Applegate Group, Inc.
Water Resource Advisors for the West

Memorandum

Date: 1/12/2024 AG Job No.: 10-118

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RE: Lake Avery Preliminary Site Studies

Applegate was tasked by the Yellow Jacket Water Conservation District (YJWCD) to perform a preliminary Hydrology Study and Hydrologic Hazard Analysis of Lake Avery in continuation of our efforts evaluating a potential enlargement of the reservoir. These efforts were recommended as next steps in our *Lake Avery Development Memo* sent to YJWCD in 2021. The following memo summarizes our efforts, findings, and future recommendations.

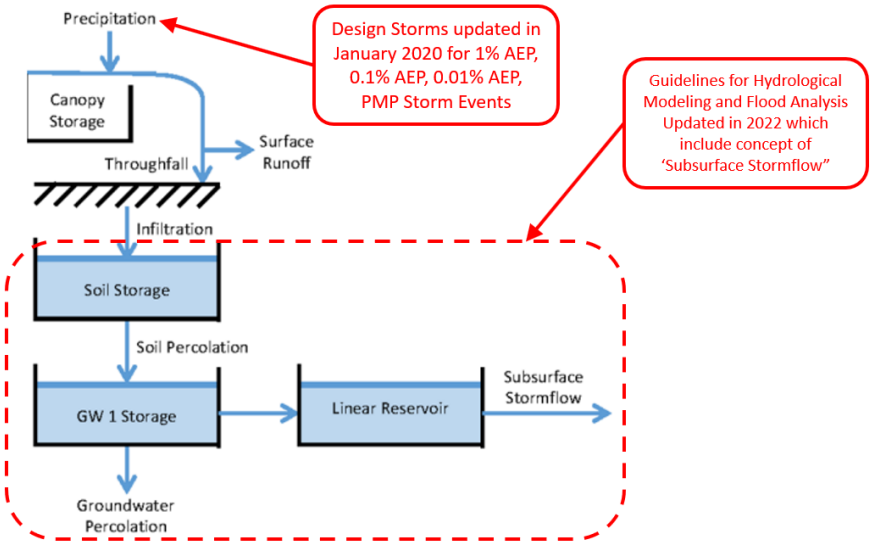
PURPOSE, NEED, AND BACKGROUND KNOWLEDGE

Increasing storage at Lake Avery to store YJWCD conditional rights was identified as a viable option in previous studies conducted for YJWCD. An increase in storage can be achieved by either enlarging the entire dam structure or modifying the hydraulic capacity of the spillway to justify a higher normal water level or a combination of those two efforts. Evaluating hydrologic conditions at Lake Avery is fundamental to understanding the feasibility of achieving additional storage at the site.

The existing Hydrology Study for Lake Avery was completed by Boyle Engineering in 1992. In this Study, the dam was assumed to be a high hazard dam and the regulations at the time required the spillway to route 75% of the Probable Maximum Flood event for high hazard structures. Since then, the Colorado Dam Safety Branch has enacted changes to the dam regulation landscape that is relevant to our analysis:

