameters were developed including NRCS soil data, frequency storm precipitation, development of PMP and Probable Maximum Floods, unit hydrographs, and basin flood routing. Dam breach floods were routed until the differences in inundation depth between the advisory flood and the IDF dam breach were less than 2 feet in the Salt River.

**Sarah B. Skigen-Caird**
Permitting Lead

resume

Ms. Skigen-Caird is the Ecology Division Manager for the Denver, Colorado, ecology practice and an environmental scientist with over 15 years of professional experience within both the public and private sector. As project manager she has developed, designed, and implemented large-scale land use and water quality programs. Sarah has worked extensively with aquatic and terrestrial ecosystems, vegetation and wildlife surveys, wetland delineations, CWA 404 permitting and NEPA/CEQA compliance, restoration of disturbed systems, and biomonitoring study design. Her experience includes field training with USFWS and the National Audubon Society for conducting avian surveys and monitoring. Additionally, as QA/QC officer for the ecological lab she oversees and provides quality assurance/quality control checks for all lab activities.

EDUCATION
M.S., Environmental Science & Policy, Johns Hopkins University
B.A., Environmental Studies, Bates College

EXPERIENCE IN THE INDUSTRY
16 years

EXPERIENCE WITH GEI
8 years

CERTIFICATIONS
40-Hour OSHA HAZWOPER

Wetland Delineator

ISA Certified Arborist SO-6152A (2008-present)

Masters Certificate in Environmental Conflict Management and Resolution, European Peace University, Austria

PROJECT EXPERIENCE

**Upper Beaver Brook Spillway Replacement, Lookout Mountain Water District, Evergreen, CO.** Lead Biologist. Performed field investigations to delineate wetlands; determine the extent of sensitive habitats, including assessments to determine any impacts to rare, threatened, or endangered species; and take lead on federal 404 permitting requirements with the U.S. Army Corps of Engineers, Omaha District prior to initiation of construction. Ultimately leading to a non-jurisdictional determination for the spillway itself. GEI also supported the District in the acquisition of a Special Use Permit from the U.S. Forest Service.

**Emergency Environmental Permitting for Dam Reconstruction, Big Elk Meadows Association, Lyons, CO.** Lead Biologist. Performed field investigations related to wetlands and sensitive habitats, as well as conducted all associated environmental permitting through FEMA and U.S. Army Corps of Engineers, Omaha District prior to construction. Additionally, we completed acquisition of a NWP 27 for the restoration of each reservoir to replace aquatic habitat as a result of flood impacts. Work included baseline surveys for potential habitat for Preble's meadow jumping mouse (*Zapus hudsonius preblei*) throughout the project area.

**Town of Hot Sulphur Springs, Drinking Water Intake Maintenance and Construction of Downstream Boulder Cross Vane on the Colorado River, Hot Sulphur Springs, CO.** Lead Biologist. Performed field investigations to delineate wetlands and determine the extent of sensitive habitats, including assessments to determine any impacts to rare, threatened, or endangered species, with specific focus on Western yellow-billed cuckoo (*Coccyzus americanus occidentalis*) and the Gunnison sage grouse (*Centrocercus minimus*). Federal 404 permitting with the U.S. Army Corps of Engineers, Sacramento District, has been completed.

**Busk-Ivanhoe Dam Modifications, Board of Water Works, City of Pueblo, Leadville, CO.** Lead Biologist. Performed field investigations to delineate wetlands and determine the extent of sensitive habitats including assessments to determine any impacts to endangered species prior to construction efforts to rehabilitate the existing reservoir.

**Dam Rehabilitation, Department of the Interior, Bureau of Indian Affairs, NM, AZ, CA, and SD.** Lead Biologist. Performed field investigations to delineate aquatic resources; determine the extent of sensitive habitats, including assessments to determine any impacts to rare, threatened, or endangered species; and led effort for acquisition of the 404 permit with the U.S. Army Corps of Engineers prior to initiation of construction. Work includes ongoing support for NEPA compliance and formulation of the Environmental Assessment for each proposed project to evaluate design alternatives. Coordination with multiple federal and tribal agencies as well as regional stakeholders has been required.

**Andrew B. Lockman, P.G.**
Geotechnical Lead

resume

Mr. Lockman is a geological engineer with expertise in dam design and tunnel engineering. He has worked on multiple water storage, water transmission, hydroelectric, and mining projects and has significant experience in site investigations, subsurface characterization, design development, risk evaluation, and construction oversight for dams and tunnels. His background includes geotechnical analysis, geologic mapping and interpretation, instrumentation design and installation, seepage and stability analyses, and developing designs for new dams and rehabilitating aging structures. He applies his diverse skills with enthusiasm and brings a team oriented, collaborative approach to each project he works on.

EDUCATION
M.S., Geological Engineering, University of Wisconsin, Madison
B.A., Geology, Western State College of Colorado

EXPERIENCE IN THE INDUSTRY
14 years

EXPERIENCE WITH GEI
5 years

REGISTRATIONS AND LICENSES
Professional Geologist, WY No. 3793

PROFESSIONAL ASSOCIATIONS
United States Society on Dams
*Construction and Rehabilitation Committee*
*Foundations Committee*
American Society of Civil Engineers

PROJECT EXPERIENCE

**Upper Beaver Brook Spillway Replacement, Lookout Mountain Water District, Evergreen, CO.** Project Engineer. Mr. Lockman performed geologic mapping and rock mass characterization for excavation and blasting designs to widen the existing spillway channel. The project required detailed characterization of rock types and discontinuities to develop efficient blasting designs and avoid potential impacts to existing structures.

**Chimney Hollow Reservoir, Municipal Subdistrict, Northern Colorado Water Conservancy District, Loveland, CO.** Field Exploration Lead. Mr. Lockman managed field investigations for a new 360-foot high hydraulic asphaltic-concrete cored rockfill dam and all appurtenant structures. He worked closely with a team of industry experts to develop foundation recommendations that meet loading conditions and address foundation seepage through bedrock and soils. The off-channel water storage reservoir is designed to hold 90,000 acre-feet of water. Related structures include a 40-foot high zoned earthfill saddle dam, a 2,700-foot long inlet/outlet tunnel through the right abutment, rock quarry, concrete lined spillway, and conveyance structures. His responsibilities included managing investigations to characterize the subsurface conditions with drilling and in-situ testing at the main dam, saddle dam, tunnel, and to evaluate available clay and rockfill borrow. Over the course of two campaigns, the investigations included ~7,000 feet of rock coring, 27 soil borings, 61 test pits, and 4 test trenches that were more than 500 feet long. He presented investigation results and foundation recommendations to the Project Review Board, the Colorado State Engineer, and the client at project milestones.

**Kings River Levee Evaluation, Kings River Conservation District, Fresno, CA.** Field Exploration Lead. Mr. Lockman managed field investigations to characterize foundation conditions for a levee system in the Central Valley of California. The project included approximately 139 miles of levees intended to provide flood protection for agricultural lands, nearby communities, and local infrastructure, as well as to convey irrigation water for farmers. Responsibilities included performing screening evaluations to target investigation locations based on anticipated flood loadings, levee geometry, and past performance, as well as managing the execution of 180 Cone Penetration Tests (CPT) and 36 mud rotary borings. The project required close coordination and communication with field staff, client, and subcontractors to meet tight schedule requirements in a demanding environment with limited site access, remote and dispersed investigation locations, and challenging soil and field logging conditions.

**Lauer Dam Rehabilitation Final Design, Bureau of Indian Affairs, Alturas, CA.** Project Manager. Mr. Lockman was responsible for overseeing the design and rehabilitation of a water storage reservoir for the Pit River Tribe in Northeastern California. His responsibilities include performing alternative analyses, facilitating risk assessments and risk reduction workshops, value engineering, design development, and characterization of material for this unique rockfill dam that utilizes a concrete wall at the dam centerline as a water barrier. Challenges include optimizing use of available on-site materials during design development, fully evaluating design

and construction risks, and coordinating between several different stakeholders. He delivered project presentations to the Pit River Tribal Council and at the Bureau of Indian Affairs Safety of Dams Conference.

**Dam Safety and Security Inspections, Bureau of Indian Affairs, Denver, CO.** Project Engineer. Mr. Lockman performed dam safety inspections and condition assessments as a component of the Bureau of Indian Affairs Safety of Dams Program. He completed condition assessments of structures based on site inspections, project performance reviews, potential failure modes analyses, operational considerations, and identified regional threats to security. Updated the risk profiles under normal operation, seismic, and hydrologic loadings. His responsibilities included completing field inspections and records reviews, coordinating with field and Tribal staff, participating in Dam Safety Advisory Team meetings, and follow up reporting. He worked with client and Tribal representatives, interviewed local law enforcement, and inspected dams. He developed risk profiles of the facilities and provided recommendations to improve the safety and security of the structures.

**Ghost Hawk Dam Rehabilitation Final Design, Bureau of Indian Affairs, Rosebud, SD.** Project Engineer. Mr. Lockman performed seismic hazard assessment to characterize the risk posed by a low-density and potentially liquefiable soil unit in the dam foundation. He developed subsurface investigation plan and laboratory testing program to characterize the target layer, and performed liquefaction triggering analysis and slope stability evaluations. He presented results to the Bureau of Indian Affairs and seismic hazard experts at the United States Bureau of Reclamation.

**Guntersville Dam Stability Analysis, Tennessee Valley Authority, Guntersville, AL.** Project Engineer. Mr. Lockman was responsible for managing field investigations, laboratory evaluations, and overseeing stability evaluations. Guntersville Dam is an earthfill dam with a large concrete spillway, four-unit powerhouse, and two locks on the Tennessee River in Northern Alabama. The stability of the dam and an associated dike were evaluated under normal operation, flood, and earthquake loading conditions. Field components of the project include soil borings, rock coring, CPT/sCPT soundings with pore pressure dissipation tests, concrete coring, and downhole geophysical surveys.

## PREVIOUS PROJECT EXPERIENCE

**Cerro Verde Tailings Storage Facility, Arequipa, Peru.** Mr. Lockman mapped the geology and performed subsurface investigations using rock coring, water pressure testing, and test pits to characterize site conditions for the proposed largest tailings storage facility in the world. The focus was on characterizing the rock mass, potential borrow sources, faults, liquefaction potential, slope stability, karst, and high permeability zones within the embankment foundation, near appurtenant structures, and in impoundment areas. Completed a Deterministic Seismic Hazard Assessment using Next Generation Attenuation ground motion prediction equations. Characterized seismic sources and the controlling earthquake, selected appropriate attenuation relations, and defined the hazard in terms of predicted ground motions. Completed design calculations for filters and drainage layers at the starter dam.

**Susitna-Watana Hydroelectric Dam, Central AK.** Mr. Lockman summarized data from geologic mapping, geotechnical investigations, and several other studies to develop subsurface profiles, characterize ground conditions, and obtain a comprehensive understanding of critical design considerations for a proposed 735-foot-high hydroelectric concrete gravity dam. He modeled the rock mass to develop preliminary rock excavation plans and evaluated the settlement potential following excavation and loading of the dam using the Rocscience Phase2 finite element modeling software.

**Seneca Pumped Storage Hydroelectric Generation Facility, Warren, PA.** Project Engineer and Deputy Project Manager. Mr. Lockman was responsible for the design, construction, and rehabilitation of an impermeable liner for a 435MW hydroelectric pumped storage facility under FERC oversight. He worked closely with the client, the FERC, and an independent Board of Consultants to advance preliminary designs, specifications, reports, and the Quality Control Inspection Plan for construction of a new reservoir floor liner at the upper reservoir. He co-facilitated and served as a Recorder for a Risk Assessment workshop related to evaluating project risks before and after construction.

**Thomas A. Daigle, P.G.**
Construction Management

resume

Mr. Daigle is a project manager whose responsibilities at GEI include conducting and managing environmental and geotechnical field investigations, evaluating remedial alternatives, overseeing remedial system operation and maintenance, and preparing compliance reports for various regulatory agencies.

Mr. Daigle has experience in civil and geotechnical construction oversight and project management as well as drill core and test pit logging, hazardous material assessments, soil and groundwater investigations, underground storage tank removal, light non-aqueous phase (LNAPL) transmissivity testing, permitting, and strategic regulatory support. He also has experience with conceptual site modeling, data analysis, sediment investigations, and vapor intrusion assessments.

EDUCATION
M.S., Geology, Northern Arizona University
B.S., Biology/Geology, Union College

EXPERIENCE IN THE INDUSTRY
13 years

EXPERIENCE WITH GEI
12 years

REGISTRATIONS AND LICENSES
Professional Geologist
NE No. G-0378,
WY No. PG-3929,
CA No. PG-9276

CERTIFICATIONS
40-Hour OSHA HAZWOPER
Adult First Aid-CPR-AED

PROFESSIONAL ASSOCIATIONS
Geological Society of America, Member
Rocky Mountain Association of Environmental Professionals, Board Member
American Association of Petroleum Geologists, Member

PROJECT EXPERIENCE

**Upper Beaver Brook Dam Spillway Improvements, Lookout Mountain Water District, Evergreen, CO.** Staff Team. Mr. Daigle managed the construction and oversight of a new 3-cycle concrete labyrinth weir spillway installed at the Upper Beaver Brook Dam west of Evergreen, Colorado. He was responsible for inspecting contractor work, ensuring quality control, managing schedule, reviewing submittals, preparing daily reports and technical memos, and communicating with the project team and State Dam Safety Division. Construction tasks included rock excavation by blasting, foundation preparation, grout curtain construction, rock anchors, winter concrete placement, and underwater dive work to improve the existing outlet works. He worked closely with the contractor, project owner, and State Dam Safety Division to address construction challenges and implement engineering solutions with minimal impact to the project budget and schedule.

**Montgomery Dam Improvements Project, Colorado Springs Utilities, Fairplay, CO.** Staff Team. Mr. Daigle managed the construction and oversight of repairs and improvements to a 105-foot-tall rockfill dam at 10,800 feet in elevation. He was responsible for inspecting contractor work, ensuring quality control, managing schedule, reviewing submittals, and communicating with the project team. Construction tasks included resealing the upstream asphaltic face of the dam, installing a new hydraulically operated upstream sluice gate, repairing the underdrain pipe, and repairing the concrete flume that supplies inflow to the reservoir. Rope and rappel gear were required to access the upstream face to identify and quantify repairs. The upstream hydraulic sluice gate was installed by a specialized industrial dive crew. He worked closely with the dive crew and project owner to overcome challenges of installing the sluice gate underwater. He performed permit-required confined space entry to inspect the sluice gate installation and the condition of the concrete discharge conduit (400-feet-long, 6-feet-diameter).

**Ivanhoe Dam Repairs, Busk-Ivanhoe Water System Authority, Pitkin County, CO.** Project Geologist. Mr. Daigle performed a review of local geologic conditions and prepared a construction cost estimate for improvements to the Busk-Ivanhoe dam, reservoir, and appurtenances. Improvements include a new outlet works structure, new discharge piping, stability berm on the downstream slope, updated spillway, new stilling basin, and new culverts. He performed construction oversight, QA/QC, and documentation for demolition, earthwork, foundation prep, concrete placement, steel pipe installation, and seepage liner repair.

**Upper Kapahi Reservoir Breach, Hawaii Department of Accounting and General Services, Kaua'i, HI.** Staff Team. Mr. Daigle served as the onsite construction manager and inspector for the engineered breach of Upper Kapahi Reservoir. The project included temporary closure of a county road that runs along the dam crest followed by excavation of the earth fill embankment down to the reservoir invert. The breach was completed by the

construction of a cast-in-place concrete culvert to pass the probable maximum flood, and then reconstruction of the embankment above the culvert and replacement of the county road. His primary job duties included in-place soil compaction testing using a nuclear moisture density gauge; daily/weekly progress reports; communication with the client, contractor, and stakeholders; review of contractor submittals and preparation of field directives; quality control inspections; document as-built conditions; and management of site health and safety.

**Hodgson-Harris Dam Modifications Final Design, Boulder County Open Space and Mountain Parks, Superior, CO.** Project Geologist. Mr. Daigle performed pre-construction field investigations including overburden and bedrock drilling, test pit activities, and local surface mapping. He collected samples for geotechnical index testing including grain size, Atterberg limits, moisture content, and proctor analysis.

**Barker System Maintenance, City of Boulder, Boulder, CO.** Project Geologist. Mr. Daigle served as construction manager and inspector during the 2012 maintenance season for the Barker Gravity Pipeline. The pipeline was built in 1905 and consists of approximately 12 miles of 36-inch diameter concrete gravity pipe that serves the City of Boulder with roughly 40 percent of its municipal water supply. GEI designed several localized repairs including short sections of pipeline replacement, several manhole replacements, manhole vault installation, and access road construction. Construction oversight involved a high level of technical knowledge and flexibility to adapt to difficult work locations and often unknown existing conditions. Mr. Daigle provided quality assurance inspections of all constructed repairs and prepared as-built plans. He performed frequent permit-required confined space entry.

**Intermountain Power Station Coal Ash Impoundment Inspection and Dam Safety Assessment, U.S. Environmental Protection Agency, Kansas North Dakota, ND.** Project Geologist. Mr. Daigle was responsible for site assessments, data reviews, and analyses at multiple coal-fired generating stations in Wyoming. The objective of the project was to assess whether coal combustion waste impoundments are stable and adequate with respect to federal dam safety standards. Potential dam safety issues included hydraulic capacity, stability, seepage, operations, geologic hazards, instrumentation, and construction and these were evaluated based on analysis, inspection, operations, or background information.

**Slope Stability Investigation and Stabilization Design, Laramie Energy, Collbran, CO.** Staff Team. Mr. Daigle performed geotechnical drilling, sampling, and analysis of an active landslide (creep) to assess slope stability in support of oil and gas drilling operations. Installed piezometers and modified slope inclinometers and collected extensive soil samples for geotechnical analysis. He worked closely with the client and GEI engineers to develop a slope stability design that provided an acceptable factor of safety and was readily constructible to meet tight drilling deadlines.

**Valero – NuStar Denver Terminal Remediation, VTD Properties, Inc., Broomfield, CO.** Mr. Daigle was responsible for the operation and maintenance of an existing LNAPL remediation system that includes an air compressor, pneumatic skimmer pumps, holding tank, and associated air/fluid piping. The existing system was previously shut down and GEI managed the reconstruction and recommissioning activities to bring the system back to full operation. He was responsible for implementing a semi-annual groundwater sampling and reporting program in compliance with Colorado Department of Public Health and Environment (CDPHE) regulations. Tasks included performing data analysis to optimize remediation system and quantify LNAPL recovery rates. Other tasks included to provide regulatory compliance reporting and develop a path forward to regulatory closure.

