NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Final Design Report

Odell Dam Safety Analysis

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1. **Project Description**

Project Name: Odell Dam Safety Analysis

Project Location: The dam in consideration is the Odell dam, located in Munds Park, Arizona. This is roughly 20 miles south of Flagstaff, Arizona. The location of the dam at center is N34°56’0.0666”, W111°38’0.5562” on the NAD83 coordinate system.

The project site can be seen in Figure 1. [1]

Figure 1: Project Site, Odell Dam, Munds Park, Arizona.

1.1 Project Understanding

The purpose of this project is to perform a safety analysis for Odell Dam, and to evaluate whether the dam can safely pass flood flows. Geotechnical and hydrologic methods will be used to evaluate aspects of dam safety. Analyses performed will follow Arizona Department of Water Resources (ADWR) guidance's and standards of practice.

The team will also consider post-burn conditions of the watershed that may impact the safety of the dam. Due to the high fire hazards in the Northern Arizona region during the months prior to and after the monsoon season, consideration post-fire floods is an important aspect of evaluation for this structure.

1.2 Current Condition

The dam is an earthen dam, gravity fed, and its primary purpose is the storage of water as a recreational lake. The dam's construction was finished in the 1940s, with multiple changes made to Odell Dam the last in 1983. [2] These changes range from reconstruction to spillway relocation. According to ADWR documentation, the dam measures to be 20 feet in height and is 460 feet long. The dam has a concrete spillway located at the south end of the structure. [3] The spillway measures 80 feet wide and 7 feet in height. The dam's status has been deemed "unsafe, non-emergency requiring remediation". [4] The current condition can be seen in Figure 2.

Figure 2: Current state of the dam's spillway.

Located on the south end of the project site. The dam's spillway currently has evidence of erosion and left over debris of the old spillway when it failed in 1983. Photograph taken by Braedan Hinojosa

1.3 Constraints and Limitations

Some potential challenges the team has experienced are established to be the following:

- Not all preexisting data could be found.
    - Missing data and documentation.
    - Outdated data and documentation.

Example: The information for the reservoir's storage capacity was limited to the storage area from the crest of the spillway to the top of the dam, and did not include any information on what the storage volume was underneath the assumed water line.

1.4 Approach

Information pertinent to a dam safety analysis includes; the existing conditions of the dam, purpose of the dam, engineering properties of the soil within the dam and the surrounding area, watershed conditions and forecasted runoff, and current geostructural conditions of the dam.

The technical approach that has been established is a series of analyses and are as follows:

1. A survey analysis to establish key features such as; height, length, and width of the dam.
2. A side slope stability analysis to determine the integrity of the dam with the water elevation equal to the top of the dam.
3. A hydrologic analysis for a spillway failure and overtopping.
4. A failure assessment to generate the most likely failure methods.

The team has been asked by Mark Lamer to provide qualitative answers for the following questions:

1. What storm event will contribute to a dam failure?
2. Determine the adequacy of the spillway capacity and side slope stability.
3. A discussion on the effects of post-fire flooding.

2. Background

2.1 Need for Dam Safety Analysis

Dam safety analysis is conducted to determine the potential hazards associated with existing dams. Many earthen dams, like that of Odell Dam, were built long ago with less restrictions and safety protocols. It is important to conduct geotechnical and hydrologic analyses of older dams to ensure that they do not pose a threat.

The Federal Emergency Management Agency [FEMA] was a resource reviewed to help with understanding the impacts of large storm events. The flood maps provided by FEMA detail the flooding that may occur during a 100 year or a 500 year storm with Odell Dam intact. This is information is useful in understanding where water will collect during a storm, but does not explicitly demonstrate the dam failing. See Appendix F for the FEMA flood maps. [6]

2.2 Past Dam Failures

Odell Dam was originally built with an earthen spillway located on the north end of the dam. In November of 1977, the owners of the dam began construction on a concrete spillway located at the south end of the dam. This construction was met with trouble in March of 1978 when the surrounding area received a rain storm that melted the snow cover. This massive flow of water undermined the spillway construction and caused the partially constructed spillway to pipe. Figure 3, shown on the right, displays an image during this failure.

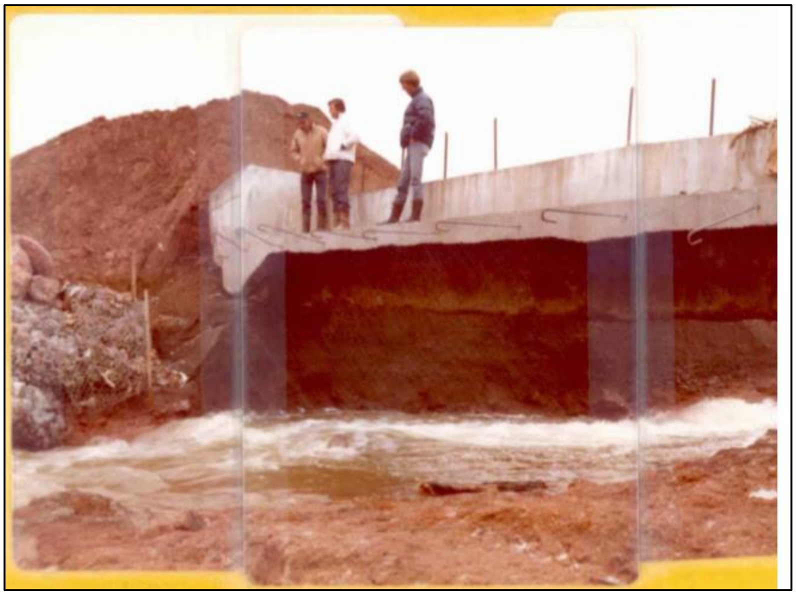

Figure 3: Previous Spillway Failure.
Piping through the bottom of the Odell Dam's spillway, during construction. Photograph by ADWR.

Construction continued and the spillway was completed in July of 1978. The spillway was designed and built with flashboards to create a weir during times of low precipitation. In December of the same year, a large storm occurred, with the flashboards attached. The flashboards, having been attached, caused an impedance on the large flow. This impedance created large forces that ripped out the flashboards and caused a catastrophic failure of the spillway, completely ripping out the structure.

The spillway was then rebuilt sometime in 1980 and is still in use to this day. [3]

3. Testing and Analysis

3.1 Surveying

A survey of the dam was conducted to gather cross-sections of the dam geometry. This geometry is needed for side slope stability modeling.

Surveying was done using a total station and prism rod. To set up the total station, three points were taken on-site at the dam location, two of which had unknown elevations and a third of which had a known elevation and became the benchmark to tie all of the points into existing elevations. A total of 130 points were taken for the dam geometry and spillway dimensions. The total station was set up directly on the south end of the dam to shoot all of the points, then repositioned to a location 530 feet away to establish the benchmark and tie the points in. Figure 4 is a visual representation of the point data loaded into AutoCAD, rendering an elevation profile. The raw point data can be found in Appendix B.

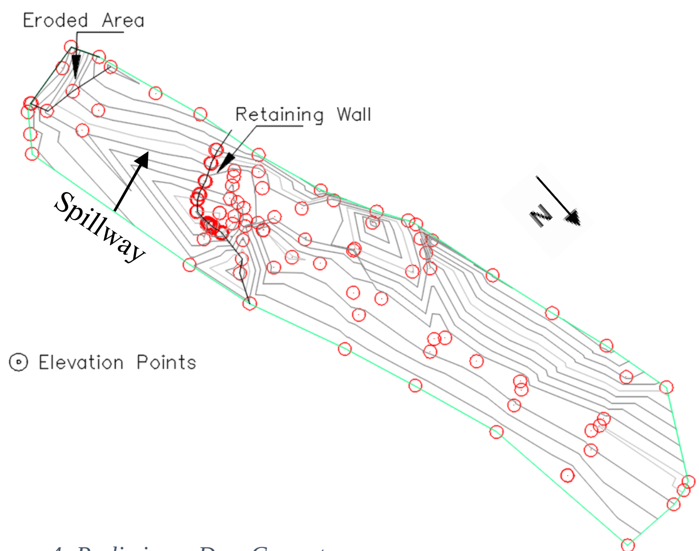

Figure 4: Preliminary Dam Geometry

3.2 Geotechnical Analysis

A geotechnical study was completed to understand how the soils in the watershed interact with rain events, such as 50 and 100 year storm events. The steps take to complete this analysis were collecting soil samples from the watershed, testing and analyzing soils in the lab, classifying the soils, and finally using RocScience to evaluate slope stability of the dam.

3.2.1 Soil Sampling

Before conducting a site visit to complete field work, the team prepared equipment for sampling. This equipment includes; a small handheld shovel, see through plastic bags with one gallon capacity, labels for bag, pens, and a bucket for carrying soil samples. A total of 7 soil samples were collected from random locations around the watershed. Each of these locations were taken from areas of different terrain type, but were representative of the surrounding areas, which varied from sample to sample. Before collecting the samples from each site, pictures were taken to establish a record of the terrain type, and the locations were noted on a map. See Appendix D for the locations of the soil samples collected.

3.2.2 Sieve Analysis

After all the soil samples were gathered, each sample was sieved in accordance with the methods provided by "*Soil Mechanics, Laboratory Manual 6^th^ Ed., Das*." [7] Table C- 1 in Appendix C lists the sieving results of each sample collected. Figure C-3 in Appendix C shows the plot generated by Table C- 1, which is used to classify the soil samples.

3.2.3 Soil Classification

The classification for each sample was determined using Figure E-1 in Appendix E which was adapted from ASTM D2487. In order to use the figure, the percentages of gravel, sand and clay within each sampled are required along with the values of D_{60}, D_{10}, D_{30}, C_u and C_c. D_{60}, D_{10} and D_{30} represent the particle sizes. D_{10} is the particle size that corresponds to 10% passing, in other words, 10% of the soil particles are finer than D_{10}, with D_{60} having 60% passing and D_{30} having 30% passing. Cu is the coefficient of uniformity and C_c is the coefficient of curvature. [8] The following equations relate the particle sizes to C_u and C_c:

$$C_u = \frac{D_{60}}{D_{10}}$$

Equation 1

$$C_c = \frac{D_{30}^2}{D_{10} * D_{60}}$$

Equation 2

Table C-2 in Appendix C, lists the values necessary for classifying the soil, as well as the soil classification.

