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# WEST CATARACT CREEK DAM FINAL DESIGN REPORT

Prepared for:

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# ACKNOWLEDGEMENTS

## Acknowledgements

Throughout the course of this project, our team would not have been able to progress as well as we did without the help of several professionals in this field. Firstly we would like to thank the Arizona Department of Water Resources (ADWR), for giving us vital documents regarding the dam's construction, various inspections, blueprints, and improvements that have occurred from 1946 to 2007. We would also like to thank Craig Brown, dam safety inspector for ADWR, for his helpfulness. When our team needed the most recent information, Craig Brown was able to ensure that we gained access to all of the more recent documents from 2007 to 2013, including ADWR's 2013 Dam Break Analysis.

It is also important to acknowledge the help from our technical advisor and capstone professors, Dr. Charles Schlinger, whose technical guidance pointed our team in the right direction and aided our analysis. Our team would also like to thank our other capstone professors, Dr. Wilbert Odem, Mark Lamer, and Dr. Bridget Bero, who gave us constructive criticism and valuable feedback that helped our team strive to become better.

# PROJECT DESCRIPTION

## Project Description

West Cataract Creek Dam is an earthen dam located about 2 miles west of Williams, AZ along Interstate 40. The exact location of the dam is portrayed below in Figure 1 (Google Maps).

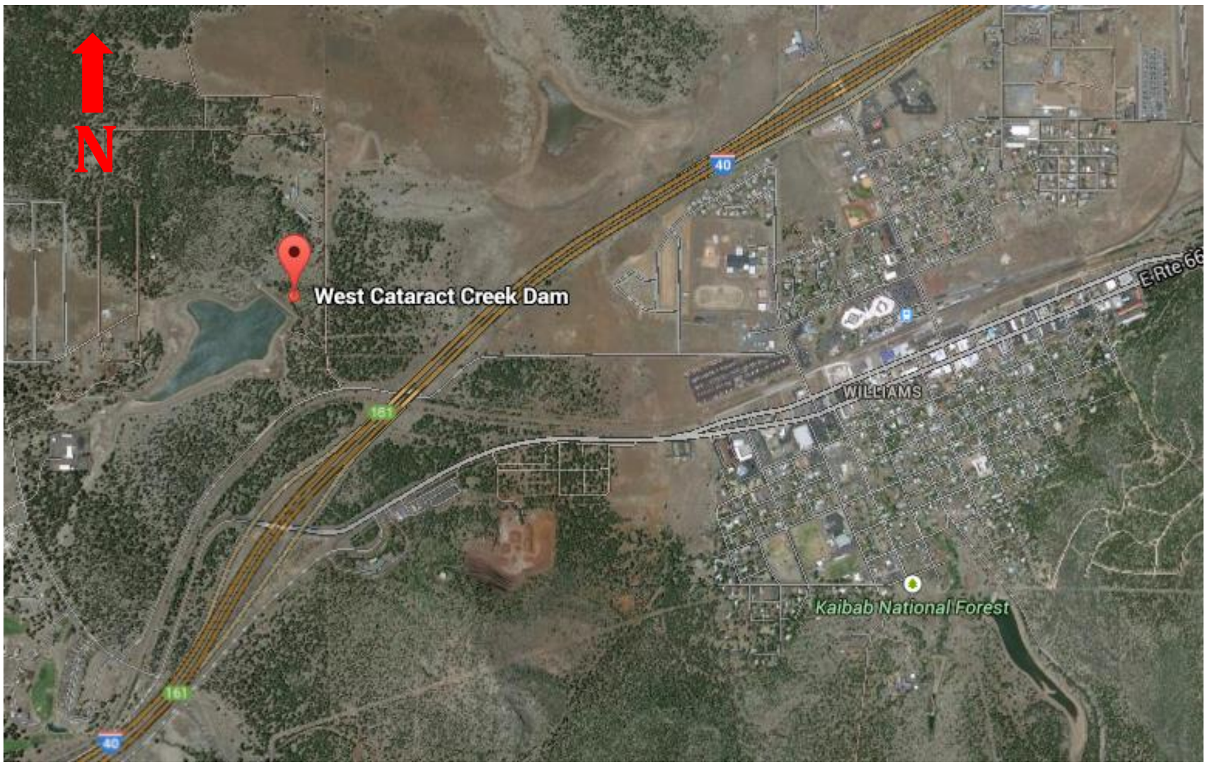


**Figure 1- Project Location (Google Maps)**

Cataract Creek is considered a “significant” safety concern by ADWR. The most recent inspection from 2013 confirms that this classification is appropriate for now but requests that a dam break analysis be performed in order to confirm it. According to ADWR, a “significant” safety concern means that a loss of life is unlikely and the economic losses are low to high in the event of a dam failure (Resources).

The goal of this project is to analyze the functionality and safety of the dam in order to determine the likelihood of a potential failure, and give recommendations based on the findings. The client would also like to know what impacts a dam break would have on the City of Williams.

# PROJECT DESCRIPTION

After a complete background check on the dam's history, four failure modes were chosen for the analysis based on the likelihood of their occurrence. These failure modes consist of: slope stability, overtopping, spillway failure, and internal erosion. All topography, geometry, geotechnical, and hydrological data necessary to complete these analyses will be collected by DAMsel in Distress Engineering. The four failure modes are also classified as either a sunny-day failure, or a rainy day failure.

## CURRENT CONDITION

The dam's geometry has not changed since improvements made in 1968.

Currently there are two issues with the dam facility. The first issue involves the outlet pipes below the dam. The valves at the end of the pipes are out of service and there is a lack of an upstream valve which causes water pressurization within the pipes. Second, there is no Emergency Action Plan (EAP) for the community downstream in the event of a dam breach.

## CONSTRAINTS AND LIMITATIONS

A couple constraints and limitations have occurred throughout this project. One of the main limitations occurred during surveying. The closest benchmark to the project site was across Interstate 40 and DAMsel in Distress Engineering did not have the appropriate equipment to tie into it. Without this benchmark, the true elevations obtained through surveying are unknown. An alternative method was also unsuccessful; the closest base station was out of range for a Network GPS Survey. However even with these constraints, elevations and distances relative to one another were still able to be accurately recorded.

Another constraint had to do with obtaining documents from the appropriate parties. Arizona Department of Water Resources only had digital copies of the records through 2007. Documents from 2007 to the present day were obtained from Craig Brown at a much later during this project's lifetime.

# Background

The dam was constructed from May 4, 1947 to November 30, 1947 in order to impound Cataract Lake for water storage and recreational purposes. The analysis that was used to design the dam included factoring in values for drainage area, discharge, runoff, design storms, and soils information. In 1967, a design analysis was done to determine the effectiveness of the dam. From March 1, 1968 to May 1, 1968, a two foot tall concrete weir was added to the spillway along with a few feet on the crest of the dam. Both designs (the original and the revision) evaluated the dam to the 100 year storm event.

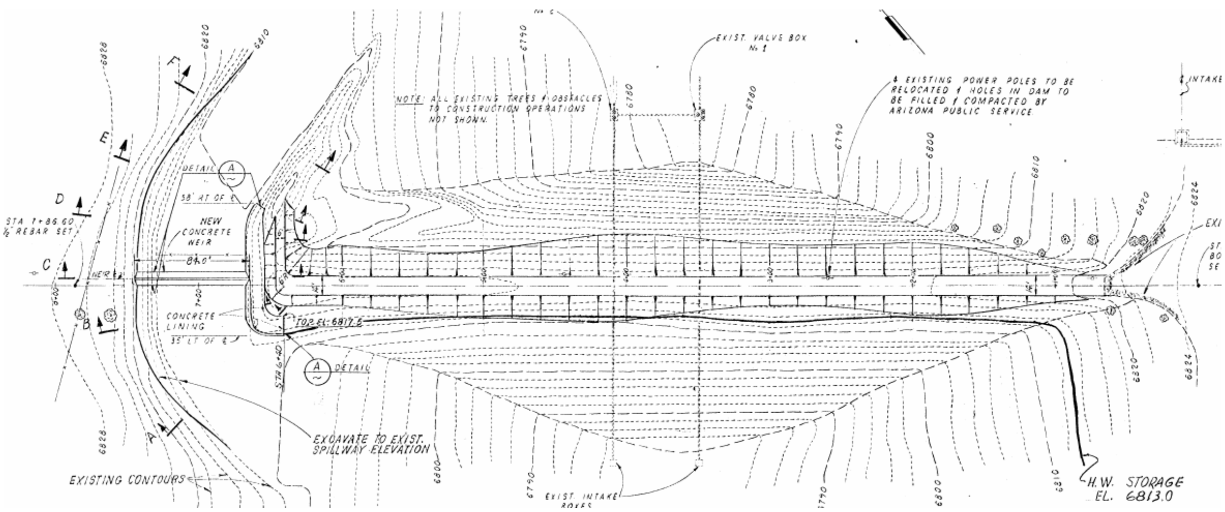


**Figure 2- 1968 As-Built Improvements (ADWR)**

Various inspections were performed from 1978 to 2011. In the more recent inspections, the dam was flagged for having pressurized pipes running through it and for not having an Emergency Action Plan (EAP) in place.

In 1982, Gonzalez Estate was constructed, and was being used to attenuate any overtopping flow from the Cataract Creek Dam.

In 2005, the spillway was widened, to a total bottom width of 80 feet. Freeboard was noted during an inspection to be 8.3 feet.

# BACKGROUND

In 2013, ADWR performed a dam break analysis detailing the effects on downstream conditions in case of a dam failure.

A complete summarized chronology of the dam's history can be found in Appendix A.

# Analysis

## SURVEYING

A survey of the dam was performed in order to get the general dimensions of the dam along with the elevations of the spillway and the crest of the dam. A comprehensive survey of the entire lake area was not required due to the availability of a topographic map, with storage capacity at each elevation that was generated when the dam was created in 1947. It was assumed that the general topography and overall capacity of the dam had not changed since the dam was created in 1947 or that if it had changed that the amount was insignificant. The difference in the elevation of the dam crest and the spillway was used as the freeboard of the dam. A sketch of the dam and spillway was created using the list of survey points in AutoCAD Civil3D and can be seen in Appendix B.

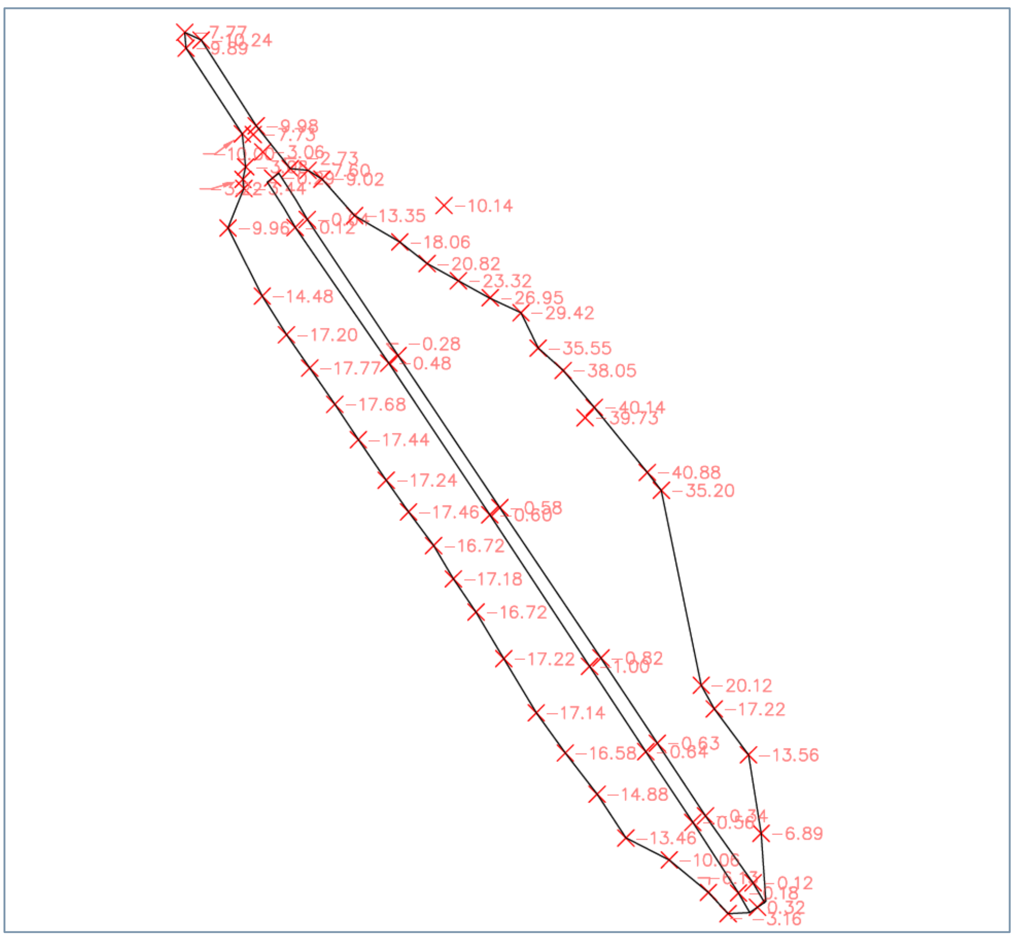


**Figure 3- Surveyed Points (AutoCAD Civil 3D)**

# ANALYSIS

## HYDROLOGY

Hydrology data for the area surrounding West Cataract Lake needed to be found and analyzed in order to approximate the impact any given flood would have on Williams, Arizona.  The first step taken to find hydrologic data was to access the Federal Emergency Management Agency's website. From the FEMA website, four floodplain maps for the City of Williams were collected and imported together into AutoCAD Civil 3D in a way that showed the entirety of the floodplains affecting Williams. In this way, it would be a simpler task to imagine the results of a dam break, since the existing floodplains would be heavily compounded by the water coming from the dam. These FEMA maps can be viewed in Appendix C (FEMA).