**Former Gas Compressor Stations LNAPL Transmissivity and Plume Stability Analysis, Kinder Morgan, TX.** Mr. Daigle was responsible for comprehensive site data review at two sites in South Texas and West Texas. The goal was to develop a recommended path forward to regulatory closure within the framework of applicable Texas regulations (Texas Railroad Commission and Texas Commission on Environmental Quality). He reviewed all historic site data to determine the LNAPL hydrogeologic condition (confined, unconfined, perched) and performed LNAPL transmissivity testing at both sites including training of new field staff. He developed an LNAPL conceptual site model and a dissolved phase plume stability analysis to benchmark the overall site conditions. He directed field and office activities and managed the schedule including client communications and regulatory meetings with the RRC. GEI's work resulted in accelerated site closure and cost savings for the client.

**Michael P. Walker, P.E.**
Principal in Charge

resume

Michael Walker has experience as a contractor, designer, and consultant for a wide variety of geotechnical, civil, structural, and environmental projects, including the evaluation and design of earth, concrete, and Roller Compacted Concrete (RCC) dams, spillways, free standing intake towers, stilling basins, outlet piping, stream diversion cofferdams, and other hydraulic structures. He has performed dam safety inspections and prepared designs for the repair of existing and construction of new structures. In addition, he has monitored the construction of modifications and performed inspection and condition assessments of existing structures. Mr. Walker is one of the authors of ERDC/GSL TR-03-14 (Proposed Design Criteria on Thin Wall Precast Panels for Hydraulic Concrete Structures) for the U.S. Army Corps of Engineers (USACE) for the use of precast concrete for in the wet construction of hydraulic structures.

EDUCATION
M.S., Civil Engineering, University of Massachusetts, Amherst
B.S., Civil Engineering, University of Massachusetts, Amherst

EXPERIENCE IN THE INDUSTRY
23 years

EXPERIENCE WITH GEI
24 years

REGISTRATIONS AND LICENSES
Professional Engineer, ME No. 13533
Professional Engineer, BC No. 181756
Professional Engineer, MN No. 50985
Civil Engineer, CA No. C 81482
Professional Engineer, KS No. 22700
Professional Engineer, NE No. CA2616
Professional Engineer, WA No. 47260
Professional Engineer, ND No. PE-6742
Professional Engineer, NV No. 019408
Professional Engineer, OK No. 24068
Professional Engineer, AL No. 30236
Professional Engineer, UT No. 7336930-2202
Professional Engineer, IN No. 10810023
Professional Engineer, KY No. 25129
Professional Engineer, IA No. 18584
Professional Engineer, OH No. 71676
Professional Engineer, OR No. 77662
Professional Engineer, LA No. 32829
Professional Engineer, TX No. 98167
Professional Engineer, VA No. 40007
Professional Engineer, NY No. 81628
Professional Engineer, PA No. 61459
Professional Engineer, NJ No. 24GE04353100
Professional Engineer, RI No. 7136
Professional Engineer, CT No. 20828
Professional Engineer, MA No. 38552
Professional Engineer, MD No. 32291
Professional Engineer, MI No. 6201-051970
Professional Engineer, DC No. 900551
Professional Engineer, WI No. 36196

PROJECT EXPERIENCE

**Flat Ledge Quarry Dam, Town of Rockport, Rockport, MA.** Staff Team. Provided evaluation of the feasibility of constructing a dam at the Flat Ledge Quarry site. Responsible for evaluation of three dam types (mass concrete, earthfill rock fill, and RCC) for the proposed location. Prepared preliminary designs to determine dam footprint and geometry, coordinated evaluation with geotechnical exploration, and prepared feasibility level cost estimates for the three dam types. Prepared portions of the final report pertaining to stability analyses, design, and cost estimating. Assisted in presentation of findings to the town selectmen and at the town meeting. Prepared preliminary design of the chosen alternative.

**Milltown Hill Dam Project, MWH, Douglas County, OR.** Staff Team. Provided final design of 190-foot-high RCC dam. The dam will consist of approximately 225,000 cubic yards of RCC in a 1,400-foot-long gravity section with a central overflow spillway. Responsible for stream diversion, excavation sequence, stability evaluations, and cost estimates. Developed detailing on drawings related to concrete, civil, and RCC construction and assisted with review of technical specifications.

**Aetna Lake Dams Geotechnical Investigation, Dewberry, Medford Lakes, NJ.** Project Manager. Responsible for geotechnical investigation for design of a new RCC dam in the footprint of a failed embankment dam. Selected boring location and laboratory testing program to develop properties for evaluation of bearing capacity, seepage, and settlement for the proposed new dam.

**Restoration of Upper and Lower Aetna Lake Dams, Dewberry, Borough of Medford Lakes, NJ.** Project Manager. Feasibility study and design for RCC replacement of two embankment dams that had failed during flooding. Evaluated costs, impacts on community, and technical feasibility for earth, concrete, and RCC alternates. Assisted in geotechnical investigations and evaluations. Prepared final design and construction services contract documents for the selected option.

**Standley Lake Dam Improvements, Farmers Reservoir and Irrigation Company, Arvada, CO.** Project Engineer. Responsible for design of grouting program to fill four 48-inch diameter outlet pipes approximately 600-feet-long. Because the work was performed while maintaining the reservoir, the grout was pumped against

the full reservoir head from the downstream end of the pipe. Also provided review of microtunneled intake tap of the reservoir.

**Big Cherry Dam, Big Stone Gap, Virginia.** Staff Team. Provided preliminary design of structural modifications to an existing dam crest to allow installation of high strength rock anchors required to increase rock stability. Evaluated dam core data for potential degradation of the concrete and sandstone matrix, crest design and proposed grade beam for anchorage support, and impacts of foundation bedrock on anchorage design.

**Helmetta and Manalapan Dam Rehabilitation, PMK Group, Helmetta Borough, NJ.** Project Manager. Responsible for design of remedial measures to bring this earth embankment dam and spillway into compliance with the New Jersey Dam Safety Standards for a Class II (significant hazard) dam. Identified dam deficiencies were inadequate hydraulic capacity, deteriorated spillway structure, dense vegetation cover on embankments, lack of control for the outlet works, and seepage. Preliminary designs to improve safety included a temporary cofferdam, temporary stream diversion system, new concrete spillway, intake structure training walls, stilling basin, auxiliary spillway, gated culvert, access road, graded filter, and raised embankment crest.

**Norfolk Dams Remedial Design, City of Norfolk Dept. of Utilities, Suffolk, VA.** Staff Team. Provided design rehabilitation of four water supply dams in the city of Norfolk. Project involved analysis of the dams to identify safety deficiencies, as well as design of modifications. Performed inspections of concrete structures and prepared reports. Designed two low-level outlet buried pipelines, free standing intake tower, and inlet and outlet structures. Outlet works design included microtunneling for installation of pipeline to replace existing low-level outlet pipe. Performed stability analysis of existing spillways and inlet towers for static and dynamic (seismic) loads. Designed modifications to spillways, training walls, and parapet wall. Designed upstream cofferdams built on existing concrete slope paving. Performed inspection and condition assessments of inlet towers, piping, and spillways. Prepared drawings and specifications for construction. One of the four dams, Lake Burnt Mills, was awarded the ASDSO National Rehabilitation Project of the Year Award for 2009.

**Canton Dam Emergency Spillway, United States Army Corps of Engineers, Canton, OK.** Project Manager. Designed a permanently anchored diaphragm wall to be used as the training wall for a new spillway. This design build project includes value engineering proposals outside of the base-bid to save the Owner time and money. Prepared design in a fast track schedule including the USACE review process.

**IEPR for C-44 Reservoir Contract No.2, USACE - Louisville District, Martin County, FL.** Project Manager. Performed Independent External Peer Review for Structural elements of a new dam used as part of a system to remove nitrogen and phosphorus from agricultural runoff in the Indian River. Reviewed the design and construction documents and provided comments to the USACE.

**Herbert Hoover Dike Construction Phase of S-269 and S-270 Culverts, Type II IEPR, United States Army Corp of Engineers.** Senior Structural Engineer. Responsible for IEPR evaluation of QA/QC measures for construction of new culverts along the length of approximately 30-foot-high, 35-mile-long dike that impounds Lake Okeechobee. Reviewed construction documentation for consistency with design intent and provided comments on modifications to QA procedures. Provided design modification recommendations based on details observed in the field.

**Allendale Dam Reconstruction, U.S. EPA - Region 1, Providence, RI.** Project Manager. Managed design of replacement dam for a breached timber cribbing and earth embankment dam at a superfund site. The breached dam allowed flows that could potentially transport contaminants in sediments upstream of the dam. The new design minimized excavation of contaminated soils by constructing a rock-bolt-anchored concrete retaining wall dam immediately downstream of the existing dam. Work included field modifications to match changed conditions found during construction. Prepared a Basis of Design Report for submittal to the USACE. Design was reviewed and approved by USACE Contingency Operations Division (USCOE) and Environmental Protection Agency (EPA).

**Charles B. Grant, P.E., S.E.**
IHC and QA/QC

resume

Charles Grant is a structural engineer specializing in dams and appurtenant structures, water resources facilities, earth retention systems, foundations, and temporary structural shoring. His areas of expertise include stability analysis of dams and hydraulic structures; design of reinforced concrete, structural steel, and timber structures; structural and geotechnical finite element analysis; seismic analysis and design; and construction management. Mr. Grant served on active duty in the U.S. Army Corps of Engineers from 1996 to 2004.

Mr. Grant is a Federal Energy Regulatory Commission (FERC) approved Part 12D Independent Consultant.

EDUCATION
M.S., Civil Engineering, University of Missouri, Rolla
B.S., Civil Engineering, Bucknell University

EXPERIENCE IN THE INDUSTRY
23 years

EXPERIENCE WITH GEI
15 years

REGISTRATIONS AND LICENSES
Structural Engineer, IL No. 081.006927
Structural Engineer, MA No. 49165
Structural Engineer, HI No. 14443
Professional Engineer, MA No. 47311
Professional Engineer, NH No. 15214
Professional Engineer, ME No. PE 15505
Professional Engineer, CA No. C83788
Professional Engineer, NY No. 095579-1
Professional Engineer, MO No. 2001004595

PROJECT EXPERIENCE

**Aetna Lakes Dam Design, Borough of Medford Lakes, Medford Lakes, NJ.** Staff Team. Mr. Grant Assisted in the design of two low-head roller-compacted concrete dams. He designed excavation support systems and performed stability analyses.

**Federal Energy Regulatory Commission Part 12D Independent Consultant, Southern California Edison, CA.** Staff Team. Mr. Grant performed dam safety inspections of fourteen high hazard potential dams, including concrete gravity, arch, multiple-arch, and rockfill dams in the Big Creek, Bishop Creek, Rush Creek, Lee Vining, and Lundy projects. He reviewed operational procedures and dam safety studies, investigations, and analyses. Made recommendations for updates and revisions to Supplemental Technical Information (STI) documents and surveillance and monitoring programs. He updated Potential Failure Modes Analysis for each dam and wrote Part 12D inspection reports.

**Herbert Hoover Dike Reach 1 Gap Closures IEPR, U.S. Army Corps of Engineers - Jacksonville District, FL.** Structural Engineer Expert Reviewer. Mr. Grant served as Structural Engineer Expert Reviewer on Type II Independent External Peer Review (IEPR) team. The project included construction of seepage barriers within Herbert Hoover Dike, a Dam Safety Action Classification System (DSAC) Class I (Very High Urgency) dam, to connect previously constructed cutoff wall to existing concrete structures. Mr. Grant performed field inspection of site and met with the project team. He provided review comments in DrChecks design review system, back-checked evaluations, and made additional comments as necessary. He assisted in preparation of IEPR review report.

**Somerset Dam Training Wall Design & Construction, Great River Hydro, LLC, Somerset, VT.** Project Manager. Mr. Grant designed a replacement spillway training wall for FERC-regulated dam. The existing spillway training wall was deteriorated beyond repair. He performed gravity stability analysis, concrete structural design, foundation design, and concrete detailing. He developed engineering drawings, technical specifications, Temporary Construction Emergency Action Plan (TCEAP), and Quality Control Inspection Program (QCIP). He reviewed contractor submittals and performed field inspection of construction. He prepared completion report and as-built record drawings.

**Maranacook Lake Dam Modification Design, Towns of Readfield & Winthrop, Maine, Winthrop, ME.** Project Manager. Mr. Grant performed a preliminary engineering study to assess various alternatives for increasing spillway capacity of dam and alleviating persistently high headwater conditions. He developed and ranked potential courses of action. He evaluated hydraulic, hydrologic, structural, environmental, and economic considerations. Following selection of Obermeyer gate option, he performed detailed structural and civil design of modification and developed construction documents for procurement.

**Rueter-Hess Dam Design, Parker Water & Sanitation District, Douglas County, CO.** Project Engineer. Mr. Grant designed a 190-foot reinforced concrete intake tower for a new earth embankment dam. His responsibilities included tower walls, deck, corbels, and gate supports. He designed a 100-foot bridge pier and foundation and implemented finite element analysis to design custom pipe connections for reservoir outlet works.

**Upper Kapahi Dam Design, State of Hawaii, Kauai, HI.** Structural Engineer of Record. Mr. Grant assisted with six-barrel reinforced concrete box culvert and wingwalls for highway passing over embankment dam crest. The design of the box culvert and wingwalls was performed in accordance with Hawaii DOT design criteria and AASHTO LRFD Bridge Design Specifications (Fifth Ed.) for AASHTO HL-93 design vehicle load and unique conditions associated with dam crest location.

**Norfolk Dams Remediation Design, City of Norfolk, Suffolk, VA.** Mr. Grant assisted in design of elements of dam safety modification program, including micropile foundation for concrete intake tower and access bridge pier. He provided engineering assistance during construction. This project was awarded the ASDSO National Rehabilitation Project of the Year Award for 2009.

**Center Hill Dam Cutoff Wall Construction, Bauer Foundation Corporation, DeKalb County, TN.** Project Engineer. Structural design consultant for design-build installation of a 300-foot-deep cutoff wall to reduce seepage through dam embankment and limestone foundation. Supervised structural design of reinforced concrete working platform and other construction facilities. Reviewed design drawings and assisted in preparation and review of technical submittals to the Owner, the US Army Corps of Engineers. Performed field inspections during construction.

**Canton Lake Dam Auxiliary Spillway Design, U.S. Army Corps of Engineers - Tulsa District, Canton, OK.** Project Engineer. Mr. Grant designed reinforced concrete anchored diaphragm walls for a 50-foot-deep spillway channel at the U.S. Army Corps of Engineers dam. The walls totaled 1,470 feet in length with a surface area of 76,000 square feet and were designed to resist differential water pressures in a rapid drawdown scenario following the Probable Maximum Flood. He also designed secant pile cutoff wall across spillway channel to resist loads from 58 feet of downstream headcutting erosion.

**Wolf Creek Generating Station, Bechtel & Nicholson Construction Co., Burlington, KS.** Project Manager. Mr. Grant designed permanent nuclear safety-related tangent pile retaining walls as part of the Wolf Creek essential service water piping replacement project. The safety-related retaining walls included a total of 22 large-diameter rock-socketed drilled shafts with a cast-in-place concrete cap beam. The drilled shafts were installed from a barge in the cooling water reservoir adjacent to the operating pumphouse and were designed to resist conventional earth retention and bulkhead wall loads as well as forces associated with tornado-generated missiles.

**Guntersville Dam Stability Analysis, Tennessee Valley Authority, Marshall County, AL.** Staff Team. Mr. Grant performed stress and stability analyses of spillway, non-overflow, powerhouse, and lock sections of TVA Guntersville Dam in accordance with TVA requirements based on FERC guidelines. He performed field investigations and laboratory testing to determine strength and stiffness properties of existing concrete and rock foundation materials. He investigated a variety of load cases, including normal pool, floods, earthquakes, and post-earthquake conditions. He performed all structural analyses using GT-STRUDL finite element analysis software. Seismic cases were evaluated using the response spectrum modal analysis procedure. Mr. Grant implemented limit equilibrium sliding stability analysis in SLOPE/W to account for non-planar section bases and dowel reinforcement of foundation.

**Upper Mechanicville Dam Stability Analysis, New York State Gas & Electric Corporation, Stillwater, NY.** Project Manager. Mr. Grant performed comprehensive stability analyses of concrete and masonry water-retaining structures in accordance with current FERC Engineering Guidelines for the Evaluation of Hydropower Projects. He analyzed and evaluated spillway, navigation lock, and various non-overflow sections for normal operating, flood, ice loading, and earthquake (post-earthquake) conditions using the conventional gravity stability analysis method. He performed earthquake analysis using the response spectrum modal analysis procedure in SAP2000.

**Daniel L. Johnson, P.E., F. ASCE**
RCC Dam Expert

resume

Mr. Johnson brings 45 years of experience supporting multidisciplinary water supply and storage projects, particularly in dam design and geotechnical engineering, with responsibilities for field investigations, laboratory testing, analyses, report preparation, construction documents, and construction management.

Mr. Johnson has been a key participant on more than 220 water supply-related and mining projects. Projects include embankment and concrete dam and reservoir projects in the U.S. and internationally. He is a recognized international expert in roller-compacted concrete (RCC) dam technology with about 35 RCC dam projects completed.

He is active in Association of State Dam Safety Officials, Unstructured Supplementary Service Data, and International Commission on Large Dams and is a respected educator on dam investigations, design, and construction sharing his extensive knowledge on dams.

EDUCATION
M.S. in Civil Engineering, Ohio University
B.S., in Civil Engineering, Ohio University

EXPERIENCE IN THE INDUSTRY
45

REGISTRATIONS/CERTIFICATIONS
Professional Engineer, CO No. 13365
Professional Engineer: CA, WY, OR

PREVIOUS PROJECT EXPERIENCE

**Gross Dam, Denver Water, Denver, CO.** Special Advisor to Denver Water on its planned 131-foot arch-RCC raise to the existing 345-foot high curved-gravity concrete dam. The works involves foundation and borrow materials investigation, structural analyses, and hydraulic analyses. (2013-2014). He was recently selected to lead the seven member Senior Technical Advisors for the final investigation and design working directly with the Stantec and AECOM team. The work involves site development for construction access and quarry, aggregate sourcing and RCC mix, and structural and hydraulic design of the dam raise. (2018–ongoing).

**Sweetheart Lake Hydropower Project, Juneau, AK.** Member of Board of Consultants. Member of three-person FERC-required Board of Consultants for the very low impact 20-MW hydropower project for the area of Juneau. The project involves a 100-foot high RCC dam, 9,000+foot-long access and penstock tunnel, surface powerplant, and ancillary equipment. (2016–ongoing).

**Thayer Creek Hydropower Project, Angoon, AK.** Technical Advisor. Mr. Johnson advised on project layout, site geology, RCC dam design, construction access and methodology, and river diversion. (2015-2016).

**Stagecoach Dam and Reservoir, Upper Yampa Water Conservancy District, Routt County, CO.** Principal Designer and Project Manager of this 150-foot-high RCC dam from the initial geotechnical and hydraulic analyses through detailed design, preparation of plans and specifications, and construction management. He provided communication with three federal agencies including Reclamation and two state agencies throughout this successful project. (1984-1988).