3.2.4 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.

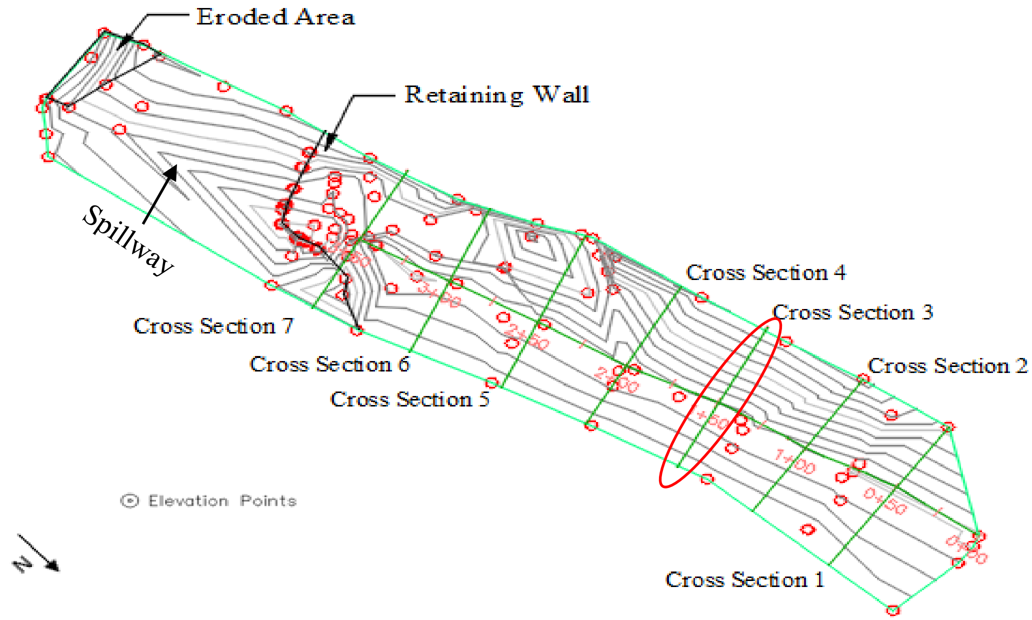

Figure 5: Overview of all AutoCAD generated cross-sections.

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.

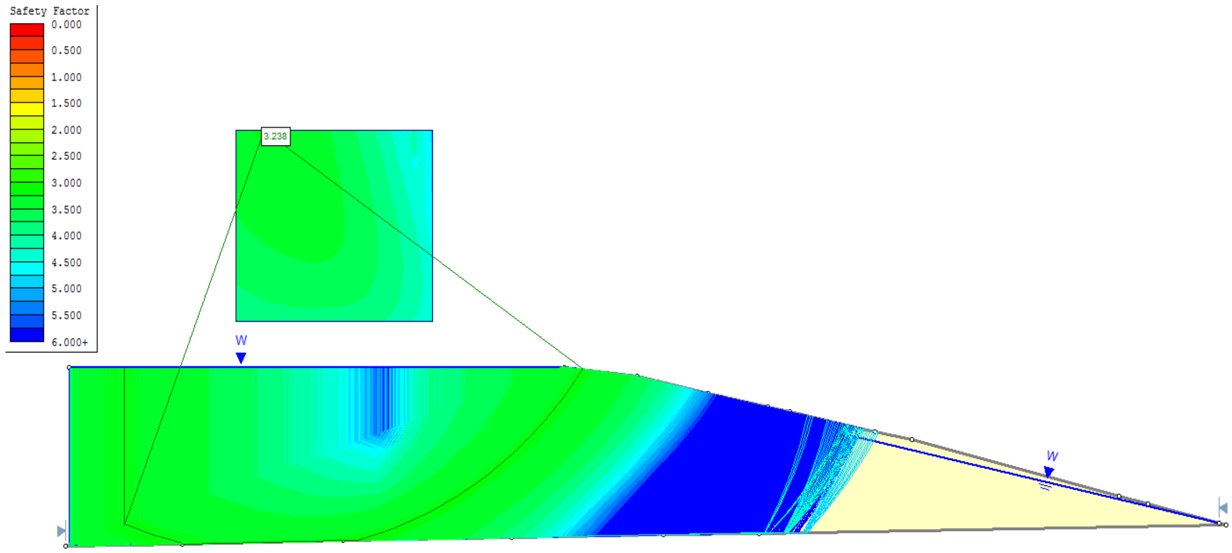

Figure 6: Results from a Heel to Toe Analysis

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.

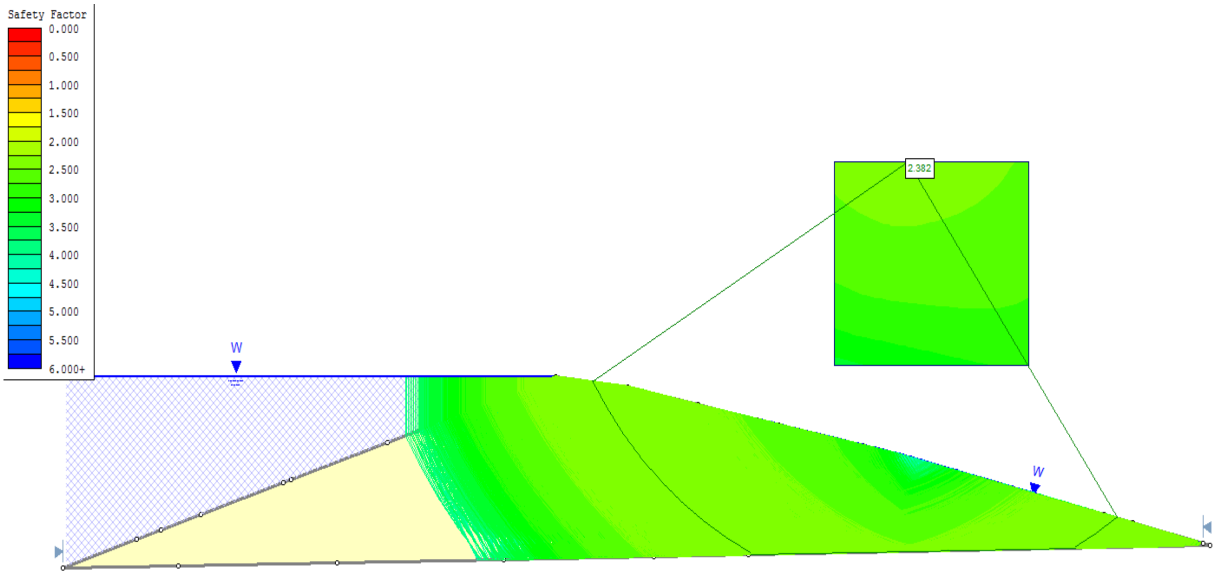

Figure 7: Results from a Toe to Heel Analysis

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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3.3 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.

3.3.1 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]

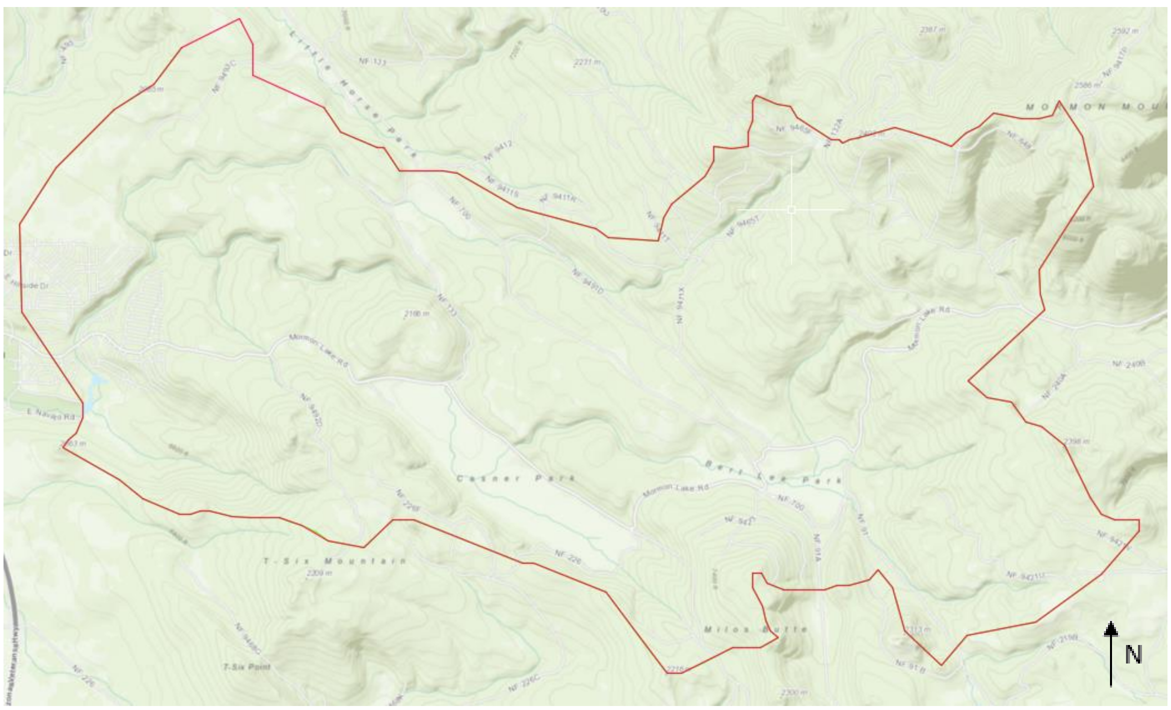

Figure 8: Odell Dam's Contributing Watershed.

3.3.2 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]

3.3.3 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]

3.3.4 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:

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

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.

3.3.5 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 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.

