New Mexico Water Resources Research Institute

A STATE-WIDE CONSORTIUM FOR WATER RESEARCH, EDUCATION, AND OUTREACH

NM WRRI Student Water Research Grant

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2. Faculty Advisor: J. Phillip King, Ph. D, P.E.

3. Project title: Real Time Monitoring of Flood Control Dams for Emergency Action Management

4. Description of research problem and research objectives.

   Problem: Many Dams across the United States and in the state of New Mexico are deficiently designed and built for their current hazard classification, and are not in satisfactory conditions. Due to these inadequacies, monitoring the dams during potential flood events is critical for alerting downstream residents, thereby limiting potential consequences of major outflow or failure. Outflow information gathered can also quantify runoff for potential downstream uses.

   Objectives: To identify, classify, and analyze the capacity, storage, inflow, and outflow of case study dams and consequently provide data that will allow for the implementation of Remote Transmitting Unit (RTU) instrumentation.

5. Description of methodology employed.

   The group had two different dams, and each dam was analyzed in terms of hydrology, and hydraulics. To complete the hydraulic analysis for each dam, as built plans were found and used to model the outlet structures of each dam. A rating table was then constructed for every stage of capacity behind the dam, and the expected flow rate from the dam was found. Storage levels were compared between as built drawings and developed terrain models. The hydraulic and storage information was then inputted into the HEC-HMS software to perform rainstorm analysis of various rain events.

6. Description of results; include findings, conclusions, and recommendations for further research.

   Our groups consists of two separate groups from the Fall 2014 Hydraulic Structures capstone class in the Civil Engineering Department at New Mexico State University. One group looked Broad Canyon Dam and the other at Apache-Brazito-Mesquite (ABM) 1 Dam. Separate reports have been compiled for completion of the class.

In terms of implementation for starting the process for installation of RTU instrumentation, ABM 1 dam has been approved and Broad Canyon Dam is still in pending approval.

7. Provide a paragraph on who will benefit from your research results. Include any water agency that could use your results.

   Our research will benefit the Elephant Butte Irrigation District (EBID), emergency response teams, as well as any citizens of Dona Ana County who are downstream from either dam. This data can be extrapolated and generalized for all dams not in satisfactory condition in New Mexico needing RTU instrumentation for flood monitoring.

8. Describe how you have spent your grant funds. Also provide your budget balance and how you will use any remaining funds. If you anticipate any funds remaining after June 15, 2015, please contact Carolina Mijares immediately. (575)646-7991; mijares@nmsu.edu

   The following summarizes the expense of the grant funds. The amount budgeted for our group was $5932.43, the following is what has been spent:

Travel to 59th Annual NM WRRI Conference	$1477.58
Remaining Balance	$4454.84

   The plan is to disperse the remaining balance to each group member as labor. Each group member will receive $742.47 each.

9. List presentations you have made related to the project.

   2014 CE 482 Hydraulic Structures – Capstone Design Presentation
   NMWRRI 59th Water Conference

10. List publications or reports, if any, that you are preparing. Remember to acknowledge the NM WRRI funding in any presentation or report that you prepare:

   Two reports were prepared and completed (one for each dam site) for the Hydraulic Structures class required for successful completion of the class. Note, NM WRRI has been acknowledged on both reports.

11. List any other students or faculty members who have assisted you with your project.

   None

12. Provide special recognition awards or notable achievements as a result of the research including any publicity such as newspaper articles, or similar.

   None

Disclaimer

This document was prepared by students for a project in the CE 482: Hydraulic Structures course in the Civil Engineering Department at New Mexico State University in Las Cruces, NM, USA. This document is intended for illustration purposes only. Do not use this document or any material from this document for planning, management, engineering, legal evidence, or any other purpose without the consulting a licensed Civil Engineer.

Acknowledgements

First and foremost, we would like to thank everyone involved in helping us complete this project.

We would like to thank the following people:

Zack Libbin	Elephant Butte Irrigation District
Dennis McCarville	Elephant Butte Irrigation District
Patrick Lopez	Elephant Butte Irrigation District
Tambri Hunteman	Dona Ana County Flood Commission
Merry Jo Fahl	Sierra Soil and Water Conservation District

We would like to give a special thanks to our advisor:

Dr. James P. King, PE	New Mexico State University, Department of Civil and Geological Engineering

Executive Summary

The target of this report is to provide a thorough summary of the research and results that have allowed for the implementation of remote radio dam stage storage monitoring systems for Apache-Brazito-Mesquite One Dam (ABM1) and Broad Canyon Dam. The purpose for completing this project was to provide results that would allow for the implementation of early warning emergency response plans in order to alert downstream residents and thereby limit the potential consequences of major outflow or dam failure. The volume of water contained by the dam would be monitored using a Remote Transmitting Unit (RTU) paired with Piezometric data sensors. The ultimate goal would then be to have this plan generalized and applied to other deficient dams across the state of New Mexico and the United States. As-built drawings and LIDAR data were used to determine elevations, reservoir area and volume, and discharge inlet/outlet specifics such as port areas, spacing, and slope. Discharge rates for each stage of storage were determined by modeling the outlets and building a rating table in Microsoft Excel. This data was summarized in an alarm Elevation table which indicates the elevations for which the monitoring system should transmit warnings. The sensor can also be used to monitor and quantify discharge flow from the outlet allowing for downstream uses, such as irrigation, drinking water or, water right appropriations. For both dams it was determined that two sensors would be placed along the slope of the dam reservoirs. For ABM1 one sensor would be placed at 2 feet above the base of the dam approximately 4026 ft. and a second sensor at 6 feet below top of emergency spillway at an elevation of 4036 ft. Likewise for Broad Canyon, one sensor would be placed at the base approximately 4032 ft. and a second sensor at approximately half the total height of the dam at an elevation of 4057 ft. Also on both dams an RTU will be placed on top of the dam at the highest elevation of the dam to monitor water the water level within the dam.

Table of Contents

Disclaimer 3
Acknowledgements 4
Executive Summary 5
Table of Figures 7
Table of Tables 8
Introduction 9
  Project Approach 9
  Objectives / Deliverables 9
  Scope and Limitations 10
Background 11
  Apache-Brazito Mesquite (ABM) 1 Dam 11
  Broad Canyon Dam 12
  Design Standards 12
  Modeling 13
  Equipment 13
  Data Sources 14
Methodology 14
  Apache Brazito Mesquite 1 14
    Precipitation 14
    Curve Numbers 14
    Sediment Storage 15
    Watershed 15
    Dam Analysis 16
    Dam Specifics 16
    Outflow 17
    HEC-HMS Model 17
  Broad Canyon Dam 18
    Sediment Storage 18
    Dam Specifics and Dam Analysis 19
    Precipitation and HEC-HMS Hydrologic Modeling 20
Results 22
  ABM1 22
    Watershed Specifics 22
    Outflow 23
    Precipitation 23
    HEC-HMS 24
  Broad Canyon 25
    Storage Capacity 25
    Discharge 26
    Rate of Rise 28
    Rates/Alarms 29

Summary....31
ABM1....31
Broad Canyon Dam....32
Future Work....35
References....36
Appendix....38
Appendix 1: Equations....38
Appendix 2: Broad Canyon As-Built Storage Capacity....40
Appendix 3: ABM1 Storage Capacity....40
Appendix 4: ABM1 Inlet Parameters....41
Appendix 5: Primary Inlet Parameters....41
Appendix 6: Secondary and Emergency Spillway Inlet Parameters....42
Appendix 7: Watershed Parameters for Broad Canyon HEC-HMS....42
Appendix 8: Broad Canyon Results....43
Appendix 9: Calculated Storage Capacity....44
Appendix 10: Summation of Discharge Calculations....45
Appendix 11: Total Reservoir Rate of Rise....46
Appendix 12: ABM1 Storage-Discharge....47
Appendix 12: ABM1 HEC-HMS Hydrographs....48
Appendix 13: EBID - Broad Canyon Dam Reservoir Stage Sensor & RTU Proposal....50
Appendix 14: Supplementary Data (See attached USB Flash Drive)....51

Table of Figures

Figure 1. C_t Values for the Las Cruces Area....16
Figure 2: HEC-HMS ABM1 watershed layout....17
Figure 3: AutoCAD Model of Broad Canyon....18
Figure 4: Secondary Inlet....19
Figure 5: Primary Inlet....19
Figure 6: Watershed Elements in HEC-HMS....20
Figure 7. HEC-HMS Watershed Mode Elements....21
Figure 8: Watershed delineation for ABM1....23
Figure 9: NRCS Type II-75 Hyetograph....24
Figure 10: Stage Storage Capacity....25
Figure 11: Broad Canyon Stage Storage Discharge....27
Figure 12: Rate of Rise....28
Figure 13: Proposed piezometer placement on ABM1....32

Table of Tables

Table 1: Lag Times for Sub-basins 22
Table 2: Weighted Curve Numbers for ABM1 22
Table 3: Rate of Rise from Ground to 50% Stage height 29
Table 4: Alarm Elevations for Apache Brazito Mesquite 1 30
Table 5: Alarm Elevations for Broad Canyon Dam 30
Table 6: Alarm Recommendations. 43

Introduction

Project Approach

According to the 2012 American Society of Civil Engineers (ASCE) Infrastructure Report Card, dam infrastructure for both the United States and the State of New Mexico have received an unsatisfactory letter grade of D. This poor score is an indication that dams across the United States including in New Mexico are consider to be deficiently designed and built for their current hazard classification; they are not in satisfactory conditions. Engineers are faced with the task of addressing and resolving these deficiencies while confronting major infrastructure funding gaps. Since the dams are known to be inadequate, monitoring their status during potential flood events is critical for alerting downstream residents, thereby limiting the potential consequences of major outflow or failure. [1] The primary motive for implementing a warning system of any nature is safety. This is the case for both Apache-Brazito-Mesquite 1 (ABM1) and Broad Canyon dams which are not currently equipped with any monitoring instrumentation and/or monitoring plan. The secondary motive is the ability to quantify the outflow of water from these dams in order to use the released water for downstream irrigation.

Objectives / Deliverables

The project objective was selected by Phillip J. King, P.E. Ph.D. on behalf of EBID to identify, classify, and analyze the capacity, storage, inflow, and outflow of ABM1 and Broad Canyon dams. Consequently providing supporting evidence of hydrological behavior to allow for the implementation of pressure sensors (piezometers). A comprehensive analysis was performed on both dams regarding and inflow and outflow during various rain events, stage storage, and dam capacity.

Recommend optimal placement of the piezometric sensors and a Remote Transmitting Unit (RTU) to best record various reservoir stages will also be provided for both dams. The monitoring equipment will allow EBID to continuously monitor the water level within the reservoirs in real time. Using the water elevation and primary spillway outflow calculations, the discharge of water

[1] (New Mexico Section of the American Society for Civil Engineers, 2012)

from the dams during various rain events would also be known. The monitoring equipment will also allow for real time tracking of any questionable and or emergency storage levels issues.

Scope and Limitations

To meet objectives, the group conducted flow calibration analysis, stage stored volume analysis, and designed instrumentation for flood and sediment control of the dams. The duration of this project was approximately 3 months starting on September 20, 2014 and was completed on December 8, 2014. This project was conducted by members listed previously and was in collaboration with Elephant Butte Irrigation District (EBID), Dona Ana Flood Commission, New Mexico State University (NMSU), and the International Boundary and Water Commission. Presentations, reports, and meetings were conducted along the way to monitor and update all parties of all progress.

The scope of work for the project included conducting the hydraulic calibration of the primary spillway at various reservoir heights including the analysis of the outflow from the primary spillway. This was accomplished by reviewing as-built designs and collecting field data of the elevations and spillway's inlet and outlet areas and through the use of LIDAR and geographical data. The primary spillway flow data will be turned over to EBID from which the volume of storm water at various dam stages can be calculated.

As a result of this project, stage storage data will be collected via remote sensors (piezometers) that will be positioned at various elevations of the dams. This data will be transmitted in real time to EBID headquarters using their existing radio telemetry system. This data would be used to determine the volume in storage, rate of rise of the water in the dam, as well as normal and auxiliary spillway flow rates. Furthermore, using this data, EBID can devise an effective early warning alarm system for emergency flood management downstream of the dam. The data type, alarm criteria, and instrumentation used on the dam could then be generalized and used as a guide for the monitoring of other dams in the state of New Mexico and the United States.

The project is limited by the ability of the group to effectively perform a detailed watershed delineation, especially of Broad Canyon Dam, as the watershed area is greater than 75 square miles. The group is also inexperienced in the use of GIS software that is now typically used to perform watershed delineations.

The research group will not be redesigning the dam infrastructure.

Background

Dams are an important structure in water control and management; the two dams considered in this research are storm water retention structures. Though the two dams differ in size they both are used to retain storm water peak flows and release that water in a controlled manner. This storm water is not typically quantified as a resource as the water is discharged in to Rio Grande River. While the remote monitoring will allow for emergency monitoring, the remote monitoring system can also be used to record discharges. These records can be used to replace a portion of yearly releases of appropriated of water from Elephant Butte Reservoir, which can then be accessible for irrigation or storage.