**Tongue River Dam RCC Spillway Evaluation, Decker, MT.** Independent Consultant to the State of Montana to provide opinion on performance of the 20-year-old RCC spillway that has ongoing deterioration. Work involved site reconnaissance, document review of past studies and trial mitigation measures, discussions with project personnel, and assessment and reporting of findings. (2017).

**Meerkat Hydropower Project, Douglas, South Africa.** Project Senior Dam Engineer on this new 20-MW hydroelectric power project on the Orange River in Central South Africa. The project involves a 30-meter high RCC dam, outlet works, penstock, spillway, and ancillary powerhouse components. Borrow material sourcing and construction sequencing are challenges in this area of high frequent storm flows and exposed basalt lava flows. (2016-ongoing).

**Demodara Dam Project, Bandarawela, Sri Lanka.** Senior Dam Engineer for the 18-meter high RCC dam and reservoir providing water to the Badulla, Haliela, and Ella Integrated Water Supply Project. The project involves investigation, alternatives evaluation and selection, preliminary and final design, and bidding assistance for

construction of the dam. Due to contractor experience, the dam was changed to conventional concrete at initiation of construction. Geologic conditions include solution-prone marble bedrock, reservoir landslides, and very large storm flows. (2012-2018).

**Pajarito Canyon RCC Flood Retarding Structure, Sundt Construction, Los Alamos, NM.** Project Principal and Technical Lead. Mr. Johnson was on the team for this 120-foot high RCC flood control dam, built as emergency mitigation for the flood potential created by the 2000 Los Alamos fires. The incredibly short 3-month design-build project overcame difficult site access and poor foundation conditions. (2000-2001).

**Bullard Creek RCC Flood Retention Dam, Lakeview, OR.** Project Manager. Mr. Johnson was responsible for the evaluation, design, and construction engineering and oversight of this 60-foot-high RCC dam. This was the first RCC dam sponsored by the NRCS and had a small budget. The design used exposed RCC and a simply constructed ogee weir spillway to minimize costs. Concepts, such as using the RCC test section as the mass for the stilling basin, further enabled the project to be built within budget. (1999).

**Upper Stillwater RCC Dam, USBR, UT.** Led a URS/Harza team for an extensive review of the construction history and the performance. USBR sponsored the evaluation at the request of the Central Utah Water Conservancy District prior to the district having the project donated to them. As a result of the study, the district did not accept the dam. (1994).

**Gibraltar Dam, City of Santa Barbara, CA.** Technical Reviewer. Gibraltar Dam required a 195-foot-high RCC buttress for a constant-radius concrete arch dam to meet DSOD seismic safety standards. The dam buttress was designed to involve a 20-foot raise; however, environmental impacts permitted the dam to be constructed only to the existing height. Mr. Johnson was a technical reviewer of the design concept and the RCC mix design and test section. (1990 to 1992).

**Concepción RCC Dam, USAID, Honduras.** Concepción Dam is a 60-meter-high RCC dam near Tegucigalpa, Honduras. The dam, originally planned as an earth-rockfill, was completed in 1990 as an RCC dam. Served as Project Manager of the feasibility studies and preliminary design for the RCC dam. (1985 to 1987).

**San Vicente RCC Dam, San Diego County Water Authority, San Diego, CA.** Member of Panel of Experts. This is a 110-foot RCC raise to the existing 290-foot-high San Vincente concrete gravity dam, located in Eastern San Diego County. The raise was designed to withstand the highly seismically active conditions in Southern California. Mr. Johnson was on a Panel of Experts for the Authority specializing in evaluating the foundation conditions beneath the existing dam and the new RCC raise, considering the potential for differential movement between the two components of the raised dam. (2006-2010).

**Toker RCC Dam, Eritrea, Africa.** Technical Oversight. Oversaw design, provided technical support, and observed construction of a 73-meter-high RCC dam located Northwest of Asmara, Eritrea. The dam was designed with limited site geotechnical information due to site assess difficulties and initial project funding. Logistics for construction involved selection of a multi-national contractor team that could deliver a successful project and delivery of materials at the relatively remote location. The project won the 2002 Grand Conceptor Award from the American Council of Engineering Companies of Colorado. (2000-2003).

**Olivenhain RCC Dam, Olivenhain Municipal Water District, Escondido, CA.** Project Manager for the investigations and preliminary design of the 4,000-acre-foot storage reservoir at the Mt. Israel site. This project involved a 180-foot-high RCC dam, outlet, and spillway designed to meet Division of Safety of Dams requirements for loading conditions and the needs of the district in operation of their water treatment plant. This project became the 24,000-acre-foot Olivenhain Dam that was completed by the San Diego County Water Authority in 2003. (1997-2001).

**Diamond Valley Lake, Metropolitan Water District, CA.** Design Manager/Technical Reviewer. This reservoir is the largest embankment dam project ever constructed in California, providing 800,000 acre-feet of storage. It involved 100 million cubic yards of fill for the three earth-rockfill embankments: East Dam, 185 feet high; a 285-foot high West Dam; and a 150-foot-high Saddle Dam. Managed design of Saddle Dam, which was to have been an RCC dam, and performed technical review for the East and West Dams. (1992-1997).

Statement of Qualifications

# TESTING & INSPECTION SERVICES

RIZZO INTERNATIONAL, INC.

certified WBENC WOMEN'S BUSINESS ENTERPRISE


**Corporate Headquarters**
Pittsburgh, PA

**Material Testing Laboratory**
Aurora, CO

# 1.0 COMPANY HISTORY

## COMPANY HISTORY

Through its Material Testing Laboratory[1] in Aurora, Colorado, RIZZO International, Inc., (RIZZO) offers high-quality construction materials testing and inspection services. RIZZO understands that it is our responsibility to provide the technical test data our clients depend on to evaluate the quality of the materials that are being incorporated into their projects.

Our hands-on experience and acute attention to detail enables our staff to provide timely, reliable test data required by the most demanding civil projects in today's industry. Our staff is trained in Roller Compacted Concrete (RCC) testing in the United States and abroad. Our business is based upon providing the best construction materials testing services when and where our clients need them.

Our Corporate Headquarters is located in Pittsburgh, Pennsylvania; our Material Testing Laboratory is located in Aurora, Colorado; and our field laboratories are typically located at our clients' project sites, such as the Panama Canal Third Set of Locks Project. We understand that most projects are around-the-clock, year-long efforts. These demands are met by our employees, who are a part of the RIZZO family, working together and supporting each other to accomplish the goals our clients set forth.

We have a proven multinational staff of engineers and technicians that are highly qualified in the inspection and testing of many types of construction materials and varied construction techniques. Our commitment to advanced training and technical expertise has provided our staff with the skills needed to deal with projects that have intense testing requirements. RIZZO has an experienced staff that specializes in Quality Assurance and Quality Control (QA/QC). We are accustomed to complex projects with multiple QA/QC provisions that often require specialized testing and inspection services. All of our technicians are ACI certified.

RIZZO is certified as a Women's Business Enterprise (WBE) by the Women's Business Enterprise National Council, the nation's largest third-party certifier of businesses owned and operated by women. We are also a WOSB. With these two designations, we can now aid our clients in meeting diversity goals for public works projects.

The company is ISO-9001:2015 Certified. RIZZO has also completed Cement and Concrete Reference Laboratory (CCRL) inspections, and has been AASHTO accredited with an R18 designation.

Our staff members have participated in many projects throughout the United States and internationally; we have developed long-term relationships with varied professionals in the construction industry. Our client approach is "Let us do what we do best, so that you can do what you do best!" We understand the materials business and know what it takes to get the job done right the first time.

- We are committed to our clients and value long-term relationships;
- Our experience and training provides our clients with a level of expertise unmatched in the industry;
- We are committed to going when and where the jobs require; and
- We come prepared to do the job right the first time.

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1 RIZZO International, Inc. (RIZZO) acquired both RIZZO Associates, Inc. and FALL LINE Testing & Inspection Services LLC in November 2017. RIZZO remains a global engineering and consulting firm headquartered in Pittsburgh, Pennsylvania US, and operates its Material Testing Laboratory in Aurora, Colorado, US. Projects contracted and/or completed under the FALL LINE Testing & Inspection Services LLC name are included throughout this SOQ.

## SERVICES

The technical expertise of our staff is evident on complex, major, heavy civil projects, whether it is a mass earth moving project, mass concrete, RCC/concrete or earthen dams, or nuclear-related jobs that require our services. Our attention to detail and previous experience enables our staff to provide the on-time reliable test data that the industry requires.

RIZZO specializes in the following:

- Construction Materials Testing;
- Construction Material Production;
- Field Testing;
- Mix Design Programs; and
- Quality Assurance and Quality Control.

### CONSTRUCTION MATERIALS TESTING

RIZZO performs laboratory tests on aggregates, soils, concrete, and RCC to confirm the characteristics of these items in conformance to project specifications. Our staff routinely participates in full-scale test sections and project construction. We perform a myriad of tests as outlined in American Society for Testing and Materials (ASTM) procedures, and unique project specifications. Specific test programs and methods include the following:

#### Accelerated Curing Test Program

This test method projects the future strength of concrete and RCC by exposing the specimens to an environment that allows them to cure at a much higher rate than normal. The accelerated program enables us to project up to 180-day strength in only a couple of weeks.

#### Aggregate Gradations

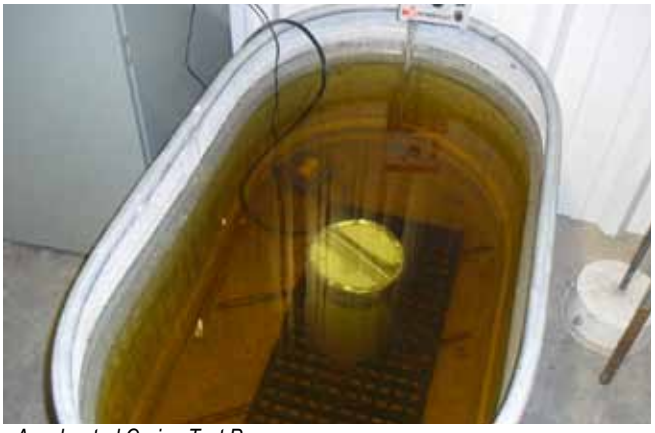
This test method is used to determine the grading of aggregates for compliance with specified requirements. It is used to provide necessary data for control of the production of various aggregate products.

#### Alkali Reactivity

This test method is used to determine the potentially harmful alkali-silica reactivity with consequent deleterious expansion of concrete in a cement aggregate combination.

#### Compressive Strength Testing

This test method consists of applying a compressive axial load to a molded concrete or RCC cylinder or core until failure occurs. The results are used as a basis for quality control of proportioning, mixing, and placing operations.



*Accelerated Curing Test Program*

*Aggregate Gradations*

*Compressive Strength Testing*

*Length Change*

### Length Change
This test method is used to assess the potential for volumetric expansion or contraction of mortar or concrete due to causes other than applied force of temperature change. This test method is useful for comparative evaluation in different mixtures of concrete or mortar.

### Modulus of Elasticity
This test method provides a stress to strain ratio value and a ration of lateral to longitudinal strain for hardened concrete and RCC.

### Moisture Content Testing
This test method is used to determine the precise moisture content of aggregate, concrete, and RCC.

### Plant Uniformity Testing
This testing method involves staff obtaining samples of produced material from the plant during uniformity testing at various stages to determine compliance with project specifications in regard to plant uniformity.

### Tensile Strength
This test method consists of applying a diametral compressive force along the length of a cylindrical concrete or RCC specimen. Tensile failure occurs rather than compressive failure because the areas of load application are in a state of triaxial compression.

### Unit Weight, Air Content, and Density Testing
This test method is used for determining the density of freshly mixed concrete. It is also used for determining the yield, cement content, and air content of concrete.

### VEBE Testing
This test method is used for determining the consistency of an extremely dry concrete mixture that is commonly used in RCC. This test is generally used in place of a slump test because of the stiffness of the concrete mix.

### Thermal Testing
Thermal behavior of dams and other mass concrete structures is always a concern. RIZZO is equipped to perform a full suite of thermal analysis tests, including; adiabatic temperature rise, coefficient of thermal expansion, thermal diffusivity, and specific heat. Our state of the art equipment and methods have be evaluated and proven under the strict requirements of the nuclear industry.

## CONSTRUCTION MATERIAL PRODUCTION
RIZZO routinely samples construction materials during the process phase and performs tests to verify compliance to specifications.

## FIELD TESTING
RIZZO specialists provide field testing implementation and oversight activities for various subsurface analytical techniques. Static and dynamic testing capabilities include plate load testing, pressuremeter testing, and static/ dynamic penetrometer testing. Our specialists are in a position to perform work using: CONTROLS equipment Digital Plate Bearing Test Apparatus, Pagani Geotechnical Equipment GTAS06 system (Cone Penetration Test), Pagani Geotechnical Equipment TG 30-20, and other comparable equipment.

*Modulus of Elasticity*

*Tensile Strength*

*VEBE Testing*

*Adiabatic Room*

## MIX DESIGN PROGRAMS

RIZZO has the ability to provide Mix Design services for projects in nearly any location, no matter how remote. With a dedicated Mix Design Facility and a fully equipped mobile testing laboratory, our services can travel to any project. We are capable of providing: RCC, conventional concrete, and grout mix design programs nationwide. Our staff is experienced and certified to do even the most extensive or complex of designs for our clients.

## QUALITY ASSURANCE AND QUALITY CONTROL

RIZZO is comprised of ACI certified technicians capable of oversight and documentation of a project's QA/QC requirements. We are accustomed to complex projects with multiple QA/QC provisions that often require specialized testing and inspection services. Our hands-on experience and accute attention to detail enables us to provide the timely, reliable test data required by the most demanding civil projects in today's industry. Particular QA/QC services include Aggregate Quality Control and Compressive Strength Testing.

In addition, we are ISO9001:2015 Certified, NUPIC audited and RIZZO's Quality Assurance Program meets the requirements of the American Society of Mechanical Engineers (ASME) "Quality Assurance Requirements for Nuclear Facility Applications", NQA-1-1994, NQA-1-2008 and the NQA-1a-2009 Addenda. There is no formal certification for the NQA-1 standards; however, the RIZZO QA Program has been found by clients to effectively implement these standards during audits conducted by Ameren Missouri, UniStar Nuclear, Sargent & Lundy, PBMR, ENEC/KEPCO E&C, MHI, Westinghouse, AREVA NP and others.

### Aggregate Quality Control

RIZZO participates in all stages of aggregate quality control, from initial plant set up through production quality control. We perform routing and specialized tests to determine the aggregates' characteristics in conformance with project specifications. In addition, we have a mobile testing laboratory that can be relocated to aggregate production sites to perform immediate testing and inspection services.

### Compressive Strength Testing

This test method consists of applying a compressive axial load to a molded concrete or RCC cylinder or core until failure occurs. The results are used as a basis for quality control of a project's proportioning, mixing, and placing operations.

*Construction Material Production*

*Plate Load Testing*

*Mix Design Programs*

*Aggregate Quality Control*

## **TAUM SAUK UPPER RESERVOIR** REBUILD PROJECT

*Taum Sauk Upper Reservoir Rebuild*

The Taum Sauk Upper Reservoir, located in Lesterville, Missouri, discharged an uncontrolled rapid release of water when it failed. The Owner, Ameren Missouri, made the decision to rebuild the dam in the original footprint using materials from the existing dam, along with natural pozzolan from a waste pond at a nearby coal-fired plant, to create the aggregate for the new Dam. The Project consisted of excavation of the existing rockfill dike for crushing into RCC aggregates, foundation preparation, and mass leveling, dental, bedding, and facing concrete, as well as placement of approximately three million cubic yards of RCC.

RIZZO was the Engineer of Record and Construction Manager. In addition, RIZZO performs Phase 1 of the Mix Design Program, soil cement testing, and operation of the on-site testing laboratory for the Rebuild of the failed dam.

### Mix Design Program

RIZZO performed the laboratory testing on aggregates from the existing rim dike of Taum Sauk Dam. Aggregates were separated into several sieve sizes after oversized aggregates were removed from the stockpile. Aggregates qualification testing was then performed to serve as a basis for the trial RCC mix designs.

Laboratory RCC mix designs with varying amount of fly ash and cement were put under the direction of RIZZO. Laboratory testing of test cylinders were then tested for compressive strength, modulus of elasticity, and split tensile strength. Accelerated test methods were also utilized to project the 365-day compressive strength, modules of elasticity, and split tensile strength.

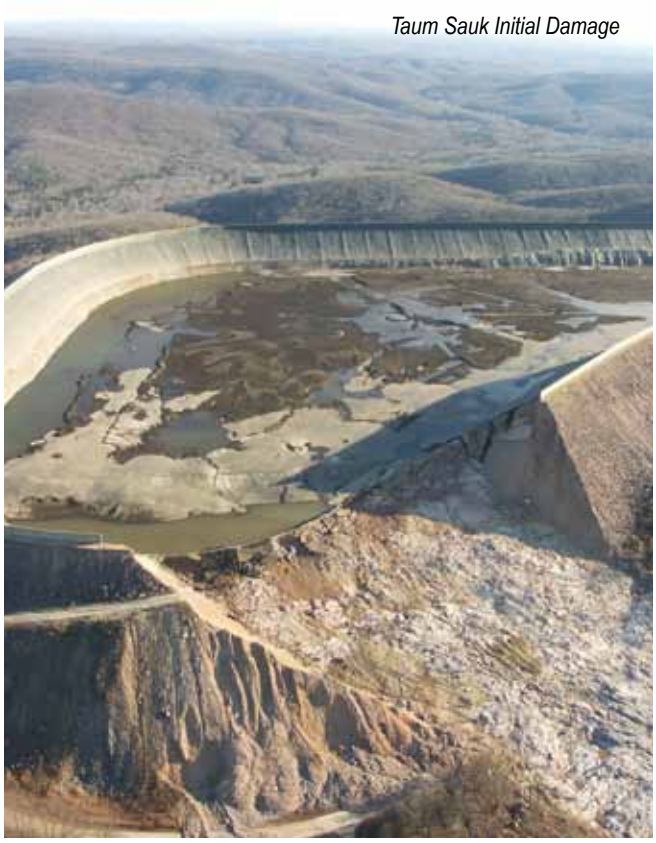
RIZZO performed soil cement testing for the reservoir floor plating of the newly constructed reservoir. Our staff provided a Mix Design Program for the soil cement portion of the Project. Testing included optimum moisture-density relationship, durability testing, and compressive strength testing of the cylinders made.

