

RocScience – Slope Stability Modeling Software

RocScience's Slide is a program that was used to evaluate Odell Dam slope stability conditions. Slide is a 2D limit equilibrium slope stability program that was used for evaluating the factor of safety regarding failure by sliding of an embankment or slope for the dam. The program computes results in terms of factors of safety and slope circle radii and origins, as well as global stability failure could occur. For this project, the third cross sectional area was chosen out of the seven cross sections. Cross section three was chosen since it is the best representation of all the cross sections because of its characteristics.

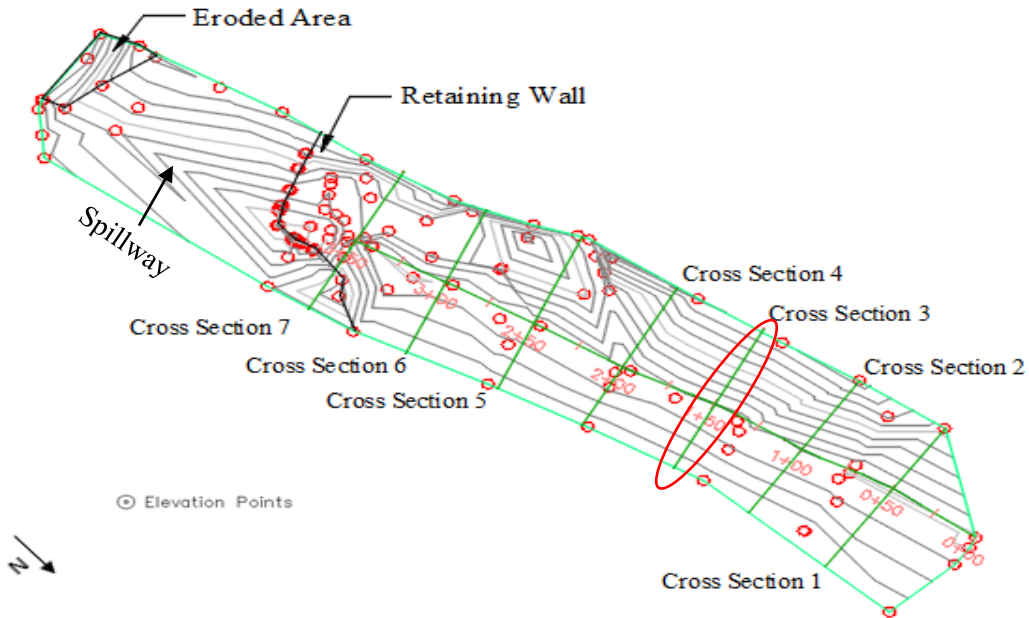


Figure 1: Overview of all AutoCAD generated cross-sections.

Figure 5 above is the surveying data retrieved using a total station and the AutoCAD software. For the RocScience Slide program, the parameters needed were the cohesion of 130 psf, the friction angle of 25.1 degrees, the unsaturated unit weight is 106 pcf and the saturated unit weight is 120 pcf.