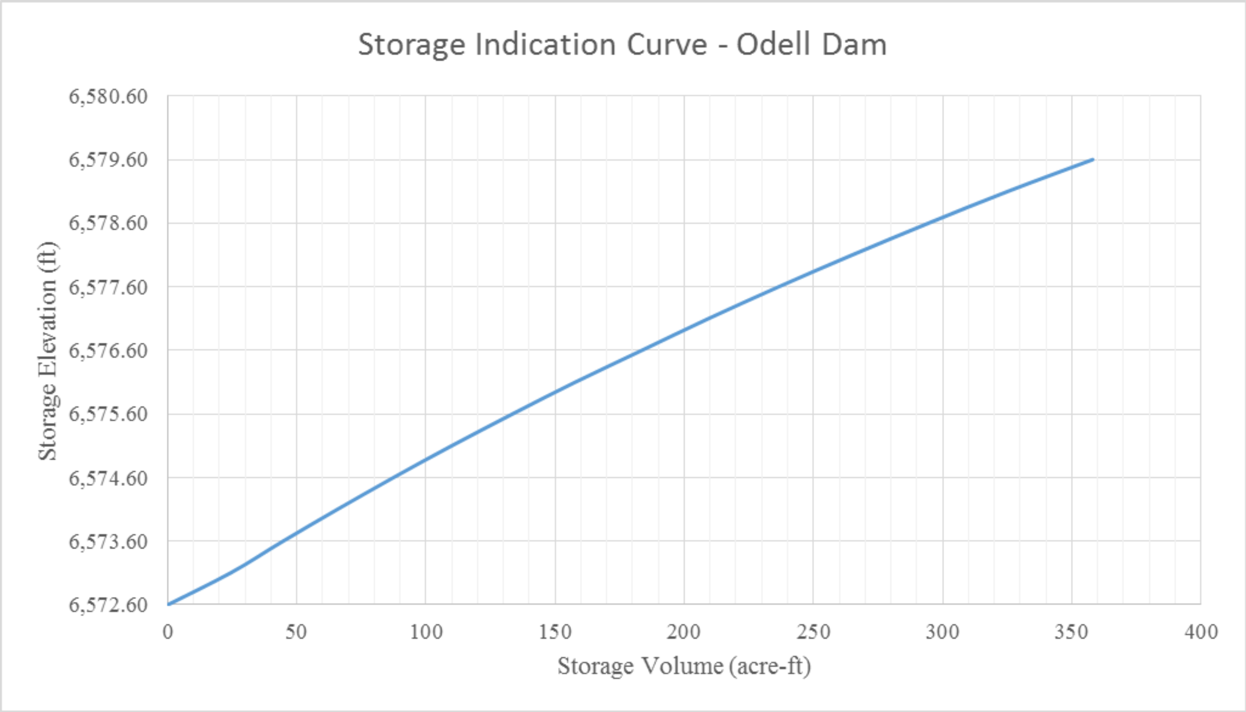

Figure 9: Reservoir Storage Indication Curve.

3.3.6 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.

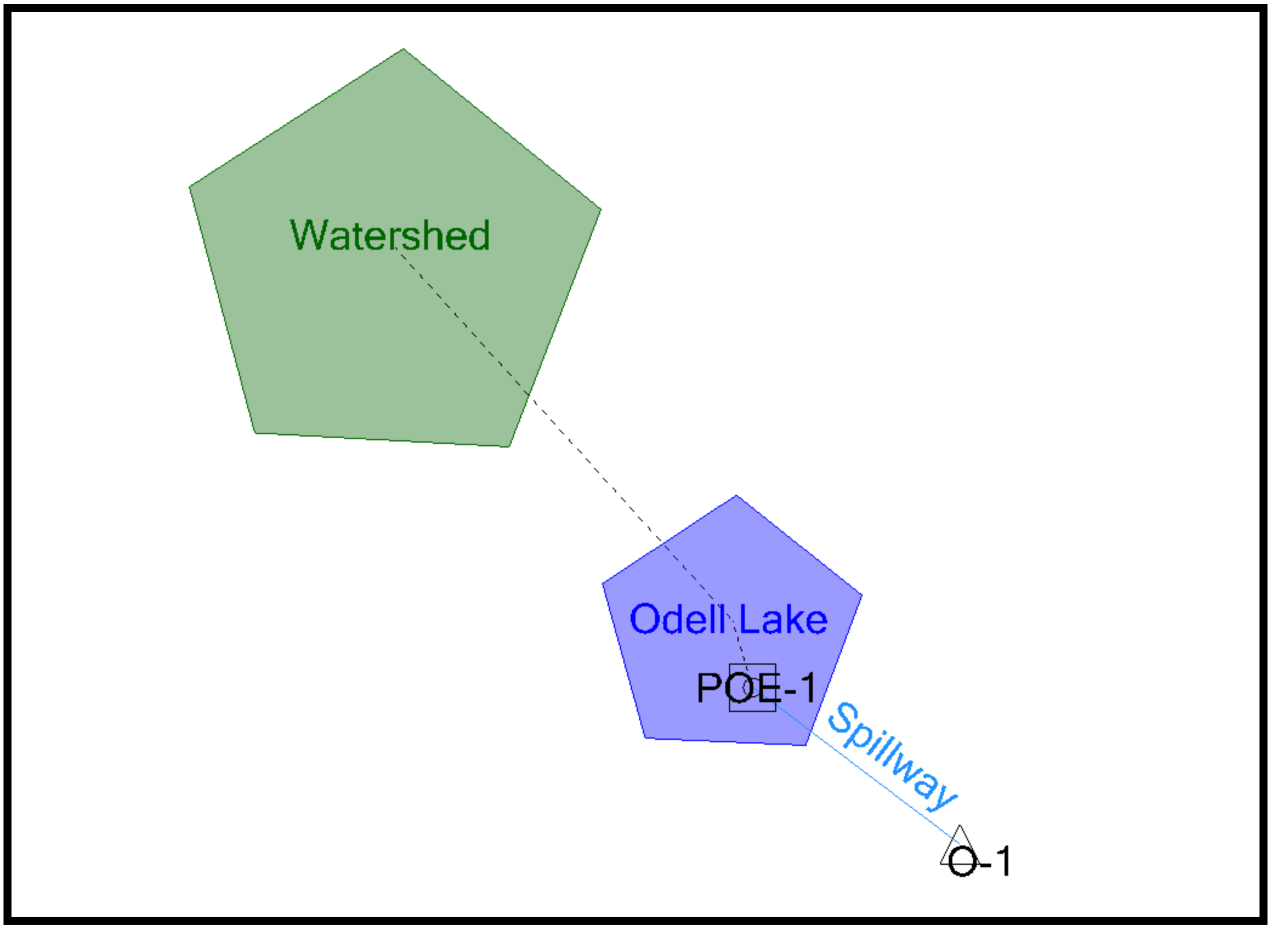

Figure 10: Bentley PondPack Model

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.*

4. Final Results

4.1 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.

4.2 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.

4.3 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.

4.4 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.

5. Summary of Project Cost

5.1 Post Cost Analysis

The overall cost for this project was calculated after the total hours for the project was established. Table 4 lists the total hours per team member per task is established. The total amount of time spent conducting this project were 510 hours.

Task Hours	Task								
Team Member	Management	Lit. Review	Surveying	Geotech.	Hydrologic	RocScience	PondPack	Reporting	Total
Braedan	25	15	10	8	20	0	20	32	130
Chandler	13	15	10	6	6	0	40	30	120
Sharlot	17	32	5	6	0	0	0	20	80
Ibrahim	13	12	5	20	0	30	0	20	100
Yaowan	13	12	5	20	0	10	0	20	80

Table 4: Final Summary of Project Hours.

Table 5 lists the overall hours and cost that were needed for completion of the Odell Safety Analysis. The project cost was broken down to the hours spent in each task at a billable rate of $75/hour. The final cost for this project was $38,250.

Cost									
Task	Management	Lit. Review	Surveying	Geotech.	Hydrologic	RocScience	PondPack	Reporting	Total
Total Hours	81	86	35	60	26	40	60	122	510
Total Cost ($)	6075	6450	2625	4500	1950	3000	4500	9150	38250

Table 5: Overall Final Cost of Analysis.

The final cost differs were under budget by $41,850 from the cost estimated in the project proposal. This is due to the project hour's estimation being higher than that of the actual amount of hours it took to complete the project. The billable rate also changed, as one rate was used through the project instead of three different rates. Table 6 is listed below to show a comparison of the preliminary estimated costs of the project.

Cost									
Task	Management	Lit. Review	Surveying	Geotech.	Hydrologic	RocScience	PondPack	Reporting	Total
Total Hours	100	40	160	100	100	100	120	150	870
Total Cost ($)	0	3888	15552	10800	10800	10440	12960	15660	80100

Table 6: Proposal Estimated Cost of Analysis.

5.2 Project Schedule

The Final Gantt Chart can be viewed in Appendix M, while the Proposal Gantt Chart can be seen within Appendix N. The differences between the Proposal Gantt Chart and Final Gantt Chart are mostly due to deadlines having been change because the literature review was not fully completed within the first semester, and time conflicts occurred due to scheduling mistakes.

Addendums for Final Gant Chart:

The State of the Art Research task was renamed Literature Review.

Addition of RocScience Slide Modeling task.

Geotechnical Analysis task was revised to Geotechnical Sampling.

Dam Failure Analysis task was removed.

Hydrologic Modeling task was renamed PondPack Modeling.

6. References

[1] “Odell Dam, Munds Park, Arizona.” Map. *Google Maps*. Google, 14 October 2014. Web. 14 October, 2014

[2] ADWR Multiple Sources. “Correspondence May 78 – March 83.” *Arizona Department of Water Resources*. N.d.

[3] B.G. Scott. “Analytical Report on Spillway Failure.” *Arizona Department of Water Resources*. 1 February, 1980.

[4] Waleed Aboshanp (personal communication via Charles Schlinger, 3 October, 2014)

[5] ADWR Multiple Sources. “Correspondence June 86 – March 07.” *Arizona Department of Water Resources*. N.d.

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[13] Larry W. Mays. “Water Resources Engineering 1st Ed.” *John Wiley & Sons, Inc. New York, USA. 2001*

[14] ADWR Multiple Sources. “Correspondence June 86 – March 07.” *Arizona Department of Water Resources*. N.d.