### Dam Rehabilitation Project

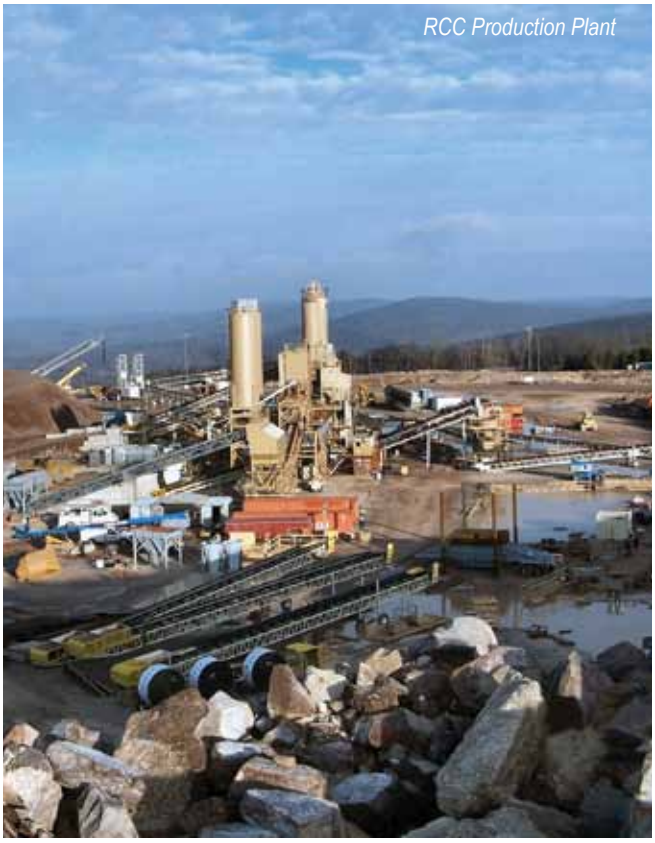
Once construction of the Dam began, RIZZO created a 6,000 square foot testing laboratory that included a 2,000 square foot concrete cylinder curing room for utilization as the quality assurance testing facility at the Project. The laboratory served as the on-site Mix Design Testing Facility, as well as RIZZO's headquarters for providing testing oversight and QA/QC for the Project. No outside materials were brought in for the rebuild. The entire reservoir was completed with existing rock from the previous reservoir. The staff was comprised of over 30 engineers and technicians that worked around the clock to provide testing services for this Award Winning Project.

Location: Lesterville, Missouri
Owner: Ameren Missouri
Client: RIZZO International, Inc. (formerly RIZZO Associates, Inc.)

## **TAUM SAUK UPPER RESERVOIR** REBUILD PROJECT



*Taum Sauk Initial Damage*



*RCC Production Plant*

*Taum Sauk Upper Reservoir Construction*

## **BEAR CREEK DAM** REMEDIATION PROJECT

*Bear Creek Dam Remediation Project*

The Tennessee Valley Authority (TVA) constructed the Bear Creek Dam in 1969 to provide flood control, recreation, water supply, and economic development benefits. The structure consists of an earth dam, a concrete overflow spillway, an intake tower, a lined tunnel, and an outlet structure.

The Dam is approximately 1,200 feet long at the crest and is 68 feet high at the maximum section. Seepage through the karst foundation was observed at the downstream toe of the Dam after first filling the reservoir in 1969 and has been a continuing issue throughout the life of the Project.

TVA determined that the earth dam would be overtopped in the event of a flood. As a result, a backup RCC Dam was built to address both the ongoing seepage issues and the Probable Maximum Flood (PMF) capacity. The remediation consisted of an RCC reinforcing structure (RCC berm) located near the toe of the existing embankment dam, including a composite grout curtain-cutoff wall seepage barrier through the karst rock foundation.

RIZZO was retained to perform the RCC Mix Design Program for various cement, fly ash, and aggregate blends for the 90,000 cubic yard RCC Project. During construction of the new RCC Dam, RIZZO mobilized to the site and built an on-site laboratory that was utilized for aggregates testing, and curing and testing of RCC and conventional concrete. RIZZO also had on-site facilities to perform accelerated concrete curing of RCC test cylinders and nuclear density gauges for compaction control.

RIZZO personnel also performed comprehensive subsurface investigation and subsequently developed all design details, drawings, and specifications for the composite seepage barrier and RCC berm from initial through final design. RIZZO also provided remediation, instrumentation and embankment monitoring.

Location: Hodges, Alabama
Owner: Tennessee Valley Authority
Client: RIZZO International, Inc. (formerly RIZZO Associates, Inc.)

## **BEAR CREEK DAM** REMEDIATION PROJECT

*Bear Creek Dam RCC*

*Bear Creek Dam RCC*

*Bear Creek Dam RCC Construction*

## **ASANA DAM** RCC MIX DESIGN

RIZZO supported the Stantec engineering efforts for the RCC mix design and construction oversight of a 200-feet tall 240,000 cubic yard hardfill dam with conventional concrete facing steps to allow for the extraction of the available copper mineral on site.

RIZZO provided supervision of an onsite laboratory, evaluation of a test panel construction as well as implementation and supervision of hardfill construction procedures. RIZZO provided supervision of other hardfill placement inspectors.

RIZZO also provided inspection services on the installation of 68 post-tensioning anchors, surface demolition of concrete, and placement of concrete overlay between piers.

Location: Moquegua Mountain Region, Peru
Owner: Quellaveco Mine
Client: Stantec

# Disclosure and Representation Statement

## DISCLOSURES

**The Respondent submitting a proposal shall answer the following questions on the basis of the immediately preceding sixty months (approximately five (5) years).** If any question is answered in the affirmative, the Respondent shall submit an attachment providing details concerning the matter, including dates, location(s), project name(s), client name(s), circumstance(s), and outcome(s).

| Question | Yes | No |
|---|---|---|
| Has the Respondent been debarred, suspended, or otherwise prohibited from doing business with any federal, state, or local government agency, or private enterprise? | | x |
| Has the Respondent been denied prequalification, declared non-responsible, or otherwise declared ineligible to submit bids or proposals for work by any federal, state, or local government agency, or private enterprise? | | x |
| Has the Respondent defaulted, been terminated for cause, or otherwise failed to complete any project that it was awarded? | | x |
| Has the Respondent been assessed or required to pay liquidated damages in connection with work performed on any project? | | x |
| Has the Respondent had any business or professional license, registration, certificate, or certification suspended or revoked? | | x |
| Have any liens been filed against the Respondent as a result of its failure to pay subconsultants, subcontractors, suppliers, or workers? | | x |
| Has the Respondent been denied bonding or insurance coverage, or been discontinued by a surety or insurance company? | | x |
| Has the Respondent been found in violation of any laws, including but not limited to, contracting or antitrust laws, tax or licensing laws, labor or employment laws, or environmental, health, or safety laws? | | x |
| Has the Respondent or its owners, officers, directors, or managers been the subject of any criminal indictment or criminal investigation concerning any aspect of the Respondent's business? | | x |
| Has the Respondent been subject to any bankruptcy proceedings? | | x |
| Are there any pending claims, judgements, lawsuits, or alternative dispute proceedings involving the Respondent with potential damages of $10,000 or more? | x | |
| Is the Respondent currently the subject of any complaint, investigation, or other legal action for alleged violations of law pending before any court or governmental agency? | | x |
| Number of explanatory attachments (additional pages) | 1 | |

## REPRESENTATIONS

The Respondent submitting a proposal makes the following representations, which it understands are required as a condition of performing the work and receiving payment for the same.

1. The Respondent possesses all applicable professional and business licenses required for performing the work in the State of Colorado.
2. The Respondent meets all insurance requirements in the sample agreement.
3. The Respondent represents that it has no conflict of interest with the District if awarded the project and any potential conflicts of interest that arise in the future will be disclosed immediately.
4. The Respondent represents that the Price Proposal offered and other information submitted in connection with its proposal were arrived at independently without consultation, communication, or agreement with any other offeror or competitor.
5. The Respondent ensures that employees and applicants for employment are not discriminated against because of their race, color, religion, sex, or national origin.

The undersigned hereby represents that all statements, representations, information, and documents provided in or with this proposal are complete, accurate, and truthful.

| | |
|---|---|
| Signature of Authorized Representative | 8/28/19<br>Date |
| Chad Masching | Vice President |
| Printed Name of Authorized Representative | Position/Title |
| GEI Consultants, Inc. | |
| Printed Name of Respondent | |

As is the case with professional corporations GEI's size, the company is engaged in and has had past instances of litigation over the past three years. There are no current or past claims over the previous three years that did or could have a material impact upon the corporation in the unlikely event of an adverse judgment.

*Final Report*

# Technical Evaluation of Firm Water Supply and Economic Revenue Improvement Strategies

*Submitted to:*
**Lookout Mountain Water District**

*Prepared by:*

MOMENTUM
Civil and Environmental Engineering

*April 20, 2020*

# Table of Contents

*Executive Summary* ..... 2

*Background* ..... 4

*Methodology* ..... 5

*Water Supply Improvement Results* ..... 8

*Water Supply Option #1: Implement SCADA to Optimize Operations* ..... 9

*Water Supply Option #2: Improve Owe-the-River Measurement and Accounting* ... 12

*Water Supply Option #3: Rehabilitate the Golden Emergency Pipeline* ..... 15

*Water Supply Option #4: Rehabilitate the Beaver Brook Pipeline* ..... 20

*Water Supply Option #5: Install a Raw Water Pipeline to LMR* ..... 21

*Hydropower Development Results* ..... 23

*Public Utilities Regulatory Policies Act (PURPA)* ..... 23

*Net Metering* ..... 24

*FERC License Exemption* ..... 24

*Hydropower Option #1: Conventional Hydropower from Upper Beaver Brook Reservoir Releases* ..... 25

*Hydropower Option #2: Pumped-Storage Hydropower between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir* ..... 29

*Hydropower Option #3: Conventional Hydropower from Lookout Mountain Reservoir Releases* ..... 35

*Conclusions and Recommendations* ..... 37

*References* ..... 39

## EXECUTIVE SUMMARY

Lookout Mountain Water District (LMWD) has worked diligently protect and enhance their water supply and operating capital. To further this goal, the District requested that Momentum Engineering identify and evaluate potential improvement strategies related to hydropower development and related water operations.

The resulting study performed a prefeasibility-level analysis of five water supply development alternatives and three hydropower development alternatives. Water supply improvements were measured based upon their ability to cost-effectively supply water storage to the District in times of drought. Hydropower development alternatives were evaluated regarding their expected benefit-cost ratio.

Two potential water supply improvements were found to increase critical storage reserves in Upper Beaver Brook Reservoir at an economical cost to the District. Installing a Supervisory Control and Data Acquisition (SCADA) system to minimize outflow from Upper Beaver Brook Reservoir is estimated to cost $90,000 and save LMWD about 20 acre-feet (AF) per year. The District is currently in the process of applying for a Colorado Water Conservation Board (CWCB) grant that, if successful, would provide $70,000 toward this project. However, one potential drawback to the SCADA project is the age and fragility of the existing Upper Beaver Brook outlet controls. Mr. Chad Mashing from GEI Consultants stated that the gate valves are weak and that an automated control of these may break internal control components. The replacement of these gates and components may need to be undertaken by the District regardless of implementing SCADA.

The second water supply alterative involves reducing releases from Upper Beaver Brook Reservoir by improving the Owe-the-River (OTR) Accounting measurement and methodology. This is the most economical water supply development option studied and has the potential to save the District about 15 AF per year. However, the major drawback of this option is the difficulty and uncertainty with its implementation.

Given the stated assumptions, only one of the hydropower alternatives proved to be feasible. Even with optimistically assuming only base capital and O&M costs, pumped storage hydropower between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir was found to have a benefit-cost ratio below 1. Run-of-the-river hydropower generation using releases from Lookout Mountain Reservoir was found to have a benefit-cost ratio of only 0.67 due to the significant cost of installing a 6728' pipeline below the reservoir's outlet. Fortunately, with an estimated benefit-cost ratio of 1.5, run-of-the-river hydropower using releases from Upper Beaver Brook Reservoir will likely be economically beneficial to LMWD if the District decides to construct a pipe from Upper Beaver Brook Reservoir to serve the water treatment plant.

In summary, Momentum Engineering recommends that the District continues to pursue both the installation of a SCADA system to automate release from Upper Beaver Brook Reservoir and the improvement of OTR Accounting procedures. Before proceeding with the implementation of the SCADA system it will be important to fully understand the condition of the existing Upper Beaver Brook Dam gate controls.

Finally, the District is currently working with several experts to decide on the best option to serve raw water to the treatment plant. If a pipeline from Upper Beaver Brook Reservoir is selected as the preferred option to serve water to the water treatment plant, Momentum Engineering recommends that the District conduct a final feasibility and design study to utilize this conveyance pipe for hydropower generation.

## BACKGROUND

As a small mountain water district, LMWD is continually presented with challenges to their water supply and operating capital. These risks to LMWD's ability to provide public water are likely to become greater in the future due to increasing senior water demands, climate change, and aging infrastructure.

Fortunately, LMWD has significant existing infrastructure and water right assets that can be creatively leveraged to meet these future challenges. Due to their ownership of multiple high elevation storage reservoirs, LMWD is interested in exploring the development of conventional and/or pumped-storage hydropower.

LMWD has requested that Momentum Engineering propose technical assistance solutions for the following objectives:

- *Provide LMWD with a firm understanding of the long-term benefits and costs associated with identified potential improvement strategies.*
- *Propose, evaluate, and document a conjunctive approach using the best performing strategies to maximize LMWD's firm water supply and economic revenue.*

This work was partially funded under a grant through the Colorado Water Resources and Power Development Authority (CWRPDA).

## METHODOLOGY

A computational model was developed using Microsoft Excel for the purpose of estimate the costs and benefits of the following scenarios:

1. No Action
2. Install pumped storage and conventional hydropower
3. Purchase/Lease additional Clear Creek basin water supply
4. Increase the operational effectiveness of existing storage reservoirs
5. Construct additional storage

Figure 1 shows a schematic of the computational model. The final model included 20 flow nodes and 4 storage volume nodes.

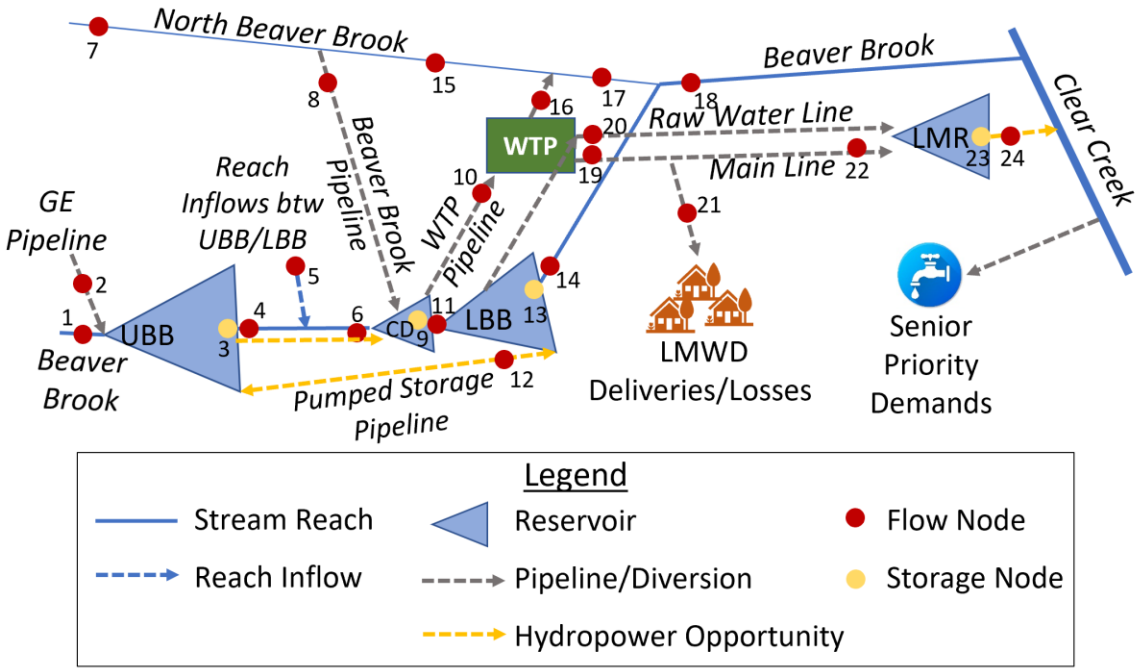



*Figure 1: Schematic of the computational model*



MOMENTUM

Once historical daily inflow data was inputted and operational logic programmed, the model's predicted storage in Upper Beaver Brook Reservoir was calibrated to LMWD's 2017-2019 measured data. An $R^2$ value of 90% was ultimately achieved after model refinement.

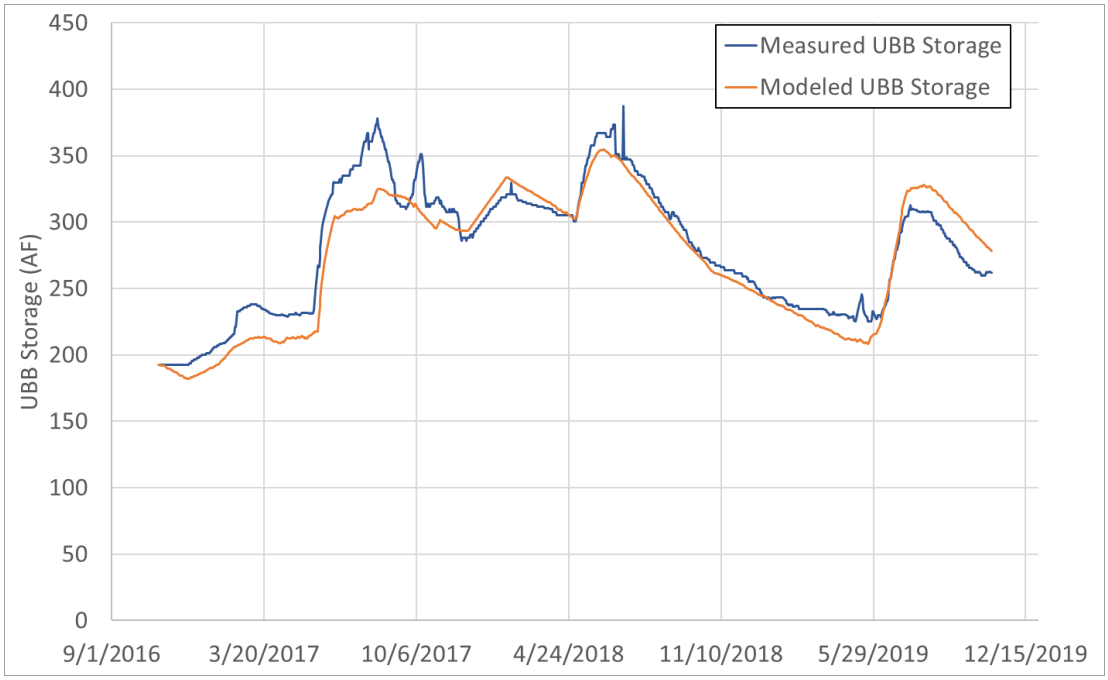
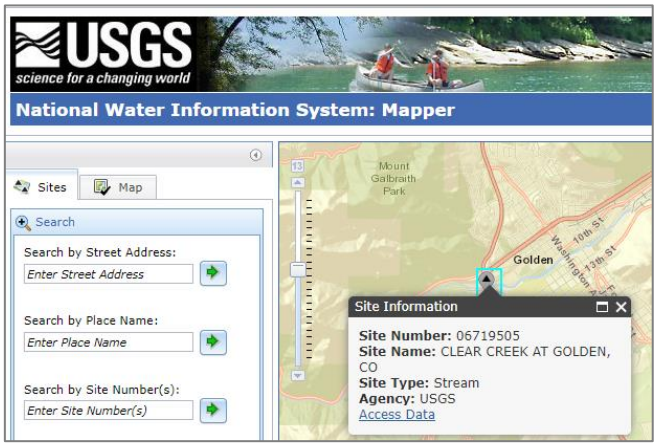
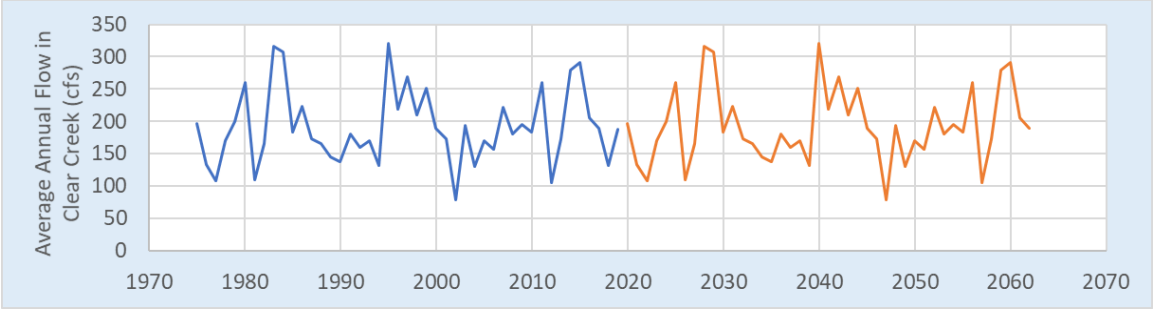



*Figure 2: Calibration of Measured versus Modeled Storage in Upper Beaver Brook Reservoir*

After the calibration to the 2017-2019 dataset, the model was projected to 45 years into the future (2017-2061) by adjusting Beaver Brook's natural flows to mimic the pattern of average annual historic flows at *USGS Gage 067195050 Clear Creek at Golden, CO* (https://waterdata.usgs.gov/nwis).