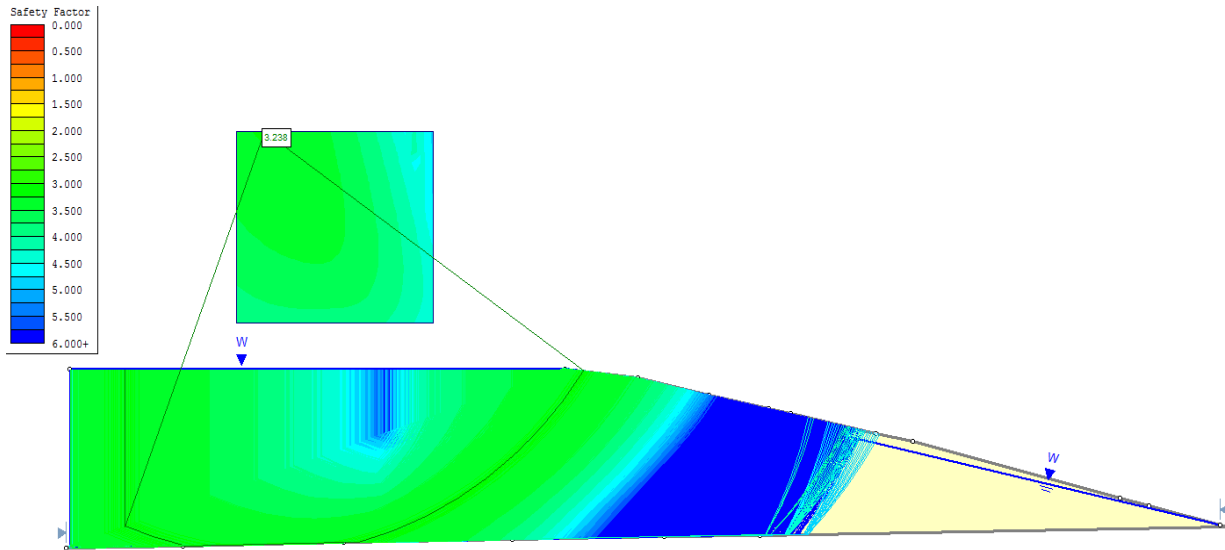


Figure 2: Results from a Heel to Toe Analysis

Figure 6, shown above, is a visual representation of the computed result from Slide showing various factors of safety (F.S.) which represent the stability of the soil. The square box above shows the minimum surface factor of safety when the results are calculated. The computation method used to determine the slip surfaces is the Bishop Method, which is designed for circular slip surfaces such as in cross section 3.

The Heel to Toe analysis means that the slopes will be analyzed using the highest elevation on the right which extends to the lower left elevation on the cross section. The water line is necessary to determine how the soils will react when pressurized under water load conditions. A F.S. higher than 1.5 is considered safe as a standard of practice. The F.S. for the minimum slip surface is 3.238.

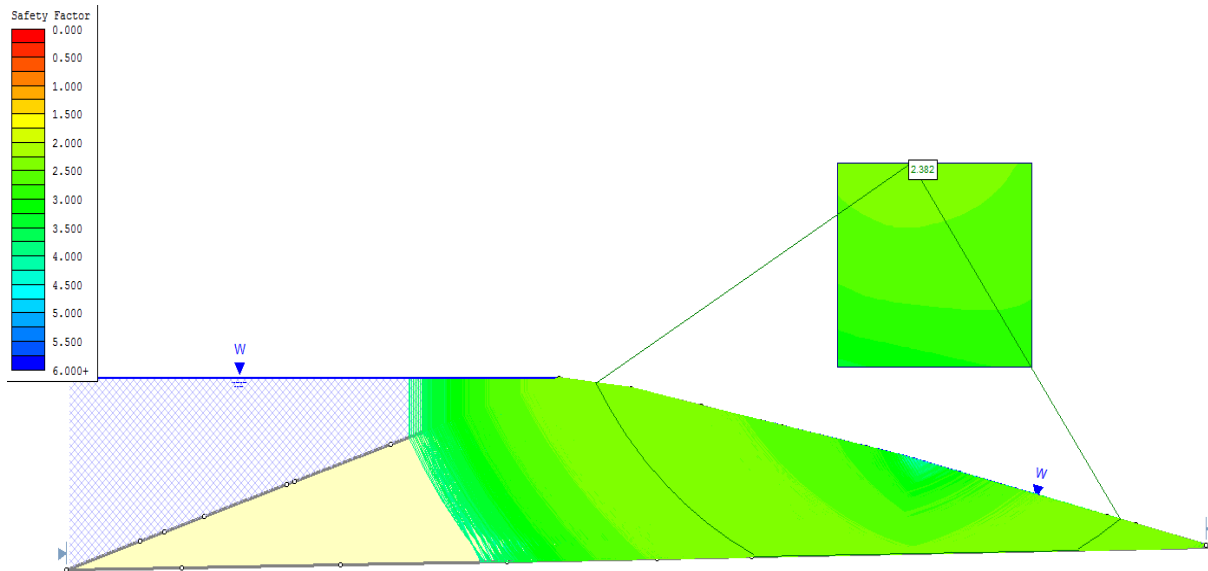


Figure 3: Results from a Toe to Heel Analysis

The analysis was for Figure 7, shown above, was conducted under the same process as in the Heel to Toe cross section, the only difference within this analysis is that the cross section was analyzed from Toe to Heel. In this figure, for a downstream slope failure, the F.S. is 2.382.

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Hydrologic Analysis

A hydrologic analysis is being conducted to determine the adequacy of the spillway located on the southern side of Odell Dam. Due to the size of the watershed, the Rational Method is insufficient for determining the amount of water runoff generated, therefore the analysis will be conducted using the Soil Conservation Service (SCS) methods. This hydrologic analysis will include: a watershed delineation, rainfall intensities, curve numbers, time of concentrations, reservoir storage, and a PondPack hydrologic modeling software analysis.