In addition to analyzing the floodplain maps from FEMA, National Streamflow Statistics software was used for the dam's regional area. The NSS software was used to achieve preliminary rough estimate hydrographs that would give a range of inflows into the reservoir. The values generated by the NSS software can also be viewed as part of Appendix C (NSS). Since these inflow hydrographs were very rough estimates and required minimal input, further analysis had to be completed using real storm data as well as actual conditions of the project area. This process will be explained further in the section titled "Overtopping".

## SLOPE STABILITY

A slope stability analysis evaluates a slope for failure using specific soil properties such as cohesion, friction angle, and soil classification, and is considered a sunny day failure. In a slope stability failure, a portion of the slope shears off at the weakest plane or slip surface. This type of failure would significantly reduce the capacity of the dam by eliminating portions of the cross sectional area. Typically, steeper slopes with weaker soil are the most susceptible to this type of failure. It is important to consider slope stability as a major failure mode for West Cataract Creek Dam since it has a relatively steep slope and because the properties of the soil that makes up the dam are unknown.

One of the most popular programs to evaluate slope stability is Slide by Rocscience. The methods within Slide used by the team for the slope stability analysis were the simplified Bishop and Janbu methods. Slide requires the user to input a two dimensional cross section of the slope in question along with soil properties, and any reservoirs or water tables relevant. The cross section for West Cataract Creek Dam was created by scaling off a contour map of the dam from the as-built drawings. This cross section was put into the software along with the reservoir at full capacity as shown in Figure 4, below.

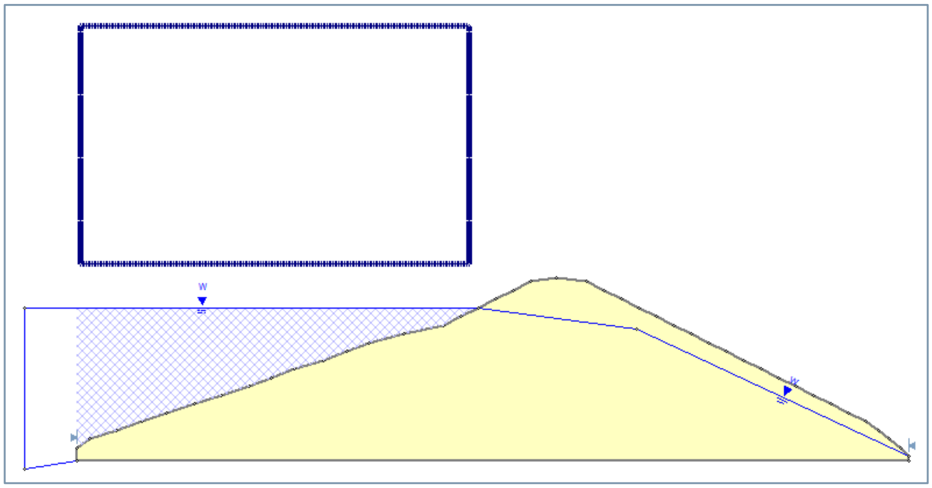

**Figure 4 - Slide Input (RocScience)**

Soil properties were assumed since no soils report for the composition of the dam was provided and soil samples were not taken as a part of the project. Initially, the general properties of clayey gravel (GC) and clayey sands (SC) were assumed based on a report of the soil found in the surrounding area of the dam. These properties yielded high factors of safety so more conservative properties were assumed. The final model in the Slide software used unconsolidated, undrained soil with a friction angle of zero. Results from the Slide software display the slip surface factors of safety in a color-coded gradient, ranging from red to blue for low to high factors of safety, respectively. Outputs from the software for the front and back slopes can be found in Figures 5 and 6, below.

# ANALYSIS

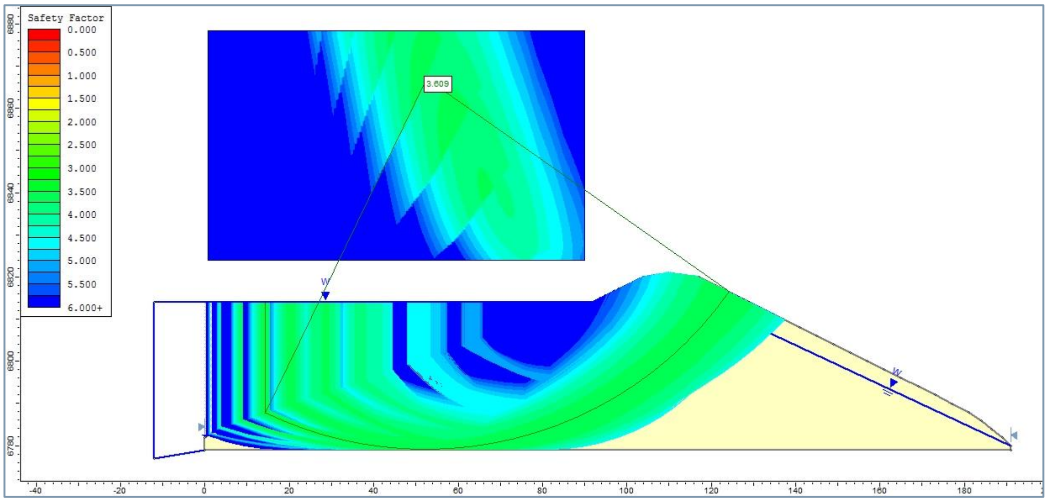


Figure 5 - Slide Ouput - Front Slope (RocScience)

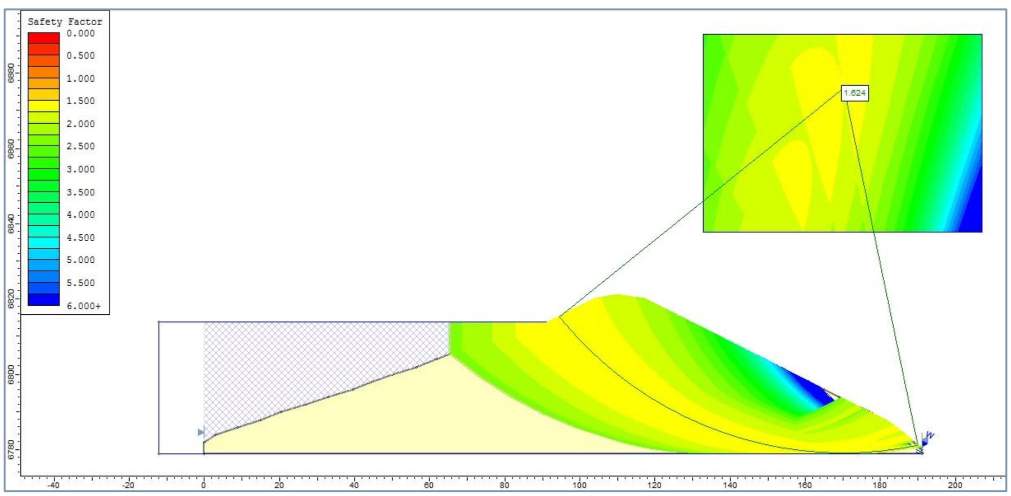


Figure 6 - Slide Output - Back Slope (RocScience)

The factors of safety of the worst case slip surfaces throughout the dam from the front and from the back were 3.6 and 1.6, respectively. Both of these values are above the required factor of safety of 1.5, resulting in a stable dam. This method of analysis can only show an estimate of the slope stability since the soil properties were assumed, however, conservative values were used to increase the confidence in the results.

# ANALYSIS

## OVERTOPPING

Overtopping is a rainy day failure when the spillway capacity of a reservoir is met and exceeded causing water from the reservoir to start flowing over the crest of the dam. Bentley PondPack was the main tool used to analyze the reservoir and spillway capacities for multiple recurrence interval storms under different conditions of the watershed. This software was chosen for the analysis because an accurate model reflecting the project area could be created, as well as the software was able to run both Pre-Burn and Post-Burn scenarios next to each other. The first step to complete this analysis was to access NOAA Atlas 14 in order to get storm data for Williams, Arizona. NOAA Atlas 14 provided the team with rainfall intensities for many different recurrence interval storms for multiple storm durations. The storm data table used for this analysis can be found in Appendix D of this document. Once the storm data was obtained, the next step the team needed to take was to delineate the watershed that feeds West Cataract Lake and compare it to the value that was found in the obtained ADWR documents. In order to do this, a topographic map of the project area was obtained from the ArcGIS website and imported it into AutoCAD Civil 3D. Once the map was in Civil 3D, the contour lines were followed in order to find the total area of land that feeds into West Cataract Lake. The total area of the watershed found by DAMsel in Distress Engineering was 6.02 square miles which was very close to the area of the watershed found by ADWR. A map of the delineated watershed can be found in Appendix D of this report. After the total watershed was found, it was decided to split the watershed into two separate catchment areas with the Interstate 40 as the dividing line. After this division was completed, the areas of the two new watersheds were found to be 3.52 square miles for the catchment south of Interstate 40 and 2.50 square miles for the catchment north of Interstate 40. Once the watershed was divided into two, the time of concentration needed to be found for each of the catchments. Time of concentration was found using the Kirpich Equation (Bains):

$$T_c = 0.0078L^{0.77}S^{-0.385}$$

Where $T_c$ is the time of concentration in minutes, L is the maximum length of flow in feet, and S is the watershed gradient in feet per foot or the difference in elevation between the most remote point of the watershed and the outlet into the reservoir divided by the maximum length of flow. The following table shows the input values for each catchment, as well as the obtained time of concentration used to create the PondPack model.

# ANALYSIS

**Table 1 - Time of Concentration Calculation**

| Catchment | Length of Flow | Gradient | Time of Concentration |
|---|---|---|---|
| North of I-40 | 13,709 feet | 0.0603 ft./ft. | 35.25 minutes |
| South of I-40 | 25,344 feet | 0.0825 ft./ft. | 50 minutes |

After getting acquainted with the PondPack software, it was decided to use the SCS Curve Method in order to predict direct runoff and infiltration from each catchment. The SCS Curve Method was created by the Soil Conservation Service and is based on the area's hydrologic soil group, hydrologic condition and land use. Since the team was asked to compare pre-burn and post-burn catchment conditions, two SCS Curve Numbers needed to be found. Using a study completed by the U.S. Forest Service Coronado National Forest that incorporated the WILDCAT4 model for runoff and infiltration and was used to estimate peak flow runoff for pre- and post-burn conditions on a fire that occurred in Arizona, curve numbers of 67.00 and 90.00 were used for pre- and post-burn conditions respectively (Greenberg and Hawkins). These two values were obtained by knowing that the hydrologic soil group of the two catchments were classified as a "C" as well as taking into account a high severity burn, since Northern Arizona is prone to wildfires.