The resulting computational model as used to first quantify water supply impacts from proposed improvements then model costs and benefits from conventional and pumped storage hydropower development.

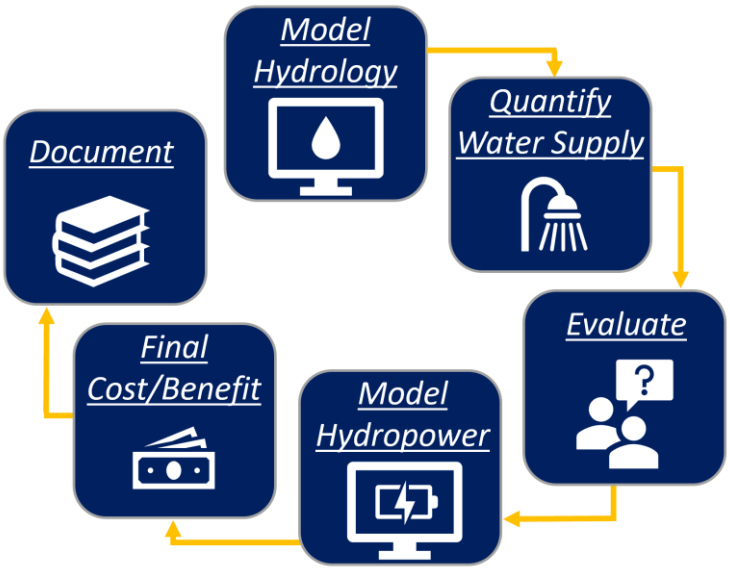



*Figure 3: General Project Methodology*

## WATER SUPPLY IMPROVEMENT RESULTS

The original scope of work was modified per information obtained during the kickoff meeting and initial modeling effort. First, it was determined that LMWD could develop a large amount of firm water supply utilizing its existing infrastructure and water rights. Therefore, the new storage was assumed to infeasible due to high cost and the complexity of permitting. Secondly, it was assumed that water available for leasing in Clear Creek basin may not be available in the future (especially in times of drought) and was therefore not a source of firm water supply. This resulted in the study focusing on the following water supply improvements:

1) Implement Supervisory Control and Data Acquisition (SCADA) to optimize reservoir operations
2) Improve Owe-the-River Measurement and Accounting
3) Rehabilitate the Golden Emergency Pipeline
4) Rehabilitate the Beaver Brook Pipeline
5) Install a raw water pipeline to maximize the use of Lookout Mountain Reservoir

Water supply improvements were evaluated on their estimated project cost and water storage increase during times of drought. Critical water storage level was defined as the 5$^{th}$ percentile of water storage in Upper Beaver Brook Reservoir (i.e. LMWD has less water storage in Upper Beaver Brook Reservoir than this value only 5% of the time).

*<u>Water Supply Option #1:</u> Implement SCADA to Optimize Operations*

The first potential water supply improvement envisions the installation of Supervisory Control and Data Acquisition (SCADA) equipment at key points throughout the LMWD system to minimize non-beneficial releases from Upper Beaver Brook Reservoir. This would involve water flow measuring stations throughout the system that would send realtime flow data to a computational program that would calculate the optimum release from Upper Beaver Brook Reservoir. The program would then send this calculated target outflow to actuators installed to control Upper Beaver Brook Reservoir's outlet gates. The outflow gates would then automatically adjust until measured outflow below Upper Beaver Brook Reservoir was within tolerance of the calculated target outflow rate.

*Figure 4: Existing Outflow Gate Controls at UBB*

This improvement is estimated to provide approximately 20 AF per year of reduced storage releases from Upper Beaver Brook Reservoir. This will result in cumulative water storage buildup (i.e. saved water can be carried over to the future years), thereby providing increased resiliency to water shortage from climate change and drought.

Costs for this potential improvement were estimated through a discussion with Josh Hanks from Intermountain Environmental (https://www.inmtn.com/). As shown in Table 1, the installation of SCADA equipment results in substantial increased critical water storage at an economical cost ($517 per AF).

*Table 1: Benefits and Costs of Installing SCADA*

| | **Install SCADA (Assuming 50% reduction in non-beneficial releases from UBB)** |
|---|---|
| Project Cost (No CWCB Grant) | $90,000 |
| Total increase in critical (5th percentile) UBB storage (AF) | 174 |
| Cost per AF of increased critical UBB storage | $517 |

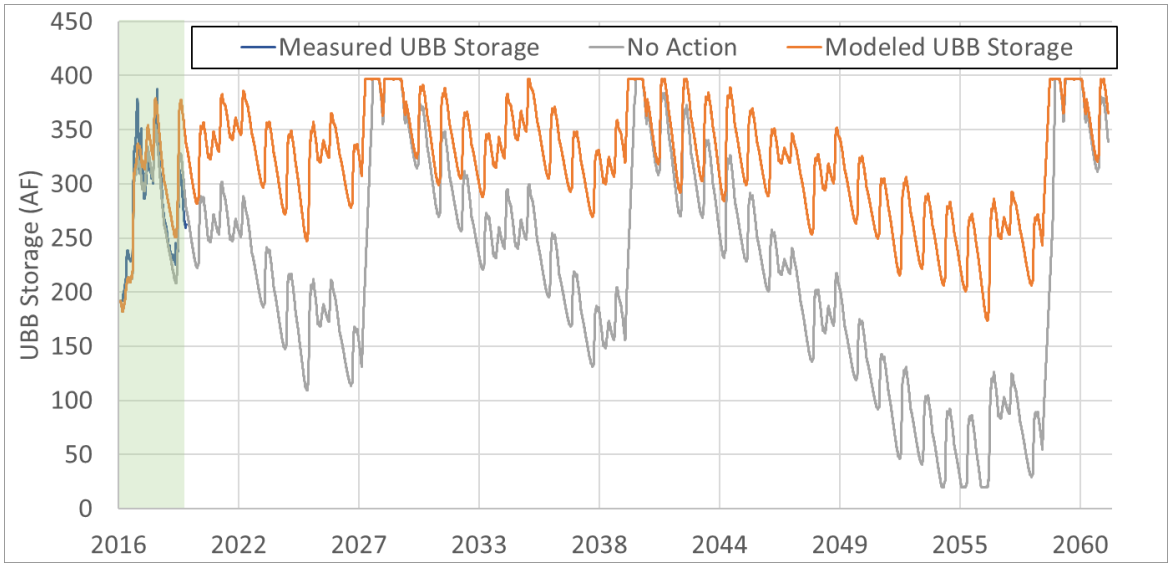



*Figure 5: Comparison of Projected UBB Storage with No Action and Installing SCADA*

The cost for the SCADA improvement may be reduced even further if the District is selected for a Colorado Water Conservation Board (CWCB) Water Supply Reserve Fund (WSRF) grant. A successful WSRF proposal would likely reduce the District's total project cost from $90,000 to $20,000 (see Table 2).

*Table 2: Benefits and Costs of Installing SCADA **assuming a CWCB WSRF grant***

| | **Install SCADA (Assuming 50% reduction in non-beneficial releases from UBB)** |
|---|---|
| Project Cost | $20,000 |
| Total increase in critical (5th percentile) UBB storage (AF) | 174 |
| Cost per AF of increased critical UBB storage | $115 |

The installation of SCADA will also reduce the labor associated with managing releases from Upper Beaver Brook Reservoir and provide additional reliability to meeting Beaver Brook instream flow requirements.

It is important to note that Mr. Chad Mashing from GEI Consultants raised a concern related to the age of the existing gate controls. He stated that the gate valves are weak and that an automated control of these may break internal control components. The replacement of these gate controls may need to be undertaken by the District regardless of implementing SCADA.

*<u>Water Supply Option #2:</u> Improve Owe-the-River Measurement and Accounting*

The District's water rights engineer is required by the State of Colorado to use Owe the River (OTR) accounting to ensure that Upper Beaver Brook Reservoir's calculated volume equals its measured volume. However, when Upper Beaver Brook Reservoir is out of priority the error in calculating the daily volume calculation (due to wind, bathymetry, stage measurement/coarseness, etc.) may be causing significant unneeded release from Upper Beaver Brook Reservoir. In 2019, the total of all adjustments showed an unmeasured loss of 36.2 AF but resulted in LMWD's Upper Beaver Brook Reservoir storage being reduced by 92.6 AF.

This is likely caused by the difficulty in getting an accurate daily storage estimate. The coarseness/inaccuracy of the reservoir volume calculation is causing inexistent fluctuations in the calculated unmeasured gains/losses.

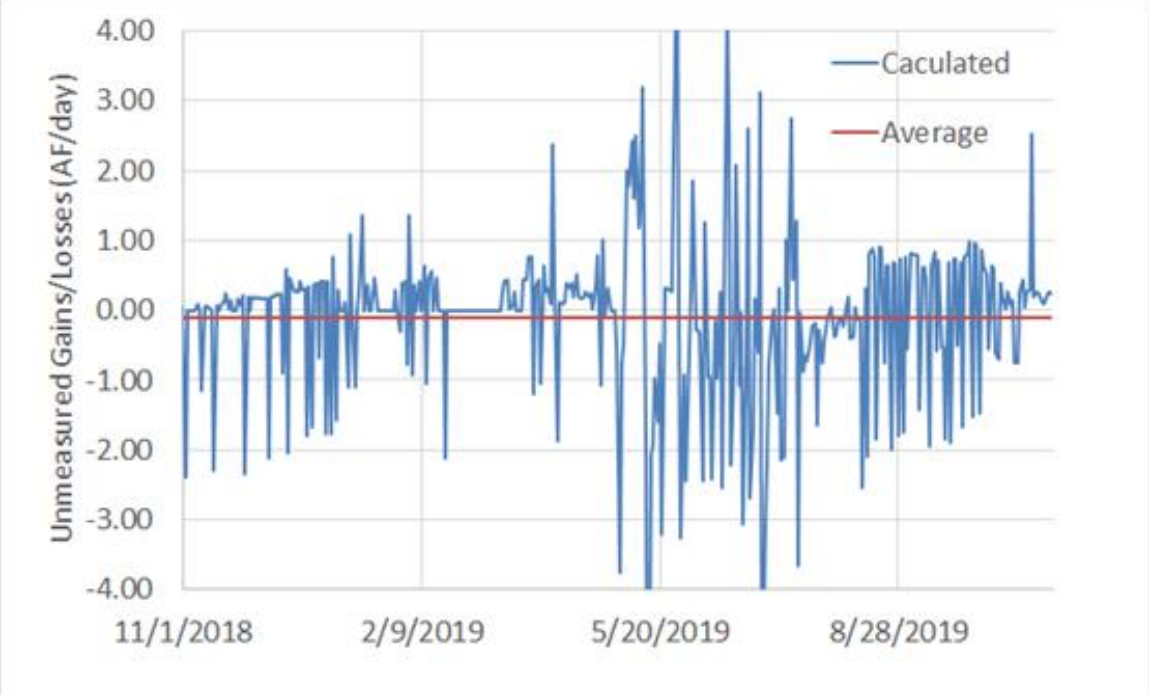



*Figure 6: Fluctuations in the Unmeasured Gains/Losses Calculation in WY2019*

If the reservoir is lower than expected, LMWD's storage account is reduced if the OTR account is low. If the reservoir is higher than expected, then the OTR account is increased and LMWD is expected to release extra water to pay this back.

Momentum Engineering has informed the District's water rights engineer of this potential improvement and has suggested the following potential improvements in order to reduce unnecessary releases:

1) Perform additional reservoir stage readings per day
2) Implement wind correction measures
3) Apply a moving average to smooth out daily volume calculations
4) Revise OTR accounting per a discussion with the State Engineer. (e.g. Revise OTR accounting by only performing OTR calculations if the cumulative Unmeasured Gains/Losses exceed 1% of storage volume.)

The chance of succeeding with this improvement strategy is less certain than the other water supply improvements. However, if successful this improvement is estimated to provide approximately 15 AF per year of reduced storage releases from Upper Beaver Brook Reservoir. This will result in cumulative water storage buildup (i.e. saved water can be carried over to the future years), thereby providing increased resiliency to water shortage from climate change and drought.

The costs associated with this improvement will be mostly related to engineering consulting time and are estimated to not exceed $25,000. As shown in Table 3, improved OTR accounting results in substantial increased critical water storage for an economical cost ($189 per AF).

*Table 3: Benefits and Costs of Improved OTR Accounting*

| | **Improved OTR Accounting** |
|---|---|
| Project Cost | $25,000 |
| Total increase in critical (5th percentile) UBB storage (AF) | 132 |
| Cost per AF of increased critical UBB storage | $189 |

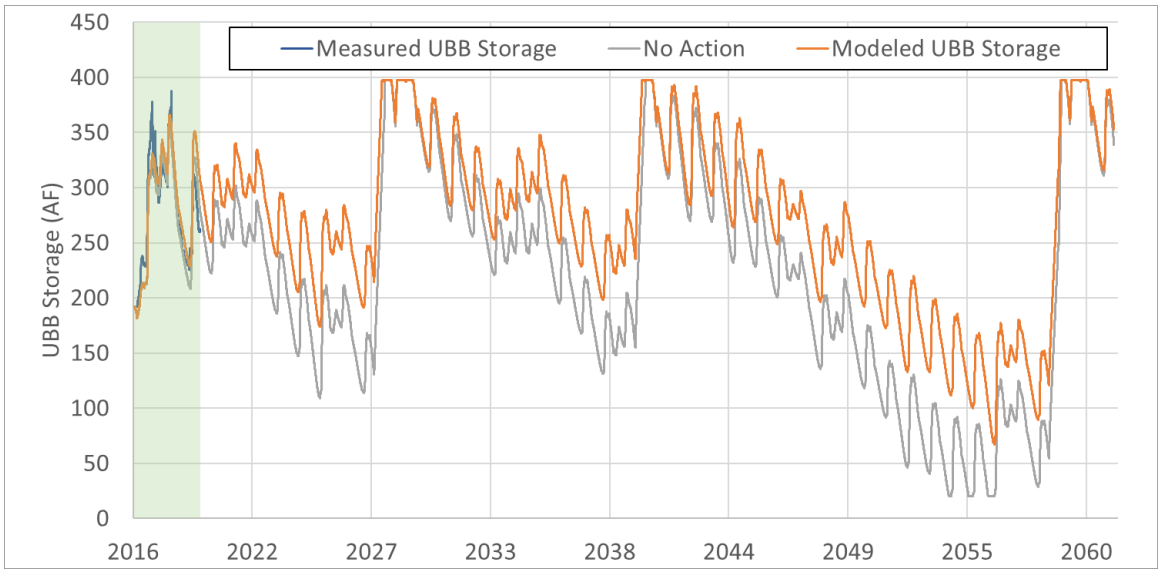



*Figure 7: Comparison of Projected UBB Storage with No Action and Improved OTR Accounting*

*<u>Water Supply Option #3:</u> Rehabilitate the Golden Emergency Pipeline*

It was recently discovered that, per the December 7th, 1934 Colorado Water Court Decree (CW60058), LMWD may have an additional water right named the "Golden Emergency Pipeline". This is a 1910 priority water right for 0.5 cfs that diverts water via 4083' pipeline from the Soda Creek Basin into the Beaver Brook Basin for use by LMWD's system.

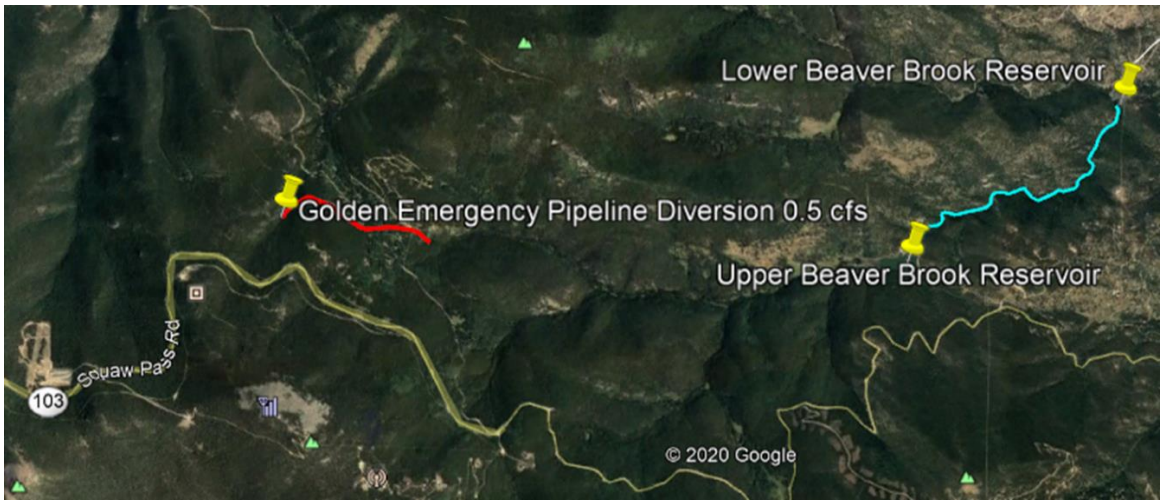



*Figure 8: Map showing the approximate location of the Golden Emergency Pipeline.*

Momentum Engineering staff conducted a field trip to the area to ascertain the existence and status of the Golden Emergency Pipeline. The diversion point along Little Bear Creek was found as well as the remains of the existing 1910 pipeline. The following images were taken from this March 19th, 2020 survey.