Watershed Delineation

The watershed was delineated, by using an ArcGIS topographic map. This map was then imported into AutoCAD, where lines could be drawn to follow the contours that separate our watershed from others. The overall area of the watershed was approximated to 19.8 square miles. The watershed delineation can be found in Appendix G. The use of only one watershed was done to obtain a conservative estimation of the water runoff generated. The breakdown of the watershed into sub basins would produce a higher time of concentration, resulting in a lower peak flow. [9]

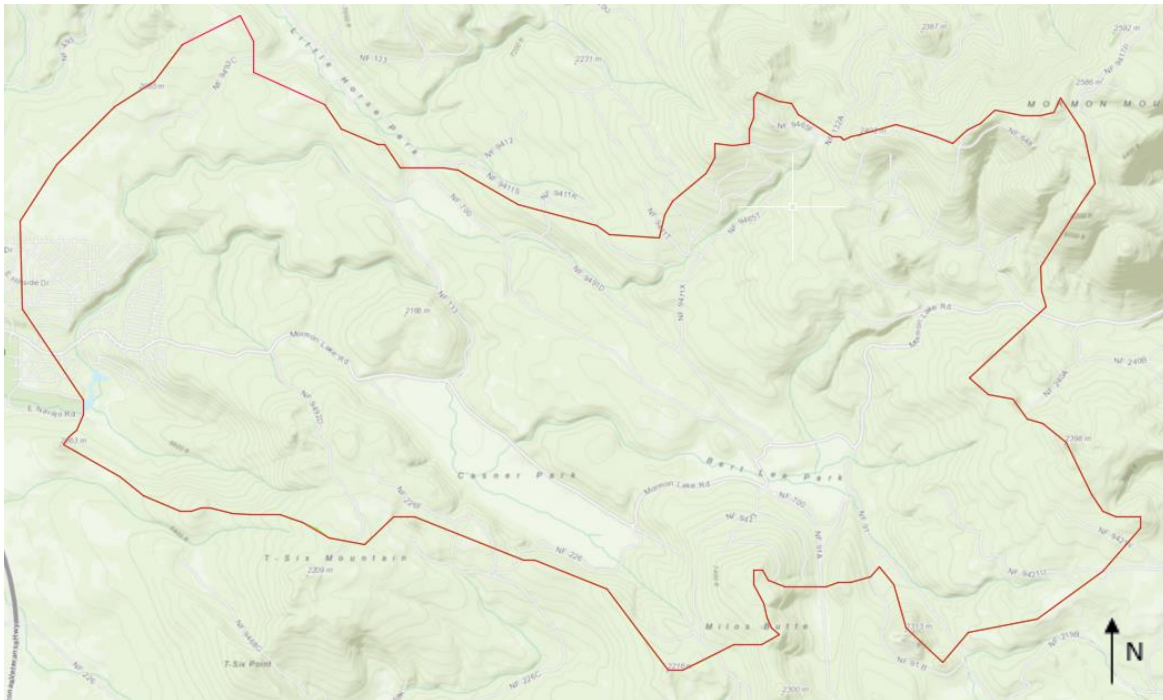


Figure 4: Odell Dam's Contributing Watershed.

Rainfall Intensities

Rainfall Intensities were found using National Oceanic and Atmospheric Administration (NOAA) Atlas 14. The intensities were established by inputting the exact coordinates of the project site into the database. Refer to Appendix H for the NOAA Atlas 14 rainfall intensities. [10]

Curve Numbers

The curve number considers multiple characteristics of the terrain within a given watershed, such as the soil group, land use, and treatment of the land. The value assigned to a curve number is indicative of the runoff coefficients of the land as well as the infiltration rate of the soil. Larger curve numbers result in more water runoff generated. Pre-burn and 80% post-burn, meaning 80% of the watershed has been burned, curve numbers were researched for this analysis.