- **Hydrologic Hazard Analysis:** In 2020, The Colorado Dam Safety Branch has updated and re-released their *Rules and Regulations for Dam Safety and Dam Construction (Rules and Regs)*. The new *Rules and Regs* introduced the concept of Hydrologic Hazard classification which determines spillway sizing criteria for dams and reservoirs. Hydrologic Hazard classification is a risk-based analysis that quantifies the expected loss of life resulting from an overtopping dam failure during a flooding event. This concept is separate from Hazard classification which determines all other design criteria and inspection requirements for dams. Hazard classification is a deterministic analysis that estimates the potential for loss of life resulting from a sunny-day failure of a dam.
- **Updated Design Storms:** The standard of practice for hydrology studies of dams in Colorado has also seen recent significant changes. The Colorado Dam Safety Branch conducted extensive climate and precipitation studies, ultimately resulting in updated design storms for use to determine inflow design floods. Previously, design storms, particularly lower frequency events, were based on very general storm data applied to the entirety of the state. Now, the state is divided into distinct regions with storms of similar characteristics defined for each region, resulting in more scientifically based design storm data that considers historical precipitation records. *Guidelines for the use of Regional Extreme Precipitation Study (REPS) Rainfall Estimation Tools* contains more details on these updated design storms and how to gather that data for analysis.
- **Updated Hydrological Modeling and Flood Analysis Guidelines:** In 2022 the Colorado Dam Safety Branch also updated their *Guidelines for Hydrological Modeling and Flood Analysis* which impacts how inflow design floods are determined for dams in the state, and thus how spillways are sized. The new guidelines incorporate many changes to the hydrology modeling but the major difference is soil mositure accounting and subsurface stormflow mechanisms are now explicitly modeled when determining a basin's response to precipitation. The guidelines also require "Reasonableness Checks" and model calibration based on the gage records, paleo flood data, and other available flood records.

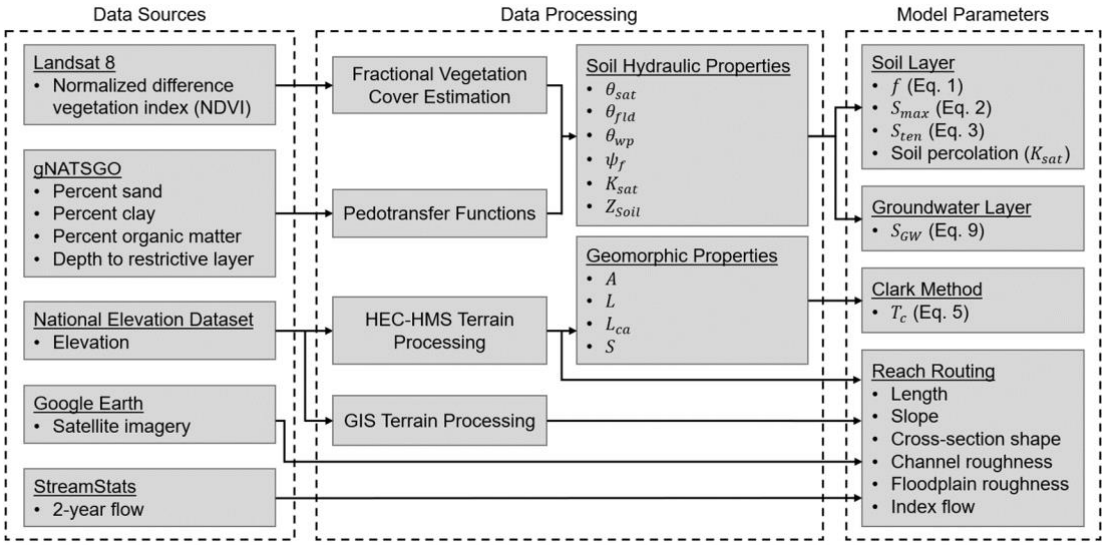
The following figure shows a simplified depiction of how basin runoff is modeled with changes to the standard of practice highlighted in **RED**.