Apache-Brazito Mesquite (ABM) 1 Dam

Apache-Brazito-Mesquite Dam 1 (ABM 1) is a small high hazard dam as classified by the 19-25-12 NMAC-2010 Rules and Regulations Governing Dam Design, Construction and Safety[2]. The dam was originally built at 29.2 feet high, 1,085 feet long excluding the emergency spillway, and with a maximum base width of 212 feet. The dam's primary source of discharge is a 24 inch culvert. At the time of its construction in July 9, 1965, the potential inundation area downstream of the dam was primarily used for agriculture. The intent of the dam when it was constructed was to provide flood protection to agricultural assets. Although primarily still an agricultural area today, an increase in population density is apparent and ever growing. With an ever increasing population in the region and further development of the built environment, the design criteria of many of the dams like ABM 1 has become one of concern.

[2] (Office of The State Engineer, 2010)

Broad Canyon Dam

Broad Canyon Dam is an intermediate earth-filled dam with a significant hazard potential. The dam was primarily designed to retard floodwater and manage sediment storage. Broad Canyon Dam is located approximately 15 miles North of Las Cruces, New Mexico (NM) and runs adjacent to the NM Highway 185. The dam is owned and maintained by the Sierra Soil and Water Conservation District located in Truth or Consequences, NM. Per the design As-built drawings, the final construction cost was $446,493.41; as of 2014, due to inflation, this cost would be approximately $2,864,485.95. The final dam parameters are 71.5 ft. in height, 1,434 ft. in length, and a maximum base width of 398 ft. The dam has two primary outlets one being a box 4-foot box culvert and the other a trapezoidal emergency spillway with a bottom width of 520 feet and a total depth of 5 feet. The dam has a 100-year sediment storage design life, and a total drainage area of 64 square miles.[3] Some current dam features include an emergency spillway that is protected by a concrete apron, and a sediment pool drain that is equipped with a trash rack. Features that the dam lacks include effective flood control and sedimentation storage monitoring systems. [4]

Design Standards

This report was completed and is supported by sources detailed in the following section. The following section not only introduces the sources but also explains their use and relevancy to the subject material presented throughout this report. The As-built drawings were the primary source for all structural design information for the dams. This includes information pertaining to the drainage, sedimentation, and geological profiles of the spillway. This information was used for the analytical determination of important values such as volumes, watershed areas, and flow rates to name a few. The book titled "Water-Resources Engineering" by Chin provided the Soil Conservation Service or SCS method for lag time which was used to complete the watershed analysis. The textbook "Open Channel Hydraulics" was also used to find relevant equations such as the energy equation that governs flow conditions in culverts.

[3] (Fox, 1975)
[4] (New Mexico Office of the State Engineer, 2010)

The New Mexico Administrative Code (NMAC) was used to define the current dam design and safety standards for the State of New Mexico. The definition, purpose, and application of an instrumentation plan was also addressed in the NMAC. A brief, yet detailed history was found in the report titled "The Broad Canyon Dam" by William J. Fox. This report was resourceful when the as-built drawings had not yet been attained as it provided basic structural information that was later confirmed by the as-built drawings. The source titled "Broad Canyon RTU Proposal" by McCarville and Libbin provided a proposal of the sensor instrumentation for both Broad Canyon Dam and ABM1 which influenced our own final design for the instrumentation. The ASCE infrastructure report card was used apply a state and national perspective the overall importance of infrastructure safety research such as the research of this report.

Modeling

The modeling software used for this project includes HEC-HMS, AutoCAD Civil 3D 2014, and ESRI ArcMap 10. HEC-HMS was used to analyze and determine the outflow of the watershed. Since the storage area of the dam defines the dam, a single stage-discharge curve was constructed to support this idea, and is illustrated in the results. In conjunction to this, the weir equation in Appendix 1 was also used to define the flow through the entering the primary spillway and discharge over the emergency spillway. Data from HEC-HMS was also used to develop a lateral inflow dam hydrograph which is illustrated throughout the Appendix, as well as the discharge hydrograph. LIDAR data was imported into AutoCAD was used to create elevation contours of the dam and determine reservoir areas at each elevation.

Equipment

The equipment that is to be placed on the dam is based off of what EBID currently uses for their monitoring systems. EBID currently uses two different types of RTU instrumentation, those being a controlled designed model, CD110 RTU with instrumentation Northwest-98 pressure transmitters and the other being Instrumentation Northwest PT2X Data Logger.

The CD110 RTU is the most commonly used RTU at their sites. The units act as the controller and collects and stores raw data readings from the pressure transmitter based on the 4-20 mili-amps (mA) scale. The pressure sensors used range from 0 to 5 psi to 0 to 50 psi.

Data Sources

LIDAR data was obtained from the Dona Ana Flood Commission for both ABM1 and Broad Canyon dams. The LIDAR data was used to determine the reservoir storage capacity and storage areas. For ABM1 as-built drawings were obtained from the Elephant Butte Irrigation District and for Broad Canyon the drawings were provided by Sierra Soil and Water Conservation District. The drawings provided all dimensional and design information of the dams which was referenced when performing all calculations.

Methodology

Due to the nature of working with two individual dams, the methodology for each dam differs slightly. The reason behind this is mostly due to the availability of information and data obtained for each of the dams. The following sections provide the best summary for the project methodology for both dams.

Apache Brazito Mesquite 1

Precipitation

The estimates for the 100, 500, and 1000 year storms were obtained from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 Precipitation Frequency Data Server (PFDS)[5]. Atlas 14 is an ongoing compilation of precipitation data within the United States which has been gathered from reported weather stations. These precipitation depths are interpolated over the land surface to allow quick and reliable rainfall predictions for storm events.

The state of New Mexico has recently adopted National Resource Conservation Service (NRCS) Type II-75 as the standard rainfall distribution which assumes that 75 percent of the rainfall occurs in the 6^{th} hour during a storm event.

Curve Numbers

Infiltration rates vary widely and are affected by subsurface permeability as well as surface intake rates. Soils are classified into four Hydraulic Soil Groups (HSG's) according to their minimum infiltration rate, which is obtained for bare soil after prolonged wetting. The HSG's

[5] (National Oceanic and Atmospheric Administration (NOAA), 2014)

consist of groups A, B, C, and D with Group A having the lowest runoff potential and the highest infiltration rate (0.30 inches per hour) and Group D having the highest runoff potential and lowest infiltration rate (0-0.05 inches per hour)[6]. The classifications of the soil in the ABM1 watershed will be determined using the NRCS web soil survey and assuming the land is open space in poor condition.

Sediment Storage

According to the data provided on the as-built the storage capacity of the dam was 354.32 Acre-feet when originally built, however using current survey data it was found to have a current total storage capacity of 310.82 Acre-feet due to sediment build up. Running a HEC-HMS model with data from the as-built the water level did not crest the emergency spillway during a 100 year/24 hour storm event. Running the same model with the more recent survey data and sediment buildup the water was found to crest the emergency spillway for this storm event. Sediment build up was first noticed by comparing the as-built drawings to an on-site visit of the dam. When looking at the inlet structure during this visit there were only three openings visible above ground on each side of the inlet while the as-built drawings showed six openings visible above ground level. A comparison AutoCAD drawing on the appendix shows that the storage capacity change is due to 6 feet of sediment built up at the inlet works which tapers out over the area of the reservoir.

Watershed

The watershed area was calculated by analyzing the USGS topographical map using AutoCAD. A delineating boundary was defined by examining ridges and arroyos which were in turn used to determine the flow path of water. The area, length, centroid, and slope of each subbasin were then calculated using measuring tools in AutoCAD. Lag Time was calculated for each subbasin using the Snyder Method. The peaking coefficient (C_p) and the watershed shape factor (C_t) were found using figure 1 which gives these values for the Las Cruces area for a given land slope. Soil curve Numbers for each subbasin was found using the Web Soil Survey[7].

[6] (Conservation Engineering Division, 1986)
[7] (United States Department of Agriculture, 2014)

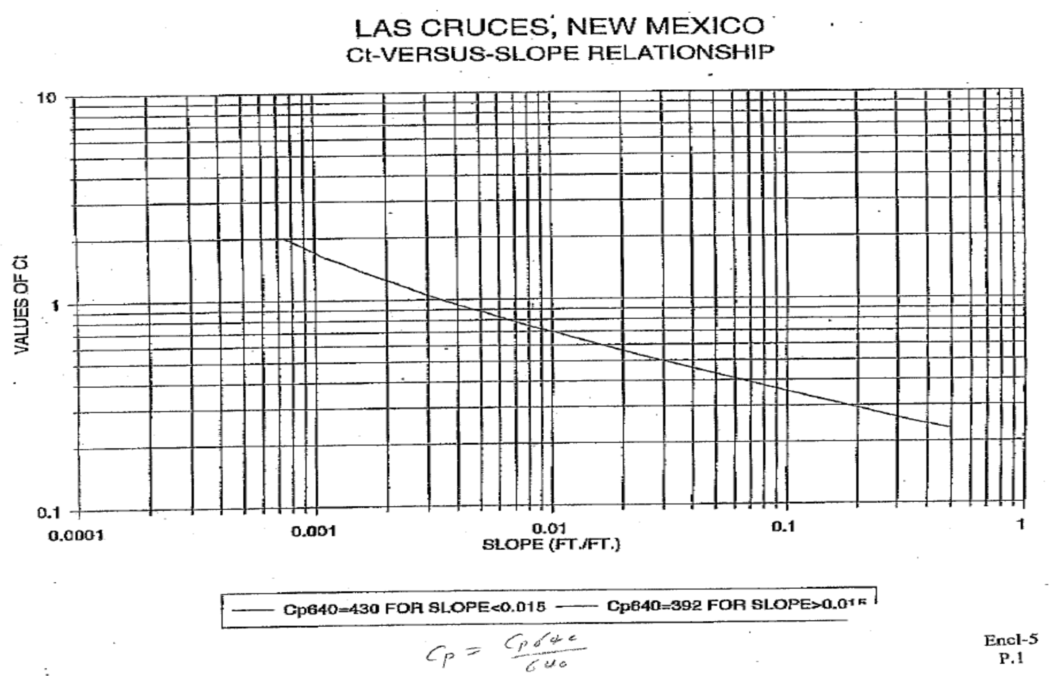

Figure 1. C_t Values for the Las Cruces Area

Dam Analysis

The water storage capacity was calculated analyzing the data from LIDAR on AutoCAD to get the area for each elevation using the trapezoidal method.

Dam Specifics

An Elevation-Storage table was created by calculating the cumulative volume of each elevation from the area for each contour with respect to elevation difference as seen in Appendix 3. Storage-Discharge table was calculated by combining different discharge sources: orifice discharge, outlet controlled discharge and weir discharge. As the elevation in water rises behind the dam the outlet works dictate volume release from the reservoir (outlet control). The controlling outlet works change over time as the basin fills with water as is shown in appendix 11.

As the elevation of water increases behind the dam, volume release occurs controlled by the primary spillway in the form of weir discharge eventually evolving to orifice discharge; eventually the emergency spillway becomes part of the controlling outlet works in combination with the primary outlet. The trapezoidal method was used to obtain reservoir storage volume from both elevation and area which assumes that there is a linear change in landscape between contour lines.

When calculating discharge through a submerged orifice a coefficient of discharge of .6 was used and the coefficient of discharge of .65 was used for the weir. Elevations for fixed structures of the dam such as the emergency spillway, crest of the dam, and the inlet and outlet culvert works had a height of 42 feet added to them from the as-builts to match the LIDAR survey data. This change in elevation was likely caused by the use of different datum points for the two data sets.

Outflow

The primary spillway discharge was calculated for various elevations using the submerged orifice equation (inlet control) eventually transitioning to the culvert flow equation (outlet control). The emergency spillway discharge was calculated using the weir equation.

HEC-HMS Model

An elevation-storage table and a storage-discharge were then created for the dam reservoir and entered into HEC-HMS to obtain a hydrograph for the storm event.

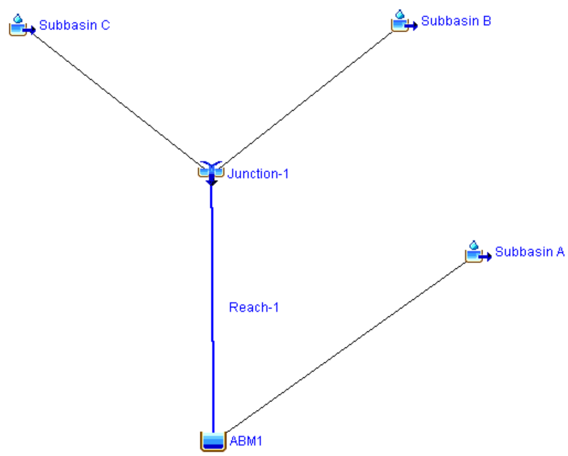

Figure 2: HEC-HMS ABM1 watershed layout.