After all the information was found for the catchments, a storage rating curve for the reservoir of West Cataract Lake needed to be calculated. ADWR simplified this process by provided storage capacities from the pond invert to the crest of the weir in the spillway, however linear interpolation needed to be done in order to estimate the capacity of the reservoir from the crest of the spillway weir to the crest of the dam. The following table show the values that were obtained for the reservoir storage, in acre-feet, compared to the water surface elevation.

**Table 2 - Reservoir Storage Capacity**

| Pond Elevation (ft) | Pond Volume (ac-ft) |
|---|---|
| 6,778.00 | 0.000 |
| 6,783.00 | 1.043 |
| 6,788.00 | 6.015 |
| 6,793.00 | 23.876 |
| 6,798.00 | 64.447 |
| 6,803.00 | 133.435 |
| 6,808.00 | 240.600 |
| 6,811.00 | 334.324 |
| 6,813.00 | 411.046 |
| 6,814.00 | 420.705 |
| 6,815.00 | 430.364 |
| 6,816.00 | 440.023 |
| 6,817.00 | 449.682 |
| 6,818.00 | 459.341 |
| 6,819.00 | 469.000 |
| 6,820.00 | 478.659 |
| 6,821.00 | 488.318 |

From this table, a storage capacity curve was created. Figure 7 shows the storage capacity curve obtained from the values in Table 2.

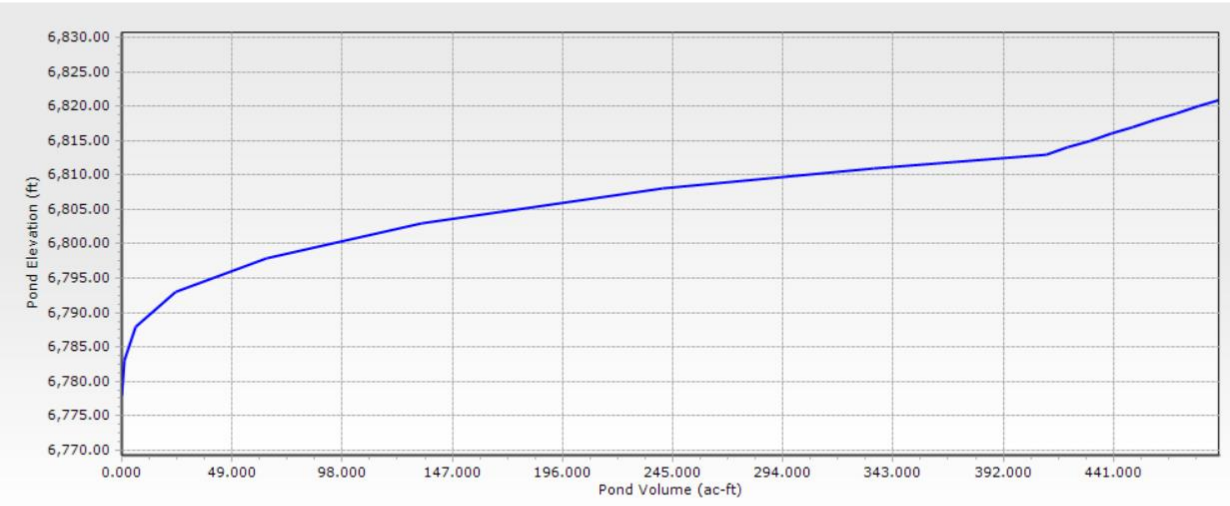


**Figure 7 - Reservoir Capacity Curve (PondPack)**

# ANALYSIS

Once the reservoir capacity was found for water surface elevations up to the crest of the dam, the emergency spillway capacity was calculated in order to find the peak flow the spillway can pass without causing the headwater to back up and flow over the crest of the dam. Since a weir was constructed in the spillway to increase the capacity of the reservoir, the Broad-Crested Weir Equation was used to calculate outflow values that the spillway can adequately pass. This equation is:

$$Q = B\left(\frac{2}{3}\right)^{3/2}(g)^{1/2}(H)^{3/2}$$

Where Q is the outflow in cubic feet per second (cfs), B is the width of the weir in feet, g is gravitational acceleration in feet per square second, and H is the water surface elevation above the crest of the weir in feet. Using a weir width of 80 feet that was obtained during the survey process, as well as a gravitational acceleration of 32.2 ft/s$^2$, Table 3 shows the outflow values obtained using the Broad-Crested Weir Equation.

**Table 3 - Outflow Capacity Table**

| Elevation (ft) | Flow (cfs) |
|---|---|
| 6813 | 0 |
| 6813.5 | 87.39 |
| 6814 | 247.17 |
| 6814.5 | 454.07 |
| 6815 | 699.09 |
| 6815.5 | 977.01 |
| 6816 | 1284.32 |
| 6816.5 | 1618.42 |
| 6817 | 1977.33 |
| 6817.5 | 2359.44 |
| 6818 | 2763.41 |
| 6818.5 | 3188.12 |
| 6819 | 3632.60 |
| 6819.5 | 4096.00 |
| 6820 | 4577.59 |
| 6820.5 | 5076.71 |
| 6821 | 5592.75 |

From the table above, it can be seen that the emergency spillway can handle a maximum outflow capacity of 5592.75 cfs at the water surface elevation equal to the crest of the dam.

# ANALYSIS

After the storm data, catchment areas, reservoir capacity and spillway capacity were entered into the PondPack model, which a layout can be found in Appendix D, models were run for the 1, 2, 5, 10, 25, 50, 100, 200, 500 and 1000 year recurrence interval storms for both pre- and post-burn conditions. Table 4 shows the relevant storms and outputs from PondPack for pre-burn conditions to show that the spillway is adequate to pass outflows from every recurrence interval storm, including the 1000 year storm.

**Table 4 - PondPack Output Table for Pre-Burn Conditions**

| Pre-Burn Conditions | | | | |
|---|---|---|---|---|
| Storm Event | Water Surface Elevation (ft.) | Reservoir Inflow (cfs) | Spillway Outflow (cfs) | Adequate? |
| 50 Year Event | 6813.91 | 1446.20 | 430.56 | Yes |
| 100 Year Event | 6815.14 | 2045.69 | 1076.34 | Yes |
| 200 Year Event | 6816.63 | 2927.75 | 2080.57 | Yes |
| 500 Year Event | 6818.52 | 4354.60 | 3650.29 | Yes |
| 1000 Year Event | 6820.01 | 5670.51 | 5090.32 | Yes |

After the pre-burn model was run, a post-burn model was completed to compare what would happen when the watershed experienced a severe burn. Table 5 shows the relevant storms and outputs from PondPack for post-burn conditions to show the adequacy of the spillway for the post-burn conditions.

**Table 5 - PondPack Output Table for Post-Burn Conditions**

| Post-Burn Conditions | | | | |
|---|---|---|---|---|
| Storm Event | Water Surface Elevation (ft.) | Reservoir Inflow (cfs) | Spillway Outflow (cfs) | Adequate? |
| 50 Year Event | 6815.15 | 5353.13 | 1079.74 | Yes |
| 100 Year Event | 6817.23 | 6354.55 | 2550.80 | Yes |
| 200 Year Event | 6819.58 | 7705.60 | 4655.45 | Yes |
| 500 Year Event | > 6820.5 | 9722.83 | > 5592.75 | No |
| 1000 Year Event | > 6820.5 | 11431.78 | >5592.75 | No |

It can be seen from the two tables above that the spillway is adequate to pass flows from any storm under pre-burn conditions, and can pass the flows from all storm events excluding the 500 and 1000 year event after the watershed experiences a severe burn.

## SPILLWAY FAILURE

Spillway Failure is another rainy day failure, defined as a scenario in which the existing concrete weir is removed during a return event. This was analyzed as a follow up to the overtopping analysis, because the consequences of a spillway failure would be the most critical during a large storm. The PondPack model set up for the overtopping analysis was used again, but starting elevation was defined as the pond invert, as opposed to the previously used 6811. This is because 6811 was chosen based on the bottom elevation of the concrete weir, but a spillway failure necessitates the weir being removed. Using both pre-burn and post-burn situations, it was clear that the removal of the concrete weir would make a substantial difference, causing much more water to pass by the dam and go on to potentially damage something downstream. The spillway failure analysis revealed that a 100 year storm in a pre-burn scenario, or a 5 year storm in a post-burn scenario would result in flows high enough to produce 2.5 feet of water going through the spillway unhindered.

## INTERNAL EROSION

Evidence of seepage at the dam site has led to concerns of internal erosion, which would be a sunny day failure. The seepage that was identified on the downstream side of the dam did not contain visible particles of soil and was insufficient to cause internal erosion. For this reason internal erosion was omitted from the analyses performed on the dam. A flow net analysis is a way to estimate seepage velocities through a dam cross-section. This method requires known soil properties, which the team was not given, making this method of analysis difficult to perform. If soil properties were assumed the analysis may be performed, but may not be realistic. Since seepage at the site was minimal and no particles were apparent and soil properties were unknown, the team decided that a flow net analysis would not be necessary.

# ANALYSIS

## ADWR DAM BREAK ANALYSIS

In October of 2013, ADWR performed a dam-break analysis in which they looked into the possibilities of a sunny-day as well as a rainy-day dam break. As one might predict, the rainy-day failure caused greater depths downstream, affecting more of Williams than the sunny day failure. In the rainy day failure, the dam was assumed to be at full capacity when it broke, resulting in all the water flooding downstream. The most affected areas affected are a hotel and a gas station about 1.5 miles downstream, which are completely flooded with about nine feet of water. I-40 and a small part of Williams consisting of less than 30 residential homes are also affected, with an average of a foot of water flooding into the area. This dam break analysis was a static dam break analysis, meaning that only the depth of water was included, and not the velocities. ADWR's static dam break analysis is included in Appendix E.

# CONCLUSION

## Conclusion

Based on the failure modes that were thoroughly analyzed throughout this project, there is not a serious chance of the dam breaking. Only extreme worst-case scenarios caused a failure, meaning that the dam and concrete weir are very unlikely to fail. The main reason that ADWR is concerned with the dam calling it a “Significant” safety concern, is because of the downstream risks involved, and the fact that the Emergency Action Plan is not finalized.

# FINAL RECOMMENDATIONS

## Final Recommendations

### RECOMMENDATION 1

This team's first recommendation is for ADWR or a third party to perform a dynamic dam break analysis, which would include velocities. The dam break analysis on downstream conditions done in October of 2013 only considered water depths and not velocities. This means that the water going into the Williams area may be a higher threat than initially determined from the static analysis.

### RECOMMENDATION 2

Our team's second recommendation is for the Emergency Action Plan to be finalized. While the EAP has been created, it has not been finalized or implemented, meaning that it cannot be used in the unlikely event of a dam break. Finalize and implement the EAP. This will become even more necessary if the dam does get changed from a significant safety concern to a high safety concern.

### RECOMMENDATION 3

Improve and repair outlet works. Existing outlet works are unable to be opened due to lack of maintenance. Downstream valves cause high pressures in the pipes, thus upstream valves should be added in order to reduce pressures in pipes. While there is currently not enough evidence to warrant an internal erosion analysis, if this problem is not fixed, then the condition of the dam may change away from its current state.

### RECOMMENDATION 4

This team's final recommendation is to remove deep-rooted vegetation. In the various inspections of this dam, vegetation was consistently noted as a concern, especially a growth of cattails downstream of the dam. In order to finally dispel any seepage concerns, this vegetation should be removed.

# SUMMARY OF PROJECT COSTS

## Summary of Project Costs

Because there are no construction or material costs associated with this project, all costs are for engineering services that were spent during this project. The proposed Gantt chart followed by the final official Gantt chart are located in Appendix F of this document due to the size of the images. The tasks do change a fair amount due to some confusion of the project's scope, but the second Gantt chart shows the final tasks with the amount of time that was closely followed.

Due to the uncertainty of the precise number of hours that should be allotted to the different tasks, there was somewhat of a discrepancy between the proposed budget and the actual budget. The following is the proposed budget, which was created for the proposal in May 2014 before the start of the project.