For the pre-burned watershed analysis, Dr. Charles Schlinger provided documentation of the Oak Creek Flood Warning Study, which provided a full watershed analysis for the watershed contributing to Oak Creek. The study lists curve numbers for the Oak Creek watershed. Part of this large watershed was in close proximity to the Odell Lake watershed, therefore the values were used for this project, as deemed valid by the projects' Technical Advisor. The curve number to be used for the pre-burn scenario is 66. Appendix I shows the images used to obtain this curve number. [11]

Post-burn curve numbers require high precision and complex analysis to obtain, and for this reason a curve number was researched. The USDA Forest service provides many different curve numbers for post-burn conditions, ranging in value from 75-91. Due to this project using an 80% post-burn scenario and a conservative analysis, a curve number of 85 was chosen. [12]

Time of Concentration

The SCS Lag Time method was used to determine the time of concentration for both the pre-burn and 80% post-burn conditions. The Lag Time method requires that the watershed under analysis to be between 300-2000 acres. [13] The following is the SCS Lag Time equation:

$$t_c = \frac{1.67 * L^{0.8} * \left(\frac{1000}{CN} - 10\right)^{0.7}}{1900 * S^{0.5}}$$

t_c = time of concentration (hours)
 L = length of longest flow path (feet)
 CN = curve number
 S = average watershed slope (%)

Table 1 summarizes the values needed to determine the time of concentrations as well as the values derived.

Scenario	Length (feet)	Slope (%)	CN	Tc (hours)
Pre-Burn	63212	13.18	66	.819
80% Post-Burn	63212	13.18	85	.563

Table 1: Time of Concentrations.

Reservoir Storage

The size and shape of the reservoir is needed to determine the storage capacity as a function of the water level elevation. ADWR has provided documentation for the storage of Odell Lake. The storage indication curve has been calculated from the crest of the spillway to the top of the dam, meaning that the analysis will be completed for a full reservoir. [14] During multiple site visits to the project location it was noted that the reservoir was as full as the crest of the spillway Figure 9 listed below is the reservoir storage indication curve.

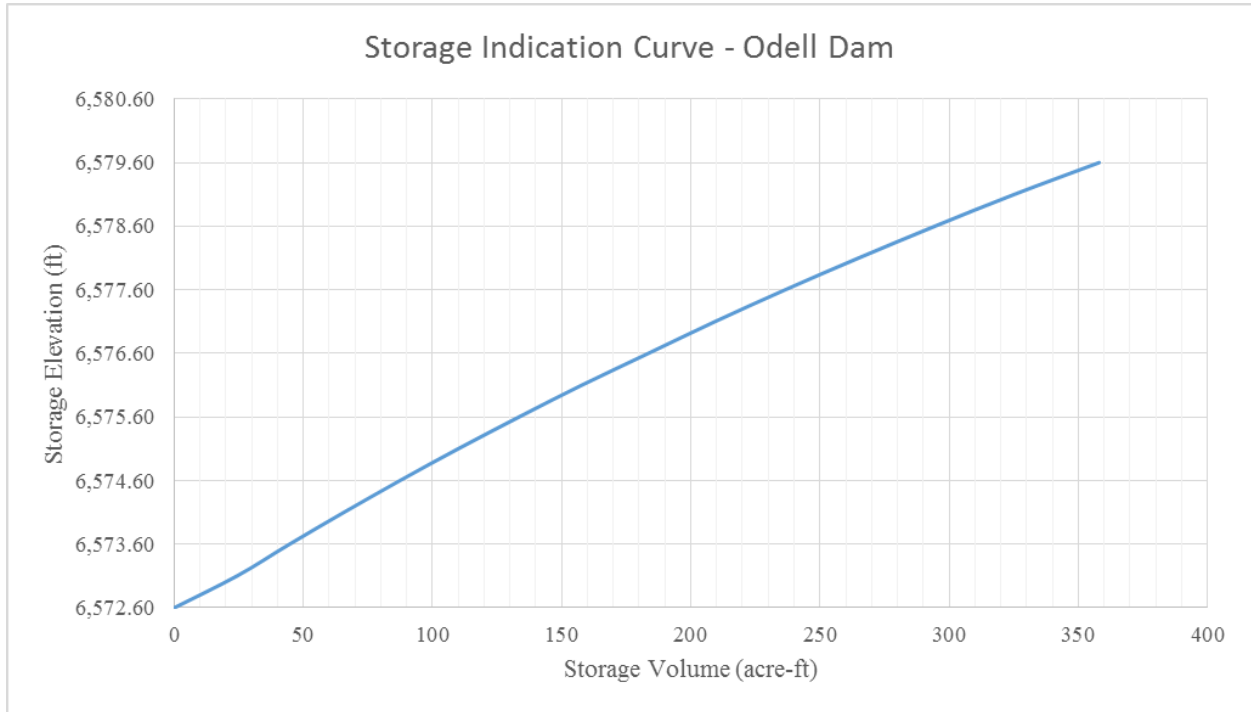


Figure 5: Reservoir Storage Indication Curve.