7. <u>Appendices</u>

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Appendix A – ADWR Doc. Inventory	Table A-1
CENE 486C – Engineering Design Capstone	Source: ADWR
Odell Dam Safety Analysis	Date Created: 10-1-14

Document Number	Document Name	Date	By
34701	3-47 Failure Report	3/18/1980	B.G.Scott
34702	Analytical Report on Spillway Failure	2/1/1980	B.G.Scott
34703	Application of Repair	11/24/1982	ADWR
34704	Bekaert Gabions Manufacturer	N/A	Beraert Gabions
34705	Correspondance June86 -March07	-	ADWR Multiple Sources
34706	Correspondance May 78 - March 83	-	ADWR Multiple Sources
34707	Correspondance Oct 71 - Nov 06	-	ADWR Multiple Sources
34708	HASP Inflow Hydrograph	9/15/1976	-
34709	Investigation of Subsoils Odell Dam	12/23/1981	Fox Consulting Engineers and Geologist
34710	Monitor Project Fact Sheet	10/8/1981	Joseph E.Costa
34711	Odell Spillway Changes	10/10/1979	-
34712	Repair for Pinewood Development	2/11/1981	Jason M Burgess, ADWR
34713	Summary Table Hydrographs	9/18/1976	-
34714	T8110-1388-A	1/7/1976	-
34715	T8110-5933-A	12/17/1975	-
34716	T8110-8290-A	12/29/1975	-
34717	Unathorized Post Failure Construction	3/1/1982	K.M. Hussain
34718	WC - Bill - Hydrology	2/22/1973	-

Table A-1 lists the document inventory for all reference materials provided by Arizona Department of Water Resources.

*Documents are available upon request.

Appendix B- Surveying Raw Point Data	Table B-1
CENE 486C – Engineering Design Capstone	Source: Chandler, Braedan
Odell Dam Safety Analysis	Date Created: 9-28-14

1	-102.148	177.115	-0.318	SS	44	-191.176	320.027	0.302	SS	87	82.549	-44.225	-17.732	SS
2	-35.778	-20.747	-7.392	SS	45	-185.336	323.306	0.322	SS	88	100.686	-75.297	-18.460	SS
3	-62.415	20.674	-7.503	SS	46	-146.716	262.043	0.115	SS	89	107.660	-83.225	-16.682	SS
4	-93.736	86.301	-7.559	SS	47	-141.873	264.876	-1.018	SS	90	114.453	-102.543	-3.883	SS
5	-119.026	134.875	-7.452	SS	48	-116.044	207.289	-0.314	SS	91	100.042	-108.577	-3.438	SS
6	-150.957	190.838	-7.443	SS	49	-86.052	155.292	-0.344	SS	92	75.560	-129.943	-4.416	SS
7	-181.037	239.876	-7.566	SS	50	-59.034	111.473	-0.335	SS	93	70.401	-119.253	-8.402	SS
8	-181.013	239.844	-7.558	SS	51	-34.772	69.082	-0.278	SS	94	84.064	-101.367	-13.080	SS
9	-229.306	281.458	-7.514	SS	52	-11.718	29.799	-0.092	SS	95	70.867	-83.829	-13.164	SS
10	-201.016	313.101	-2.051	SS	53	-11.782	30.203	-0.040	SS	96	57.082	-94.768	-8.500	SS
11	-163.624	255.986	-2.211	SS	54	-2.015	10.140	-0.161	SS	97	75.527	-130.574	-2.220	SS
12	-132.676	203.045	-2.327	SS	55	40.060	26.807	-14.823	SS	98	69.750	-132.328	-2.080	SS
13	-95.693	145.122	-1.654	TR	56	15.616	69.644	-16.574	SS	99	54.344	-130.576	-2.711	SS
14	-70.203	95.950	-2.659	SS	57	-6.464	105.433	-16.649	SS	100	40.760	-129.429	-3.439	SS
15	-37.541	37.280	-1.145	SS	58	-24.735	92.860	-9.807	SS	101	9.987	7.087	-3.616	SS
16	-18.064	-10.886	-2.795	SS	59	-40.285	132.842	-10.294	SS	102	18.954	8.633	-3.942	SS
17	-9.219	-6.746	-1.452	SS	60	-18.670	146.246	-17.736	SS	103	25.115	9.684	-4.299	SS
18	-9.009	-6.763	0.925	SS	61	-43.054	188.228	-18.120	SS	104	29.218	10.009	-5.141	SS
19	-7.896	-6.344	0.512	SS	62	-69.040	229.293	-17.751	SS	105	7.296	12.266	-4.381	SS
20	-13.248	1.521	-0.317	SS	63	-91.596	266.774	-18.975	SS	106	3.663	16.548	-4.739	SS
21	-8.078	-6.489	0.928	SS	64	-120.240	308.126	-11.028	SS	107	-5.223	18.175	-5.422	SS
22	-13.595	1.685	0.789	SS	65	-113.125	280.420	-14.362	SS	108	-9.106	17.513	-6.040	SS
23	-13.655	1.692	0.792	SS	66	383.656	361.423	-18.790	SS	109	-18.611	15.906	-8.440	SS
24	-14.256	1.127	0.777	SS	67	386.892	364.524	-18.826	SS	110	-31.667	15.236	-11.800	SS
25	-14.270	1.037	-0.931	SS	68	132.450	230.822	-18.097	SS	111	-41.537	13.826	-13.794	SS
26	-14.009	1.589	-0.733	SS	69	1.067	-15.503	0.136	SS	112	-38.057	145.105	-5.322	SS
27	-9.421	-4.256	0.253	SS	70	1.131	-15.631	1.702	SS	113	-27.614	142.473	-5.707	SS
28	-9.235	-4.404	1.029	SS	71	0.835	-16.338	2.026	SS	114	-17.727	138.586	-6.028	SS
29	-10.116	-4.841	1.040	SS	72	9.312	-15.245	-1.383	SS	115	-7.784	135.274	-6.587	SS
30	-10.407	-4.859	-1.726	SS	73	9.193	-15.312	-0.118	SS	116	-5.186	129.944	-6.831	SS
31	-8.337	-8.220	-1.437	SS	74	9.700	-15.870	-0.089	SS	117	0.870	108.194	-6.700	SS
32	-8.136	-8.136	0.914	SS	75	12.631	-13.655	-2.549	SS	118	8.830	78.574	-6.673	SS
33	-7.421	-7.744	0.890	SS	76	12.696	-13.804	-1.532	SS	119	3.269	56.541	-6.787	SS
34	-7.299	-7.617	0.514	SS	77	13.022	-14.531	-1.595	SS	120	-2.693	37.784	-6.740	SS
35	-6.778	-8.641	0.666	SS	78	21.700	-9.738	-5.408	SS	121	17.169	29.274	-6.696	SS
36	-6.681	-8.518	2.490	SS	79	21.901	-9.813	-4.690	SS	122	28.708	26.805	-6.661	SS
37	-7.484	-9.091	2.818	SS	80	22.170	-10.602	-4.668	SS	123	-6.769	26.318	-6.123	SS
38	-7.219	8.744	-0.147	SS	81	34.212	-5.737	-9.208	SS	124	-18.250	58.836	-5.964	SS
39	-30.498	49.827	0.242	SS	82	34.209	-5.942	-8.850	SS	125	-25.787	92.133	-5.455	SS
40	-54.964	92.060	-0.092	SS	83	34.580	-6.539	-8.861	SS	126	-467.344	-250.614	-18.426	SS
41	-86.873	147.963	-0.171	SS	84	43.489	-2.001	-12.194	SS	127	-275.709	-85.088	0.358	SS
42	-121.894	208.064	-0.150	SS	85	43.525	-2.929	-12.100	SS	128	129.872	233.522	-18.441	SS
43	-150.187	256.298	-0.201	SS	86	68.108	-13.520	-16.934	SS					

Table B-1 lists the raw surveying point data generated by the Total Station System.

Appendix C – Sieve Analysis Results	Table C-1
CENE 486C – Engineering Design Capstone	Source: Yaowan Ma
Odell Dam Safety Analysis	Date Created: 10-1-2014

Sieve	Sample A	Sample B	Sample C	Sample D	Sample E	Sample F	Sample G
Sieve Opening (mm)	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn	Percent Finer 100-ΣRn
4.75	77.59	80.28	93.05	82.64	71.28	85.23	66.62
2	48.04	63.58	82.79	70.97	54.14	64.03	54.33
0.841	23.35	46.9	65.1	59.39	38.67	32.72	43.28
0.4	12.55	37.82	48.91	46.51	27.27	16.12	34.41
0.25	7.62	31.27	36.84	35.9	20.67	9.41	28.24
0.177	5.65	27.6	31.55	30.13	17.74	7.22	24.81
0.105	3.62	21.93	24.23	21.73	14.46	5	20.11
0.074	2.5	16.9	9.11	15.86	7.72	4	8.89
0.01	-0.21	0.13	1.41	0.27	0.33	-0.47	-1

Table C-7: Sieve Analysis Results

Appendix C – Sieve Analysis Results	Table C-2
CENE 486C – Engineering Design Capstone	Source: Yaowan Ma
Odell Dam Safety Analysis	Date Created: 10-1-2014

Sample	Gravel	Sand	Clay	D60 (mm)	D10 (mm)	D30 (mm)	Cu	Cc	Classification
A	22.41%	75.09%	2.71%	2.9	0.35	1.2	8.3	1.42	Well-graded sand with gravel
B	19.72%	63.38%	16.77%	1.8	0.035	0.2	51.4	0.635	Cinder
C	6.95%	83.94%	7.70%	x	x	x	x	x	Clayey sand
D	17.36%	66.78%	15.59%	0.9	0.035	0.18	25.7	1.03	Well-graded sand with clay & gravel
E	28.72%	63.57%	7.39%	2.7	0.09	0.5	30	1.03	Well-graded sand with clay & gravel
F	14.77%	81.23%	4.47%	1.8	0.25	0.75	7.2	1.25	Well-graded sand
G	33.38%	57.73%	9.89%	3	0.075	0.282	40	0.353	Poorly-graded sand with silt

Table C- 8: Soil Classification Calculated Values.