*Figure 9: Golden Emergency Pipeline Image #1 from March 19th, 2020 Site Visit*

*Figure 10: Golden Emergency Pipeline Image #2 from March 19th, 2020 Site Visit*

*Figure 11: Golden Emergency Pipeline Image #3 from March 19th, 2020 Site Visit*

*Figure 12: Golden Emergency Pipeline Image #4 from March 19th, 2020 Site Visit*

*Figure 13: Golden Emergency Pipeline Image #5 from March 19th, 2020 Site Visit*

As evidenced by the photos, the existing pipeline is currently defunct and would need to be completely rebuilt to resume water diversion to the Beaver Brook Basin. For the purposes of this analysis, it was assumed that this improvement would cost approximately $50 per installed linear foot of pipeline plus approximately an additional $100,000 for legal and engineering costs, totaling $300,000. It was also assumed that the flow at the Golden Emergency Pipeline diversion point would be 7.5% of the inflow of Upper Beaver Brook Reservoir. This was estimated by comparing drainage areas between these two diversion points.

As shown in Table 4 and Figure 14, the rehabilitation of the Golden Emergency Pipeline is estimated to provide an increase of 57 AF in critical storage and for a cost of $5,263 per AF.

*Table 4: Benefits and Cost of GE Pipeline Rehabilitation*

| | **Rehabilitate the GE Pipeline** |
|---|---|
| Project Cost | $300,000 |
| Total increase in critical (5th percentile) UBB storage (AF) | 57 |
| Cost per AF of increased critical UBB storage | $5,263 |

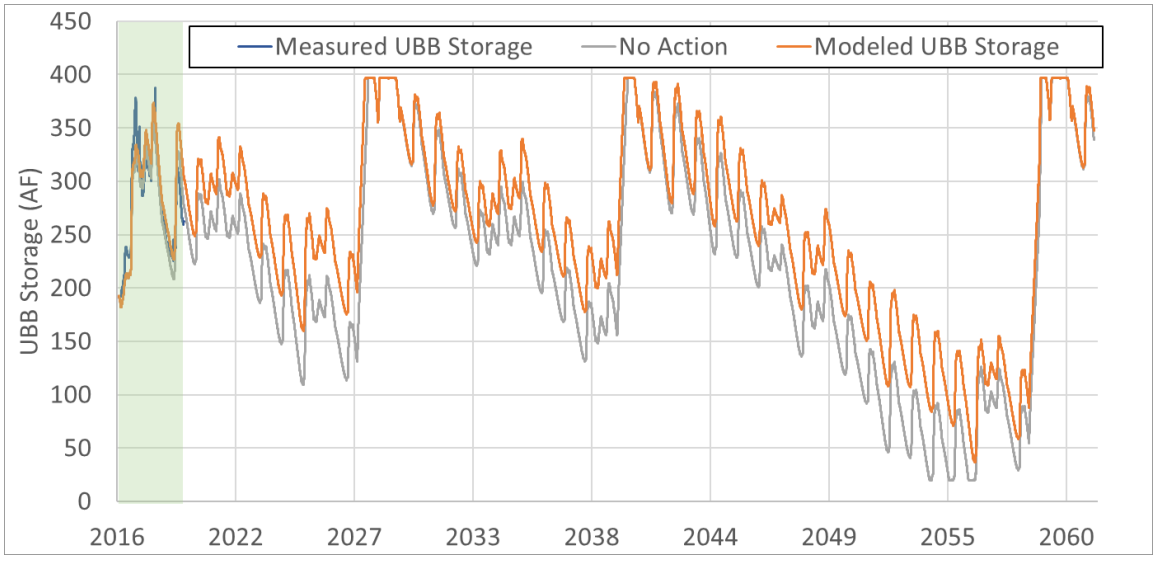



*Figure 14: Comparison of Projected UBB Storage with No Action and GE Pipeline Rehabilitation*

*<u>Water Supply Option #4:</u> Rehabilitate the Beaver Brook Pipeline*

The Beaver Brook Pipeline is a 1917 priority water right owned by LMWD for the diversion of up to 3.13 cfs of water from North Beaver Brook to Lower Beaver Brook Reservoir. This 700-foot pipeline was severed by the construction of the existing water treatment plant.

*Figure 15: Aerial imagery showing the approximate location of the Beaver Brook Pipeline.*

It was found that rehabilitating the Beaver Brook Pipeline would not provide significant benefit to the District. This is mostly due to significant reach inflows between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir during times when the District is able to exercise their 1917 Beaver Brook Pipeline right. Water above and beyond the instream flow right is simply not needed during these times.

*<u>Water Supply Option #5:</u> Install a Raw Water Pipeline to LMR*

LMWD uses only about 0.3 cfs of its 3.5 cfs Golden Pipeline Water Right. One option to more fully utilize this water right is to install a second pipeline to convey raw water to Lookout Mountain Reservoir while LMWD is in the process of replacing their Main Line. This would provide much greater conveyance capacity and eliminate the costly requirement of treating water before storing in Lookout Mountain Reservoir. Water storage in Lookout Mountain Reservoir would then be exchanged to reduce releases from Upper Beaver Brook Reservoir.

The costs of installing this second line were estimated to be $20 per foot for the 8 miles of Main Line needing replacement and $100 per foot for the 2 miles of Main Line that have already been replaced plus $100,000 for engineering/contingency for a total project cost of $2,000,800.

As showing in Table 5, this option provides a 214 acre-foot increase in critical storage but requires $9,350 per AF to achieve this.

*Table 5: Benefits and Costs of Installing a Raw Water Line to LMR*

| | **Install a Raw Water Line to LMR** |
|---|---|
| Project Cost | $2,000,800 |
| Total increase in critical (5th percentile) UBB storage (AF) | 214 |
| Cost per AF of increased critical UBB storage | $9,350 |

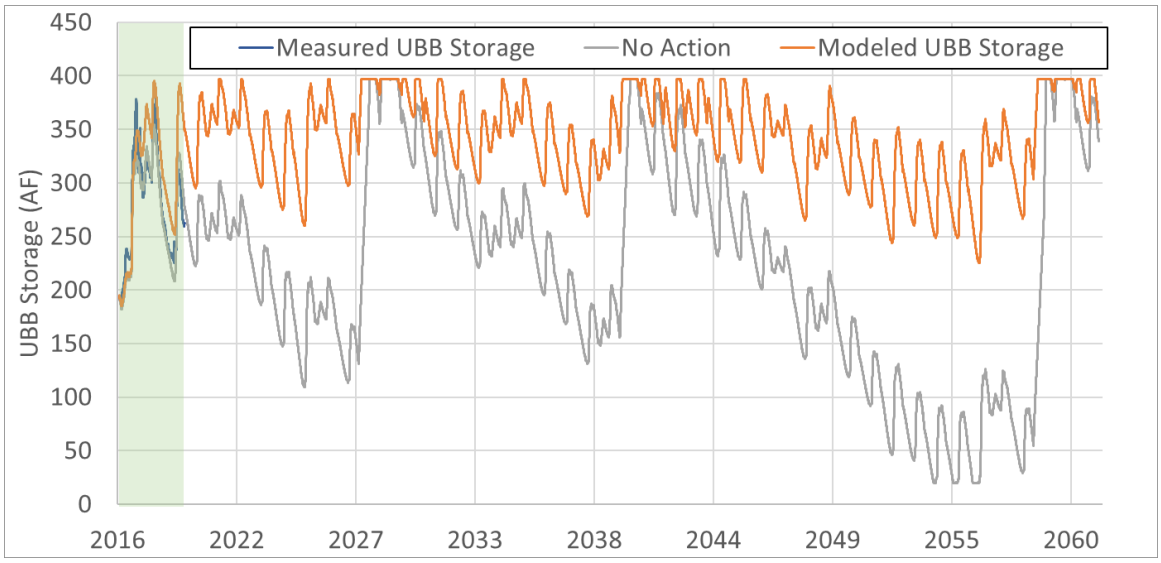



*Figure 16: Comparison of Projected UBB Storage with No Action and Installing a Raw Water Line to LMR*

## HYDROPOWER DEVELOPMENT RESULTS

The following are the potential hydropower configurations that were investigated:

1) Conventional Hydropower from Upper Beaver Brook Reservoir Releases
2) Pumped-Storage Hydropower between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir
3) Conventional Hydropower from Lookout Mountain Reservoir releases

Due to the substantial water savings and low cost of Water Supply Option #1 it was assumed that LMWD would implement SCADA before implementing these hydropower options. This assumption impacts available water supply and flow timing for hydropower development. It was also assumed that Lower Beaver Brook Reservoir would be rebuilt to accommodate reservoir fluctuations for the "pumped-storage" option and the raw water line to Lookout Mountain Reservoir would be constructed for the "Conventional hydropower from Lookout Mountain Reservoir" option.

### *Public Utilities Regulatory Policies Act (PURPA)*

Congress passed the Public Utilities Regulatory Policies Act (PURPA) in 1978 establishing a new class of generating facilities, referred to as "Qualifying Facilities" (QF), receiving special rate and regulatory privileges. One reason for this was to "encourage the expeditious development of hydroelectric potential at existing small dams". Once such QF is a *Small Power Production Facility* defined as "A facility generating 80 MW or less using renewable (hydro, wind or solar), biomass, waste, or geothermal resources."

There are generally three categories of QF benefits: (1) the right to sell energy or capacity to a utility, (2) the right to purchase certain services from utilities, and (3) relief from certain regulatory burdens (PURPA, 1978).

*Net Metering*

Offsetting retail electric expenses is often the most profitable way to implement a small hydropower project. Electricity generation systems are often tied to the utility's electric grid to add flexibility in the timing of power use by the owner. In these cases, utilities offer what is called a "net metering" agreement for customer electric generation. Under a net metering agreement power companies would provide power at times when the on-site renewable generation is less than the customer demand and would accept surplus power that exceeds customer demand. The power generated and used would be balanced on each monthly bill. A monthly net surplus of power generated by the customer would provide credits to offset a net shortfall in generated power in subsequent billing periods. This allows a customer to offset the cost they would have paid to a utility for electricity.

*FERC License Exemption*

In certain cases, projects may qualify for an exemption from licensing. Those receiving an exemption are exempt from the requirements of Part I of the Federal Power Act. However, the exempted project is subject to mandatory terms and conditions set by federal and state fish and wildlife agencies and by the Commission, and do not convey the right of eminent domain. Getting an exemption can be a more simplified process than applying for a license. Exemptions are issued in perpetuity. FERC issues two types of exemptions (https://www.ferc.gov/industries/hydropower/gen-info/licensing/exemptions.asp):

1. Small hydropower projects, which are 10 megawatts or less, that will be built at an existing dam, or projects that utilize a natural water feature for head or an existing project that has a capacity of 10 megawatts or less and proposes to increase capacity.
2. Conduit exemption that would be issued for constructing a hydropower project on an existing conduit (for example irrigation canal). Conduit exemptions are authorized for generating capacities 40 megawatts or less. The conduit has to have been constructed primarily for purposes other than power production.

*<u>Hydropower Option #1:</u> Conventional Hydropower from Upper Beaver Brook Reservoir Releases*

LMWD is current exploring several options related delivering water to the treatment plant. One concept involves the decommissioning of Lower Beaver Brook Reservoir and the installation of a pipeline from Upper Beaver Brook Reservoir to the water treatment plan. This water delivery pipeline could be used to generate hydropower. There are approximately 550 feet of elevation loss over the 1.7 miles between Upper Beaver Brook Reservoir and the water treatment plant. Friction losses during pipeline transmission could be minimized by using larger diameter pipe.

LMWD's water treatment plant diverts approximately 115 AF per year. However, the District would not be limited to this volume of water for hydropower generation. Additional hydropower benefit would be realized by LMWD by utilizing additional pass-through flows from the reservoir. The total annual release from Upper Beaver Brook Reservoir is approximately 415 AF per year. The District would need to apply for a non-consumptive water right to divert these flows.

This combination of high flow and elevation drop creates significant potential for generating conventional run-of-the-river hydropower below Upper Beaver Brook Reservoir. Figure 17 provides a schematic of a run-of-the-river conventional hydropower project.

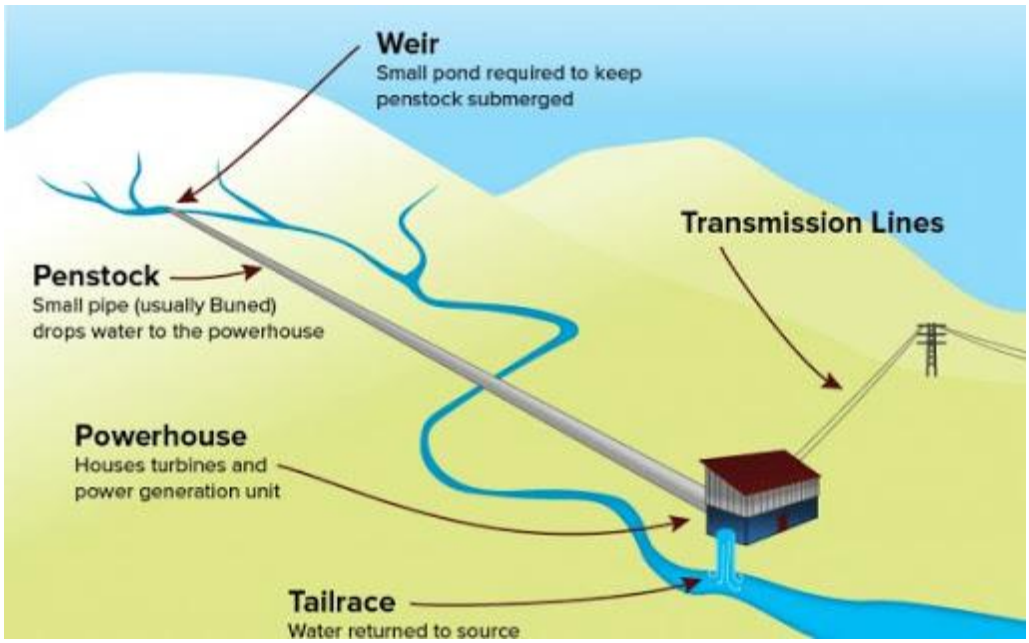



*Figure 17: Schematic of a run-of-the-river conventional hydropower project*

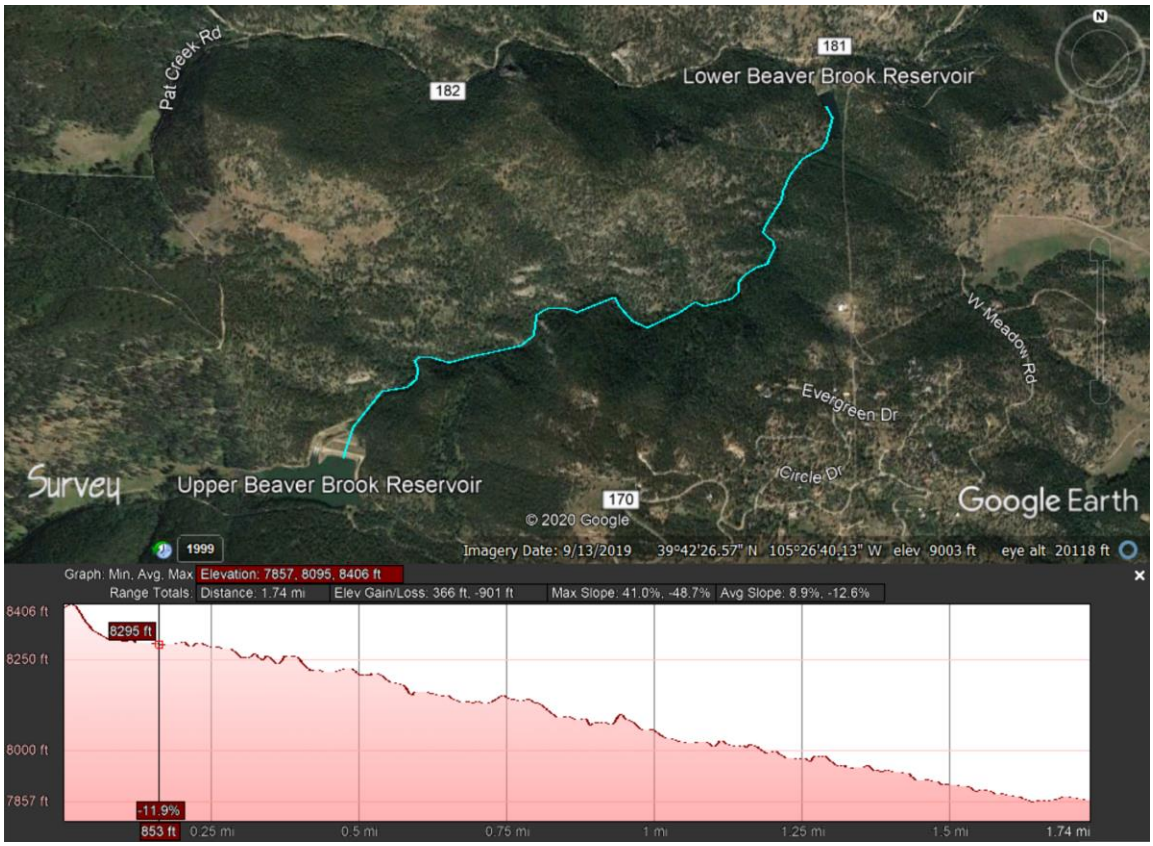



*Figure 18: Map and elevation profile of a potential hydropower pipeline between UBB and LBB.*

## Quantification of Benefits

Daily water flow available for power generation was quantified using modeled releases from Upper Beaver Brook Reservoir as estimated by the 45-Year Water Supply Model. A 60$^{th}$ percentile flow rate of 0.6 cfs (270 GPM) was used to size a 6" pipeline. Water flow for hydropower generation was then limited to this diversion capacity. The pipeline was assumed to lose 10 feet of head due to friction losses and a 90% turbine efficiency was assumed.

Under these assumptions and modeled daily flow release from Upper Beaver Brook Reservoir average power generation was estimated to be 165,757 kilowatt-hours (kwh) per year. This equates to approximately $18,996 per year (2020 dollars) in gross revenue, assuming a net metering agreement and the average residential power cost rate of 11.46 cents per kwh.