Bentley PondPack – Hydrologic Modeling Software

Bentley PondPack has been used to establish the amount of water runoff generated within the watershed that contributes to the Odell Dam, as well as determining the peak flows through the spillway for various storm events. Figure 10 shows an image of the model made within PondPack. The runoff generated within the Watershed travels to Odell Lake, which then routes the water through the Pond Outlet Exit (POE-1) and finally out of the Spillway and Outlet (O-1). For the model to run properly, the software needs time depth tables, area of watershed, time of concentrations, and curve numbers.

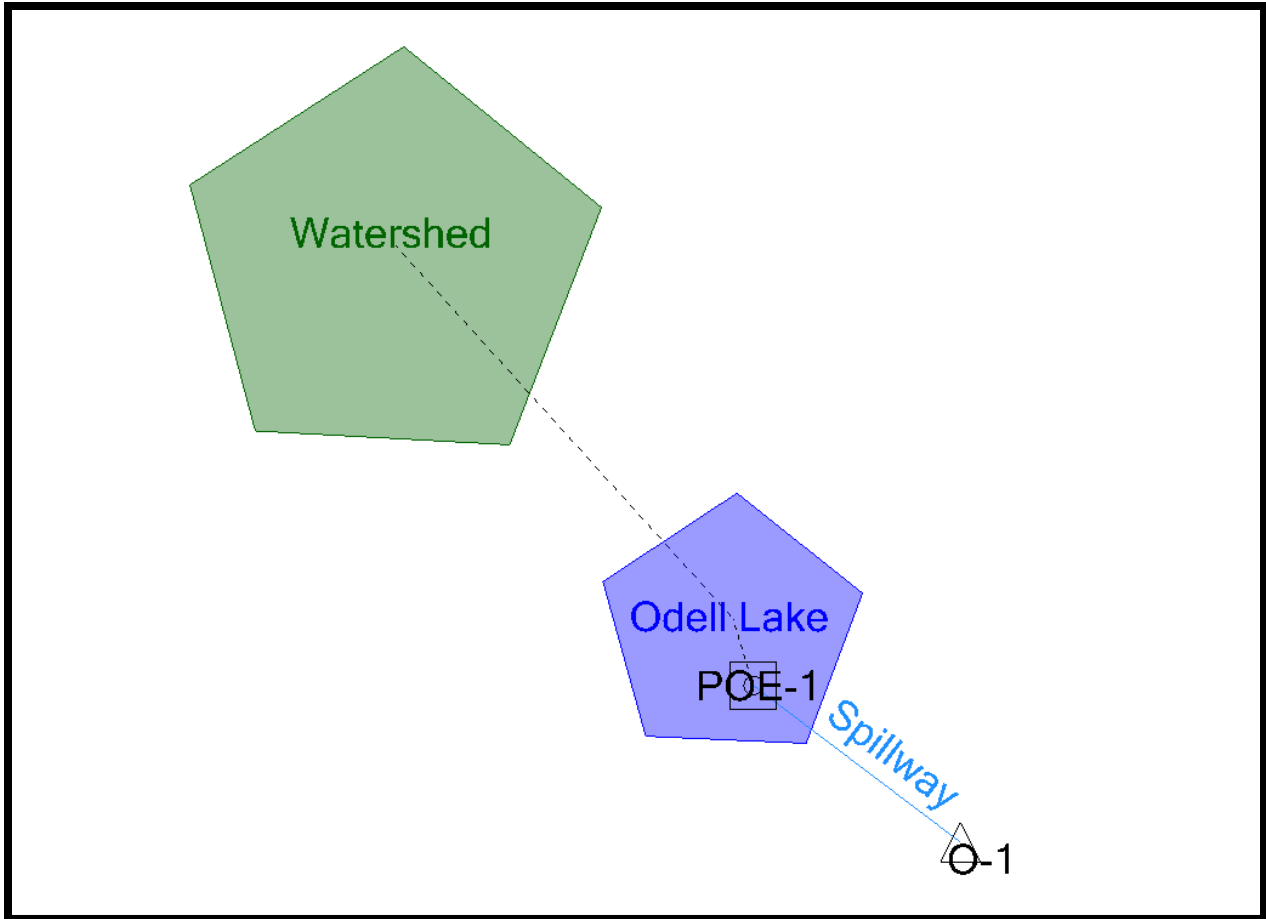


Figure 6: Bentley PondPack Model

NOAA Atlas 14 provided data that was used to make the time depth tables needed within PondPack, but the model required data that had to be linearly interpolated due to gaps in the data. PondPack requires time depth tables that have data for a specific increment of time. This analysis used 30 minute intervals for a duration of six hours, whereas NOAA only provided data for 30 minute, 1 hour, 2 hour, 3 hour, and 6 hour duration depths. Six hours is a standard storm duration used by ADWR when analyzing spillway capacity. Tables J-1 and K-1, found in Appendix J and K, show the time depth tables generated using the NOAA Atlas 14 and the curves generated within PondPack.