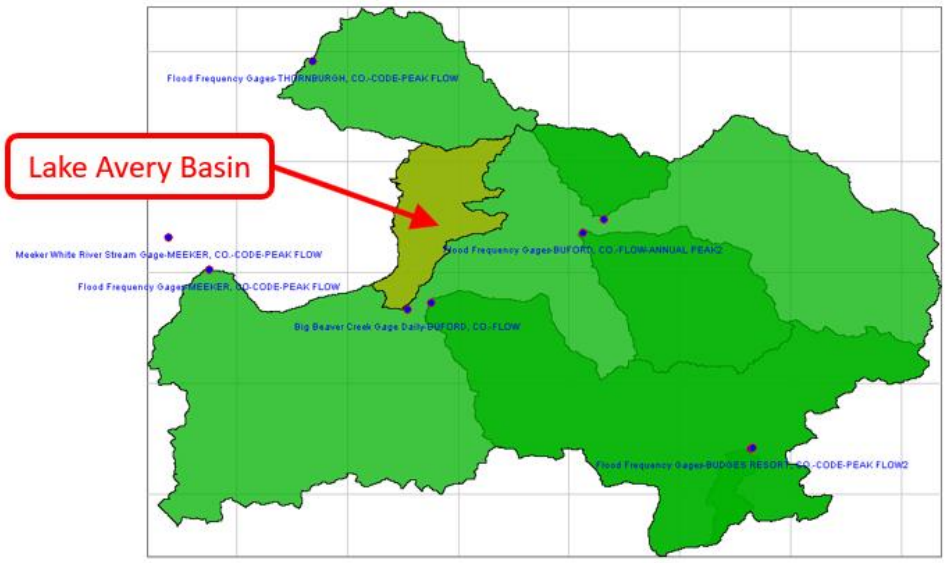
Colorado Dam Safety branch has indicated that the changes discussed above have generally resulted in less intense inflow design storms on the West Slope and more intense inflow design storms on the Front Range and Eastern Plains compared to the previous standard of practice. This creates an opportunity for dams on the West Slope, such as Lake Avery, to increase storage without enlarging the embankment by justifying lower inflow design floods which is the main driver of our efforts.

PRELIMINARY HYDROLOGY STUDY

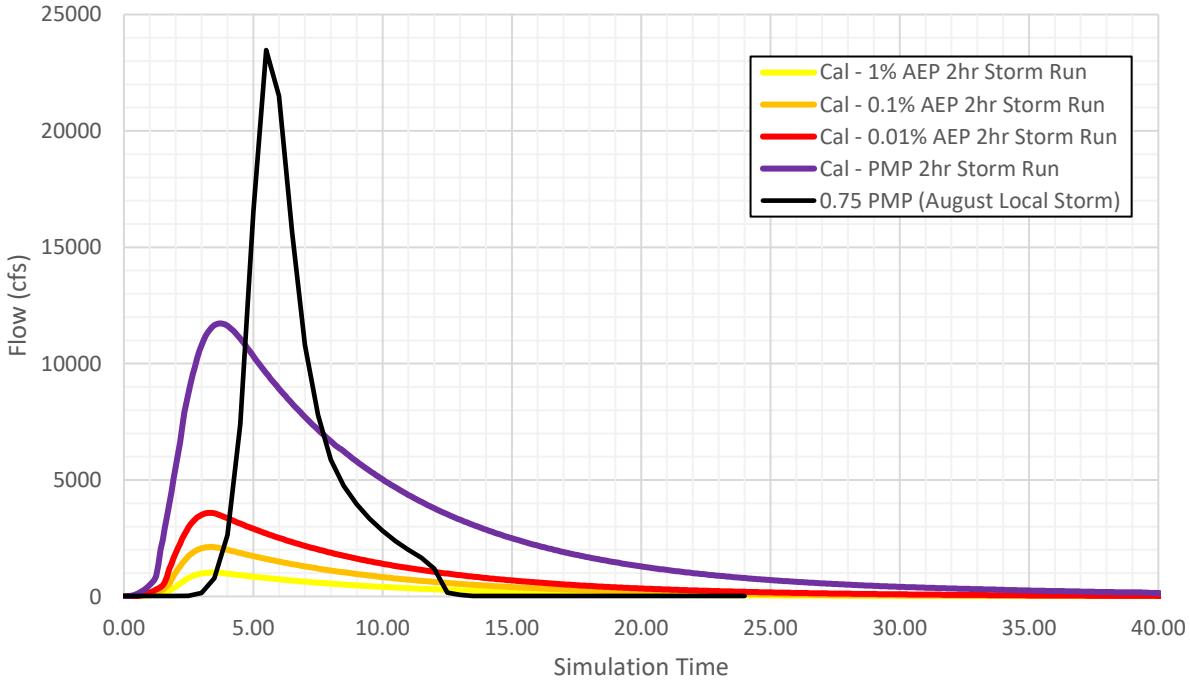
Applegate conducted a preliminary Hydrology Study per the recently updated *Guidelines for Hydrological Modeling and Flood Analysis* and *Guidelines for use of Regional Extreme Precipitation Study (REPS) Rainfall Estimation Tools*. A hydrologic model was developed utilizing HEC-HMS with input parameters determined via the *Guidelines*. The following figure shows a flow chart taken from the *Guidelines for Hydrologic Modeling and Flood Analysis* overviewing model parameters incorporated into the HEC-RAS model.