Appendix C – Sieve Analysis Results	Figure C-3
CENE 486C – Engineering Design Capstone	Source: Ibrahim Atout
Odell Dam Safety Analysis	Date Created: 10-1-2014

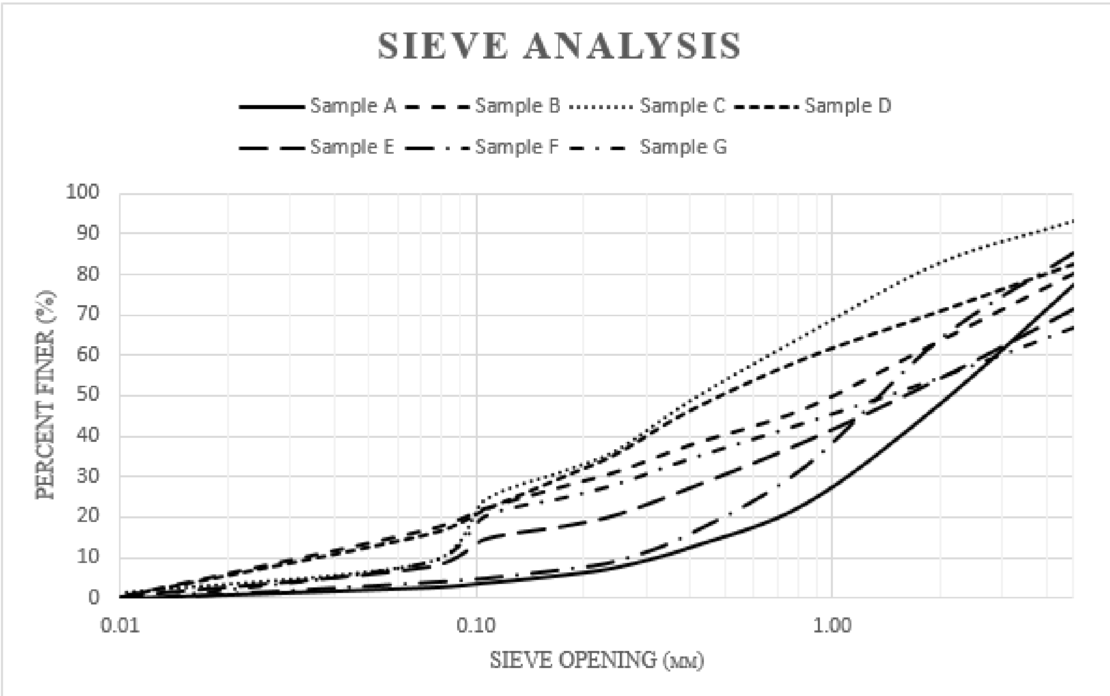

Figure C- 3: Graphical Representation of Table 1.

Appendix D- Locations of Sampling	Figure D-1
CENE 486C – Engineering Design Capstone	Source: Braedan Hinojosa
Odell Dam Safety Analysis	Date Created: 9-14-14

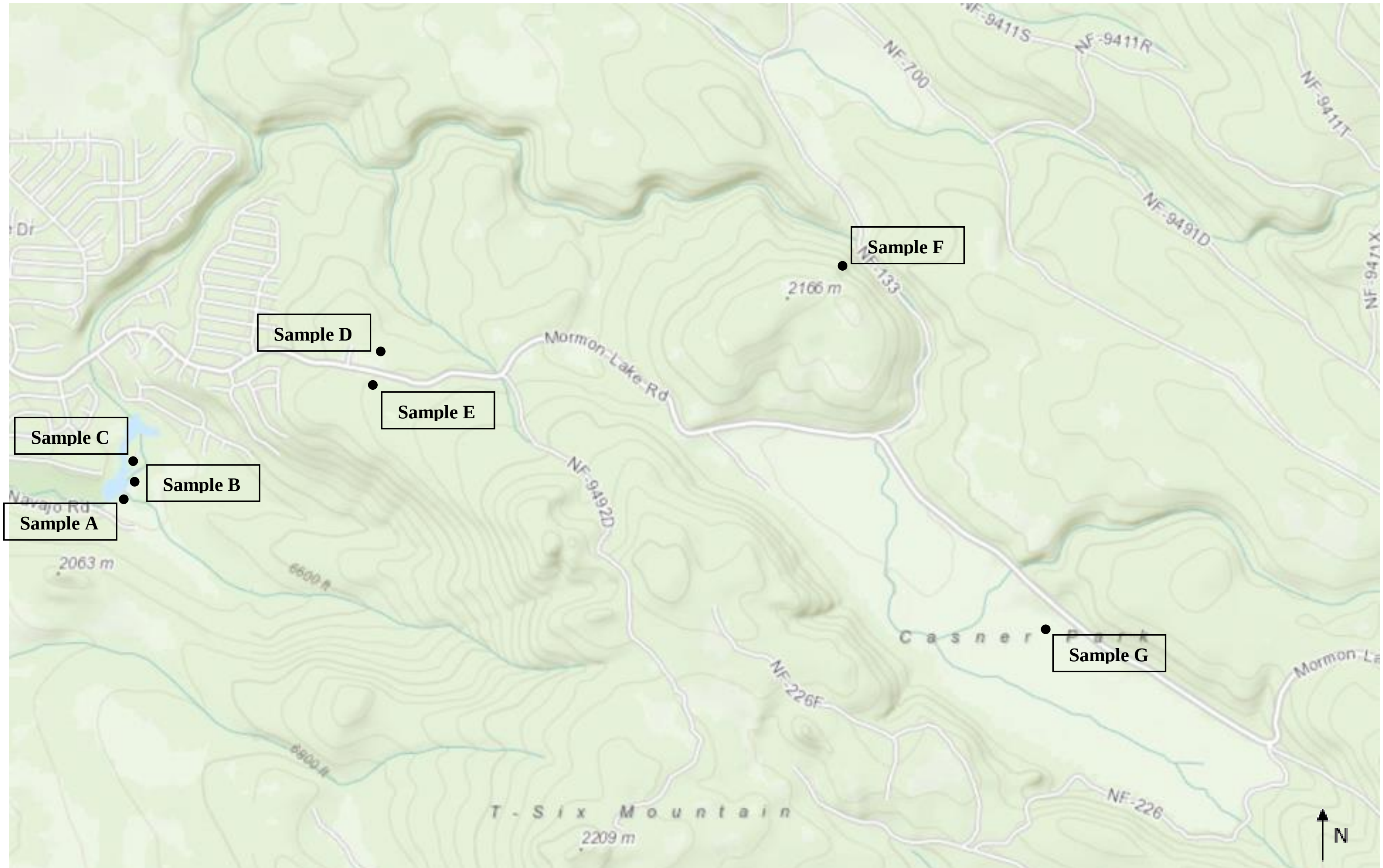

Figure D-1 illustrates the approximate locations of the soil samples collected.

Appendix E – Classification Flow Chart	Figure E-1
CENE 486C – Engineering Design Capstone	Source: Braedan Hinojosa
Odell Dam Safety Analysis	Date Created: 10-16-14

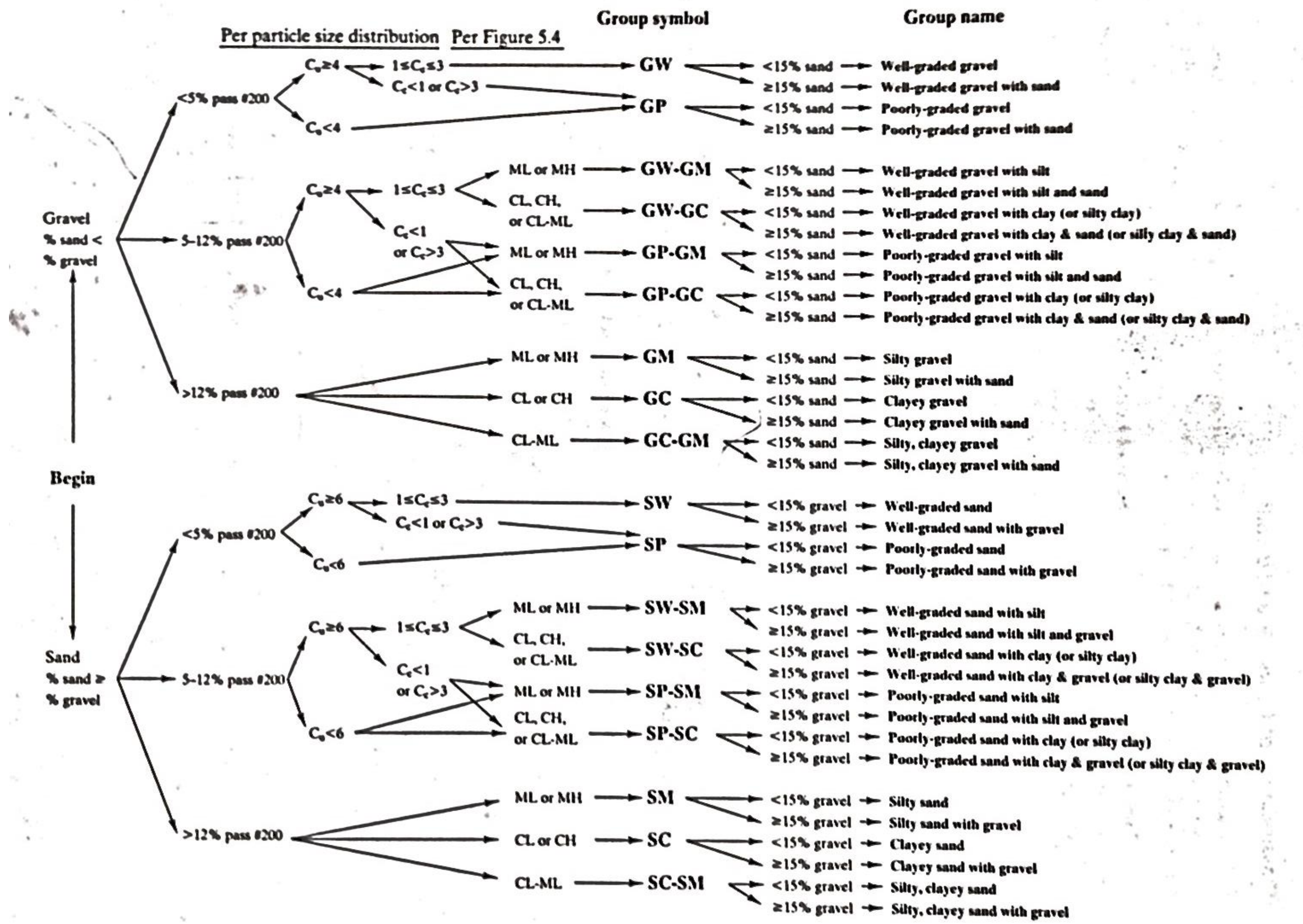

Figure E-1 is a flow chart for the classification of coarse-grained soils. Adapted from ASTM D2487.