**Table 6 - Proposed Cost Summary**

| Task | Total Hours | Total Cost per Task | Billable Rate (20% additional) |
|---|---|---|---|
| Site Surveying and Inventory | 48 | $3,600 | $4,320 |
| Geotechnical Analysis | 64 | $4,800 | $5,760 |
| Hydro Analysis | 64 | $4,800 | $5,760 |
| Dam Breach Analysis | 64 | $4,800 | $5,760 |
| Overtopping and Erosion Analysis | 32 | $2,400 | $2,880 |
| Sliding and Earthquake Analysis | 32 | $2,400 | $2,880 |
| Bearing Capacity Analysis | 32 | $2,400 | $2,880 |
| | | **Billed Total:** | $30,240 |

Some tasks were dropped because other tasks took much more time than originally predicted, and the billable rate per hour was decreased to compensate for this unexpected change. All of the updated values can be seen in the table on the following page, which is the most recent version of the budget:

# SUMMARY OF PROJECT COSTS

**Table 7 - Updated Cost Summary**

| Task | Total Hours | Billable Rate | Total Cost |
|---|---|---|---|
| Literature Review | 199 | $40/hr. | $7,960 |
| Website | 11.5 | $75/hr. | $863 |
| Site Surveying & Inventory | 27 | $75/hr. | $2,025 |
| Hydro Analysis | 65 | $75/hr. | $4,875 |
| Overtopping Analysis | 43.5 | $75/hr. | $3,263 |
| Erosion Analysis | 17 | $75/hr. | $1,275 |
| Slope Stability Analysis | 48.5 | $75/hr. | $3,638 |
| Spillway Failure Analysis | 27 | $75/hr. | $2,025 |
| Final Report* | 76.5 | $75/hr. | $5,738 |
| Total Hours | 515 | Total Cost | $31,662 |

This new total cost is the official number that the client will be charged for the team's dam safety analysis.

# References


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Resources, Arizona Department of Water. 20 March 2007. *ADWR.* 4 September 2014.

RocScience Slide 6.0, *Software*

# Appendix A

# West Cataract Creek Dam Chronology

**Timeline for West Cataract Creek Dam**

- Dam was designed in 1946, with the following factors considered
  - Drainage area of 5.5 square miles
    - Run-off factor of 20-25%
  - Discharge of 2,000 cfs
  - Maximum 1 hour precipitation of 3.3 inches
  - Design 100 year flood was 1.5 inches/hour for 3 hours
  - Soil samples were taken, and were run through tests to find various properties
- Dam was constructed from May 4, 1947 to November 30, 1947
- In 1967, a design analysis was done to determine the effectiveness of the dam
  - Peak discharge was re-computed as 3600 cfs
  - Drainage area of 6.2 square miles
  - 100 year 1 hour rainfall was 2.3 inches
  - Time of concentration was calculated as 60 minutes
- Revision from March 1, 1968 to May 1, 1968
  - 2 foot concrete wall placed across spillway
- Inspection in 1978
- Gonzalez Estate constructed just before 1982, and was being used to hold overtopping flow from the West Cataract Creek Dam
- 8 feet of freeboard confirmed during April 10, 1984 inspection
  - 3 feet during 100 year flood
  - No freeboard during PMP storm
- As of 1986 inspection
  - Cited inadequate spillway capacity, causing the dam to be a significant safety concern
  - Licensed in July 18, 1986
  - Valves tested in January 1986-no issues
    - Left in open position
  - Spillway enlargement due to happen
    - *Unclear if this was done*
  - Recommended calculating 100-year flood and ½ PMF flows, and modify spillway accordingly
- EAP plan was adopted by Williams in 1986 that applied to all dams owned by Williams
- Inspection on October 1, 1997
  - Valve box needs repaired

- Inspection from May 30, 2001
    - Rusted valves
    - No maintenance on outlet valves
    - Evidence of seepage
- On July 10, 2001, spillway was still reported to be inadequate
- On August 10, 2001, ADWR began sending monthly notices to the city of Williams about the Significant Safety Concern for West Cataract Creek Dam
- May 2004 inspection
    - Outlet Pipe without Upstream Controls resulting in pressurized pipes through the dam
    - Evidence of seepage
- In 2005, spillway was widened, to a bottom width of 75 feet
    - Freeboard now 8.3 feet
    - Shotcrete and riprap used to reduce the noticed seepage in April 2005
- Final notice from ADWR to Williams, Arizona was on March 20, 2007
    - Around this time, Williams stated that responsibility for the dam changed to the Kaibab National Forest
- As of 2013, a draft for an Emergency Action Plan supposedly exists, but has not been put in place

# Appendix B

# Survey Data

1. Survey Data

# Survey Data

| Northing | Easting | Elevation | Notes |
|---|---|---|---|
| 104.080 | -63.095 | -7.770 | Spillway Wall (N) |
| 37.580 | -18.520 | -7.730 | Spillway Wall (S) |
| 99.070 | -52.460 | -10.240 | Spillway Edge |
| 93.765 | -62.240 | -9.890 | Spillway Edge |
| 37.920 | -25.620 | -10.000 | Spillway Edge |
| 43.210 | -16.610 | -9.975 | Spillway Edge |
| 26.230 | -12.350 | -3.065 | Top of Concrete |
| 2.500 | -24.600 | -3.435 | Top of Concrete |
| 16.565 | -23.465 | -3.085 | Top of Concrete |
| 8.400 | -25.260 | -3.225 | Top of Concrete |
| 15.395 | 5.550 | -2.730 | Backside Slope Edge |
| 9.255 | -5.935 | -0.290 | Top of Dam Point |
| 14.270 | 17.075 | -7.595 | Backside Slope Edge |
| -23.245 | -34.950 | -9.955 | Front Side SE |
| 8.600 | 26.185 | -9.015 | BS SE |
| -67.550 | -12.635 | -14.480 | FS SE |
| -15.225 | 47.450 | -13.350 | BS SE |
| -92.610 | 3.120 | -17.205 | FS SE |
| -32.300 | 76.750 | -18.060 | BS SE |
| -114.385 | 18.260 | -17.770 | FS SE |
| -46.370 | 94.600 | -20.820 | BS SE |
| -137.940 | 34.520 | -17.675 | FS SE |
| -57.590 | 114.955 | -23.315 | BS SE |
| -160.910 | 49.855 | -17.445 | FS SE |
| -68.510 | 135.615 | -26.950 | BS SE |
| -187.275 | 67.940 | -17.235 | FS SE |
| -78.365 | 155.625 | -29.425 | BS SE |
| -207.930 | 82.540 | -17.460 | FS SE |
| -101.320 | 166.850 | -35.550 | BS SE |
| -229.825 | 98.770 | -16.720 | FS SE |
| -115.950 | 183.100 | -38.050 | BS SE |
| -251.490 | 111.685 | -17.175 | FS SE |
| -139.930 | 203.295 | -40.135 | BS SE |
| -273.025 | 126.365 | -16.720 | FS SE |
| -303.435 | 144.470 | -17.220 | FS SE |
| -338.580 | 165.605 | -17.140 | FS SE |
| -364.795 | 184.510 | -16.575 | FS SE |
| -391.570 | 205.215 | -14.885 | FS SE |
| -420.010 | 223.875 | -13.455 | FS SE |
| -417.030 | 311.870 | -6.890 | BS SE |

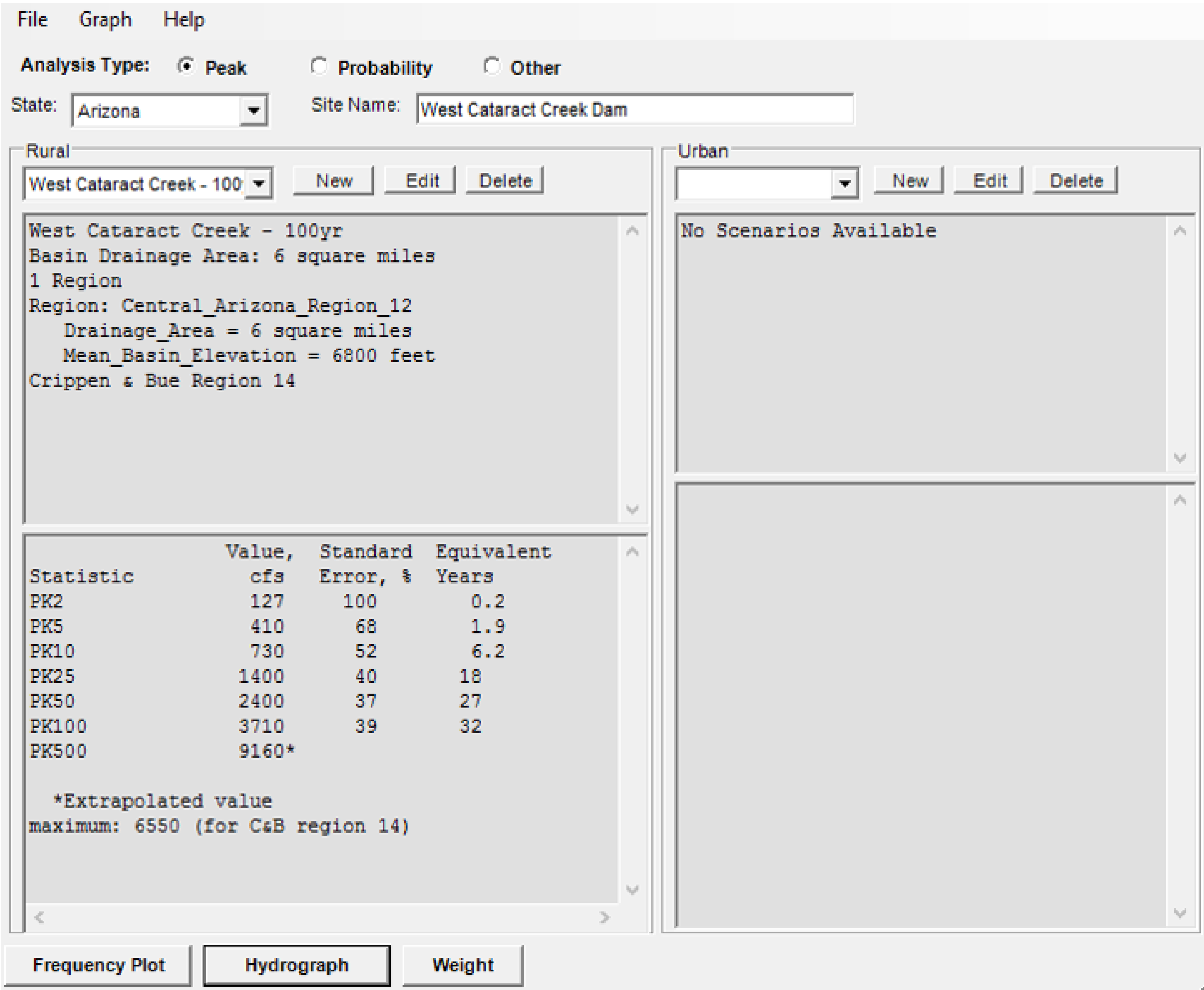
| | | | |
|---|---|---|---|
| -434.300 | 252.075 | -10.055 | FS SE |
| -365.950 | 303.670 | -13.560 | BS SE |
| -455.435 | 277.560 | -6.130 | FS SE |
| -336.160 | 281.425 | -17.225 | BS SE |
| -469.295 | 290.425 | -3.155 | FS SE |
| -320.720 | 272.890 | -20.120 | BS SE |
| -465.130 | 309.430 | 0.315 | Top Center of Dam - South |
| -455.805 | 297.140 | -0.175 | FS Top Edge |
| -449.215 | 306.635 | -0.125 | BS TE |
| -409.935 | 267.415 | -0.565 | FS TE |
| -405.680 | 275.705 | -0.345 | BS TE |
| -363.865 | 236.805 | -0.645 | FS TE |
| -358.395 | 244.320 | -0.630 | BS TE |
| -308.355 | 200.275 | -0.995 | FS TE |
| -302.940 | 207.685 | -0.815 | BS TE |
| -209.785 | 135.400 | -0.605 | FS TE |
| -205.120 | 141.905 | -0.575 | BS TE |
| -111.115 | 69.700 | -0.485 | FS TE |
| -106.265 | 75.730 | -0.285 | BS TE |
| -22.845 | 8.775 | -0.125 | FS TE |
| -17.660 | 16.620 | -0.035 | BS TE |
| -146.730 | 197.345 | -39.730 | BS SE |
| -182.195 | 237.850 | -40.885 | BS SE |
| -193.895 | 246.950 | -35.195 | BS |
| -8.610 | 105.595 | -10.140 | Second Nail |