The hydrology model was refined and calibrated based on flood frequency analysis of nearby gage records performed according to *Guidelines for Determining Flood Flow Frequency Bulletin 17C* published by the United States Geological Survey (USGS). The following map shows USGS stream gages near Lake Avery's basin considered in our analysis (**BLUE** dots show gage station locations while drainage basins for each are shown in **GREEN**).



Ultimately, only USGS Stream Gages 09250000(Milk Creek near Thornburgh), 0903300 (River at Budges Resort), and 09302450 (Lost Creek near Buford) were utilized for calibration as they had an adequate number of records and basin characteristics most similar to Lake Avery's drainage basin. Inflow design flood hydrographs generated from the calibrated HEC-HMS hydrology model are shown in the following chart alongside the inflow design flood hydrograph from the Boyle Engineering 1994 Hydrology Study.



The following table summarizes storm volumes and peak flows generated from each storm.

Storm Characteristic	Design Storm				
	1% AEP 2hr Storm	0.1% AEP 2hr Storm	0.01% AEP 2hr Storm	PMP 2hr Storm	0.75 PMP from 1994 Hydrology Study
Peak Inflow	1,031 cfs	2,129 cfs	3,591 cfs	11,730 cfs	23,472 cfs
Runoff Volume	717 ac-ft	1,473 ac-ft	2,511 ac-ft	8,862 ac-ft	5,857 ac-ft

Our updated preliminary Hydrology Study shows peak flows significantly less than those generated from the inflow design flood from the Boyle Engineering's 1994 Hydrology Study. Storm volume from the 1994 Hydrology Study however is within the range of storm volumes determined from this analyis. This is consistent with Colorado Dam Safety experience that design floods on the West Slope will generally be less intense than design storms determined with older Hydrologic Analysis methods.

PRELIMINARY HYDROLOGIC HAZARD ANALYSIS

As previously mentioned, the recently updated *Rules and Regs* now incorporate the concept of Hydrologic Hazard that determines the inflow design flood and thus spillway sizing for dams and reservoirs in Colorado. This concept classifies dams into Low, Significant, High, or Extreme Hydrolgoic Hazard Groups based on the expected loss of life and significant damage resulting from an overtopping dam failure initiated by a storm event exceeding the spillway capacity. Design rainfall events, and thus inflow design floods, are prescribed for spillway design based on the Hydrologic Hazard designation of the structure per the following table taken from the *Rules and Regs.*

Hydrologic Hazard	Consequence Criteria	Critical Rainfall
Extreme	Life loss potential greater than 1	Probable Maximum Precipitation
High	Life loss potential less than 1	0.01% AEP Storm Event
Significant	No life loss potential but significant damage expected	0.1% AEP Storm Event
Low	No life loss potential or significant damage expected	1% AEP Storm Event