NOTES TO USERS

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Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) Zone 12N. The **horizontal datum** was NAD 83, GRS80. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

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NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242**, or visit its website at http://www.ngs.noaa.gov.

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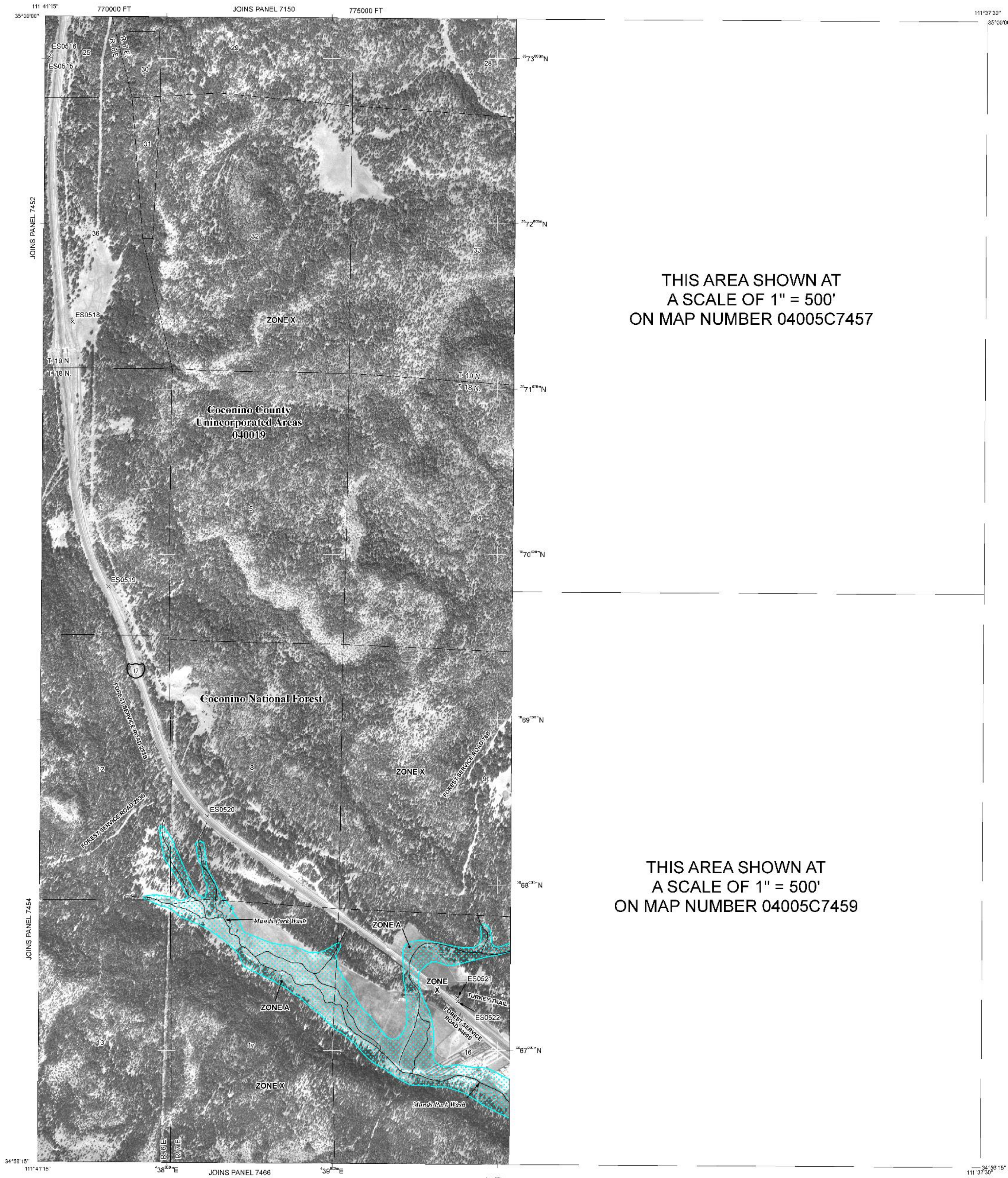

LEGEND

SPECIAL FLOOD HAZARD AREAS SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

	1% annual chance floodplain boundary
	0.2% annual chance floodplain boundary
	Floodway boundary
	Zone D boundary
	CBRS and OPA boundary
	Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.
	Limit of Moderate Wave Action
513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988

(A)———(A)	Cross section line
(23)- - - -(23)	Transect line
87°07'45", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
76000mN	1000-meter Universal Transverse Mercator grid values, zone NAD 1983 UTM Zone 12
600000 FT	5000-foot grid values: Arizona State Plane coordinate system, Central zone (FIPSZONE 0202), Transverse Mercator projection
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
M1.5	River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
September 3, 2010

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 1000'

500 0 1000 2000 FEET

300 0 300 600 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 7460G

FIRM
FLOOD INSURANCE RATE MAP

COCONINO COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 7460 OF 8475

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
COCONINO COUNTY	040019	7460	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04005C7460G

EFFECTIVE DATE
SEPTEMBER 3, 2010

Federal Emergency Management Agency

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LEGEND

SPECIAL FLOOD HAZARD AREAS SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Area formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X — Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X — Areas determined to be outside the 0.2% annual chance floodplain.

ZONE D — Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% annual chance floodplain boundary

0.2% annual chance floodplain boundary

Floodway boundary

Zone D boundary

CBRS and OPA boundary

Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

Limit of Moderate Wave Action

~~~ 513 ~~~ Base Flood Elevation line and value; elevation in feet*

(EL 987) Base Flood Elevation value where uniform within zone; elevation in feet*

* Referenced to the North American Vertical Datum of 1988

(A)——(A) Cross section line

(23)- - - -(23) Transect line

87°07'45", 32°22'30" Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere

$^{42}76^{000m}$N 1000-meter Universal Transverse Mercator grid values, zone NAD 1983 UTM Zone 12

600000 FT 5000-foot grid values: Arizona State Plane coordinate system, Central zone (FIPSZONE 0202), Transverse Mercator projection

DX5510 × Bench mark (see explanation in Notes to Users section of this FIRM panel)

● M1.5 River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
September 3, 2010

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your Insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET

150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 7459G

FIRM

FLOOD INSURANCE RATE MAP

COCONINO COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 7459 OF 8475

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
COCONINO COUNTY	040019	7459	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04005C7459G

EFFECTIVE DATE
SEPTEMBER 3, 2010

Federal Emergency Management Agency

Appendix F – FEMA Flood Maps

Figure F-2

CENE 486C – Engineering Design Capstone

Source: FEMA

Odell Dam Safety Analysis

Date Created: 9-3-10
~~~

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0' North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) Zone 12N. The **horizontal datum** was NAD 83, GRS80. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was derived from U.S. Geological Survey Digital Orthophoto Quadrangles produced at a scale of 1:12,000 from photography dated 1992 or later.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

Contact the **FEMA Map Service Center** at 1-800-358-9616 for information on available products associated with this FIRM. Available products may include previously issued Letters of Map Change, a Flood Insurance Study report, and/or digital versions of this map. The FEMA Map Service Center may also be reached by Fax at 1-800-358-9620 and its website at http://www.fema.gov/msc.

If you have **questions about this map** or questions concerning the National Flood Insurance Program in general, please call **1-877-FEMA MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov.

LEGEND

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1% annual chance floodplain boundary

0.2% annual chance floodplain boundary

Floodway boundary

Zone D boundary

CBRS and OPA boundary

Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths or flood velocities.

Limit of Moderate Wave Action

~~ 513 ~~~	Base Flood Elevation line and value; elevation in feet*
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* Referenced to the North American Vertical Datum of 1988

(A)———(A)	Cross section line
(23)- - - - -(23)	Transect line
87°07'45", 32°22'30"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83), Western Hemisphere
476000mN	1000-meter Universal Transverse Mercator grid values, zone NAD 1983 UTM Zone 12
600000 FT	5000-foot grid values: Arizona State Plane coordinate system, Central zone (FIPSZONE 0202), Transverse Mercator projection
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
● M1.5	River Mile

MAP REPOSITORY
Refer to listing of Map Repositories on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
September 3, 2010

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

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MAP SCALE 1" = 500'

250 0 500 1000 FEET

150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 7467G

FIRM

FLOOD INSURANCE RATE MAP

COCONINO COUNTY, ARIZONA
AND INCORPORATED AREAS

PANEL 7467 OF 8475
(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
COCONINO COUNTY	040019	7467	G

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
04005C7467G

EFFECTIVE DATE
SEPTEMBER 3, 2010

Federal Emergency Management Agency

Appendix F – FEMA Flood Maps	Figure F-3
CENE 486C – Engineering Design Capstone	Source: FEMA
Odell Dam Safety Analysis	Date Created: 9-3-10

Appendix G- Watershed Delineation	Figure G-1
CENE 486C – Engineering Design Capstone	Source: Chandler Hammond
Odell Dam Safety Analysis	Date Created: 9-25-14