Broad Canyon Dam

Sediment Storage

The As-Builts were the primary source for information on the dam structure. The theoretical methodology for this project was to obtain staged area and volume of the reservoir, discharge flow, and the ideal storm events. The as-builts provided the original structure elevation, reservoir volume, and drainage structure information. The structure elevation was used to determine the depth of sediment storage behind the basin. First the sedimentation height from the LIDAR data had to be verified in order to prove that the created area contours were correct. To do this the sediment storage was determined from measurements taken of the primary inlet structure. First the height from the lowest construction joint to the top of the built up sedimentation was measured using a standard measuring tape. This value was then added to the distance between the sedimentation build up to the top of the primary inlet structure. Then this value was subtracted from the total height of the inlet structure, note that the total height was already known via the as-builts. This calculated sedimentation height was then compared to the sedimentation height from the LIDAR data and since the values agreed it was said that the

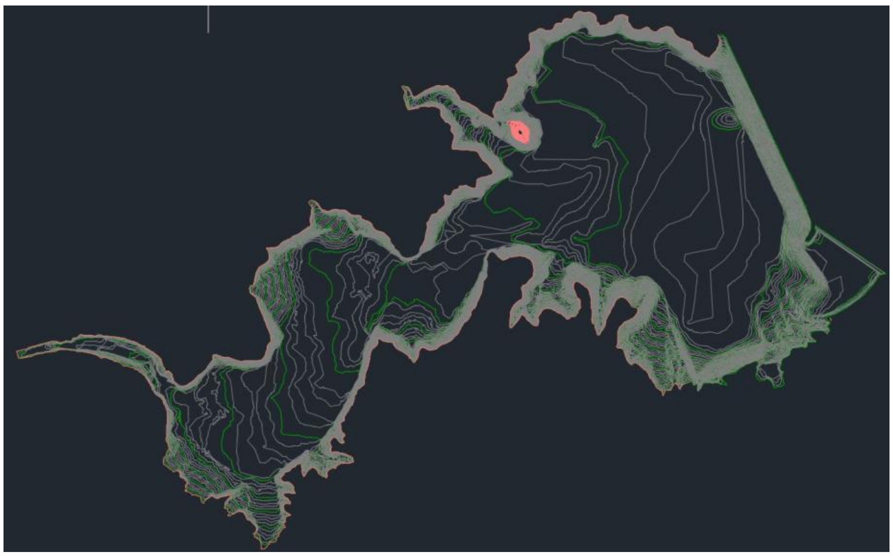

Figure 3: AutoCAD Model of Broad Canyon

elevation contours were correct. The sediment level is at 4031.08 feet, comparatively the lowest contour was at 4032 feet. Next, AutoCAD was used to estimate to area and length of the contour lines as shown in Figure 3. The storage capacity at each elevation was then calculated by using the equation for the volume of a trapezoidal prism, see Appendix 1.


Figure 4: Primary Inlet

Dam Specifics and Dam Analysis

There are two outlets for which water can drain out of the dam reservoir. The primary outlet is a 4-foot box culvert and the secondary outlet is the emergency spillway. The box culvert is effective at all elevations and the emergency spillway becomes effective when water is at an elevation of 4080 ft. which is the elevation at which the dam is considered to have breached. Water enters the primary outlet via two inlets, the primary and secondary inlets. The primary inlet is effective when water is below the elevation of 4052 ft. There are 16 rectangular ports, 2 ft. apart from center to center, on the primary inlet structure for which water can flow through, due to sedimentation buildup only 7 of these ports are currently available. The first port that water can flow through is located at 4032 ft. Water flows through the ports and into the 30 inch (in.) reinforced concrete pipe and then exits out of the primary outlet. This structure is shown in Figure 4 to the left. The secondary inlet structure becomes effective when water is at an elevation of 4052 ft. The secondary inlet structure also has rectangular ports for which water flows through, however there are only two ports on the secondary inlet structure, 1 ft. apart from center to center. There is also a 12 by 4 ft. opening at the top of the secondary inlet structure for which water can flow through, this becomes effective when water reaches and elevation of 4057 ft. Water flows into the ports and openings and then into the same 30 in. reinforced concrete pipe as the primary inlet structure and out of the primary outlet, the 4-ft. box culvert. The secondary inlet is shown in Figure 5. The rectangular inlet ports, rectangular inlet opening, and box culvert outlet were treated as rectangular orifices and the emergency


Figure 5: Secondary Inlet

spillway was treated a trapezoidal weir. The primary and secondary outflows were determined at different elevations, with the varying inlet structures being taken into consideration. These outflow values are shown in Appendix C. To determine the outflow values for the orifices, the area of the orifices first had to be determined. The area of the rectangular orifices were determined using the equation for area of a rectangle as listed in Appendix 1

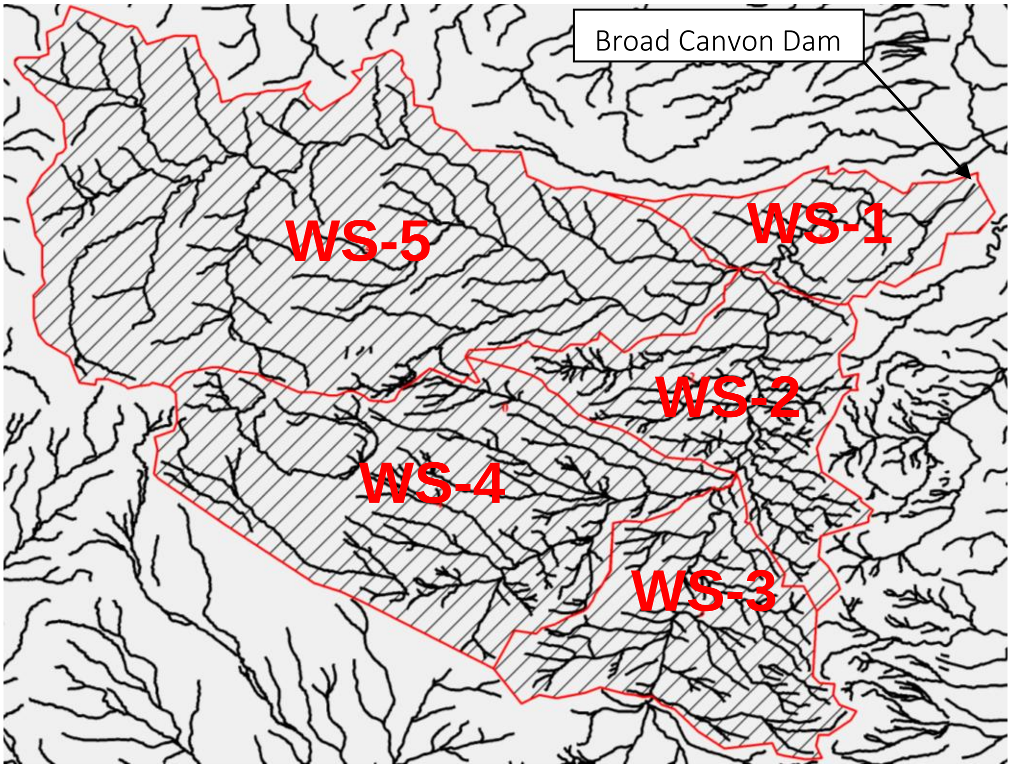

Figure 4: Watershed Elements in HEC-HMS.

Precipitation and HEC-HMS Hydrologic Modeling

Once the area was known the outflow was determined for varying elevations, having taken into consideration the inlet ports and openings. The principle of continuity was applied for the calculations of outflow. Once outflow values were known, HEC-HMS was used to model the watershed precipitation events. To determine watershed run off, all of the following had to be determined; lag time, slope for various reaches, soil types within the watershed, rain storm precipitation, time of concentration, and lag times for each element within the model.

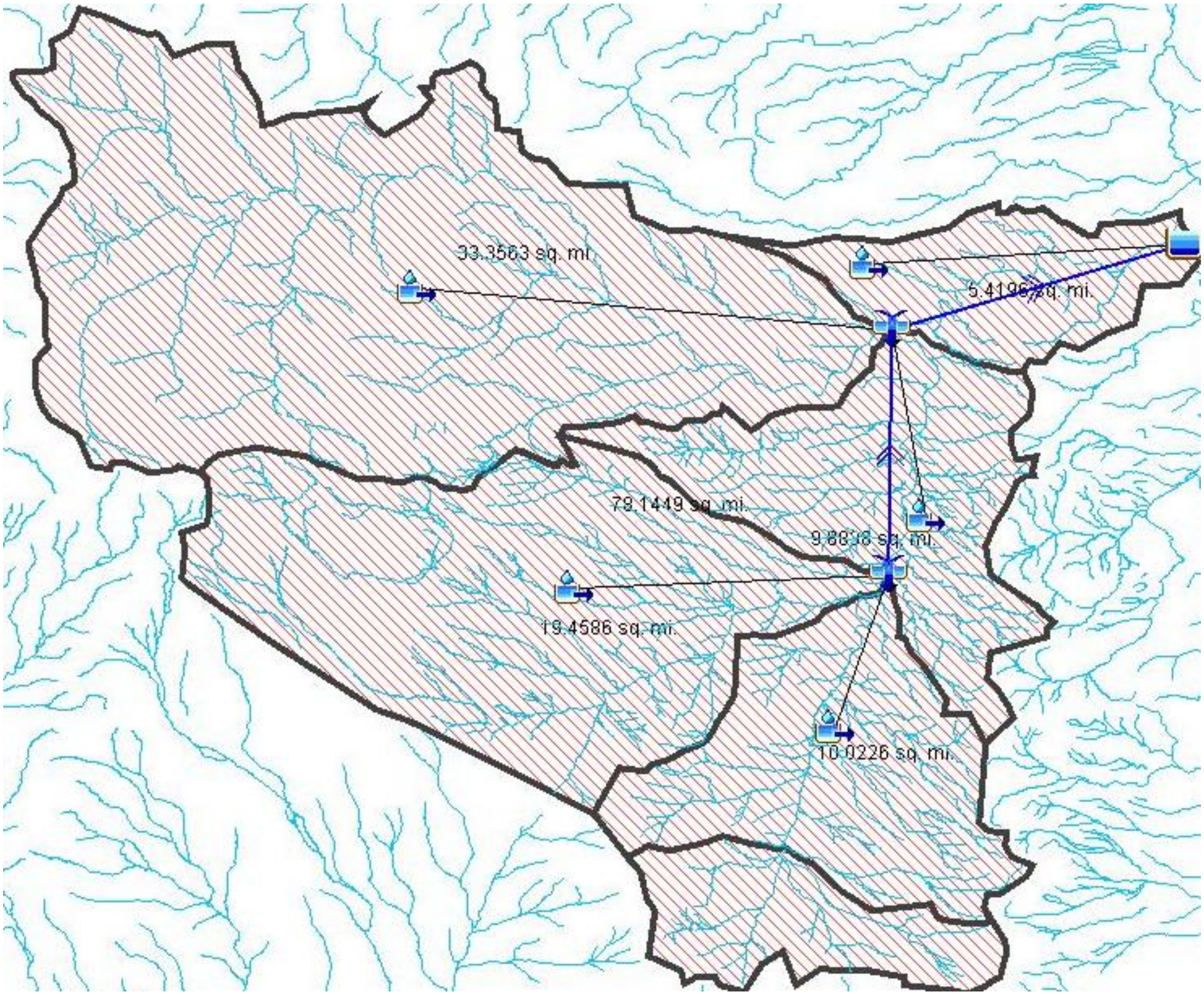

Figure 5. HEC-HMS Watershed Mode Elements

Results

ABM1

Watershed Specifics

The watershed for ABM1 was divided into 3 subbasins based on the auxiliary reaches emerging from the main channel. Lag times for the subbasins were calculated using the intermediate calculations shown on Table 3 and were found to be .5491 hours for subbasin A, .5077 hours for subbasin B, and 1.2166 hours for subbasin C.

Table 1: Lag Times for Sub-basins

	Subbasin A	**Subbasin B**	**Subbasin C**
Area (mi^2)	0.38	0.41	2.67
Flow path (mi)	1.28	1	7.07
Flow path to centroid of subbasin (mi)	0.69	0.68	3.14
Change in height along flow path (ft.)	180	140	1260
Slope	0.0266	0.0265	0.0338
C_t	0.57	0.57	0.48
C_p	0.6125	0.6125	0.6125
t_L (hrs)	0.5491	0.5077	1.2166

The soil in subbasin A, B and the lower half of C is graded as Group A while the upper half of subbasin C is graded as Group D soil. The calculated curve numbers for these subbasins can be seen in Table 4.

Table 2: Weighted Curve Numbers for ABM1

Basin	**% A**	**% D**	**CN**
Subbasin A	100	0	68
Subbasin B	100	0	68
Subbasin C	57.2	42.8	77

The reach between subbasin B and the dam was determined to be a triangular shaped channel with dimensions taken halfway between contour lines as the channel exits subbasin B. It has a length of 3221 feet, a slope of .022, a manning's n of .025 (clean, straight, full stage, no rifts or deep pools), and a 40.7 foot horizontal run for every 1 foot of rise.