The watershed area, time of concentrations, and curve numbers derived are summarized in the following table. These numbers along with the storage indication curve are the specific parameters

PondPack Parameter	Pre-Burn	80% Post-Burn
Watershed Area (acres)	12,669.640	12,669.640
Time of Concentration (hours)	0.819	0.563
Curve Numbers	66	85

needed for the PondPack model to run its analysis. Table 2 shows the parameters of the PondPack

Table 2: PondPack Parameters.

software.

Table 3, shown below, lists the peak inflows generated from the watershed, the peak outflows through the spillway, and whether the spillway is adequate for that specific storm event. Figures L-1 to L-8 in Appendix L. show the hydrographs generated in PondPack for the runoff generated from the watershed.

Storm Events	Pre-burn Conditions			Post-burn Conditions		
	Peak Inflow (cfs)	Peak Outflow (cfs)	Spillway Adequate?	Peak Inflow (cfs)	Peak Outflow (cfs)	Spillway Adequate?
2 Year	281.07	204.73	Yes	3443.26	1519.19	Yes
5 Year	538.79	411.23	Yes	6900.47	3167.07	Yes
25 Year	2914.50	1457.56	Yes	15484.56	N/A*	No
50 Year	4530.26	2401.13	Yes	19860.76	N/A*	No
100 Year	6617.25	3614.45	Yes	24891.91	N/A*	No
200 Year	9073.63	N/A*	No	30404.36	N/A*	No
500 Year	13164.09	N/A*	No	38575.88	N/A*	No
1000 Year	17056.60	N/A*	No	45669.15	N/A*	No

Table 3: PondPack Inflow and Outflow

- *Spillway capacity ~ 4500 cfs. After spillway capacity is reached, PondPack will not give outflow data.

Final Results

RocScience Slide Modeling

A geotechnical model of an Odell Dam cross-section was created within Slide to show the F.S. for the minimum side slope slip surface. The Heel to Toe analysis resulted in a F.S. of 3.238, whereas the Toe to Heel analysis lead to a F.S. of 2.382. The Toe to Heel analysis shows that the F.S. of 2.382 is the limiting value, however, it is larger than 1.5 and therefore safe.

Bentley PondPack Modeling

A hydrologic model of Odell Lake, Odell Dam, and the surrounding watershed was created to determine the flows generated during various storm events as well as the watershed during pre-burn and 80% post-burn conditions.

The pre-burned watershed model resulted in the spillway capacity being reached between the 100-200 year storm events and between the 5-25 year storm events for the 80% post-burn model.

The PondPack model will not give outflow results once the spillway capacity has been reached, subsequently the software displays warning messages noting that the inflow is greater than the outflow.

Post-burn Discussion

Given Northern Arizona's terrain and vegetation, post burn hydrologic studies become necessary when analyzing larger watersheds.

A post-burned watershed drastically reduces the time of concentration, which in-turn increases the water runoff generated exponentially. This has the probable effect of creating detrimental damage to areas located downstream of the dam.

Another adverse effect would be the accumulation of debris from the burned vegetation. The debris collecting and making its way to the reservoir decreases its storage capacity as well as increasing the weight of the homogenous water mixture. The added debris will result in higher stresses on the dam as well as creating blockages in the spillway.

Final Recommendations

It is encouraged that Pinewood Country Club, look into previous ADWR recommendations to preform basic maintenance on the dam. This maintenance includes but is not limited to rodent holes, dense vegetation, cracks within the training wall and spillway, and debris within outlet of the spillway.

Our analysis also shows that the dam's spillway cannot hold the minimum incoming design flood required by ADWR. Our analysis shows that the spillway will be inadequate between the 100 and 200 year storm event for pre-burn conditions. The team suggest that the spillway should be re-examined, at the cost of Pinewood Country Club.

These conditions dramatically change once 80% post-burn conditions were examined, to which the dam's spillway indicated inadequate between 5 and 25 year storm event.