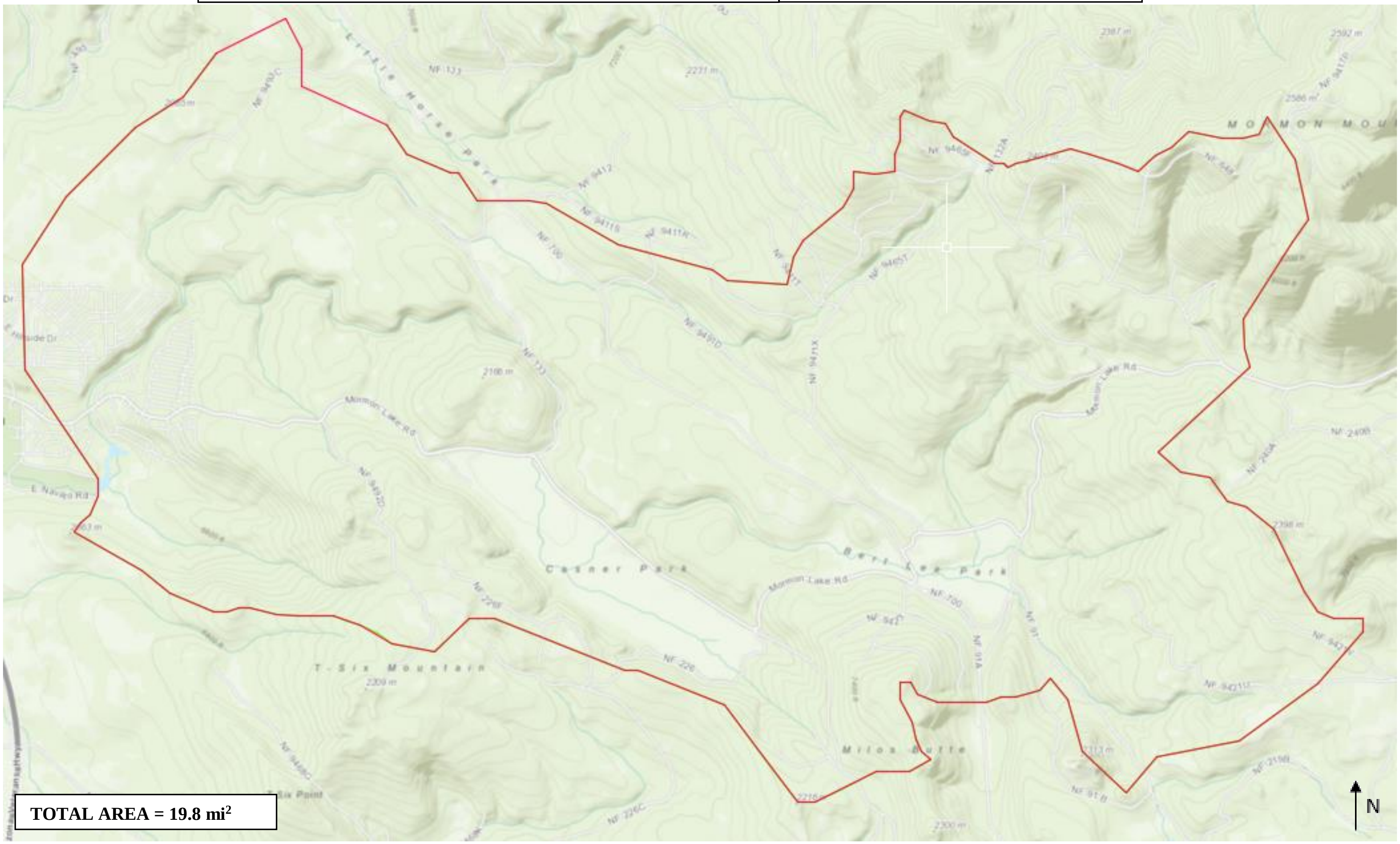


Figure G-1 shows the delineated watershed that encompasses the project area.

<u>Appendix H – NOAA Atlas 14’ Intensities</u>	Figure H-1
CENE 486C – Engineering Design Capstone	Source: NOAA Atlas 14’
Odell Dam Safety Analysis	Date Created: 10-19-14

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

Duration	Annual exceedance probability (1/years)								
	1/2	1/5	1/10	1/25	1/50	1/100	1/200	1/500	1/1000
5-min	3.73 (3.19–4.36)	5.42 (4.63–6.30)	6.64 (5.65–7.72)	8.29 (7.00–9.60)	9.61 (8.06–11.1)	11.1 (9.18–12.8)	12.6 (10.3–14.6)	14.7 (11.9–17.2)	16.6 (13.2–19.6)
10-min	2.84 (2.43–3.31)	4.13 (3.52–4.80)	5.05 (4.30–5.87)	6.31 (5.33–7.30)	7.31 (6.14–8.46)	8.41 (6.98–9.74)	9.55 (7.84–11.1)	11.2 (9.03–13.1)	12.6 (10.0–14.9)
15-min	2.34 (2.01–2.74)	3.41 (2.91–3.96)	4.18 (3.55–4.86)	5.22 (4.40–6.04)	6.04 (5.07–6.99)	6.95 (5.77–8.05)	7.90 (6.48–9.16)	9.26 (7.46–10.8)	10.4 (8.27–12.3)
30-min	1.58 (1.35–1.84)	2.30 (1.96–2.67)	2.81 (2.39–3.27)	3.51 (2.97–4.06)	4.07 (3.41–4.71)	4.68 (3.89–5.42)	5.32 (4.36–6.17)	6.24 (5.03–7.29)	7.02 (5.57–8.29)
60-min	0.978 (0.837–1.14)	1.42 (1.21–1.65)	1.74 (1.48–2.02)	2.17 (1.84–2.52)	2.52 (2.11–2.91)	2.90 (2.41–3.36)	3.29 (2.70–3.82)	3.86 (3.11–4.51)	4.35 (3.45–5.13)
2-hr	0.554 (0.486–0.638)	0.789 (0.690–0.906)	0.961 (0.834–1.10)	1.20 (1.03–1.37)	1.39 (1.19–1.59)	1.60 (1.36–1.84)	1.83 (1.53–2.09)	2.15 (1.76–2.47)	2.43 (1.95–2.80)
3-hr	0.404 (0.359–0.460)	0.558 (0.494–0.634)	0.673 (0.592–0.763)	0.830 (0.725–0.940)	0.957 (0.829–1.08)	1.10 (0.942–1.25)	1.25 (1.06–1.42)	1.47 (1.22–1.68)	1.65 (1.35–1.90)
6-hr	0.254 (0.230–0.283)	0.339 (0.305–0.377)	0.401 (0.360–0.446)	0.487 (0.434–0.541)	0.555 (0.491–0.616)	0.631 (0.553–0.701)	0.708 (0.612–0.789)	0.816 (0.694–0.915)	0.905 (0.757–1.02)
12-hr	0.165 (0.149–0.183)	0.217 (0.196–0.241)	0.254 (0.228–0.281)	0.301 (0.270–0.334)	0.338 (0.300–0.373)	0.376 (0.331–0.417)	0.414 (0.362–0.460)	0.468 (0.404–0.523)	0.511 (0.436–0.574)
24-hr	0.100 (0.090–0.113)	0.135 (0.120–0.152)	0.160 (0.142–0.180)	0.192 (0.169–0.215)	0.217 (0.191–0.243)	0.243 (0.213–0.273)	0.269 (0.234–0.303)	0.305 (0.263–0.344)	0.334 (0.285–0.377)
2-day	0.061 (0.055–0.069)	0.083 (0.074–0.093)	0.098 (0.088–0.110)	0.119 (0.105–0.133)	0.134 (0.119–0.150)	0.151 (0.133–0.169)	0.168 (0.147–0.188)	0.192 (0.165–0.215)	0.210 (0.180–0.237)
3-day	0.044 (0.040–0.050)	0.060 (0.054–0.067)	0.072 (0.064–0.080)	0.087 (0.077–0.097)	0.099 (0.087–0.110)	0.111 (0.098–0.124)	0.124 (0.109–0.139)	0.143 (0.123–0.160)	0.157 (0.135–0.177)
4-day	0.036 (0.032–0.040)	0.049 (0.044–0.054)	0.058 (0.052–0.065)	0.071 (0.063–0.079)	0.081 (0.071–0.090)	0.092 (0.081–0.102)	0.103 (0.090–0.114)	0.118 (0.102–0.132)	0.130 (0.112–0.146)
7-day	0.024 (0.021–0.026)	0.032 (0.029–0.036)	0.038 (0.034–0.042)	0.046 (0.041–0.051)	0.053 (0.047–0.058)	0.059 (0.052–0.066)	0.066 (0.058–0.073)	0.076 (0.066–0.085)	0.084 (0.072–0.094)
10-day	0.019 (0.017–0.021)	0.025 (0.023–0.028)	0.030 (0.027–0.033)	0.035 (0.032–0.039)	0.040 (0.036–0.044)	0.044 (0.039–0.049)	0.049 (0.043–0.054)	0.055 (0.048–0.061)	0.060 (0.052–0.067)
20-day	0.013 (0.012–0.014)	0.017 (0.015–0.019)	0.019 (0.017–0.021)	0.023 (0.020–0.025)	0.025 (0.022–0.027)	0.027 (0.024–0.030)	0.029 (0.026–0.033)	0.032 (0.029–0.036)	0.034 (0.030–0.038)
30-day	0.010 (0.009–0.011)	0.014 (0.012–0.015)	0.016 (0.014–0.017)	0.018 (0.016–0.020)	0.020 (0.018–0.022)	0.022 (0.019–0.024)	0.023 (0.021–0.026)	0.025 (0.022–0.028)	0.027 (0.024–0.030)
45-day	0.008 (0.007–0.009)	0.011 (0.009–0.012)	0.012 (0.011–0.014)	0.014 (0.013–0.016)	0.016 (0.014–0.018)	0.017 (0.015–0.019)	0.019 (0.016–0.021)	0.020 (0.018–0.023)	0.022 (0.019–0.025)
60-day	0.007 (0.006–0.008)	0.009 (0.008–0.011)	0.011 (0.010–0.012)	0.012 (0.011–0.014)	0.014 (0.012–0.015)	0.015 (0.013–0.017)	0.016 (0.014–0.018)	0.017 (0.015–0.019)	0.018 (0.016–0.021)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of annual maxima series (AMS).