# Appendix C

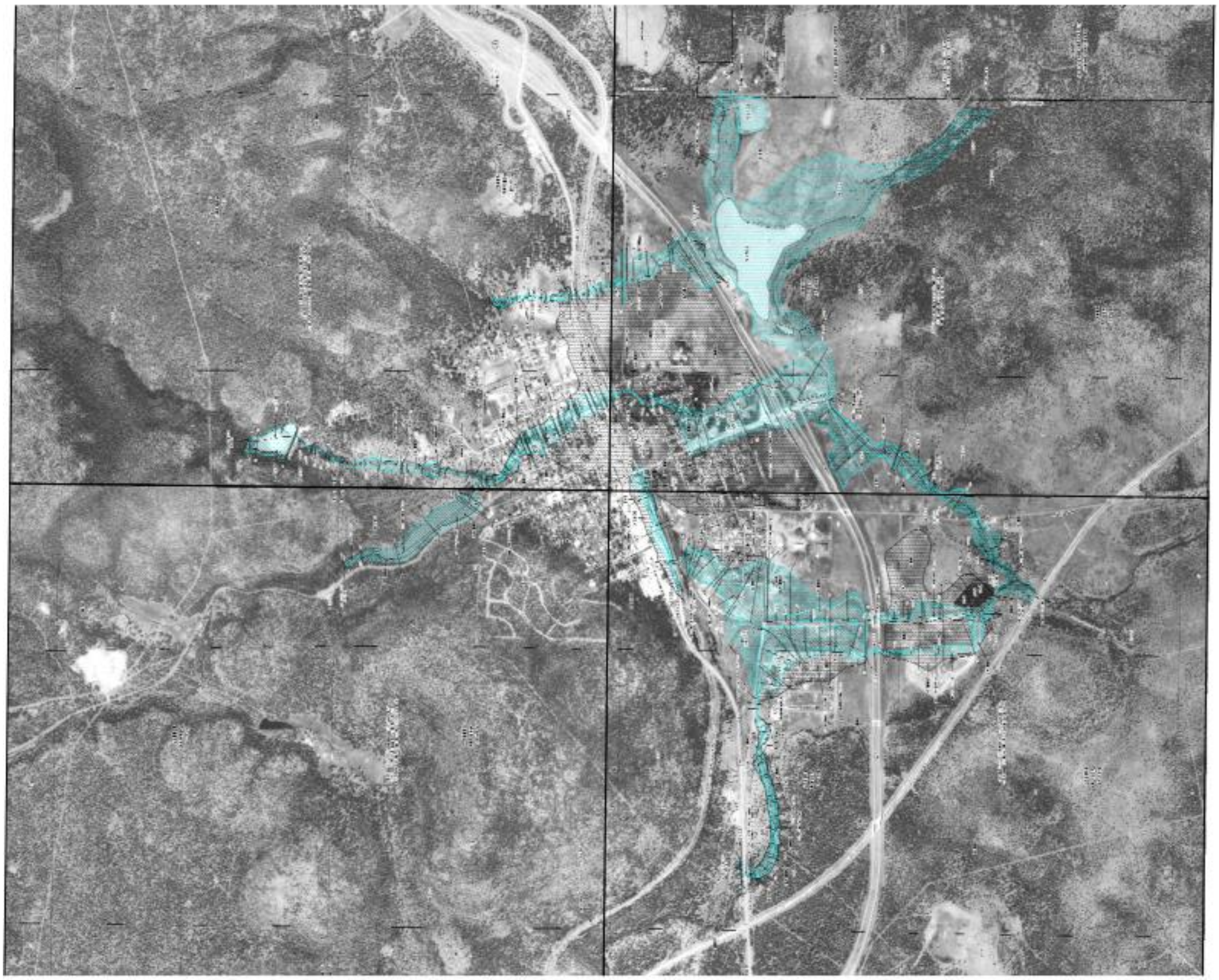
# HYDROLOGY DATA

1. NSS output
2. FEMA dFIRM Map

# NSS Output


File Graph Help
Analysis Type: Peak Probability Other
State: Arizona
Site Name: West Cataract Creek Dam
Rural
West Cataract Creek - 100
New Edit Delete
West Cataract Creek - 100yr
Basin Drainage Area: 6 square miles
1 Region
Region: Central_Arizona_Region_12
Drainage_Area = 6 square miles
Mean_Basin_Elevation = 6800 feet
Crippen & Bue Region 14
Statistic Value, cfs Standard Error, % Equivalent Years
PK2 127 100 0.2
PK5 410 68 1.9
PK10 730 52 6.2
PK25 1400 40 18
PK50 2400 37 27
PK100 3710 39 32
PK500 9160*
*Extrapolated value
maximum: 6550 (for C&B region 14)
Urban
New Edit Delete
No Scenarios Available
Frequency Plot
Hydrograph
Weight

FEMA Floodplains



# Appendix D

# Overtopping Analysis

1. NOAA Atlas 14 Storm Data
2. Watershed Delineation
3. Bentley PondPack Model

# NOAA Atlas 14 Storm Data

**PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]**

| Duration | Average recurrence interval (years) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 5 | 10 | 25 | 50 | 100 | 200 | 500 | 1000 |
| 5-min | **2.81** (2.44-3.28) | **3.64** (3.14-4.22) | **4.91** (4.24-5.70) | **5.98** (5.12-6.92) | **7.50** (6.36-8.65) | **8.77** (7.38-10.1) | **10.2** (8.42-11.7) | **11.7** (9.54-13.5) | **13.9** (11.1-16.2) | **15.8** (12.4-18.6) |
| 10-min | **2.14** (1.85-2.50) | **2.76** (2.39-3.22) | **3.74** (3.22-4.34) | **4.55** (3.90-5.27) | **5.71** (4.84-6.58) | **6.68** (5.62-7.70) | **7.73** (6.41-8.92) | **8.87** (7.26-10.3) | **10.6** (8.44-12.3) | **12.0** (9.41-14.1) |
| 15-min | **1.77** (1.53-2.06) | **2.28** (1.98-2.66) | **3.09** (2.66-3.58) | **3.76** (3.22-4.35) | **4.72** (4.00-5.44) | **5.52** (4.64-6.36) | **6.38** (5.30-7.37) | **7.34** (6.00-8.49) | **8.72** (6.98-10.2) | **9.92** (7.77-11.7) |
| 30-min | **1.19** (1.03-1.39) | **1.54** (1.33-1.79) | **2.08** (1.79-2.41) | **2.53** (2.17-2.93) | **3.17** (2.69-3.66) | **3.71** (3.13-4.28) | **4.30** (3.57-4.97) | **4.94** (4.04-5.72) | **5.88** (4.70-6.86) | **6.68** (5.23-7.87) |
| 60-min | **0.736** (0.638-0.859) | **0.951** (0.823-1.11) | **1.29** (1.11-1.49) | **1.57** (1.34-1.81) | **1.97** (1.67-2.27) | **2.30** (1.93-2.65) | **2.66** (2.21-3.07) | **3.06** (2.50-3.54) | **3.64** (2.91-4.25) | **4.13** (3.24-4.87) |
| 2-hr | **0.437** (0.384-0.502) | **0.554** (0.486-0.635) | **0.732** (0.640-0.838) | **0.882** (0.767-1.00) | **1.10** (0.949-1.25) | **1.28** (1.09-1.46) | **1.48** (1.25-1.69) | **1.70** (1.41-1.94) | **2.03** (1.64-2.33) | **2.30** (1.82-2.66) |
| 3-hr | **0.325** (0.288-0.370) | **0.411** (0.364-0.468) | **0.528** (0.468-0.600) | **0.628** (0.554-0.712) | **0.772** (0.674-0.874) | **0.893** (0.772-1.01) | **1.03** (0.879-1.17) | **1.18** (0.992-1.34) | **1.40** (1.15-1.60) | **1.58** (1.28-1.83) |
| 6-hr | **0.201** (0.180-0.225) | **0.249** (0.224-0.280) | **0.309** (0.277-0.347) | **0.362** (0.323-0.405) | **0.437** (0.387-0.490) | **0.499** (0.438-0.559) | **0.566** (0.491-0.635) | **0.639** (0.546-0.719) | **0.745** (0.624-0.845) | **0.833** (0.686-0.952) |
| 12-hr | **0.129** (0.115-0.145) | **0.159** (0.143-0.179) | **0.195** (0.174-0.219) | **0.225** (0.200-0.252) | **0.265** (0.235-0.297) | **0.297** (0.261-0.333) | **0.330** (0.288-0.370) | **0.363** (0.314-0.409) | **0.415** (0.355-0.471) | **0.459** (0.388-0.524) |
| 24-hr | **0.075** (0.070-0.079) | **0.093** (0.088-0.099) | **0.116** (0.109-0.123) | **0.134** (0.127-0.143) | **0.160** (0.150-0.170) | **0.180** (0.168-0.191) | **0.201** (0.186-0.214) | **0.223** (0.204-0.237) | **0.252** (0.229-0.270) | **0.275** (0.247-0.296) |
| 2-day | **0.045** (0.043-0.049) | **0.057** (0.053-0.061) | **0.071** (0.066-0.076) | **0.082** (0.077-0.088) | **0.098** (0.091-0.105) | **0.111** (0.102-0.118) | **0.124** (0.114-0.132) | **0.137** (0.125-0.147) | **0.156** (0.140-0.168) | **0.170** (0.152-0.184) |
| 3-day | **0.032** (0.030-0.035) | **0.041** (0.038-0.044) | **0.051** (0.048-0.055) | **0.059** (0.055-0.063) | **0.071** (0.066-0.076) | **0.080** (0.074-0.086) | **0.090** (0.082-0.096) | **0.100** (0.091-0.107) | **0.114** (0.103-0.123) | **0.125** (0.111-0.135) |
| 4-day | **0.026** (0.024-0.028) | **0.032** (0.030-0.035) | **0.041** (0.038-0.044) | **0.048** (0.044-0.051) | **0.057** (0.053-0.061) | **0.065** (0.060-0.069) | **0.073** (0.067-0.078) | **0.081** (0.074-0.087) | **0.093** (0.084-0.100) | **0.102** (0.091-0.111) |
| 7-day | **0.018** (0.016-0.019) | **0.022** (0.021-0.024) | **0.027** (0.026-0.029) | **0.032** (0.030-0.034) | **0.038** (0.035-0.041) | **0.043** (0.040-0.046) | **0.048** (0.044-0.052) | **0.054** (0.049-0.057) | **0.061** (0.055-0.066) | **0.067** (0.060-0.072) |
| 10-day | **0.014** (0.013-0.015) | **0.017** (0.016-0.019) | **0.021** (0.020-0.023) | **0.025** (0.023-0.026) | **0.029** (0.027-0.031) | **0.033** (0.030-0.035) | **0.036** (0.033-0.038) | **0.040** (0.036-0.042) | **0.044** (0.040-0.047) | **0.048** (0.043-0.052) |
| 20-day | **0.009** (0.009-0.010) | **0.012** (0.011-0.012) | **0.014** (0.013-0.015) | **0.016** (0.015-0.017) | **0.019** (0.017-0.020) | **0.020** (0.019-0.022) | **0.022** (0.020-0.024) | **0.024** (0.022-0.025) | **0.026** (0.024-0.028) | **0.028** (0.025-0.030) |
| 30-day | **0.008** (0.007-0.008) | **0.009** (0.009-0.010) | **0.011** (0.011-0.012) | **0.013** (0.012-0.014) | **0.015** (0.014-0.016) | **0.016** (0.015-0.017) | **0.018** (0.016-0.019) | **0.019** (0.017-0.020) | **0.021** (0.019-0.022) | **0.022** (0.020-0.024) |
| 45-day | **0.006** (0.006-0.006) | **0.007** (0.007-0.008) | **0.009** (0.009-0.010) | **0.010** (0.010-0.011) | **0.012** (0.011-0.013) | **0.013** (0.012-0.014) | **0.014** (0.013-0.015) | **0.015** (0.014-0.017) | **0.017** (0.015-0.018) | **0.018** (0.016-0.020) |
| 60-day | **0.005** (0.005-0.006) | **0.007** (0.006-0.007) | **0.008** (0.007-0.008) | **0.009** (0.008-0.010) | **0.010** (0.009-0.011) | **0.011** (0.010-0.012) | **0.012** (0.011-0.013) | **0.013** (0.012-0.014) | **0.014** (0.013-0.015) | **0.015** (0.013-0.016) |