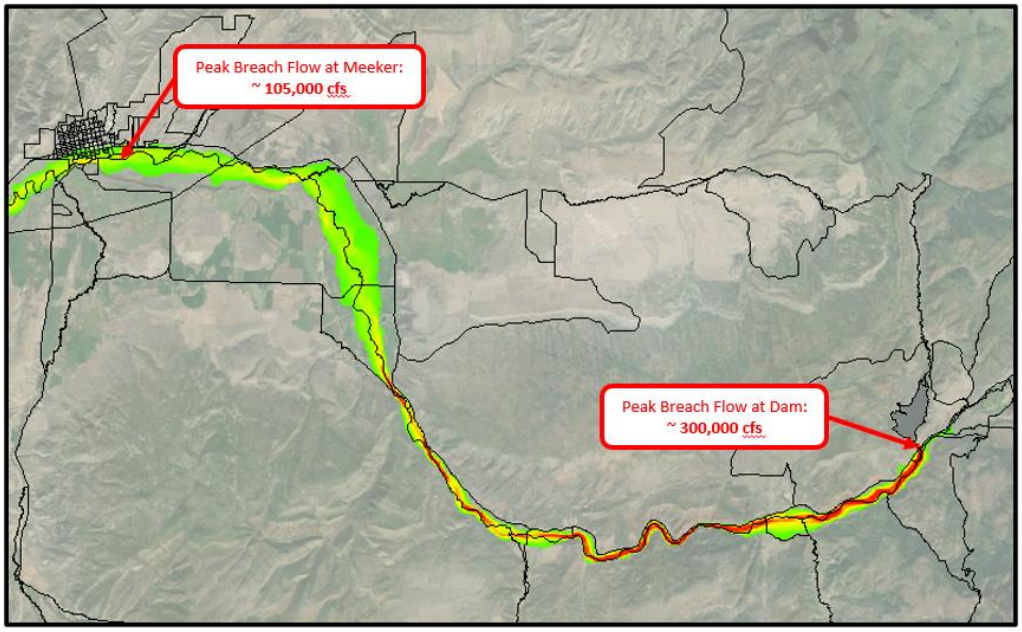
A preliminary Hydrologic Hazard Analysis was completed for Lake Avery following recommendations presented in *Guidelines for Hydrologic Hazard Analysis* and *Guidelines for Dam Breach Analysis*. Hydrologic Hazard analysis can be broken down to the following general steps:

1. Development of overtopping dam failure breach parameters
2. Breach flood modeling and routing
3. Consequence analysis of the resulting inundation area.

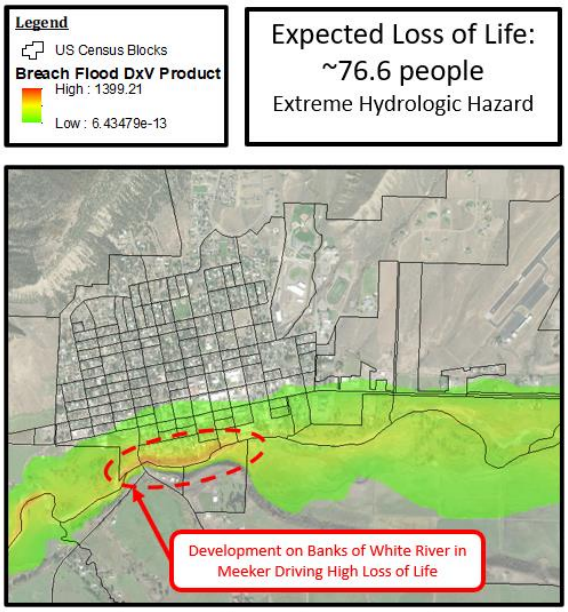
Hydrologic Hazard analysis is an iterative process started by assuming an initial Hydrologic Hazard designation and then repeating the analysis as necessary by increasing the Hydrologic Hazard rating assumption until the consequences match the criteria for that Hydrologic Hazard rating as shown in the table above.

Our analysis assumed an initial High Hydrologic Hazard rating. Breach parameters were determined per *Guidelines for Dam Breach Analysis* and input into the HEC-HMS model to generate a breach flow hydrograph. DSS-WISE Web (2D hydraulic modeling online platform hosted by FEMA) was utilized to route the breach flow hydrograph through the downstream reach. 2D model results were then used to estimate consequences resulting from an overtopping breach failure of Lake Avery.