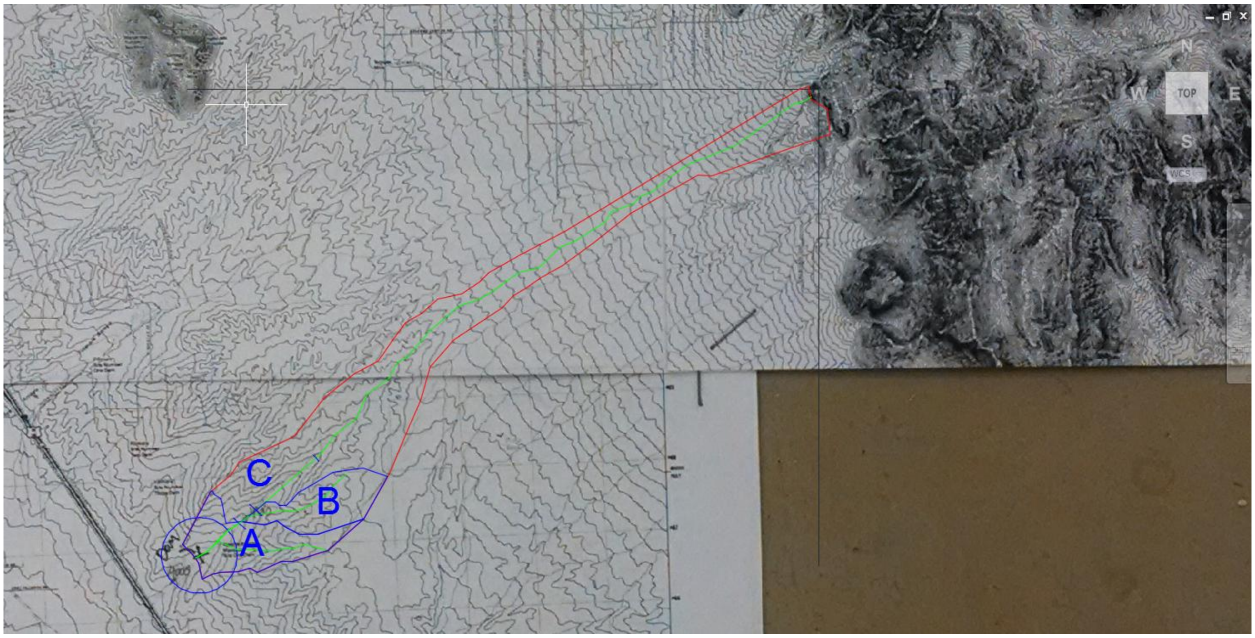

Figure 6: Watershed delineation for ABM1

Outflow

The primary spillway flow is controlled by the orifice opening at the entrance to the culvert at lower water elevations and later switches to outlet control due to culvert head loss at a height of 6 feet above ground elevation with a peak discharge of 34.0 cubic feet per second.

The emergency spillway flow has a peak discharge of 1967 cubic feet per second at the maximum water height.

Precipitation

The precipitation amount over a 24 hour period for 100, 500, and 1000 year storm events was found to be 3.80 inches, 5.02 inches, and 5.63 inches respectively (figure 9) in Appendix 14[8]. The hyetograph for the 100 year 24 hour storm can be seen in figure 7 with tables for the values of this storm as well as the 500 year and 1000 year storm events.

[8] (National Oceanic and Atmospheric Administration (NOAA), 2014)

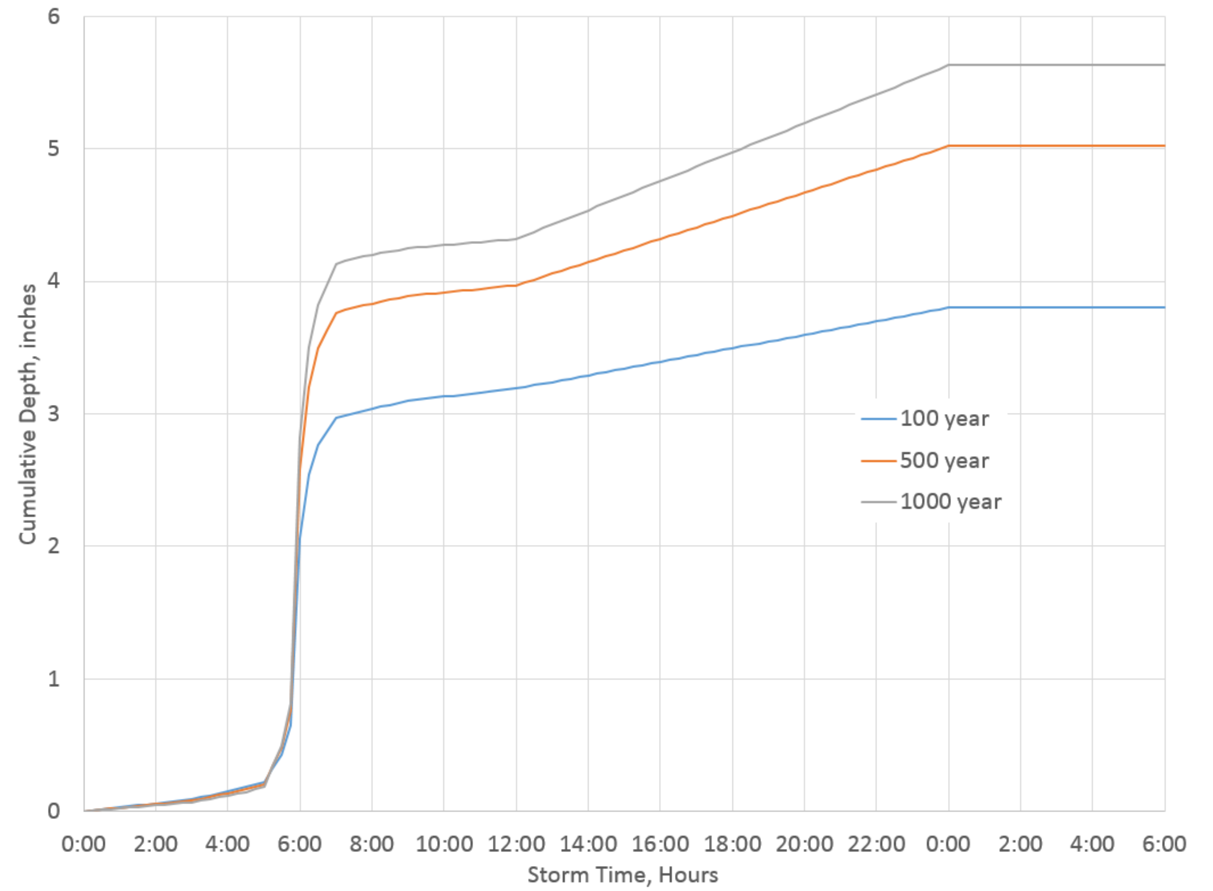

Figure 7: NRCS Type II-75 Hyetograph

HEC-HMS

Upon the input of these characteristics into HEC-HMS ABM1 dam was found to overtop the emergency spillway in all three rainstorm events. The 100 year storm event overtops the emergency spillway 19 hours and 15 minutes into the storm, the 500 year storm event overtops the emergency spillway 14 hours and 10 minutes into the storm, and the 1000 year storm event overtops the emergency spillway 13 hours and 40 minutes into the storm (figures 11, 12, and 13) in Appendix 12.

Broad Canyon

Using the contour elevations from the data given, the total volume and outflow were able to be calculated at one foot intervals of water height in the reservoir. For calculations of the reservoir storage capacity, the elevations and area per contour lines that were found were used. The contour lines area was used in one foot intervals and by multiplying per interval the total storage capacity of the reservoir was found at 5807.2 acre-feet at 4085 foot elevation.

Storage Capacity

The storage capacity of the dam reservoir was retrieved from both the as-built drawings and the LIDAR data calculations. Figure 8 shows a graphical comparison of these results. See Appendix 2 for a table of the as-built and calculated storage capacity data. Figure 8 below, shows that the two are not quite the same and have a difference of nearly 1,200 acre-ft.

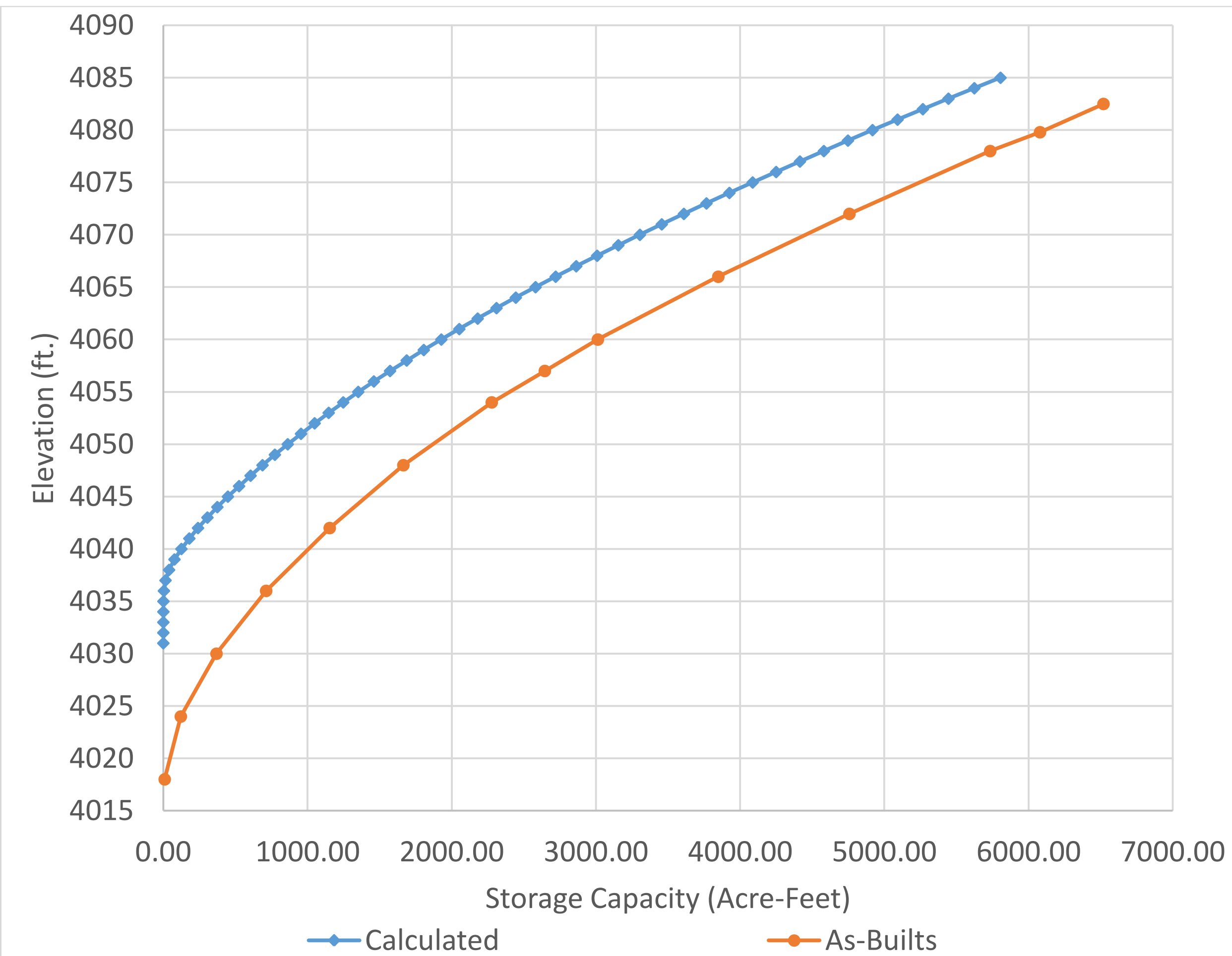

Figure 8: Stage Storage Capacity

Discharge

For calculations of the discharge, there are a total of sixteen ports on the primary inlet structure. However, due to sedimentation buildup, only seven of these ports are currently available. For the open seven ports, the flow through the ports was calculated using the submerged orifice equation at different elevations. The total flow at each elevation was calculated by the summation of the flows of all the ports for the each given elevation. Next the flow was determined for the circular culvert that connected the main inlet to the secondary inlet at different elevations. The pipe discharge at each elevation using Manning' equation for pipe discharge of the circular culvert and treating the box culvert as being inlet controlled. Finally, the emergency spillway was factored into the total flow once the height of the water reached and passed the height of the emergency spillway weir at an elevation of 4080 ft. until the height of the dam at an elevation of 4085 feet. The following table is a compilation of the Broad Canyon Stage Discharge that includes the sum of the discharge from the circular culvert and box culvert, the weir discharge, and total discharge.

Figure 9, shows the discharge from the primary and secondary outlets as well as a combined total discharge. The discharge from the primary outlet is first linear from 0 to 137.2 CFS this is due to the fact that water is flowing only through the primary inlet structure. Once the primary inlet structure becomes submerged the 30 inch concrete pipe then controls the discharge from 137.2 CFS to 187.7 CFS. Once the concrete pipe becomes fully submerged, the secondary inlet controls the discharge from 195.9 CFS to 496.2 CFS.