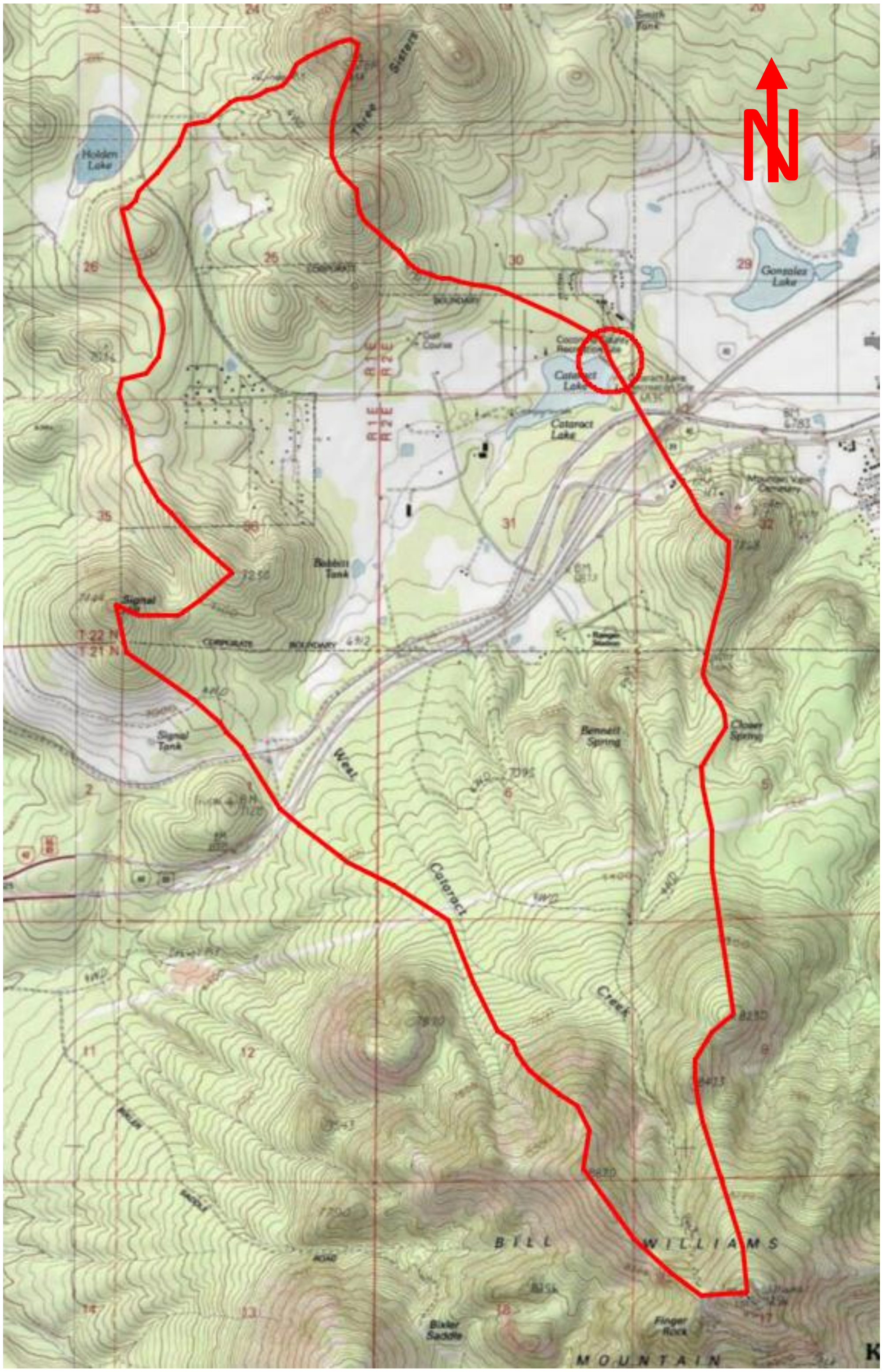
[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

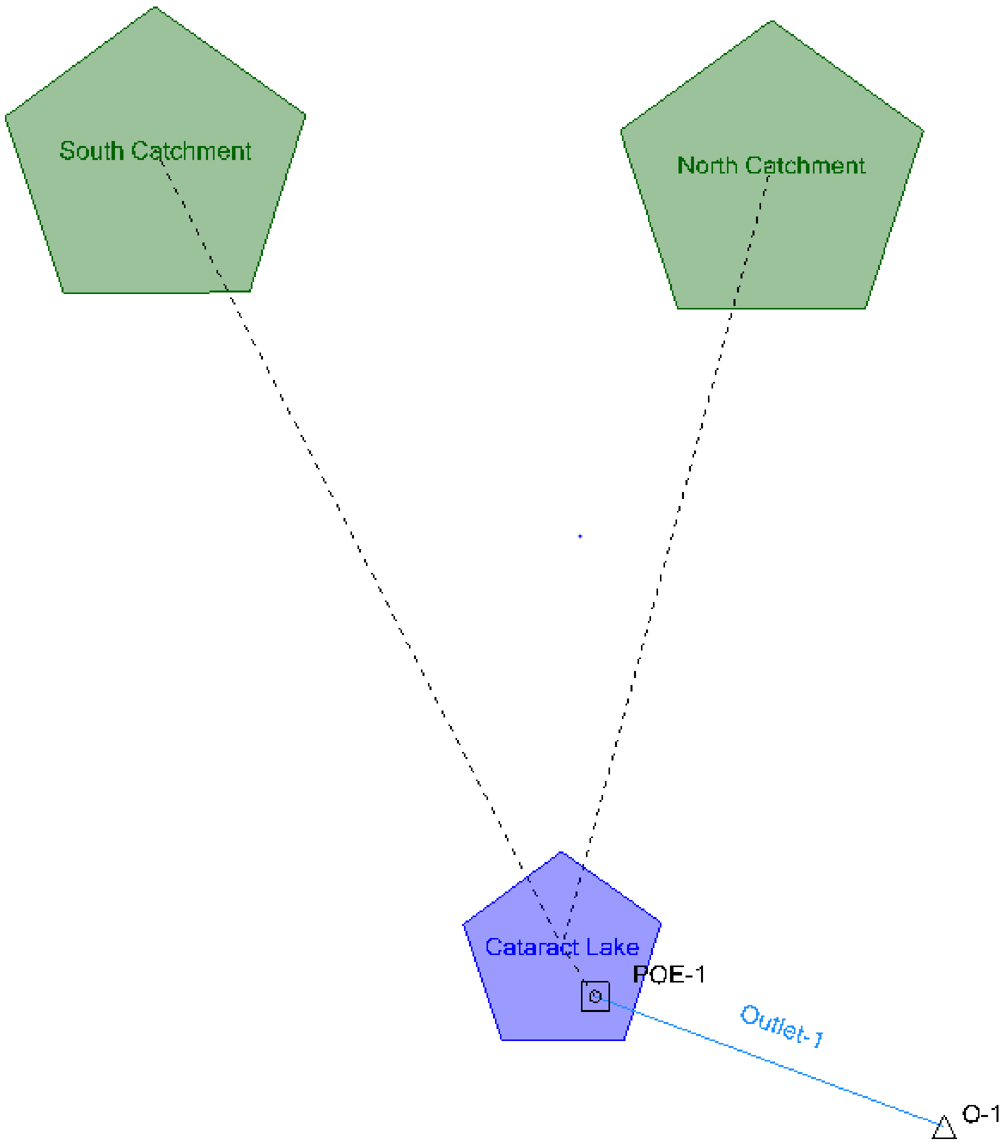
Please refer to NOAA Atlas 14 document for more information.