Consequence analysis entails identifying the Population at Risk (PaR) impacted by the overtopping breach flood and then estimating Loss of Life by applying fatality rates to the PaR based on the hydraulic conditions they experience. The PaR for this analysis was determined based on US Census Block data data within the breach flood inundation area. Fatality rates were assumed from fatality rate curves published by the United States Bureau of Reclamation (USBR). Loss of life was then estimated by applying fatality rate curves to the PaR based on the maximum depth-velocity products they experienced per the 2D modeling results. The following figure shows the overtopping breach flood and the resulting Loss of Life estimate.



Overview Map of Overtopping Breach Flood



Blowup of Results at Meeker

Our analysis estimated a Loss of Life of 76 people resulting from the overtopping failure of Lake Avery, which greatly exceeds the consequence criteria for an Extreme Hydrologic Hazard structure. **We believe Lake Avery would likely receive an Extreme Hydrologic Hazard designation from the Colorado Dam Safety Branch and thus the Probable Maximum Flood is the spillway sizing criteria.** Please note that the Probable Maximum Flood determined as part of our analysis is different from the 0.75 Probable Maximum Flood determined in Boyle Engineering's 1994 Hydrology Study.

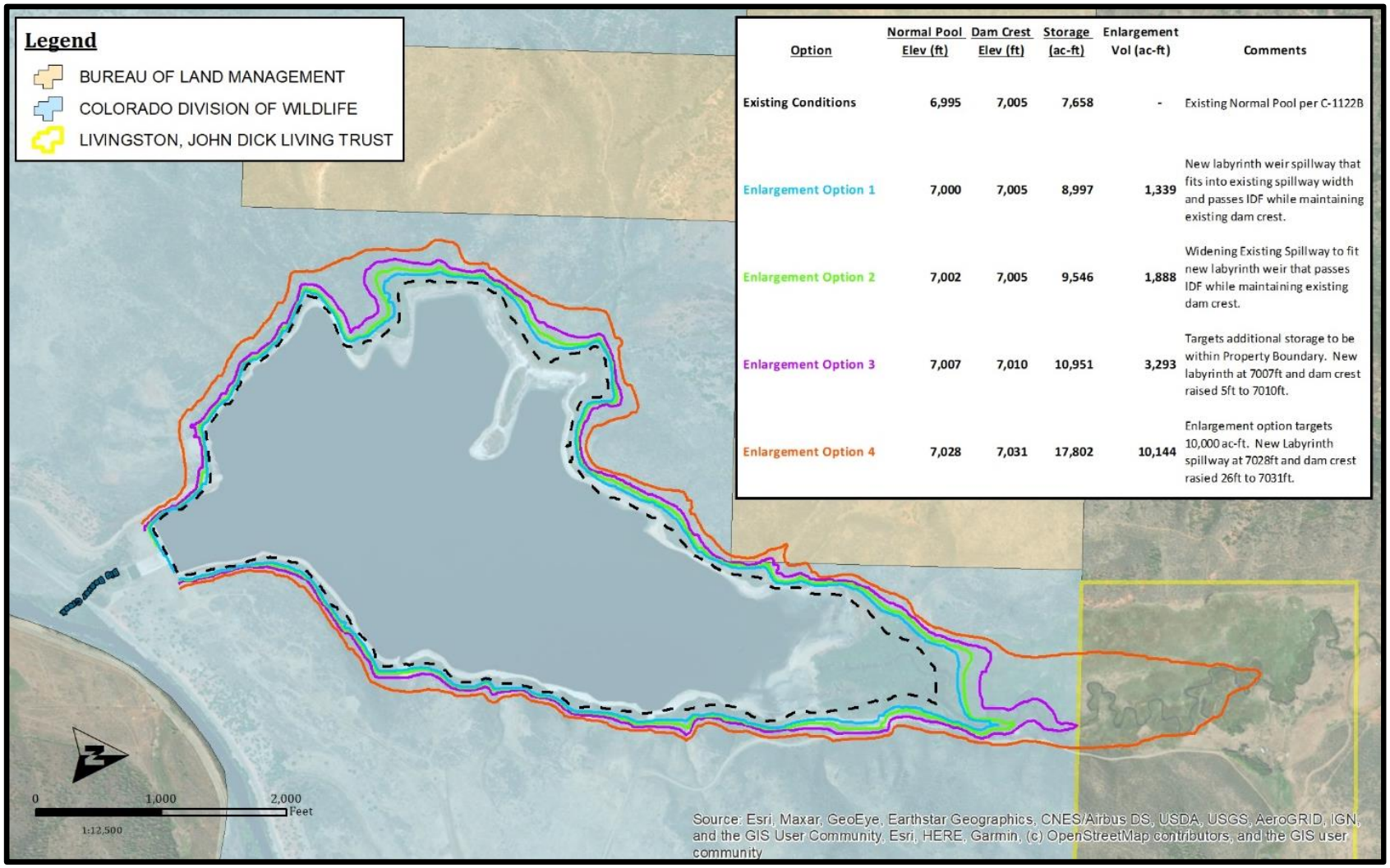
The majority of Loss of life estimated in this analysis originates from developments on the banks of the White River in Meeker impacted by severe hydraulic conditions during the breach flood. It is also worth noting that the estimated breach flows of 300,000cfs at the breach itself which attenuated to 105,000 cfs at the town of Meeker are orders of magnitude larger than peak inflow design flood values determined from the preliminary Hydrology Study. This indicates that further refinement of the inflow design flood or attempting an incremental Hydrologic Hazard analysis approach will not likely justify a lower Hydrologic Hazard rating.