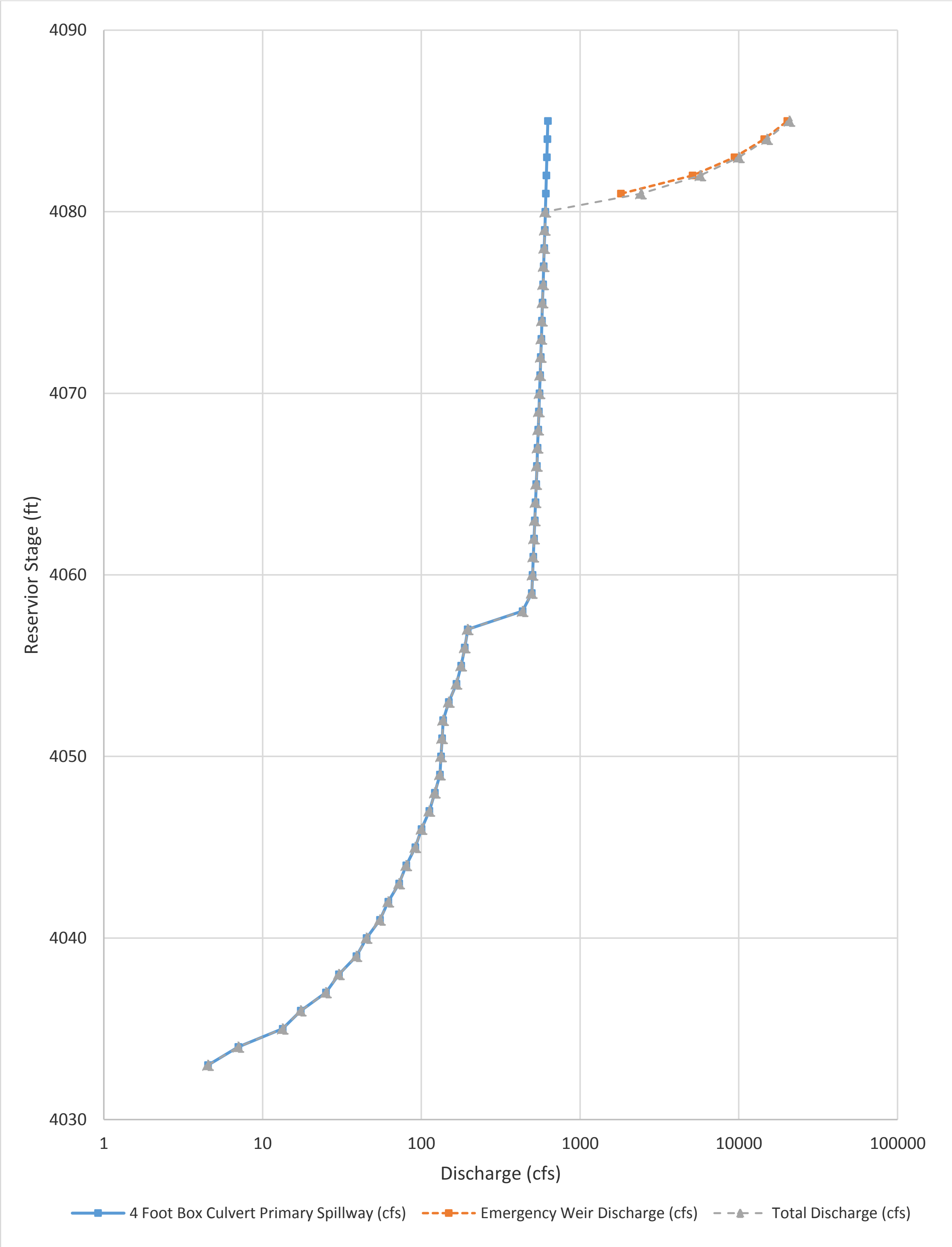

Figure 9: Broad Canyon Stage Storage Discharge

Rate of Rise

The following graph shows the change of stage relevant to time (ft/min) for 10 year, 50 year, 100 year, 500 year, 1000 year storm, and an event producing an 18” rainfall event. The 500 year, 1000 year, and 18” event breached the emergency spillway, as seen by the total elevations being greater than 4080 feet. These events were created in the HEC-HMS modeling software, which provided the time series data to create the following graphs. The software take the expected runoff based on watershed parameters and when paired with stage out flow data of reservoir and the stage area data, can provide the change in height of the modeled reservoir and watershed. The data in Figure 10 show the rate of rise at the greatest slope from the Stage vs. Height graph in Appendix 7.

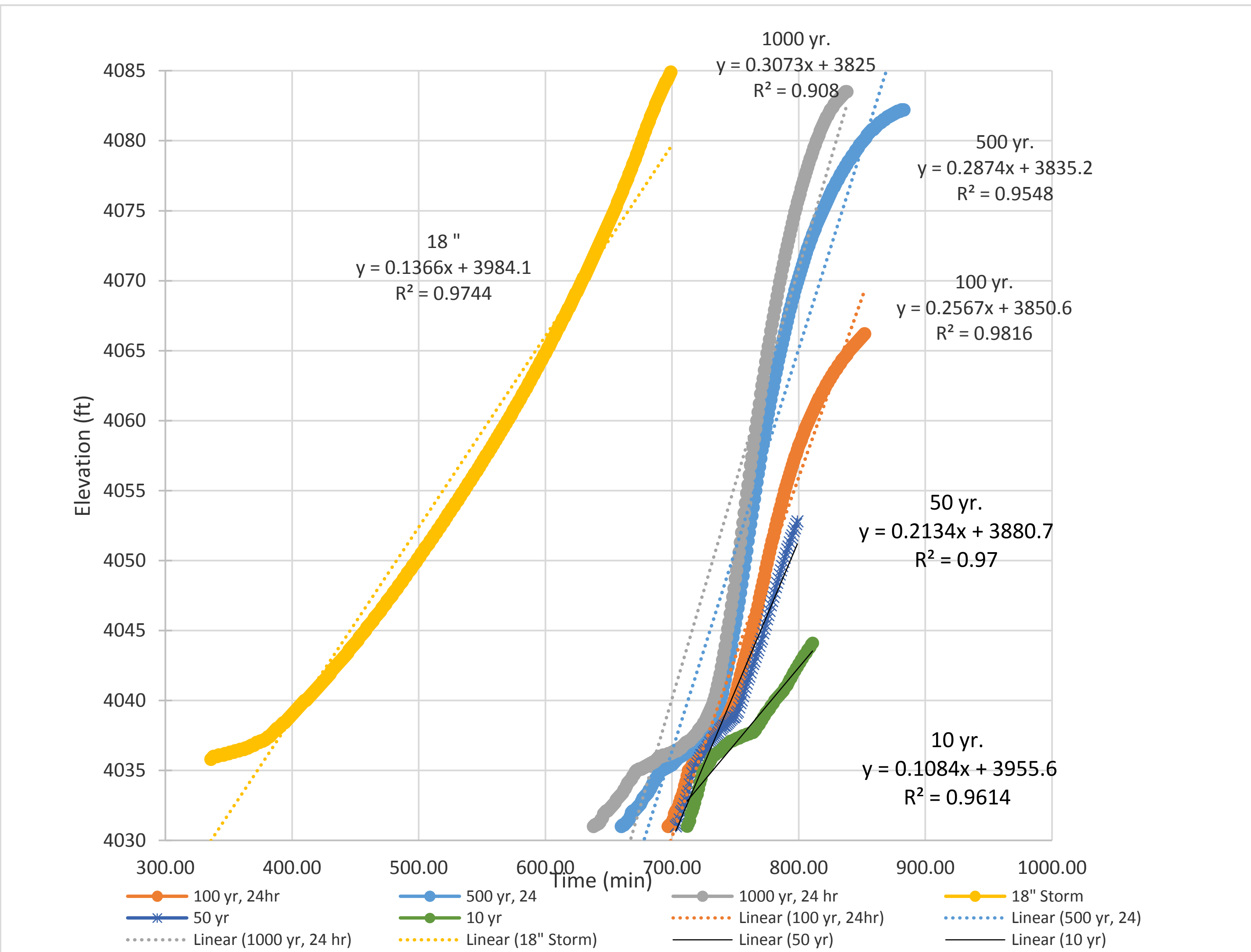

Figure 10: Rate of Rise

Appendix 8: Broad Canyon Results

Table shows the summary results from HEC-HMS for each precipitation event modeled. The most important information from this table is the peak elevation of the storage in the reservoir, and the time of peak inflow. Our data shows the max linear slope found within the plotted time series data from HEC-HMS for the various precipitation events from ground elevation to the peak storage elevation. The rate of rise shows the expected change in elevation foot per minute for each storm.

Table 3: Rate of Rise from Ground to 50% Stage height

Rain Event	Precipitation (in)	Elevation 2 (ft.)	Elevation 1 (ft.)	Time 2 (min)	Time 1 (min)	Rate of Rise (ft/min)	Emergency Spillway Flow	Dam Over top
10yr, 24 hr	2.25	4058.0	4031	1434	712	0.037	N	N
50yr, 24 hr	3.07	4058.0	4031	828	703	0.216	N	N
100yr, 24 hr	3.46	4057.9	4031	799	697	0.264	N	N
500yr, 24 hr	4.45	4057.9	4031	771	660	0.242	Y	N
1000yr, 24 hr	4.93	4058.1	4031	764	638	0.215	Y	N
18" Event	18.00	4058.0	4031	557	280	0.097	Y	Y

The data provides the rate of rise from water at reservoir ground level to 50% storage height or 4057 ft. The rate of rise or change of elevation versus time is slightly increased compared to the previous set of data.

Rates/Alarms

The following two tables explain how much time is available from the time water is first measured behind the dam, and how much time until the emergency spillway begins to flow from that storage elevation. These times allow for the emergency action plans (EAPs) to have certain timelines implemented by a point in a specific storm. ABM1 Breached during the 100, 500, and 1000 year storms, while Broad Canyon came within 0.1 feet of breaching during a 100 year storm. Early warning monitoring is paramount, once the dams rise above half of their capacity the available time begins decreasing rapidly, with only about an hour available for the 500 year storm of both dams to the beginning of flow from the spillway.

Table 4: Alarm Elevations for Apache Brazito Mesquite 1

		Time to Emergency Spillway Overflow (hours)		
Alarm Levels	**Height (ft.)**	**100 yr.**	**500 yr.**	**1000 yr.**
Water in dam	0.1	9:15	5:30	5:35
Water flowing	2	7:55	4:00	4:00
Rate of change in water elevation	.5ft/5 min	7:10	2:05	1:35
50% Capacity	13	5:25	1:05	0:45
Flow imminent (2 feet below spillway)	16	3:45	0:35	0:20
Emergency spillway flow occurring	18	0:00	0:00	0:00

Table 5: Alarm Elevations for Broad Canyon Dam

		Time to Emergency Spillway Overflow from ground (hours)		
Alarm Levels	**Height (ft.)**	**100 yr.**	**500 yr.**	**1000 yr.**
Water in dam, Elev. 4031 ft.	0.1	08:48	04:15	02:59
Water flowing	2	09:39	03:58	02:41
Rate of change in water elevation	.5 ft/ min	08:38	01:58	01:16
50% Capacity	28	07:01	01:01	00:35
Flow imminent (2 feet below spillway)	54	00:00	00:16	00:07
Emergency spillway flow occurring	56	DNE	00:00	00:00

Summary

ABM1

At the conclusion of the comprehensive hydrological study it was determined that the emergency spillway will overtop during any storm including or exceeding an NRCS Type II-75 100 year storm. Apache-Brazito Mesquite Dam 1 does not meet current safety standards, an early warning system is vital for aiding Elephant Butte Irrigation District (EBID) in implementing the existing emergency action plan in a timely manner.

Telemetry results entailing heights of interest and the rate of change of water elevation for 100, 500, and 1000 years storms is shown below. Table 4 also indicates the amount of time remaining before overtopping the emergency spillway at these heights of interest for each storm event. It was found that if the water level rises at a rate greater than or equal to .5ft/5 minutes that emergency spillway flow is probable.

When a .5ft/5min rate of rise has recently been detected and the water level reaches 16 feet above the base elevation of the dam emergency spillway flow would be imminent, as can be seen in table 3 above. In this scenario it would be recommended that EBID implement their emergency action plan processes. However, the final decision of when to implement this plan would be determined by EBID.

It is recommended that telemetry be retrieved every 30 minutes until water is detected by the sensors, at this time the frequency of readings would be increased to 5 minutes increments. This would allow EBID to obtain accurate readings during significant rainfall events without depleting power source reserves when no significant rainfall is occurring. Table 3a and 3b describe the range of responsibility and operation for each piezometer to be implemented. Actual range of operation will be determined by EBID based on equipment preference and availability.

The method used for analyzing this dam can be implemented for other dams that no longer meet the required safety standards. This would provide a cost effective solution to give an early warning to residents downstream of flood protection dams.