Estimates from the table in csv format: precipitation frequency estimates Submit

# Watershed Delineation

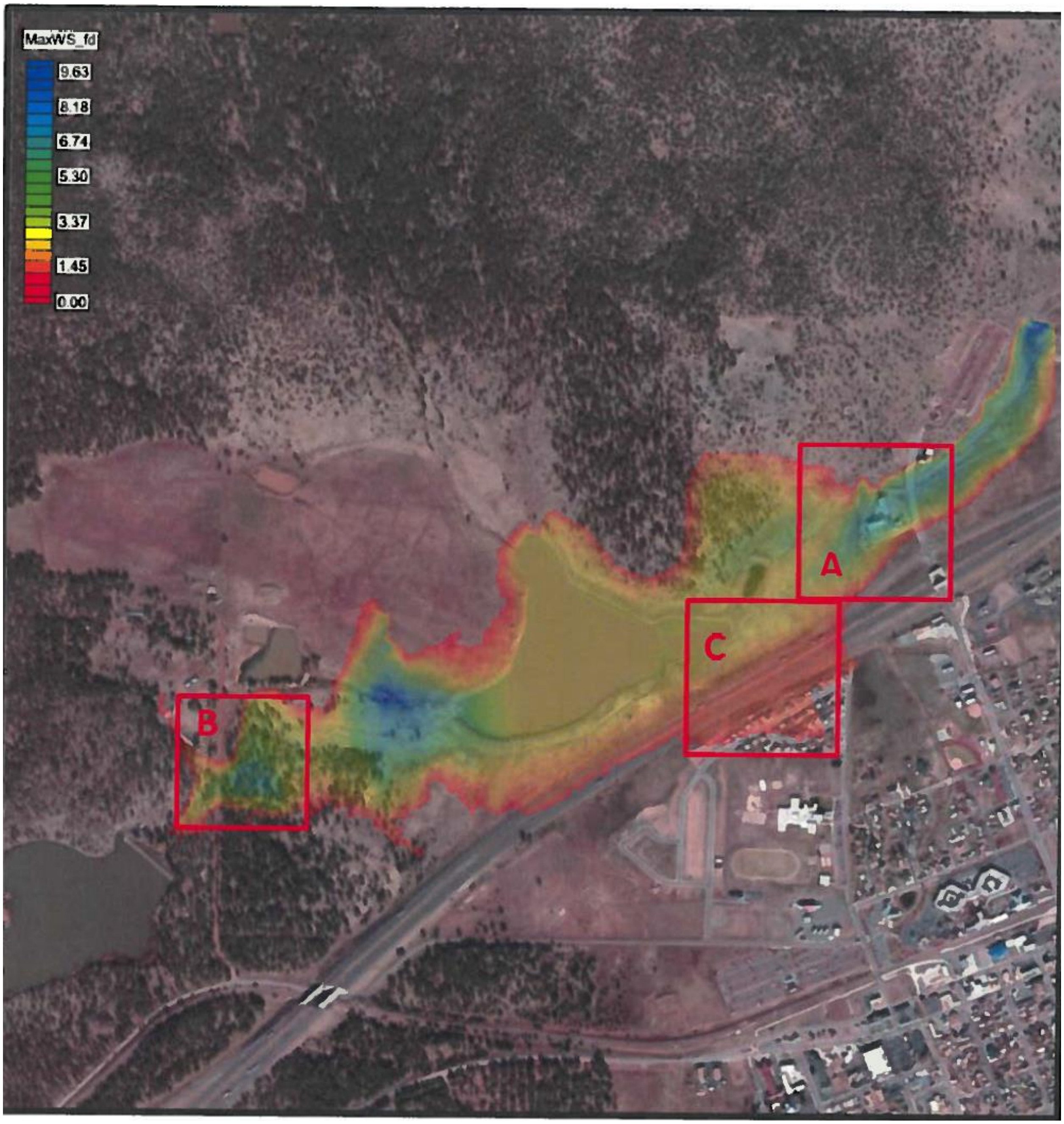



Bentley PondPack Model


South Catchment
North Catchment
Cataract Lake
POE-1
Outlet-1
O-1

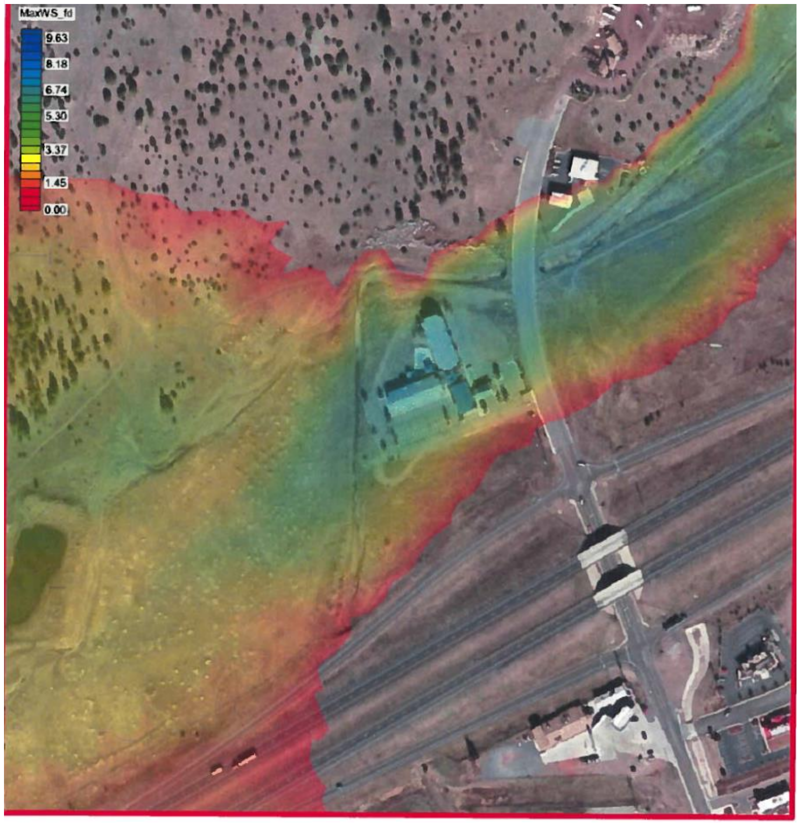
# Appendix E

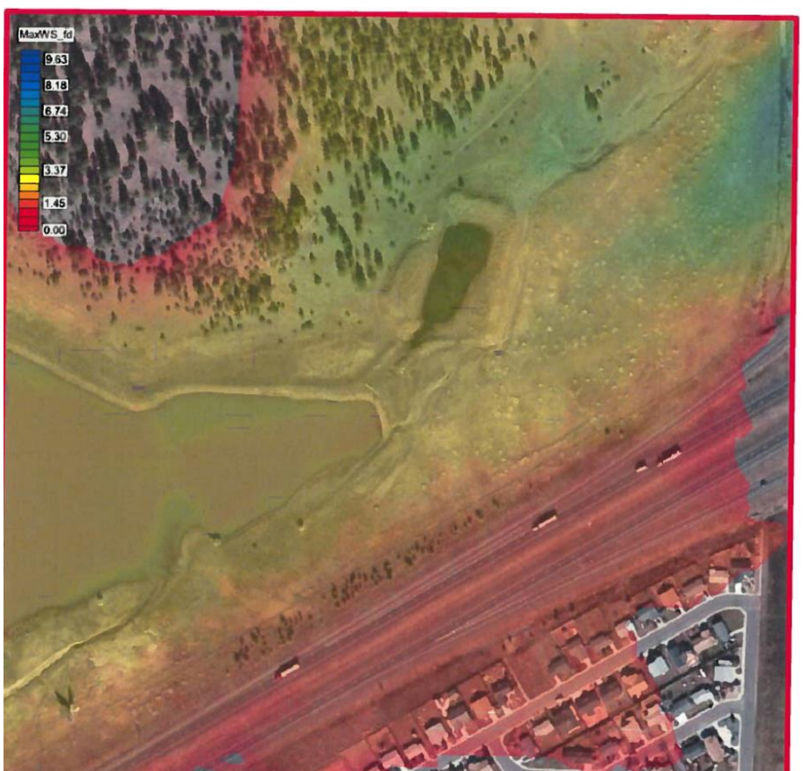
# ADWR Dam Safety Analysis



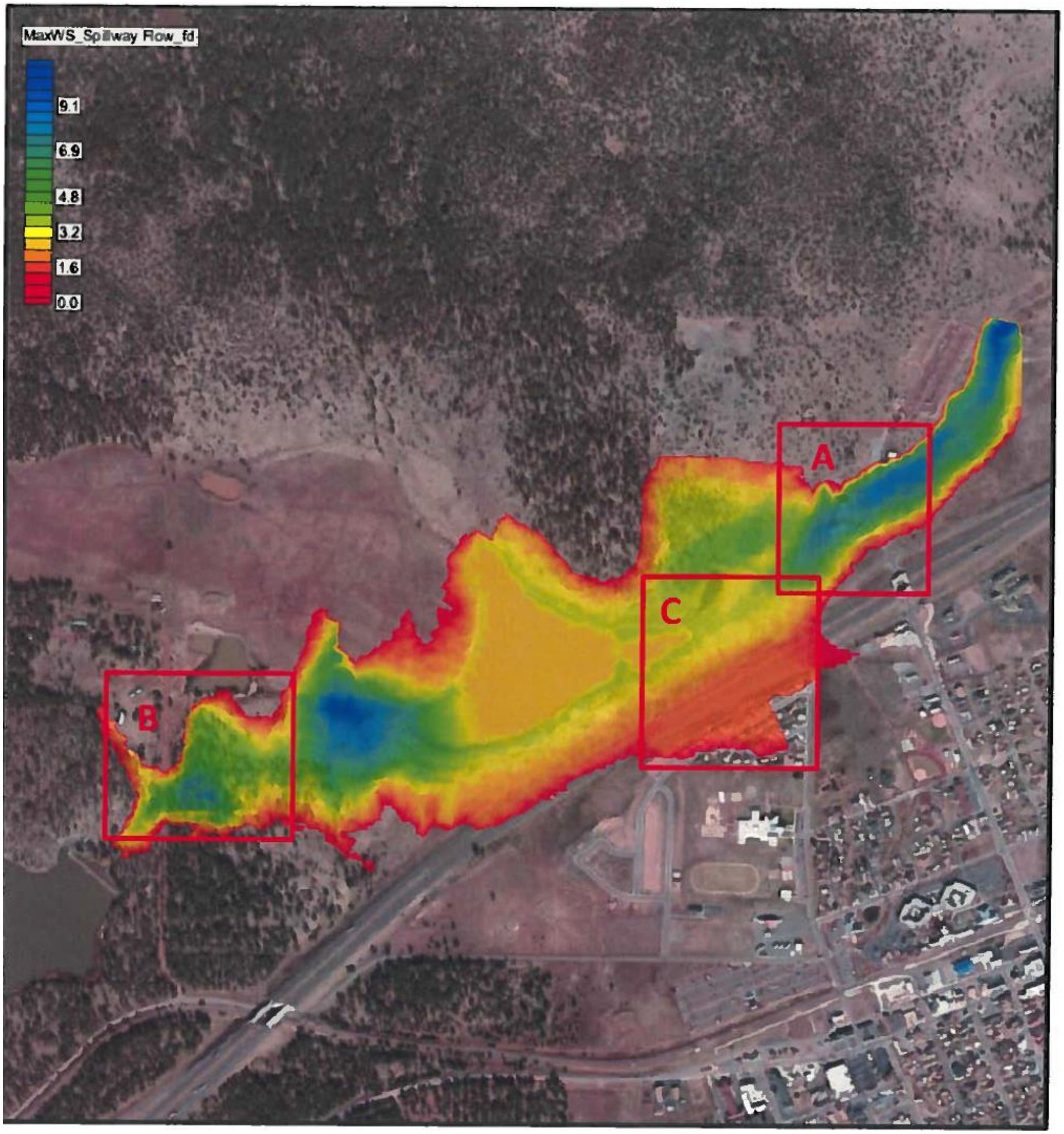

*Downstream Effects of a Sunny Day Failure as determined by ADWR*

*Affected hotel and gas station north of I-40*



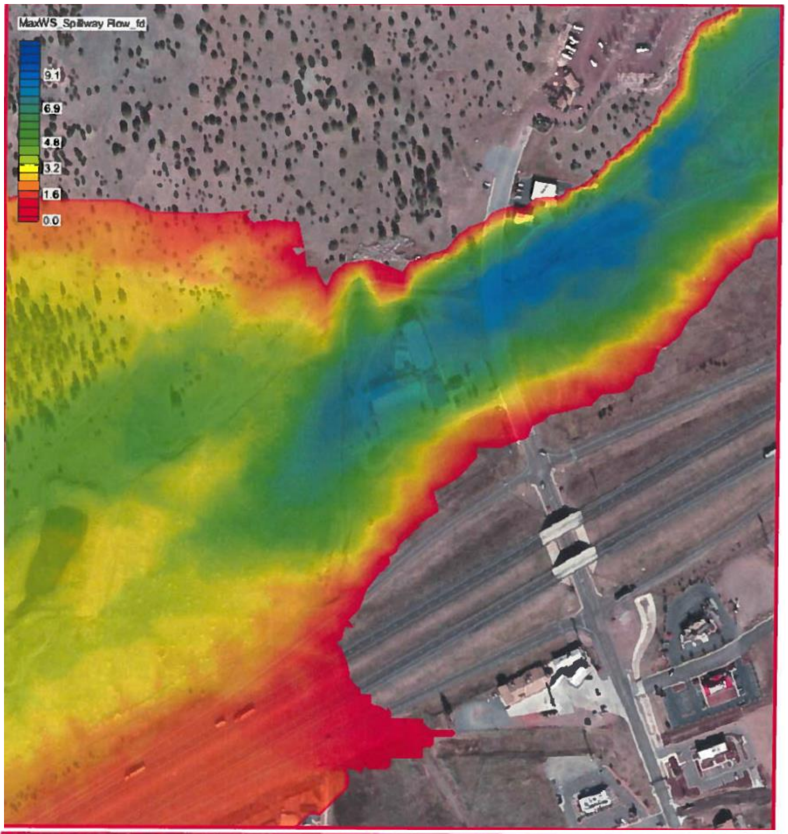



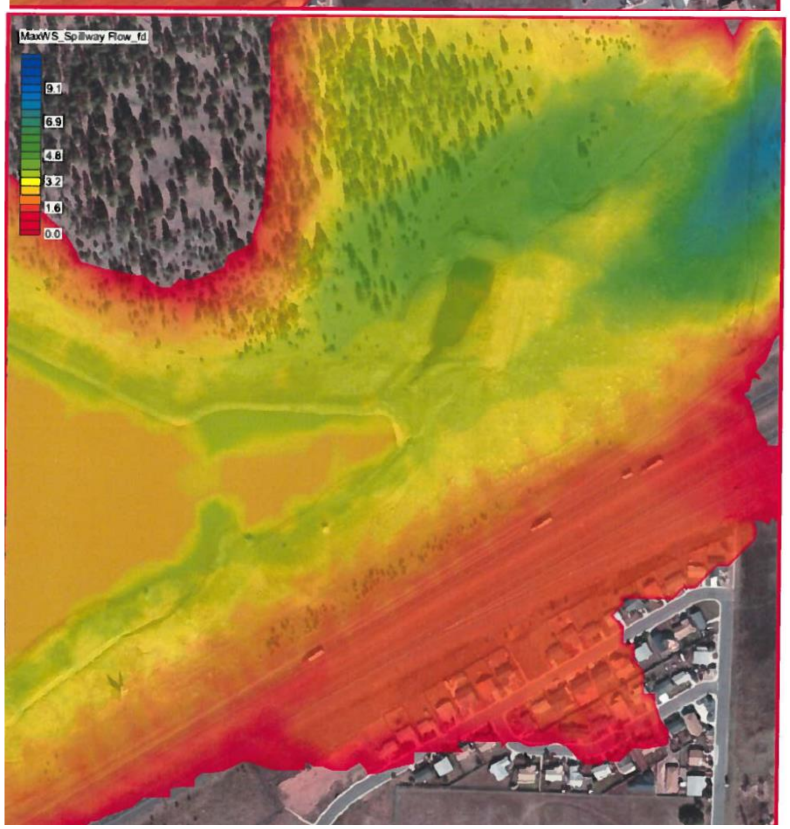

*Depth of water over I-40 as well as affected Williams homes.*




*Downstream Effects of a Rainy Day Failure as determined by ADWR*

*Affected hotel and gas station north of I-40*



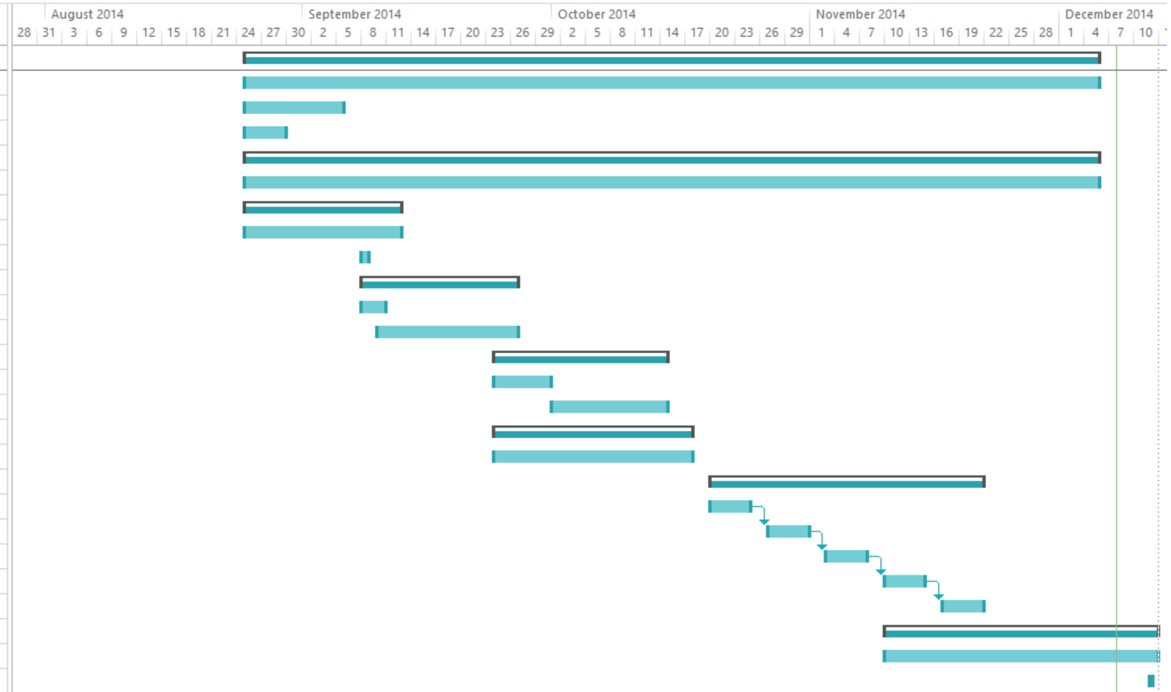

*Depth of water over I-40 as well as affected Williams homes.*

# Appendix F

# Gantt Charts

GANTT CHART

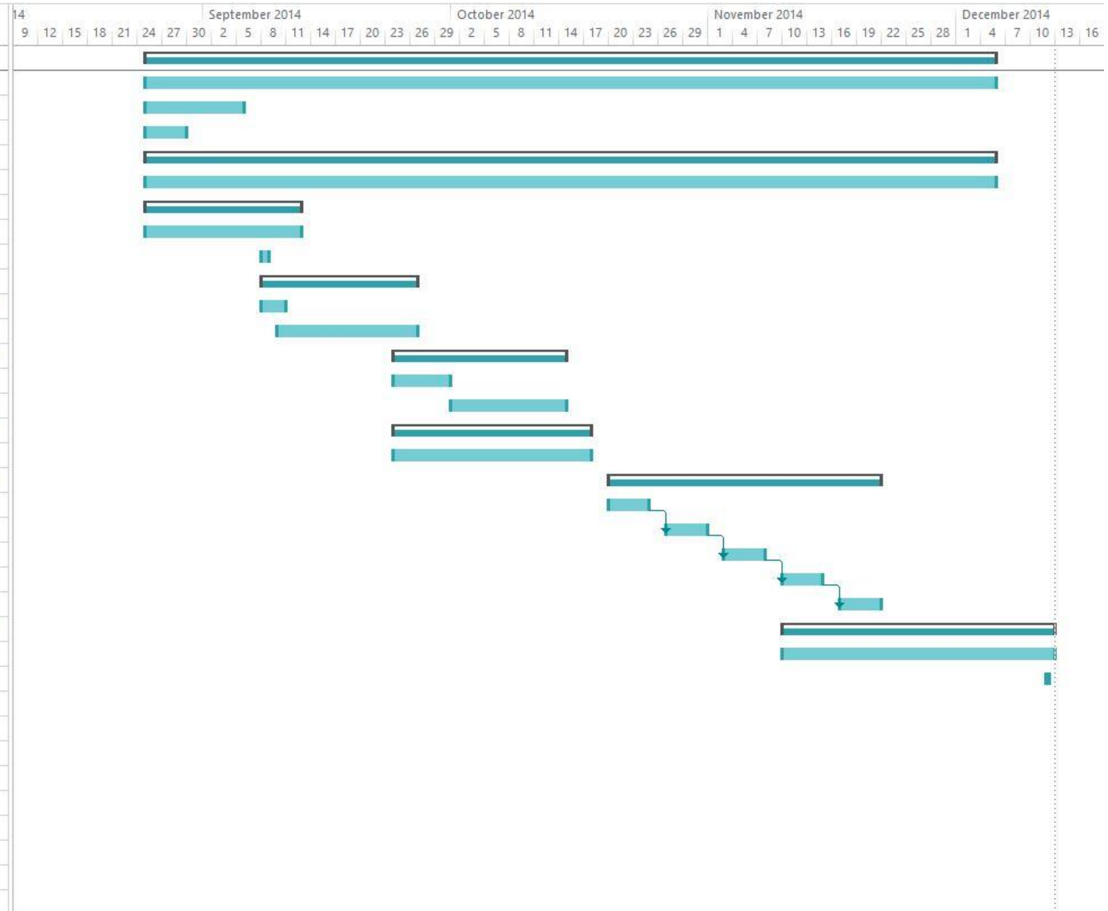
| | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Literature Review** | **75 days** | **Mon 8/25/14** | **Fri 12/5/14** |
| 2 | Research on Dam Failures | 75 days | Mon 8/25/14 | Fri 12/5/14 |
| 3 | Background Information | 10 days | Mon 8/25/14 | Fri 9/5/14 |
| 4 | Document Procurement | 5 days | Mon 8/25/14 | Fri 8/29/14 |
| 5 | **Website** | **75 days** | **Mon 8/25/14** | **Fri 12/5/14** |
| 6 | Website | 75 days | Mon 8/25/14 | Fri 12/5/14 |
| 7 | **Site Surveying/Inventory** | **15 days** | **Mon 8/25/14** | **Fri 9/12/14** |
| 8 | Obtain Elevation Data | 15 days | Mon 8/25/14 | Fri 9/12/14 |
| 9 | Collect Soil Samples | 1 day | Mon 9/8/14 | Mon 9/8/14 |
| 10 | **Geotechnical Analysis** | **15 days** | **Mon 9/8/14** | **Fri 9/26/14** |
| 11 | Obtain Pervious Soil Reports | 3 days | Mon 9/8/14 | Wed 9/10/14 |
| 12 | Analyze Soil Properties | 13 days | Wed 9/10/14 | Fri 9/26/14 |
| 13 | **Hydro Analysis** | **15 days** | **Wed 9/24/14** | **Tue 10/14/14** |
| 14 | Collect Upstream Data | 5 days | Wed 9/24/14 | Tue 9/30/14 |
| 15 | Hydrostatic Analysis | 10 days | Wed 10/1/14 | Tue 10/14/14 |
| 16 | **Dam Breach Analysis** | **18 days** | **Wed 9/24/14** | **Fri 10/17/14** |
| 17 | Hazard Analysis Downstream | 18 days | Wed 9/24/14 | Fri 10/17/14 |
| 18 | **Dam Failure Mode Analysis** | **25 days** | **Mon 10/20/14** | **Fri 11/21/14** |
| 19 | Overtopping Analysis | 5 days | Mon 10/20/14 | Fri 10/24/14 |