IMPLICATIONS TO LAKE AVERY STORAGE OPTIONS

Our preliminary Hydrology Study and Hydrology Hazard analyses were used to refine the potential enlargement option for Lake Avery identified in a previous study. Enlargement options take advantage of the reduced size of the inflow design flood(Probable Maximum Flood, shown as a **PURPLE** line in the hydrograph figure) to achieve additional storage by modifying the spillway configuration in addition to enlarging the dam embankment. The following 4 options were identified which are presented in order of increasing complexity and cost;

- **Enlargement Option 1** proposes raising the spillway invert by 5ft and modifying the spillway with a labyrinth weir in the existing spillway width. The spillway is sized to pass the inflow design flood while maintaining the existing dam crest without enlargement. This option results in 1,339 ac-ft of additional storage.
- **Enlargement Option 2** proposes raising the spillway invert by 7ft and widening the spillway with a new labyrinth weir all while maintaining the existing dam crest without enlargement. This option results in 1,888 ac-ft of additional storage.
- **Enlargement Option 3** proposes raising the spillway invert 12ft with a labyrinth weir and raising the dam crest by 5ft to achieve additional storage contained within Colorado Parks and Wildlife's property boundary. This option results in 3,293 ac-ft of additional storage.
- **Enlargement Option 4** proposes raising the spillway invert 33ft with a labyrinth weir and raising the dam crest by 26ft to target 10,000 ac-ft of additional storage.

These enlargement options are also shown in the Map on the following page.



Option	Normal Pool Elev (ft)	Dam Crest Elev (ft)	Storage (ac-ft)	Enlargement Vol (ac-ft)	Comments
Existing Conditions	6,995	7,005	7,658	-	Existing Normal Pool per C-1122B
Enlargement Option 1	7,000	7,005	8,997	1,339	New labyrinth weir spillway that fits into existing spillway width and passes IDF while maintaining existing dam crest.
Enlargement Option 2	7,002	7,005	9,546	1,888	Widening Existing Spillway to fit new labyrinth weir that passes IDF while maintaining existing dam crest.
Enlargement Option 3	7,007	7,010	10,951	3,293	Targets additional storage to be within Property Boundary. New labyrinth at 7007ft and dam crest raised 5ft to 7010ft.
Enlargement Option 4	7,028	7,031	17,802	10,144	Enlargement option targets 10,000 ac-ft. New Labyrinth spillway at 7028ft and dam crest rasied 26ft to 7031ft.