## Quantification of Costs

This analysis used the USBR's Hydropower Assessment Tool (https://www.usbr.gov/power/AssessmentReport/index.html) to quantify potential plant costs. These costs were further refined using a similar sized run-of-the-river small hydropower project (Creasey Hydroelectric Project FERC No. P-13829).

The resulting total capital cost for the Upper Beaver Brook Run-of-the-River Hydropower Project was estimated to be $106,771 (not including the penstock) with O&M costs of $5,997 per year (2020 Dollars).

## Benefit Cost Ratio and Discussion

The benefit-cost ratio for this project was found to be 1.5 assuming a 30-year project life. Expected net benefits were estimated to be $283,248 (2020 Dollars).

This hydropower concept is completely infeasible without a preexisting pipeline. However, if the District decides to construct a pipeline from Upper Beaver Brook Reservoir to supply water to the treatment plant Momentum Engineering advises LMWD to proceed with a final feasibility study for this Upper Beaver Brook Conventional Hydropower Project. This final feasibility study should be performed before constructing pipe from Upper Beaver Brook Reservoir as a larger diameter pipe may be more beneficial for generating hydropower.

*<u>Hydropower Option #2:</u> Pumped-Storage Hydropower between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir*

Pumped-storage hydropower involves the pumping of water from a lower elevation reservoir to a higher elevation reservoir when hourly power prices are low then releasing water from the higher elevation reservoir to generate hydropower when daily power prices are high. Typical benefits of pumped-storage hydropower include grid regulation and economic revenue generation. Below is a schematic of a simplified pumped storage configuration from Kaunda et al. (2012).

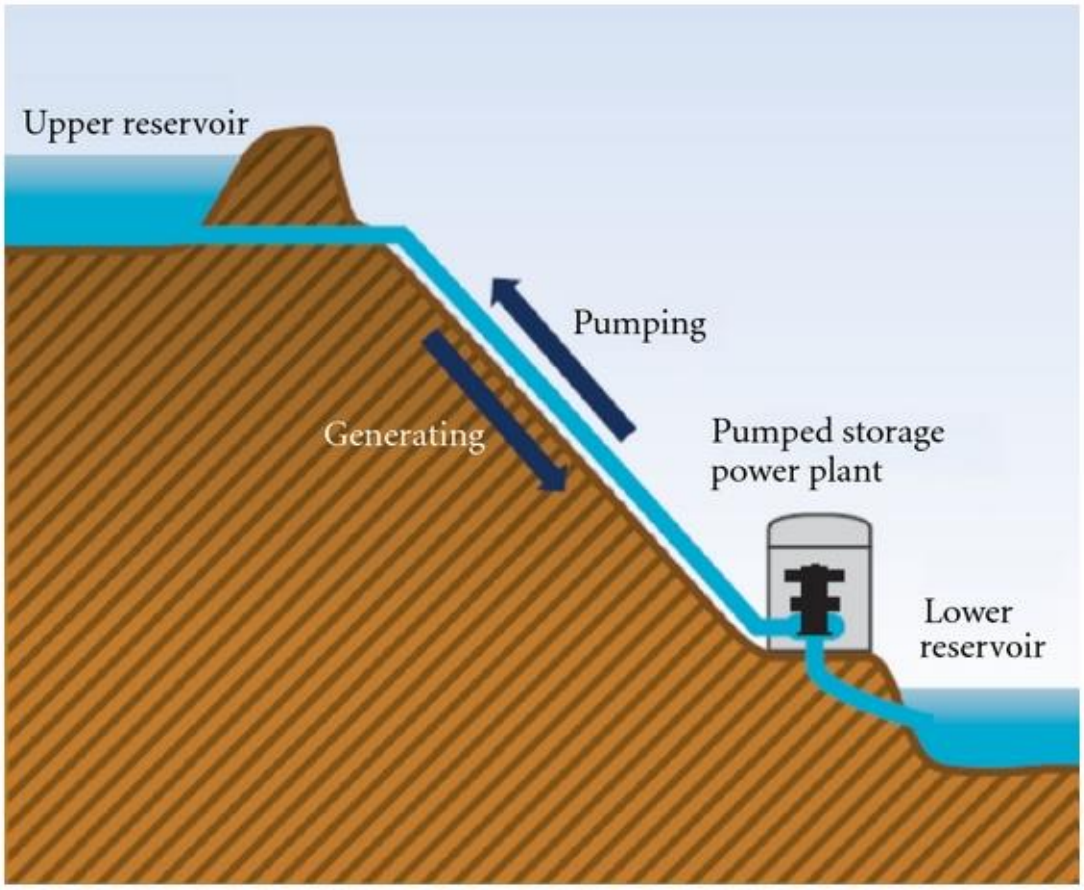



*Figure 19: Schematic of a simplified pumped storage configuration from Kaunda et al. (2012).*

The potential for pumped-storage hydropower exists between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir. Momentum Engineering performed a pre-feasibility level benefit-cost analysis for a pumped-storage hydropower project at Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir. An hourly pumped storage hydropower model was developed to determine the present value of potential economic benefits for the proposed project.

**Quantification of Benefits**

A pumped hydropower project would provide economic benefit to the District by pumping water from Lower Beaver Brook Reservoir to Upper Beaver Brook Reservoir when hourly power costs are low and releasing water from Upper Beaver Brook to Lower Beaver Brook to generate hydropower when hourly power prices are high.

Hourly wholesale power cost data wholesale prices for Colorado from 2020 through 2039 for 80 different Northwest hydro conditions were provided by Mr. John Ollis from the Northwest Power and Conservation Council (https://www.nwcouncil.org/). These data were used to estimate

It was assumed that 25 AF of Lower Beaver Brook Reservoir's 30.8 AF of storage could be used for pumped storage on a daily basis. This would result in a flow rate of 37.8 cfs and a 30-inch diameter pipe if pumping and generation each occur over an 8-hour time period. Under these assumptions, the LMWD Pumped Hydropower Project would require an installed capacity of 1.76 Megawatts (MW).

First, the average from the 80 different Northwest hydro conditions was used to predict future wholesale hourly power pricing. Daily pumping cost was calculated by multiplying the daily pumping potential by the minimum 8-hour average daily power pricing. Daily generating revenue was calculated by multiplying the daily power generation potential by the maximum 8-hour average daily power pricing. An efficiency of 90% was assumed for

both pumping and generation. Gross daily revenue was quantified as the daily generating revenue less daily pumping cost.

An average annual gross revenue of $123,283 (2020 Dollars) was found over the 20-year gross revenue analysis.

**Quantification of Costs**

Momentum Engineering reached out to Obermeyer Hydro, Inc. (http://www.obermeyerhydro.com) to propose a small pumped hydropower solution for the District.

Obermeyer Hydro is a leading innovator in the field of water control technology for over 25 years and has been working with the National Renewable Energy Laboratory (NREL) with support from the Department of Energy (DOE) on the development of Cost Effective Small Scale Pumped Storage Configuration to provide the following advantages when compared to conventional reversible, ternary machines, or separate pumps and turbines in a buried powerhouse:

- Submersible machines are compact and factory assembled and tested, reducing on-site work and construction costs.
- Energy storage within the power converter equipment provides virtual instantaneous transition between supplying and absorbing energy from the grid.
- Geologic risk and constraints are reduced, opening more potential sites to economical development.

Obermeyer Hydro has reviewed the parameters of this potential project in detail and has provided a pre-feasibility cost estimate of $800 per installed kilowatt. The project is assumed to be a 1.76 MW project and would therefore require a base cost of $1,408,860. This capital cost estimate does not include the following components:

- A 9040’ 30-inch diameter penstock from Upper Beaver Brook Reservoir to Lower Beaver Brook Reservoir
- A 50’ deep by 4’ diameter reversable-turbine shaft located near Lower Beaver Brook Reservoir
- Miscellaneous concrete work
- Small buildings/Fencing to protect equipment
- Inlet structures at both reservoirs
- Permitting/Engineering/Legal

The USBR’s Hydropower Assessment Tool was used to quantify fixed annual O&M costs of $50,856 per year (2020 dollars) for a 1.76 MW project. This annual expense estimate did not include variable O&M, FERC charges, insurance, taxes, management/office/overhead, or the major repairs fund.

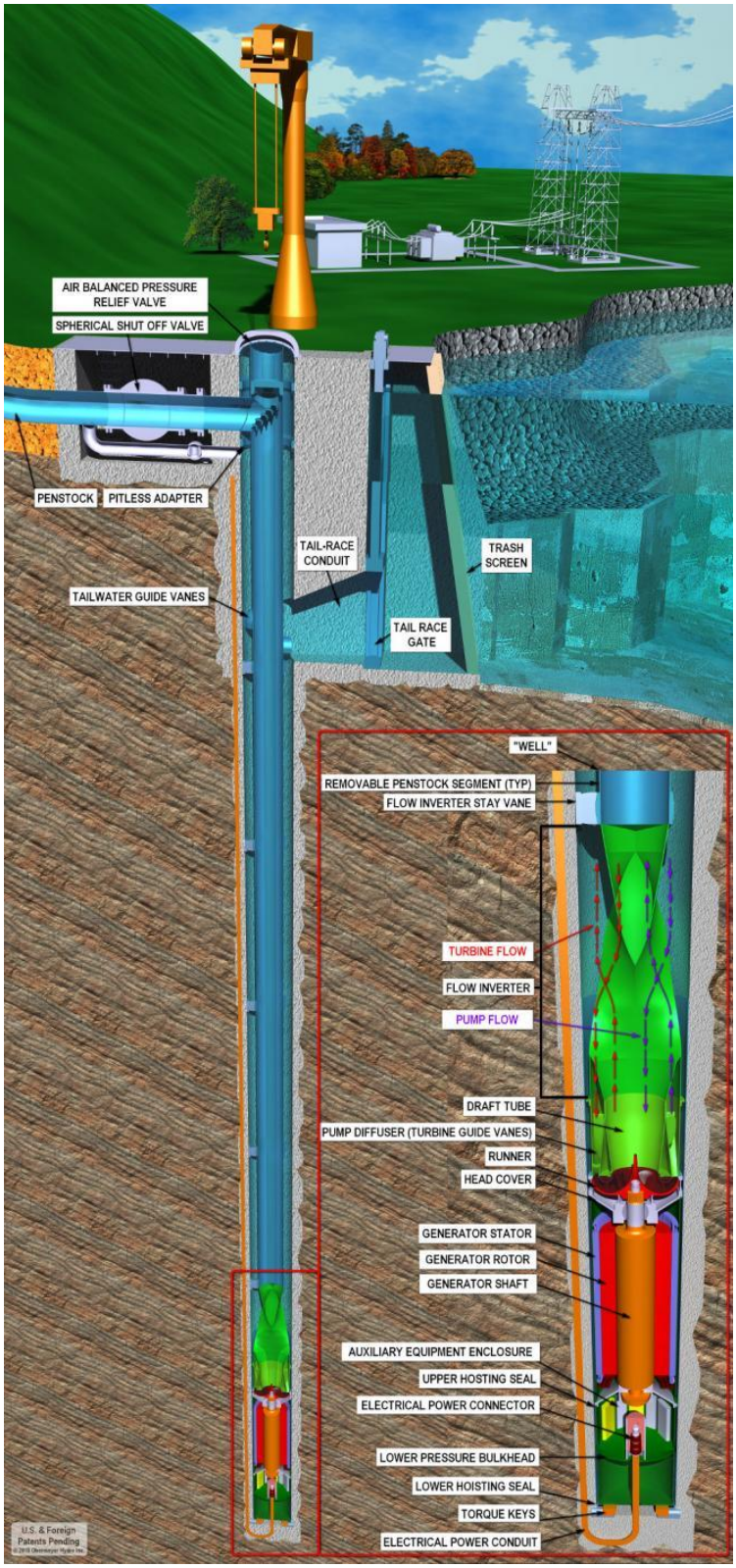



*Figure 20: Schematic of the Obermeyer Hydro's Small Scale Pumped Storage Configuration (Image Source: http://www.obermeyerhydro.com/PumpedStorage).*



MOMENTUM

**Benefit Cost Ratio and Discussion**

Assuming a Discount Rate of 4.375% and a 50-year project life the benefit-cost ratio for the pumped project was found to be 0.996. This benefit-cost ratio is under one even with only using the base capital cost of $800 per install KW and limiting annual costs to fixed O&M.

Additional concerns associated with the pumped storage project include the following:

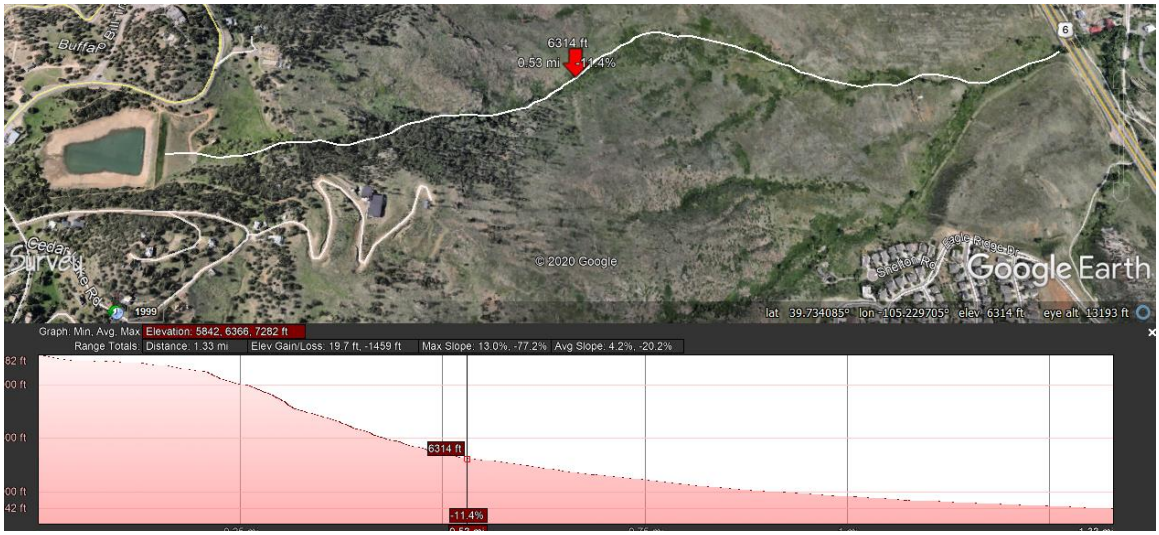
- District cash flow to fund this large project
- Turbidity of water in Lower Beaver Brook Reservoir during power generation
- Reduction in available storage for water supply in both the upper and lower reservoirs.
- Risk associated with power cost projection uncertainty

If the District would like to explore this option further the next step would be to discuss the project with their energy provider. This may result in unforeseen benefits and ultimately a more favorable benefit-cost ratio.

*<u>Hydropower Option #3:</u> Conventional Hydropower from Lookout Mountain Reservoir Releases*

Water Supply Option #5 (Install a raw water line to Lookout Mountain Reservoir) would provide the ability to divert substantial flow to Lookout Mountain Reservoir. This water would ultimately be used for exchange and released east of Lookout Mountain Reservoir down a steep gulley to join Clear Creek.

There exists a potential to develop conventional hydropower from these releases. The terrain drops about 1400' in elevation over the first 1.25 miles from Lookout Mountain Reservoir. This option will require the District to secure a non-consumptive water right to divert flows through the Golden Pipeline for hydropower generation.




**Quantification of Benefits**

Daily water flow available for power generation was quantified using modeled releases from Upper Beaver Brook Reservoir as estimated by the 45-Year Water Supply Model. A 60$^{th}$ percentile flow rate of 0.43 cfs (195 GPM) was used to size a 6" pipeline. Water flow for hydropower generation was then limited to this diversion capacity. The pipeline was

assumed to lose a total 30 feet of head due to friction losses and a 90% turbine efficiency was assumed.

Under these assumptions and modeled daily flow release from Lookout Mountain Reservoir average power generation was estimated to be 270,741 kilowatt-hours (kwh) per year. This equates to approximately $31,027 per year (2020 dollars) in gross revenue, assuming a net metering agreement and the average residential power cost rate of 11.46 cents per kwh.

**Quantification of Costs**

This analysis used the USBR's Hydropower Assessment Tool (https://www.usbr.gov/power/AssessmentReport/index.html) to quantify potential plant costs. These costs were further refined using a similar sized run-of-the-river small hydropower project (Creasey Hydroelectric Project FERC No. P-13829).

The resulting total capital cost for the Lookout Mountain Reservoir Run-of-the-River Hydropower Project including the penstock was estimated to be $582,199 with O&M costs of $9,255 per year (2020 Dollars). The 6" diameter steel above-ground penstock was estimated to cost $50 per foot plus 10% for engineering and 20% for contingencies.

**Benefit Cost Ratio and Discussion**

The benefit-cost ratio for this project was found to be 0.67 assuming a 30-year project life. This project also requires the long-term effort of installing a raw supply water line along LMWD's 12-mile main line.

## CONCLUSIONS AND RECOMMENDATIONS

This study performed a prefeasibility-level analysis of five water supply development alternatives and three hydropower development alternatives.

Water supply improvement were measured based upon their ability to cost-effectively supply water storage to the District in times of drought. The following table summarizes the performance of these five potential water supply alternatives.

*Table 6: Summary of water supply alternatives*

| Option ID | Description | Project Cost | Total increase in critical (5th percentile) UBB storage (AF) | Cost per AF of increased critical UBB storage |
|---|---|---|---|---|
| 1 | Install SCADA | $90,000 | 174 | $517 |
| 2 | Improved OTR Accounting | $25,000 | 132 | $189 |
| 3 | Rehabilitate the Golden Emergency Pipeline | $300,000 | 57 | $5,263 |
| 4 | Rehabilitate the North Beaver Brook Pipeline | No Significant Benefits | | |
| 5 | Install a Raw Water Line to LMR | $2,000,800 | 214 | $9,350 |

As shown in Table 6, two potential water supply improvements were found to economically increase critical storage reserves in Upper Beaver Brook Reservoir. Installing a SCADA system to minimize outflow from Upper Beaver Brook Reservoir is estimated to cost $90,000 and save about 20 AF per year. The District is currently in the process of applying for a Colorado Water Conservation Board (CWCB) grant that, if successful, would provide $70,000 toward this project. One potential drawback to the SCADA project is the age and fragility of the existing Upper Beaver Brook outlet controls. Mr. Chad Mashing from GEI Consultants stated that the gate valves are weak and that an automated control of these may break internal control components. The replacement of these gates and components may need to be undertaken by the District regardless of implementing SCADA.

The second water supply alterative involves reducing mandated releases from Upper Beaver Brook Reservoir by improving the Owe-the-River Accounting measurement and methodology. This is the most economical option and has the potential to save the District about 15 AF per year. The major drawback of this option is the difficulty in its implementation as the State Engineer will need to approve any modification of LMWD's water accounting.