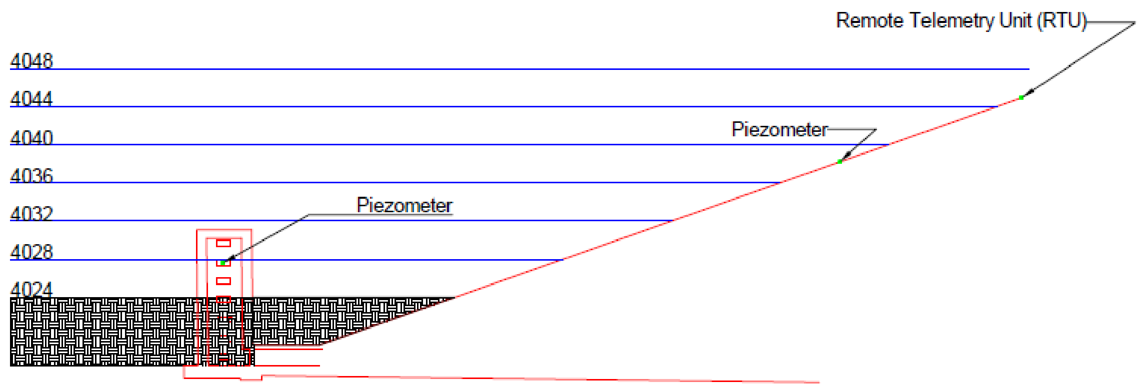

Figure 11: Proposed piezometer placement on ABM1

Broad Canyon Dam

In summary, the research group achieved results that allow for the implementation of RTU instrumentation by identifying, classifying, and analyzing the capacity, storage, inflow, and outflow of Broad Canyon Dam.

As-built drawings and LIDAR data were used to determine elevations, the reservoir area and volume of the dam, discharge inlet and outlet parameters such as port areas and spacing. Using this information stage storage discharge rates were determined using excel and AutoCAD. This data was summarized in an alarm Elevation table which indicates the elevations for which the monitoring system should transmit warnings.

As indicated in the results there was a 1,200 acre-foot difference in storage capacity between the calculated storage capacity and the storage capacity obtained from the use of the as-built drawings. This difference in area could have occurred in the drawing of the contours in AutoCAD as the original 1 foot LiDAR data had many closed and erroneous contours that had to be joined together to allow for closed polylines that could show the enclosed area. The other main difference could have also occurred in the original estimation of the areas as the methods used are unknown and could have associated errors that lead to an overestimation of the total area and storage of the reservoir. Finally, sedimentation also effected this difference with a total amount of sediment in the reservoir is found to be approximately 13’ from the original elevation. The journal article by Fox, explains the total drainage area to be 64.4 square miles while the final delineation of the watershed led to a total area of 78.8 square miles. The 3m USGS data from DAFC was used in this estimation and had an associated 3m resolution. The differences in methods compared to the methods used 40 years ago could have led to underestimation or overestimation of the total area by either party. There were also breaks in the flow lines in couple areas, and when further inspected from satellite imagery these were due to small dams. These dams could have been built after the construction date of Broad Canyon Dam, nonetheless these dams were included in any storm analysis due to providing a conservative design as information on these other dams was not readily available. A more complete hydrologic modeling could have been done by subdividing the larger sub water sheds down to smaller areas and more precise surveys could have been completed on other reaches within those watersheds. This would require more time to complete unique watershed analysis, for soil analysis, slope determination, lag times, and reach geometry. The SCS method of watershed analysis used does not have an area limitation, and the curve number used in the watersheds was taken as a weighted average and provided an accurate estimate of the soils.

For discharge, the results obtained seem reasonable that is that once the secondary inlet becomes fully submerged the discharge will remain linear after the primary spillway becomes outlet controlled. Weir discharge occurs after the primary outlet structure is fully submerged, this is why the discharge for the secondary outlet remains 0 until the water reaches 4080 ft. and thereafter the flow linearly increases. The total discharge line takes the flow of both primary and secondary outlet structures into consideration. The 18” PMP event seems to have some erroneous numbers as the dam was overtopped before the peak of the storm had reached the structure, as seen in the HEC-HMS results in Table 1, where the peak outflow occurred one hour before the peak inflow, 11:38 hours, versus 12:38 hours. This difference is due to unknown flow to be expected as the dam is over topped and breached.

During the rate of rise, our slope to obtain rate of rise between the different year storms had an error of approximately 2% to 10%. This error could have been caused by human error in calculating from the as-built or current calculations as well the data from various software programs or websites.

To safely avoid false alarms while providing for correct times the max rate of rise to be allowed should be at 2.5 feet per hour or 0.042 feet per minute. The 0.042 feet per minute is greater than the 10 year storm which will allow for smaller storms to move through without alarm, while also being less than the rate of rise seen by larger storms, especially the 18" PMP event which had a smaller slope than the other smaller storms. The 50 year will still sound an alarm, though no action should be required as this is the design storm for the dam. The 100 year storm comes extremely close to emergency spillway, and should be expected to flow from the spill way as there is possibilities for underestimation of storm runoff or overestimation of discharge. Other alarms are listed above in the following table that illustrates the modeled time for water to reach certain stages within the dam.

Finally the placement of the sensors was determined. The first sensors will be placed on the lowest part of the dam. A second sensor will be placed on the dam to serve as a backup in case of the failure of the first sensor. This sensor will be placed at 4057 ft. which is at the same elevation as the secondary inlet structure. The 0 psi to 50 psi sensors have a range of 0 to 115 feet of water which is more than the total reservoir height of 54 feet. The construction drawing created by EBID shows a gravel cover placed over a perforated pipe, this will allow the water to infiltrated to the sensors, and will protect the dam face from erosion, meeting the NMAC-12 requirements for modification of the dam face.[9][10] The placement of the sensor and RTU should also be north of the primary inlet, along the dam, so the RTU can have line of site with the antennae tower.[11] If a severe storm were to occur, with the sensors are in place, and with the newly calculated rate of rise for the reservoir, proper authorities will be able to implement an emergency action plan should the storm require and keep the population surrounding the dam alert and safe.

[9] (McCarville & Libbin, 2014)
[10] (New Mexico Office of the State Engineer, 2010)
[11] (King, PhD. P.E., 2014)

Future Work

One main goal of this research was to provide a method that could be generalized and utilized for future use with any dam. Due to time constraints and the amount and type of information present for each of the dams presented, two methods were provided and although similar they are essentially different. Furthermore, it would be ideal to combine the two methods into one. The next step to take would be to submit one complete methodology to EBID and work with them to have it tested and eventually applied. From this point, if effective, the method could then be generalized and released to be used for other dams across the State of New Mexico and the United States.

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Appendix

Appendix 1: Equations[12]

Volume of a Trapezoidal Prism can be calculated using the following:

$$V = V_1 + A_1(\Delta Elev) + \frac{\Delta Area * \Delta Elev}{2}$$

Where:
V = Volume of trapezoidal prism
V_1 = Initial volume
A_1 = Initial area

Area of a rectangular orifice:

$$A = l * w$$

Where:
l = length of the rectangular weir in feet
w = width of the rectangular weir in feet

Submerged inlet orifice equation:

$$Q = C_d A_o \sqrt{2g(HW)}$$

Where:
c_d = coefficient of discharge
A_0 = cross-sectional area of inlet
HW = head on the inlet invert of the culvert

Cipoletti (Trapezoidal) Weir Outflow Equation:

$$Q = C_d \frac{2}{3} b \sqrt{2g} h^{\frac{3}{2}}$$

Where:
Q = Flow (cfs)
c_d = Coefficient of Discharge
b = Base Width (ft.)
g = Gravity (32.2 ft/s^2)
h = Height of Weir (ft.)

Snyder Method for Lag Time[13]:

$$t_L = C_t(L \times L_c)^{0.3}$$

Where:
tL= Lag time in hours
Ct= Watershed Shape factor
L= flow length in Miles
Lc= flow length to centroid in Miles

[12] (Sturm, 2009)
[13] (Chin D. , 2006)

The Peaking Coefficient (Cp) and Ct were found using graph 2 which gives these values for the Las Cruces area for a given land surface slope[14]. Soil Curve Number for each subbasin was found using Web Soil Survey.

Culvert Flow Equation:

$$Q = A\sqrt{\frac{2g(H_w - T_w + S_0 L)}{1 + K_e + f\frac{L}{4R}}}$$

Where:
Q = Flow (cfs)
H_w = Headwater (ft.)
T_w = Tailwater (ft.)
S_0 = Slope
K_e = Exit Headloss Coefficient
g = Gravity (32.2 ft/s^2)
A = Cross Sectional Area (ft.^{2})
f = Friction Factor
R = Hydraulic Radius (ft.)

SCS Lag Time[15]:

$$T_L = \frac{(L)^{0.8}(S+1)^{0.7}}{1900(S_0)^{0.5}}$$

Where,
T_L = Lag Time (min)
L= Longest length of flow
S=$\frac{1000-10*CN}{CN}$ (in)
S_0 = Slope

Emergency spillway discharge for different water elevations.

$$Q = C_{dw}\frac{2}{3}b_w\sqrt{2g}(y-h)^{3/2}$$

Where,
bw = Width of the emergency weir
$C_{dw} =$ Discharge Coefficient for the weir

Trapezoidal method

$$S_c = V_\circ + (A_\circ \times \Delta h) + \frac{(\Delta A \times \Delta h)}{2}$$

Where,
Sc= Storage Capacity
$V_\circ$ = Volume for previous elevation
$A_\circ$ = Area for the previous elevation
Δh = Change in elevation
ΔA = Change in area

[14] (Conservation Engineering Division, 1986)
[15] (Chin D. A., 2013)

Appendix 2: Broad Canyon As-Built Storage Capacity[16]

Data	Elevation	Water Surface Acres	Cumulative Storage	
			Acre Foot	Inch, Run Off
Top of Dam Effective	4082.5	0.76	6520.00	1.908
Crest of Emergency Spillway	4079.8	171.00	6080.00	1.780
(Detention of 50 Year Volume)	4078	108.25	5734.38	1.678
	4072	157.14	4758.24	1.393
	4066	146.00	3848.82	1.127
	4060	132.42	3013.50	0.882
Crest of Principle Spillway	4057	123.50	2645.58	0.774
(Sediment Storage for 100 Years)	4054	112.91	2277.60	0.667
	4048	91.42	1664.64	0.487
	4042	78.86	1153.80	0.338
	4036	65.10	712.92	0.209
	4030	52.59	368.58	0.108
	4024	29.85	121.26	0.035
Original Ground Elevation	4018	7.08	9.50	0.002

Appendix 3: ABM1 Storage Capacity

Elevation	Area of water surface (ft^2)	Area of water surface (acres)	Storage capacity (acre-feet)	
4046	1320780	30.32	310.82	Top of Dam
4044	1204042	27.64	252.85	High Water Line
4042	1082239	24.84	200.37	Emergency Spillway
4040	907984	20.84	154.68	
4038	794413	18.24	115.60	
4036	676714	15.54	81.82	
4034	556886	12.78	53.50	
4032	437894	10.05	30.67	
4030	269043	6.18	14.44	
4028	152641	3.50	4.76	
4026	18208	0.42	0.84	
4024	0	0.00	0.00	

[16] (Sierra Soil and Water Conservation District & Elephant Butte Irrigation District, 1970)

Appendix 4: ABM1 Inlet Parameters

	Inlet Orifice	Emergency Spillway	Culvert	
			Inlet	Outlet
Base Elevation	3984.30	3999.80	3974.00	3969.76
Area/Width	2.76	200.00	3.14	
Length			206.00	
$C_d/C_w/K_e$	0.60	0.65	0.50	
Manning's n			0.03	
Slope			0.02	
f*L/(4R)			15.17	
R			0.50	
P_{wet}			6.28	
Tail Water				2.00

Appendix 5: Primary Inlet Parameters

Parameter	Primary Inlet (Port) Orifice	30" Culvert	
		Inlet Invert	Outlet Invert
Base Elevation	4032	4018	4015.90
Area (ft^2)/Width(ft.)	1.12	4.91	-
Length (ft.)	-	96	-
$C_d/C_w/K_e$	0.6	0.5	-
Manning n	-	0.013	-
Slope	-	0.022	-
f*L/(4R)	-	1.31	-
Hydraulic Radius (ft.)	-	0.63	-
P_{wetted} (ft.)	-	7.85	-
Tailwater (ft.)	-	-	2

Appendix 6: Secondary and Emergency Spillway Inlet Parameters

Parameter	Secondary Inlet (Port) Orifice	Emergency Weir Spillway	4' x 4' Culvert	
			Inlet Invert	Outlet Invert
Base Elevation	4057	4080	4015	4013.50
Area (ft^2)/Width(ft.)	48	520	15.89	-
Area (Port)	2.50		220	-
$C_d/C_w/K_e$	0.6	0.65	0.5	-
Manning n	-	-	0.01	-
Slope	-	-	0.01	-
f*L/(4R)	-	-	1.37	-
Hydraulic Radius (ft.)	-	-	1.13	-
P_{wetted} (ft.)	-	-	14.11	-
Tailwater (ft.)	-	-	-	2