| 20 | Sliding Analysis | 5 days | Mon 10/27/14 | Fri 10/31/14 |
| 21 | Bearing Capacity Analysis | 5 days | Mon 11/3/14 | Fri 11/7/14 |
| 22 | Earthquake Failure Analysis | 5 days | Mon 11/10/14 | Fri 11/14/14 |
| 23 | Internal Erosion Analysis | 5 days | Mon 11/17/14 | Fri 11/21/14 |
| 24 | **Final Report** | **25 days** | **Mon 11/10/14** | **Fri 12/12/14** |
| 25 | Report | 25 days | Mon 11/10/14 | Fri 12/12/14 |
| 26 | Presentation | 0.13 days | Fri 12/12/14 | Fri 12/12/14 |




*Proposed Gantt Chart*

GANTT CHART

| | Task Name | Duration | Start | Finish |
|---|---|---|---|---|
| 1 | **Literature Review** | **75 days** | **Mon 8/25/14** | **Fri 12/5/14** |
| 2 | Research on Dam Failures | 75 days | Mon 8/25/14 | Fri 12/5/14 |
| 3 | Background Information | 10 days | Mon 8/25/14 | Fri 9/5/14 |
| 4 | Document Procurement | 5 days | Mon 8/25/14 | Fri 8/29/14 |
| 5 | **Website** | **75 days** | **Mon 8/25/14** | **Fri 12/5/14** |
| 6 | Website | 75 days | Mon 8/25/14 | Fri 12/5/14 |
| 7 | **Site Surveying/Inventory** | **15 days** | **Mon 8/25/14** | **Fri 9/12/14** |
| 8 | Obtain Elevation Data | 15 days | Mon 8/25/14 | Fri 9/12/14 |
| 9 | Collect Soil Samples | 1 day | Mon 9/8/14 | Mon 9/8/14 |
| 10 | **Geotechnical Analysis** | **15 days** | **Mon 9/8/14** | **Fri 9/26/14** |
| 11 | Obtain Pervious Soil Reports | 3 days | Mon 9/8/14 | Wed 9/10/14 |
| 12 | Analyze Soil Properties | 13 days | Wed 9/10/14 | Fri 9/26/14 |
| 13 | **Hydro Analysis** | **15 days** | **Wed 9/24/14** | **Tue 10/14/14** |
| 14 | Collect Upstream Data | 5 days | Wed 9/24/14 | Tue 9/30/14 |
| 15 | Hydrostatic Analysis | 10 days | Wed 10/1/14 | Tue 10/14/14 |
| 16 | **Dam Breach Analysis** | **18 days** | **Wed 9/24/14** | **Fri 10/17/14** |
| 17 | Hazard Analysis Downstream | 18 days | Wed 9/24/14 | Fri 10/17/14 |
| 18 | **Dam Failure Mode Analysis** | **25 days** | **Mon 10/20/14** | **Fri 11/21/14** |
| 19 | Overtopping Analysis | 5 days | Mon 10/20/14 | Fri 10/24/14 |
| 20 | Sliding Analysis | 5 days | Mon 10/27/14 | Fri 10/31/14 |
| 21 | Bearing Capacity Analysis | 5 days | Mon 11/3/14 | Fri 11/7/14 |
| 22 | Earthquake Failure Analysis | 5 days | Mon 11/10/14 | Fri 11/14/14 |
| 23 | Internal Erosion Analysis | 5 days | Mon 11/17/14 | Fri 11/21/14 |
| 24 | **Final Report** | **25 days** | **Mon 11/10/14** | **Fri 12/12/14** |
| 25 | Report | 25 days | Mon 11/10/14 | Fri 12/12/14 |
| 26 | Presentation | 0.13 days | Fri 12/12/14 | Fri 12/12/14 |




*Final Gantt Chart*