Given the stated assumptions, only one of the hydropower alternatives proved to be feasible. Even with optimistically assuming only base capital and O&M costs, pumped storage hydropower between Upper Beaver Brook Reservoir and Lower Beaver Brook Reservoir was found to have a benefit-cost ratio below 1. Run-of-the-river hydropower generation using releases from Lookout Mountain Reservoir was found to have a benefit-cost ratio of only 0.67 due to the significant cost of installing a 6728' pipeline below the reservoir's outlet. However, with an estimated benefit-cost ratio of 1.5, run-of-the-river hydropower using releases from Upper Beaver Brook Reservoir will likely be economically beneficial to LMWD if the District decides to construct a pipe from Upper Beaver Brook Reservoir to serve the water treatment plant.

In summary, Momentum Engineering believes that LMWD has several options for increasing water supply and recommends that the District continues to pursue both the installation of a SCADA system to automate release from Upper Beaver Brook Reservoir and improved OTR Accounting. Before proceeding with the implementation of the SCADA system it will be important to fully understand the condition of the existing Upper Beaver Brook Dam gate controls. The District's water rights engineer, Cristy Radabaugh, has been informed of the general concept for improving OTR Accounting and can advise the District if this is worth further investigation.

Finally, if a pipeline from Upper Beaver Brook Reservoir is selected as the preferred option to supply water to the treatment plant, it is recommended that the District conduct a final feasibility and design study to utilize this conveyance pipe for hydropower generation.

## REFERENCES

Kaunda, Chiyembekezo & Kimambo, Cuthbert & Nielsen, Torbjørn. (2012). Hydropower in the Context of Sustainable Energy Supply: A Review of Technologies and Challenges. ISRN Renewable Energy. 2012. 10.5402/2012/730631.

Public Utility Regulatory Policies Act (PURPA). 1978. Pub. L. No.95-617, 92 Stat. 3117

# EXHIBIT F



## FEDERAL EMERGENCY MANAGEMENT AGENCY

### RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

## NEPA DETERMINATION

**Non Compliant Flag:** No **EA Draft Date:** 05/21/2019 **EA Final Date:** 06/10/2019

**EA Public Notice Date:** 05/23/2019 **EA Fonsi** 06/12/2019 **Level:** EA

**EIS Notice of Intent** **EIS ROD Date:**

**Comment** The Lookout Mountain Water District (LMWD) has requested assistance from FEMA to address identified dam safety deficiencies at the Lower Beaver Brook Dam in Clear Creek County, Colorado. The proposed project is to replace the existing 114-year-old rockfill embankment dam with a new concrete gravity dam. The proposed dam will be designed and constructed to be in conformance with the State of Colorado Division of Water Resources, Dam Safety Branch Rules and Regulations for Dam Safety and Dam Construction. The new concrete dam will be constructed immediately downstream of the existing dam and will not result in additional storage capacity or increased discharges during routine flow conditions. Public notification that the draft EA was available for public review and comment was published in the Golden Transcript newspaper on May 23, 2019. The draft EA was available for public review and comment for 15 days at the LMWD office and on their website. No substantive comments were received, and the draft became final on June 10, 2019. - djones58 - 06/12/2019 18:31:03 GMT

Based upon the information contained in the referenced Final EA completed in accordance with the National Environmental Policy Act, and FEMA¿s implementing regulations (FEMA Directive 108-1) for environmental considerations, it is found that the proposed project, with the prescribed mitigation measures and stipulations, would have no significant adverse impact on the human environment. As a result of this Finding of No Significant Impact (FONSI), an Environmental Impact Statement will not be prepared.

- djones58 - 06/12/2019 18:35:54 GMT

## EXTRAORDINARY

| Extraordinary Circumstance Code | Description | Selected ? |
|---|---|---|
| | No Extraordinary Circumstances were selected | |

## ENVIRONMENTAL LAW / EXECUTIVE ORDER

| Environmental Law/ Executive Order | Status | Description | Comment |
|---|---|---|---|
| Bald and Golden Eagle Protection Act (BGEPA) | Completed | Review concluded | Removal of vegetation in the project area has the potential to impact migratory birds and raptors. The proposed actions are subject to compliance with the Bald and Golden Eagle Protection Act (BGEPA). See project conditions. - djones58 - 06/12/2019 18:08:04 GMT |
| Clean Air Act (CAA) | Completed | Project will not result in permanent air emissions - Review concluded | |
| Coastal Barrier Resources Act (CBRA) | Not Applicable | Project is not on or connected to CBRA Unit or otherwise protected area - Review concluded | |
| Clean Water Act (CWA) | Completed | Project would affect waters, including wetlands, of the U.S. | Beaver Brook is assumed to qualify as a water of the US under the jurisdiction of the USACE. Therefore, the sub-recipient shall consult with USACE to determine project requirements. See project |

## RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

| Environmental Law/ Executive Order | Status | Description | Comment |
|---|---|---|---|
| | | | conditions. - djones58 - 06/12/2019 18:05:02 GMT |
| | Completed | Project may require Section 404/401 or Section 9/10 (Rivers and Harbors Act) permit, including qualification under Nationwide Permits - Review concluded | |
| Coastal Zone Management Act (CZMA) | Not Applicable | Project is not located in a coastal zone area and does not affect a coastal zone area - Review concluded | |
| Executive Order 11988 - Floodplains | Completed | Located in floodplain or effects on floodplain/flood levels | Per FIRM panel number 08019C0235E, effective 07/17/2012), the project (including the storage reservoir behind the dam) is located in Zone A. All practicable alternatives would contain project features located in the 100-year floodplain. No permanent modification of the floodplain would occur. Any impacts to adjacent floodplains would be temporary and characteristic would remain unchanged. The action would have a beneficial effect on the existing structures located below the dam by reducing the potential for uncontrolled release as a result of dam failure. Additionally, the project is functionally dependent at its location. Full 8 Step documentation is included in project file. As part of the EA, a Public Notice intent to complete an action in the floodplain was advertised in the Golden Transcript on November 22, 2018 and May 23, 2019. No substantive comments were received during the 15 day comment periods. Affidavit of publication is included in the project file. See project conditions related to floodplain. - djones58 - 06/12/2019 18:17:10 GMT |
| | Completed | Beneficial Effect on Floodplain Occupancy/Values - Review concluded | |
| Executive Order 11990 - Wetlands | Completed | Located in wetlands or effects on wetlands | Wetlands were identified in some sections of the project area. All practicable alternatives would contain project features located wetlands. The affected wetland area has been calculated to be approximately .12 acres of fringe wetlands. Wetland impacts would include excavation and grading of the area immediately adjacent to the existing dam and installation of bank stabilization and erosion control around the new dam and spillway. Measures to avoid or minimize impacts to the adjacent wetlands were incorporated into the engineering and design of the proposed alternative. Remaining wetland impacts will be identified and mitigated as part of |

## RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

| Environmental Law/ Executive Order | Status | Description | Comment |
|---|---|---|---|
| | | | compliance with the Clean Water Act Section 404 permit requirements. Implementation of standard BMP and mitigation measures described in the above referenced EA is required. As part of the EA, a Public Notice intent to complete an action in wetlands was advertised in the Golden Transcript on November 22, 2018 and May 23, 2019. No substantive comments were received during the 15 day comment periods. Affidavit of publication is included in the project file. See project conditions related to wetland impacts. - djones58 - 06/12/2019 18:23:00 GMT |
| | Completed | Possible adverse effect associated with constructing in or near wetland | |
| | Completed | Review completed as part of floodplain review - Review concluded | |
| Executive Order 12898 - Environmental Justice for Low Income and Minority Populations | Completed | No Low income or minority population in, near or affected by the project - Review concluded | |
| Endangered Species Act (ESA) | Completed | Listed species and/or designated critical habitat present in areas affected directly or indirectly by the federal action | FEMA made a determination that the proposed project will have ¿no effect¿ on the Least Tern, Pallid Sturgeon, Piping Plover, Western Prairie Fringed Orchid, Whooping Crane, Canada lynx, greenback cutthroat trout, and the North American wolverine. Additionally, FEMA has made a determination that the proposed project ¿may affect, not likely to adversely affect¿ for the Mexican spotted owl. USFWS concurred with FEMAs determinations - Tails No: 06E24000-2019-I-0091. See conditions. - djones58 - 06/12/2019 18:04:27 GMT |
| | Completed | May affect, but not likely to adversely affect species or designated critical habitat (FEMA determination/USFWS/NMFS concurrence attached) - Review concluded | |
| Farmland Protection Policy Act (FPPA) | Completed | Project does not affect designated prime or unique farmland - Review concluded | |
| Fish and Wildlife Coordination Act (FWCA) | Completed | Project does not affect, control, or modify a waterway/body of water - Review concluded | |

## RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

| Environmental Law/ Executive Order | Status | Description | Comment |
|---|---|---|---|
| Migratory Bird Treaty Act (MBTA) | Completed | Project located within a flyway zone | See project conditions. - djones58 - 06/12/2019 18:05:41 GMT |
| | Completed | Project has potential to take migratory birds | |
| | Completed | Contact made with USFWS - Review concluded | |
| Magnuson-Stevens Fishery Conservation and Management Act (MSA) | Completed | Project not located in or near Essential Fish Habitat - Review concluded | |
| National Historic Preservation Act (NHPA) | Completed | Standard Section 106 review | FEMA determined the Lower Beaver Brook Dam (5CC.2566) to be eligible for inclusion on the NRHP. The scope of work calls for the removal of the dam, thus the proposed undertaking constitutes an adverse effect. The CO SHPO concurred with FEMAs eligibility determination and finding of adverse effect on February 19, 2019 (CHS # 72892). A Memorandum of Agreement (MOA) was prepared to resolve the adverse effect to the Lower Beaver Brook Dam. See MOA executed May 6, 2019 for project stipulations to mitigate the adverse effect of the Undertaking on historic properties. - djones58 - 06/12/2019 17:50:38 GMT |
| | Completed | Building or structure 50 years or older or listed on the National Register in the project area and activity not exempt from review | |
| | Completed | Determination of Historic Properties Affected (FEMA finding/SHPO/THPO concurrence attached) | |
| | Completed | Adverse Effect Determination (FEMA finding/SHPO/THPO concurrence attached) | |
| | Completed | Resolution of Adverse Effect completed. (MOA attached) - Review concluded | |
| | Completed | Project affects undisturbed ground | |
| | Completed | Project area has no potential for presence of archeological resources | |
| | Completed | Determination of no historic properties affected (FEMA finding/SHPO/THPO | |

## RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

| Environmental Law/ Executive Order | Status | Description | Comment |
|---|---|---|---|
| | | concurrence or consultation attached) - Review concluded | |
| State Air Quality Laws | Completed | Review concluded | See project conditions. - djones58 - 06/12/2019 18:07:11 GMT |
| State Hazardous Materials and Solid Waste Laws | Completed | Review concluded | See project conditions. - djones58 - 06/12/2019 18:07:18 GMT |
| State Water and Soil Laws | Completed | Review concluded | See project conditions. - djones58 - 06/12/2019 18:07:25 GMT |
| Wild and Scenic Rivers Act (WSR) | Completed | Project is not along and does not affect Wild and Scenic River - Review concluded | |

## CONDITIONS

**Special Conditions required on implementation of Projects:**

This finding is conditioned on the following mitigation and stipulations:

1. The District must obtain all applicable federal, tribal, state and local permits, approvals, etc. and comply with all permit requirements and conditions.

2. The District must coordinate with the local and/or Clear Creek County Floodplain Administrator to obtain a Floodplain Development Permit and complete a CLOMR and a LOMR, if required.

3. The District shall consult with the USACE to determine final project requirements. The sub-recipient is responsible for obtaining any needed permits and verifying and complying with all permit requirements, including wetland mitigation, any permit conditions, preconstruction notification requirements, and regional conditions as provided by the Army Corps of Engineers. The sub-recipient is responsible for implementing, monitoring, and maintaining all Best Management Practices (BMPs) and Pre- Construction Notification (PCN) conditions of applicable nationwide permits.

4. The District must coordinate with the Colorado Department of Public Health and Environment (CDPHE) and obtain appropriate Clean Water Act Section 401 Water Quality certifications, as applicable.

5. The District must obtain and comply with a Colorado Department of Public Health and Environment (CDPHE) National Pollutant Discharge Elimination System Construction Stormwater permit.

6. In order to minimize impacts to the adjacent wetlands, appropriate erosion and sediment control measures must be installed to control the discharge of pollutants from the construction site. Any impacts to jurisdictional wetlands must be mitigated based on the terms and conditions of the Section 404 CWA permit.

7. The District must coordinate with the State of Colorado Division of Water Resources Dam Safety Branch and obtain all required permits.

8. The following best management practices will be employed to mitigate any potential effect to the Mexican spotted owl (USFWS, 2012).

- Disturbance activities would be limited to the boundaries of the demarcated subareas.

- Activities would take place between the hours of construction activities would be limited to daytime hours (7 a.m. to 9 p.m. in the summer months and 8 a.m. to 6 p.m. during winter months). No nighttime activities would occur, as this is

prime foraging hours for the Mexican spotted owl.

9. Removal of vegetation in the project area has the potential to impact migratory birds and raptors. The proposed actions are subject to compliance with the Bald or Golden Eagle Protection Act (BGEPA). In accordance with US Fish and Wildlife (USFWS) guidelines, the applicant is responsible for obtaining and complying with any necessary permits from USFWS. To avoid impacts to migratory birds and raptors, no large trees should be removed from April to September, which is the nesting/fledging period for eagles. If work must occur during the nesting season, a bird survey can be completed. If active nests are observed in the project area, appropriate USFWS buffer zones and/or work restrictions may be required. If no activity is observed, then no restrictions would apply. See https://www.fws.gov/birds/policies-and-regulations.php for guidance.

Source of condition: NEPA Determination Monitoring Required: No

10. The District will create and implement a species management plan for the site to avoid encroachment of invasive species into the project area. The management plan would provide on-going weed control during and after site construction

11. The applicant and all parties must comply with applicable Stipulations of the Memorandum of Agreement (MOA) among FEMA, Colorado Department of Homeland Security and Emergency Management (DHSEM), State Historic Preservation Officer (SHPO), and the Lookout Mountain Water District (executed May 6, 2019).

12. If cultural resources are encountered during project activities, work would be stopped, and FEMA and the Colorado State Historic Preservation Officer (SHPO) must be notified.

13. Fill materials (soil, boulders, and/or riprap, etc.) must be obtained on-site or from previously approved sources (Colorado State Licensed Pits, existing commercial sources, existing contractor or County Stockpiles); otherwise additional coordination with FEMA and the Colorado SHPO will be required to obtain necessary approvals.

14. The District is responsible for complying with all Colorado Air Pollution Control Division (APCD) regulations as applicable. All sources of potential construction and oil and gas projects that will produce air emissions in Colorado may require a construction or oil and gas permit. The first step to obtain a permit is to determine whether your project will need an Air Pollution Emissions Notice (APEN). Information on APENs and air permits is found at www.colorado.gov/pacific/APEN. Please contact James DiLeo at Colorado Dept of Public Health and Environments Air Pollution Control Division at 303-692-3127 or jim.dileo@state.co.us if you have any questions or need additional information.

15.Contractor and/or Subcontractors will properly handle, package, transport, and dispose of hazardous materials and/or waste in accordance with all local, State, and Federal regulations, laws, and ordinances. If hazardous substances are released to the project area during construction, these Federal, State, and local requirements must be followed in response and cleanup.

16. All waste material associated with the project must be disposed of properly and not placed in identified floodplain or wetland areas.

17. Construction traffic should be closely monitored and controlled as appropriate. All construction activities will be conducted in a safe manner in accordance with OSHA requirements. To alert motorists and pedestrians of project activities, appropriate signage and barriers will be on site prior to and during construction activities. During construction activities, the construction site(s) will be fenced off to discourage trespassers. The District will coordinate with the County on long-term road improvement.

18. The District must implement standard Best Management Practices (BMP) to minimize erosion and sedimentation; reduce emissions, fugitive dust, fuel leaks and spills, and noise; control invasive species and comply with all applicable federal, tribal, state and local requirements.

Source of condition: NEPA Determination Monitoring Required: No

**Standard Conditions:**

Any change to the approved scope of work will require re-evaluation for compliance with NEPA and other Laws and Executive Orders.

## RECORD OF ENVIRONMENTAL CONSIDERATION (REC)

**Project** PDMC-PJ-08-CO-2017-002 (0)

**Title:** Risk Reduction Spillway and Dam Safety Modifications at Lower Beaver Brook

This review does not address all federal, state and local requirements. Acceptance of federal funding requires recipient to comply with all federal, state and local laws. Failure to obtain all appropriate federal, state and local environmental permits and clearances may jeopardize federal funding.

If ground disturbing activities occur during construction, applicant will monitor ground disturbance and if any potential archeological resources are discovered, will immediately cease construction in that area and notify the State and FEMA.

**RESOLUTION OF THE**
**LOOKOUT MOUNTAIN WATER DISTRICT**
**Application for financing of Beaver Brook corridor construction with CWCB**

**Resolution # 9/20-2**

**WHEREAS**, the Lookout Mountain Water District (the "**District**") is a quasi-municipal corporation and political subdivision of the State of Colorado, located within Jefferson County, organized pursuant to Article 1 of Title 32, Colorado Revised Statutes, known as the "Special District Act"; and

**WHEREAS**, the District has approved capital improvements and construction projects in the Beaver Brook corridor, including replacing Lower Beaver Brook dam, replacing the outlet works at Upper Beaver Brook dam, adding a SCADA system for the corridor and installing a pump and tank to help feed the Water Treatment Plant; and

**WHEREAS**, the District has held an election per § 32-1-1101, C.R.S. and been authorized by the electors to issue debt to finance improvements in the Beaver Brook corridor, including the replacement of Lower Beaver Brook dam; and

**WHEREAS**, the District and its staff have analyzed the District's financing options to complete these improvements and found terms offered through the State of Colorado, Colorado Water Conservation Board's ("CWCB") Water Project Loan Program to be the most attractive for the District;

**NOW THEREFORE, BE IT RESOLVED** BY THE BOARD OF DIRECTORS OF LOOKOUT MOUNTAIN WATER DISTRICT, JEFFERSON COUNTY, COLORADO, THAT:

1. The District may apply for up to $3,500,000 in loan to be repaid over a 30 year term with a final rate and application fees to be negotiated.

2. In accordance with the approval by Electors, these loans will only be used to finance projects approved within the scope of the ballot language.

3. This Resolution is and shall constitute a legislative measure of the District, which may be modified only by formal resolution of the Board of Directors of the District.

4. This Resolution was passed by the Board of Directors by a vote of ___5_ to __0__ on this ____14_____ Day of __September____, 2020.

Barbara Nevins
President

**CERTIFICATION**

The undersigned secretary of the Lookout Mountain Water District certifies that the foregoing Resolution is a true, complete and correct copy of a Resolution of the Board of Directors of the Lookout Mountain Water District duly and regularly entered by the Board at its regular public meeting held on.

Nickie M Holder
Secretary