Appendix 7: Watershed Parameters for Broad Canyon HEC-HMS

Element	Area(mi^2)	Length (mi.)	Length (ft.)	Top Elevation	Bottom Elevation	Slope	CN	S (in)	TL(min)
WS 1	5.41	5.41105	28570.344	4740	4020	0.025200957	84	1.93134	25.8355
WS 2	9.88	5.55781	29345.242	4960	4310	0.022150098	86	1.67754	26.4243
WS 3	10.02	6.38660	33721.222	4920	4460	0.013641261	77	2.92715	49.2035
WS 4	19.46	9.31744	49196.094	6480	4460	0.041060171	74	3.51029	42.2691
WS 5	33.36	14.19280	74937.97	6500	4320	0.029090727	85	1.74506	49.6726
Reach BC	--	4.33252	22875.727	4320	4020	0.013114337	-		14.1212
Reach CC	--	3.57347	18867.90	4460	4320	0.00742001	-		16.0925

Appendix 8: Broad Canyon Results

Table 3: HEC-HMS Results

Storm	10yr, 24 hr	50yr, 24 hr	100yr, 24 hr	500yr, 24 hr	1000yr, 24 hr	18" PMP
Peak Inflow (cfs)	7,245.2	19,696.8	26,831.2	46,669.7	56,764.9	337,512.8
Time of Peak Inflow (hr:min)	(13:16)	(13:01)	(12:57)	(12:51)	(12:49)	(12:38)
Peak Outflow (cfs)	468.5	561.7	596.7	8,097.2	15,654.5	20,026.5
Time of Peak Outflow (hr:min)	(25:35)	(25:53)	(25:57)	(15:11)	(14:19)	(11:38)
Total Inflow (AC-FT)	2,044.7	4,344.3	5,572.4	8,917.3	10,625.4	62,617.5
Total Outflow (AC-FT)	1,555.6	3,240.8	4,036.8	7,359.2	9,065.2	424.0
Peak Storage (AC-FT)	1,713.0	3,724.5	4,901.0	5,365.3	5,641.9	62,193.5
Peak Elevation (ft)	4,058.2	4,072.7	4,079.9	4,082.6	4,084.1	4,084.9

Table 4: Rate of Rise from ground to Peak Storage Elevation.

Rain Event	Precipitation (in)	Elevation 2 (ft.)	Elevation 1 (ft.)	Time 2 (min)	Time 1 (min)	Rate of Rise (ft/min)	Emergency Spillway Flow	Dam Over top
10yr, 24 hr.	2.25	4058.2	4031	1539	712	0.033	N	N
50yr, 24 hr.	3.07	4072.7	4031	1556	703	0.049	N	N
100yr, 24 hr.	3.46	4079.9	4031	1560	697	0.057	N	N
500yr, 24 hr.	4.45	4082.6	4031	915	660	0.202	Y	N
1000yr, 24 hr.	4.93	4084.1	4031	860	638	0.239	Y	N
18" Event	18	4084.9	4031	699	280	0.129	Y	Y

Table 6: Alarm Recommendations.

Alarm Levels	Elevation (ft)	Time (min.)					
		10 year	50 year	100 year	500 year	1000 year	18" PMP
Water in dam	4031.1	712	703	697	660	638	280
Rate of change in water elevation ft/min	-	0.037	0.216	0.264	0.242	0.215	0.097
50% of total dam elevation	4058.0	1434	828	799	771	764	557
1 foot below the spillway	4079.0	N/A	N/A	1395	843	810	672
Spillway flow occurring	4080.0	N/A	N/A	N/A	851	814	676
Time from 4058’ to 4079’	-	N/A	N/A	596	72	46	115

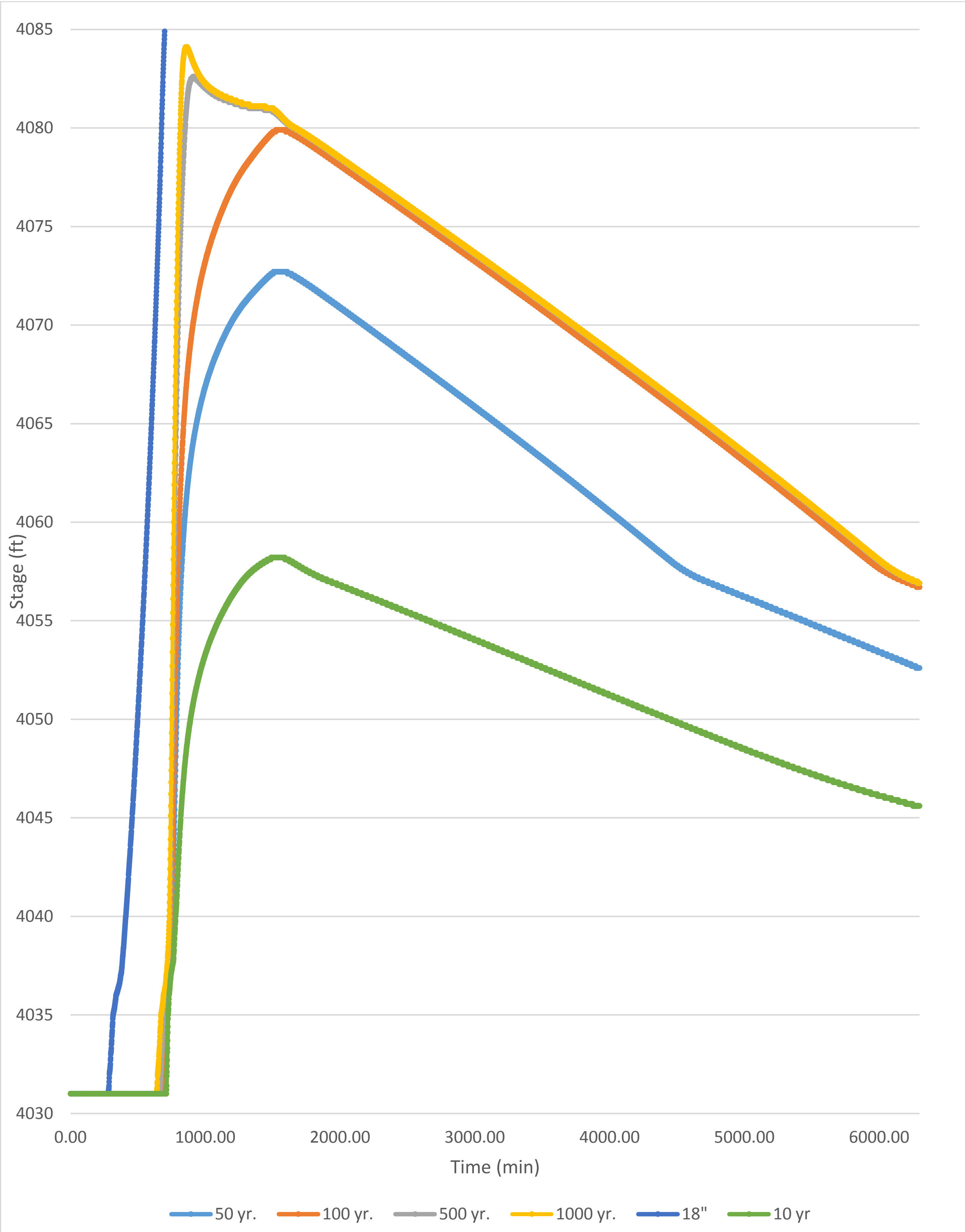
Appendix 9: Calculated Storage Capacity

Elevation (ft.)	Area of water surface (ft^2)	Area (Acre)	Storage Capacity (Acre-ft)
4085	7951286.68	182.536	5806.02
4084	7864527.68	180.544	5624.48
4083	7772218.18	178.425	5444.99
4082	7692458.96	176.594	5267.48
4081	7599253.03	174.455	5091.96
4080	7522584.25	172.694	4918.39
4079	7330550.98	168.286	4747.90
4078	7224838.38	165.859	4580.82
4077	7139704.02	165.859	4414.96
4076	7062381.64	163.905	4250.08
4075	6976346.93	162.130	4087.06
4074	6902893.50	160.155	3925.92
4073	6807986.42	158.468	3766.61
4072	6733281.15	154.575	3610.09
4071	6641337.54	152.464	3456.57
4070	6555850.73	150.501	3305.09
4069	6464992.60	148.416	3155.63
4068	6358103.52	145.962	3008.44
4067	6263069.35	143.780	2863.57
4066	6150693.33	141.200	2721.08
4065	6022912.68	138.267	2581.35
4064	5910939.58	135.696	2444.36
4063	5746116.87	131.912	2310.56
4062	5622429.86	129.073	2180.07
4061	5487924.10	125.985	2052.54
4060	5373114.25	123.350	1927.87
4059	5225548.31	119.962	1806.22
4058	5102727.12	117.142	1687.66
4057	4947653.37	113.582	1572.30
4056	4829000.66	110.858	1460.08
4055	4608677.18	105.800	1351.75
4054	4461353.34	102.418	1247.64
4053	4320761.02	99.191	1146.84
4052	4180840.12	95.979	1049.25
4051	4055350.72	93.098	954.71
4050	3962288.70	90.961	862.68
4049	3805081.19	87.352	773.53
4048	3659417.53	84.009	687.85
4047	3542343.98	81.321	605.18
4046	3435559.54	78.869	525.09
4045	3299236.94	75.740	447.78
4044	3083905.57	70.797	374.51
4043	2910400.89	66.813	305.71
4042	2775700.75	63.721	240.44
4041	2465130.06	56.591	180.29
4040	2336022.74	53.628	125.18
4039	1844015.02	42.333	77.20
4038	1425792.43	32.732	39.66
4037	709315.94	16.284	15.16
4036	262620.08	6.029	4.00
4035	21975.47	0.504	0.73
4034	12993.39	0.298	0.33
4033	6048.54	0.139	0.11
4032	1905.91	0.044	0.02
4031	0.00	0.000	0.00

Appendix 10: Summation of Discharge Calculations

	Stage (ft.)	4 Foot Box Culvert Primary Spillway (cfs)	Emergency Weir Discharge (cfs)	Total Discharge (cfs)
Ground	4031	0.0	0.0	0.0
	4032	0.0	0.0	0.0
9th orifice from bottom at primary inlet	4033	4.5	0.0	4.5
	4034	7.0	0.0	7.0
	4035	13.4	0.0	13.4
	4036	17.4	0.0	17.4
	4037	25.1	0.0	25.1
	4038	30.3	0.0	30.3
	4039	39.0	0.0	39.0
	4040	45.2	0.0	45.2
	4041	54.9	0.0	54.9
	4042	62.0	0.0	62.0
	4043	72.5	0.0	72.5
	4044	80.4	0.0	80.4
	4045	91.7	0.0	91.7
	4046	100.3	0.0	100.3
	4047	112.4	0.0	112.4
	4048	121.7	0.0	121.7
	4049	131.0	0.0	131.0
	4050	133.1	0.0	133.1
	4051	135.1	0.0	135.1
	4052	137.2	0.0	137.2
	4053	149.0	0.0	149.0
	4054	166.5	0.0	166.5
	4055	178.3	0.0	178.3
	4056	187.7	0.0	187.7
	4057	195.9	0.0	195.9
	4058	434.5	0.0	434.5
	4059	496.2	0.0	496.2
	4060	501.9	0.0	501.9
	4061	507.5	0.0	507.5
	4062	513.0	0.0	513.0
	4063	518.5	0.0	518.5
	4064	524.0	0.0	524.0
	4065	529.3	0.0	529.3
	4066	534.7	0.0	534.7
	4067	539.9	0.0	539.9
	4068	545.1	0.0	545.1
	4069	550.3	0.0	550.3
	4070	555.4	0.0	555.4
	4071	560.5	0.0	560.5
	4072	565.5	0.0	565.5
	4073	570.5	0.0	570.5
	4074	575.4	0.0	575.4
	4075	580.3	0.0	580.3
	4076	585.2	0.0	585.2
	4077	590.0	0.0	590.0
	4078	594.8	0.0	594.8
	4079	599.5	0.0	599.5
Emergency Spillway	4080	604.2	0.0	604.2
	4081	608.9	1808.3	2417.2
	4082	613.5	5114.6	5728.2
	4083	618.1	9396.2	10014.3
	4084	622.7	14466.3	15089.0
Top of Dam	4085	627.2	20217.3	20844.5

Appendix 11: Total Reservoir Rate of Rise



Appendix 12: ABM1 Storage-Discharge

Elevation of interest	Stage (ft)	Pipe Discharge (cfs)	Outlet Control (cfs)	Orifice (cfs)	Weir Discharge (cfs)	Total Discharge(cfs)
Ground	4024	0	0	0	0	0
	4025	0	0	0	0	0
Orifice	4026	0	0	0	0	0
	4027	0	0	0	0	0
	4028	0	0	0	0	0
	4029	0	0	0	0	0
	4030	0	0	0	0	0
	4031	0	0	0	0	0
	4032	0	0	0	0	0
	4033	11.12	22.47	11.12	0	0
	4034	17.33	23.3	17.33	0	0
	4035	21.84	24.11	21.84	0	0
	4036	24.89	24.89	25.56	0	0
	4037	25.64	25.64	28.81	0	25.64
	4038	26.37	26.37	31.73	0	26.37
	4039	27.09	27.09	34.4	0	27.09
	4040	27.78	27.78	36.88	0	27.78
	4041	28.46	28.46	39.2	0	28.46
Emergency	4042	29.12	29.12	41.39	0	29.12
	4043	29.77	29.77	43.47	0	29.77
	4044	30.4	30.4	45.46	0	30.4
	4045	31.03	31.03	47.39	0	31.03
Top of dam	4046	31.63	31.63	49.19	0	31.63
	4047	32.23	32.23	50.95	0	32.23
	4048	32.82	32.82	52.66	62.21	95.03
	4049	33.39	33.39	54.31	914.25	947.64
	4050	33.96	33.96	55.91	2269.49	2303.45
	4051	34.52	34.52	57.47	3981.25	4015.77
	4052	35.06	35.06	58.98	5986.44	6021.5

Appendix 12: ABM1 HEC-HMS Hydrographs

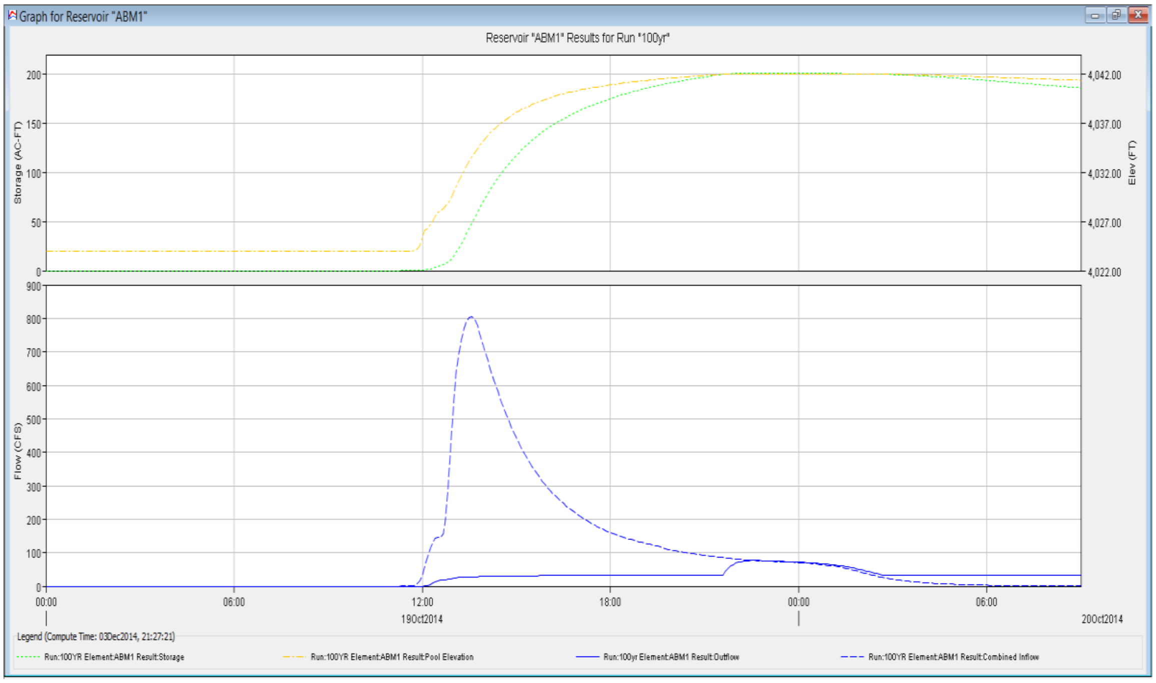


Figure 11. HEC-HMS 100-yr storm event for ABM1.

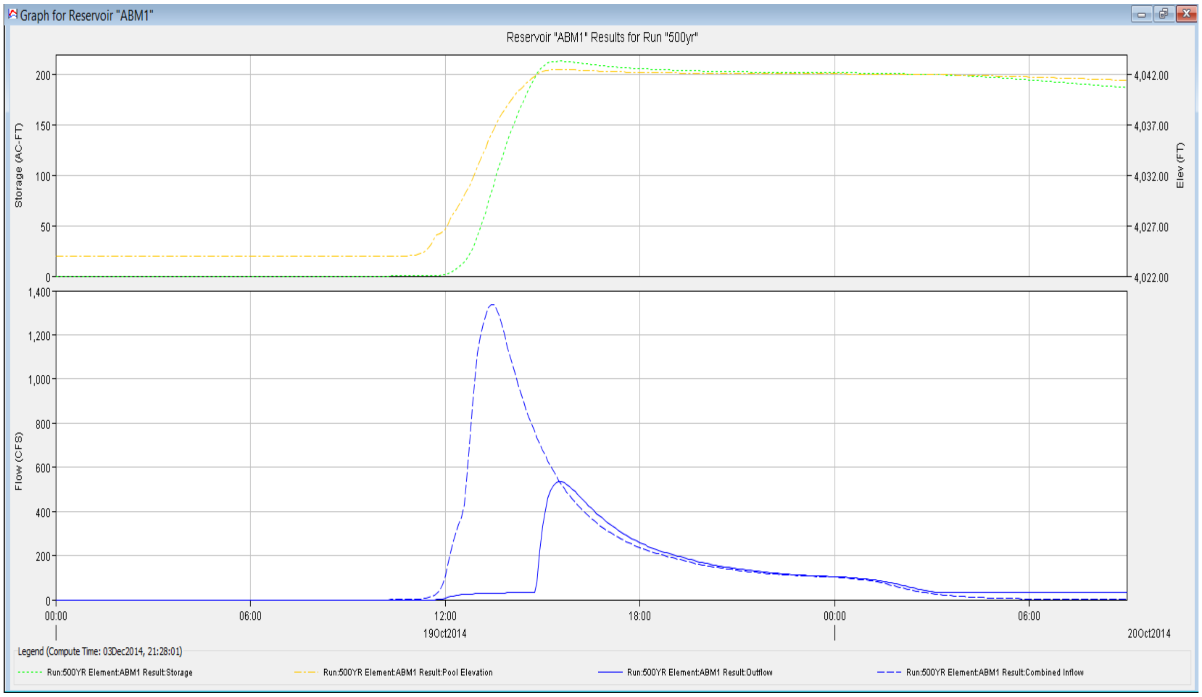


Figure 12. HEC-HMS 500-yr storm event for ABM1.

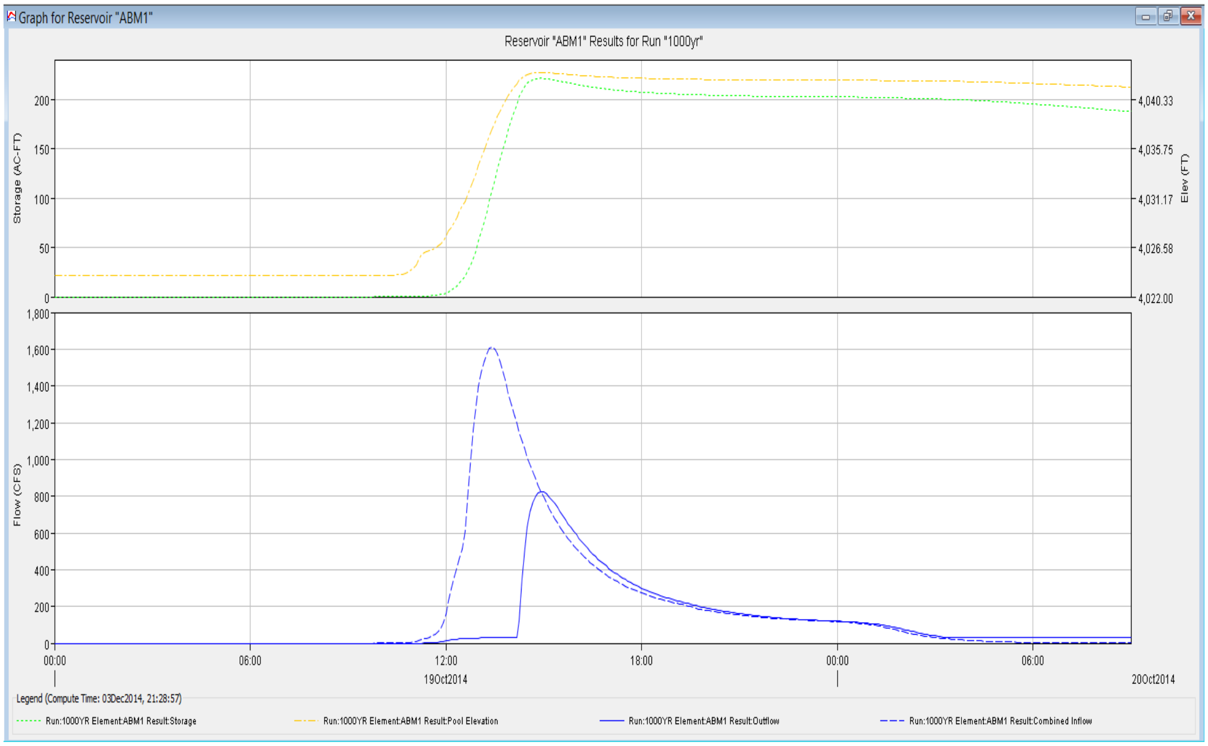


Figure 13. HEC-HMS 1000-yr storm event for ABM1.

Appendix 13: EBID - Broad Canyon Dam Reservoir Stage Sensor & RTU Proposal[17]

See Following Page

[17] (McCarville & Libbin, 2014)

Appendix 14: Supplementary Data (See attached USB Flash Drive)

Appendix A: Broad Canyon Dam As-Built[18]

See file "Appendix A: Broad Canyon As-Built" on the attached USB Flash Drive.

Note: The page number is what is being referenced throughout the report, not the sheet number.

PAGE	SHEET # (PER AS-BUILTS)	DESCRIPTION
1	1	COVER SHEET
2	1A	FILING SHEET/HYRDROGRAPH
3	2	LOCATION MAP
4	BLANK	LAND RIGHTS MAP
5	3	TOPOGRAPHIC MAP
6	3A	TOPOGRAPHIC MAP
7	4	PLAN
8	5	PROFILE OF DAM & CROSS SECTION OF EM. SP.
9	6	PRINCIPLE SPILLWAY PLAN AND PROFILE
10	7	TRASH GUARD DETAILS
11	8	SEDIMENT DRAIN REINFORCEMENT STEEL
12	9	30 INCH PIPE DETAILS
13	10	INLET LAYOUT
14	11	INLET REINFORCING STEEL
15	12	INLET REINFORCING STEEL
16	13	INLET REINFORCING STEEL
17	14	PRINCIPLE SPILLWAY CONDUIT DETAILS
18	15	CONDUIT REINFORCING STEEL
19	15A	CONDUIT REINFORCING STEEL
20	16	OUTLET BASIN
21	17	OUTLET BASIN REINFORCING STEEL
22	18	OUTLET BASIN REINFORCING STEEL
23	19	OUTLET BASIN REINFORCING STEEL
24	20	EMERGENCY SPILLWAY DETAILS LAS UVAS NO. 6
25	21	GEOLOGY - PLAN AND PROFILES
26	22	GEOLOGY - PROFILE AND BORROW GRIDS
27	23	GEOLOGY - PROFILE AND BORROW GRIDS
28	24	GEOLOGY - EMERGENCY SPILLWAY

[18] (Sierra Soil and Water Conservation District & Elephant Butte Irrigation District, 1970)

Appendix B: Hydrologic Soil Group Data[19]

See folder “Appendix B: Hydrologic Soil Group Data” on the attached USB Flash Drive.
Within the folder contain soil survey data for 5 sub-watersheds for the whole water shed region at Broad Canyon Dam.

Content	File Name
Water Shed 1	WSSWatershed1.pdf
Water Shed 2	WSSWatershed2.pdf
Water Shed 3	WSSWatershed3.pdf
Water Shed 4	WSSWatershed4.pdf
Water Shed 5	WSSWatershed5.pdf

Appendix C: Point Precipitation Frequency Estimates[20]

See file “Appendix C: Point Precipitation Frequency Data Server” on the attached USB Flash Drive.

Appendix D: USGS National Hydrography Dataset[21]

See file “Appendix D: NHD325211” on the attached USB Flash Drive.

Appendix E: Dona Ana Flood Commission 1 ft. LiDAR[22]

See file “Appendix E: DAC 1-ft Data” on the attached USB Flash Drive.

Appendix F: ABM1 Dam As-builts.

See file “ABM1 Dam As-Builts” on the attached USB Flash Drive.

19 (United States Department of Agriculture, 2014)

20 (NOAA Atlas 14, 2014)

21 (United States Geological Survey, 2014)

22 (Dona Ana Flood Comission, 2014)