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 annual exceedance probability) 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.

Appendix I – Oak Creek Flood Warning	Figure I-1
CENE 486C – Engineering Design Capstone	Source: Oak Creek Flood Warning
Odell Dam Safety Analysis	Date Created: September 1990

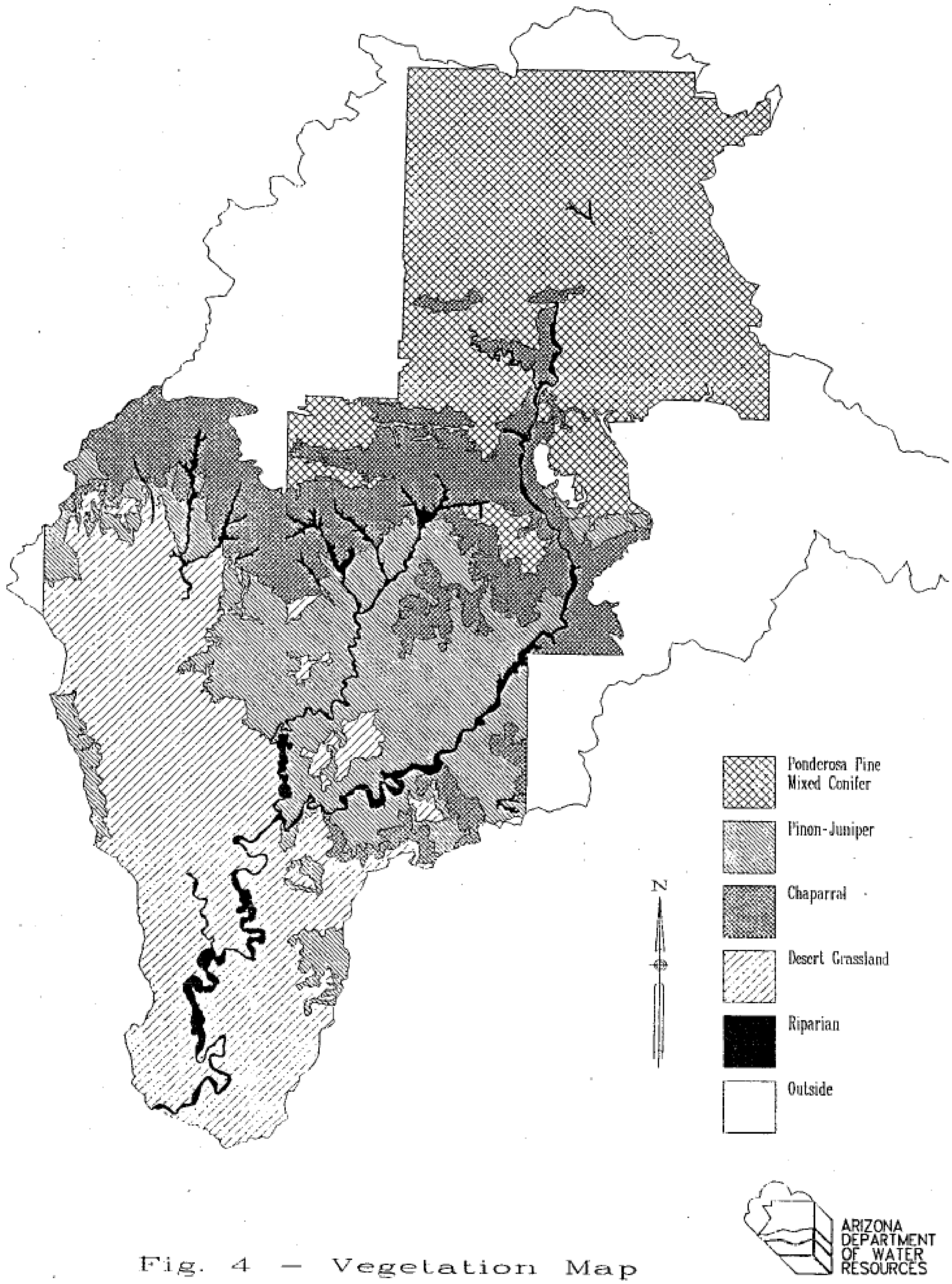
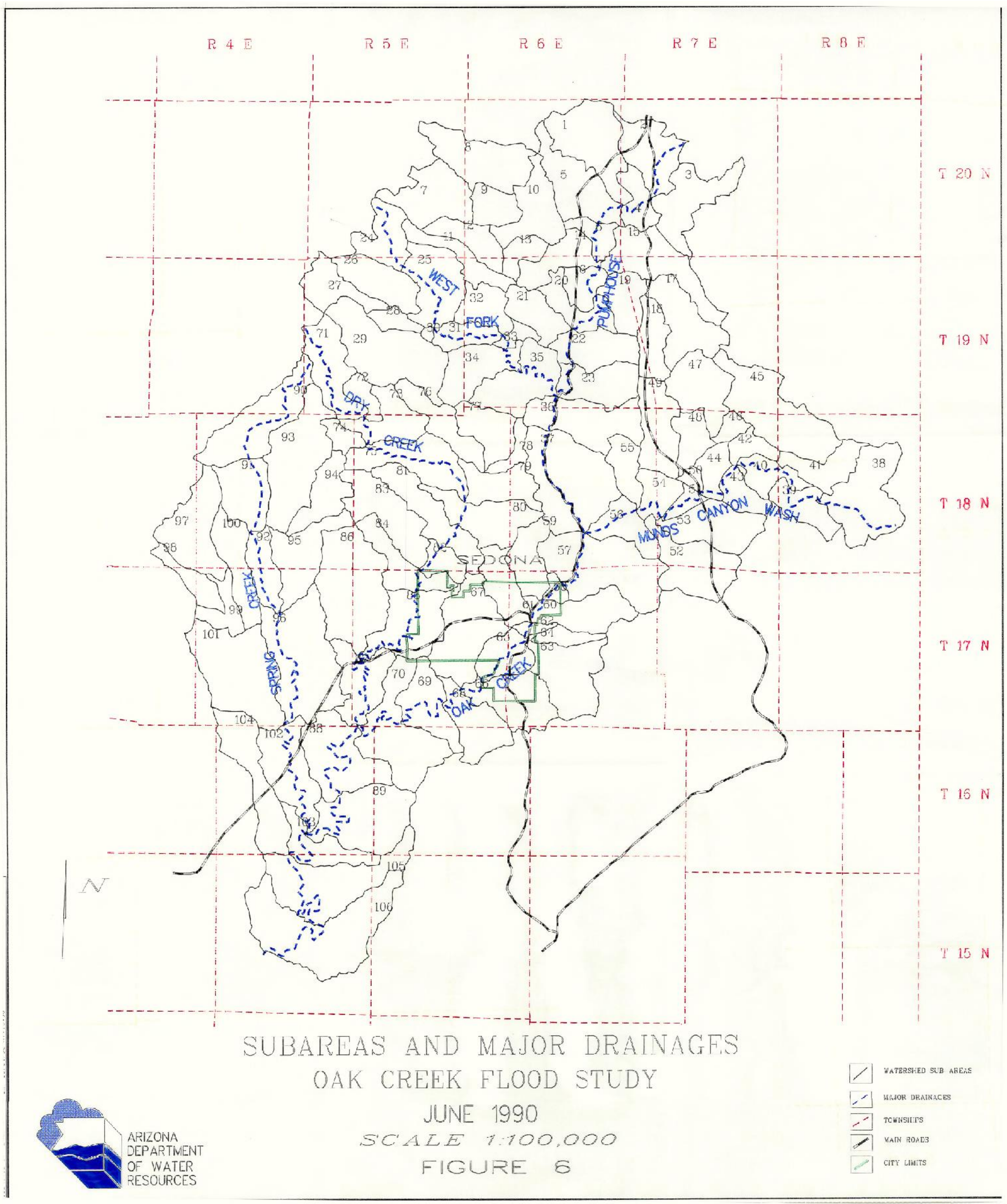


Fig. 4 — Vegetation Map

Appendix I – Oak Creek Flood Warning	Figure I-2
CENE 486C – Engineering Design Capstone	Source: Oak Creek Flood Warning
Odell Dam Safety Analysis	Date Created: June 1990



<u>Appendix J – Time Depth Table</u>	Table J-1
CENE 486C – Engineering Design Capstone	Source: Chandler Hammond
Odell Dam Safety Analysis	Date Created: 12-1-2014

Time Depth Table (inches)		Strom Event									
		1 Year	2 Year	5 Year	10 Year	25 Year	50 Year	100 Year	200 Year	500 Year	1000 Year
Duration Time Step (hours)	0.5	0.68	0.88	1.18	1.43	1.77	2.04	2.34	2.66	3.12	3.51
	1	0.84	1.09	1.46	1.76	2.19	2.53	2.9	3.29	3.86	4.35
	1.5	0.905	1.165	1.54	1.855	2.3	2.66	3.055	3.475	4.085	4.6
	2	0.97	1.24	1.62	1.95	2.41	2.79	3.21	3.66	4.31	4.85
	2.5	1.02	1.295	1.67	2	2.46	2.84	3.255	3.705	4.36	4.905
	3	1.07	1.35	1.72	2.05	2.51	2.89	3.3	3.75	4.41	4.96
	3.5	1.118333	1.406667	1.781667	2.115	2.58	2.965	3.38	3.831667	4.49	5.036667
	4	1.166667	1.463333	1.843333	2.18	2.65	3.04	3.46	3.913333	4.57	5.113333
	4.5	1.215	1.52	1.905	2.245	2.72	3.115	3.54	3.995	4.65	5.19
	5	1.263333	1.576667	1.966667	2.31	2.79	3.19	3.62	4.076667	4.73	5.266667
	5.5	1.311667	1.633333	2.028333	2.375	2.86	3.265	3.7	4.158333	4.81	5.343333
	6	1.36	1.69	2.09	2.44	2.93	3.34	3.78	4.24	4.89	5.42

Table J-1: Time depth table, interpolated for Bentley PondPack Parameters.

Appendix K – Time Depth Curves	Table K-1
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

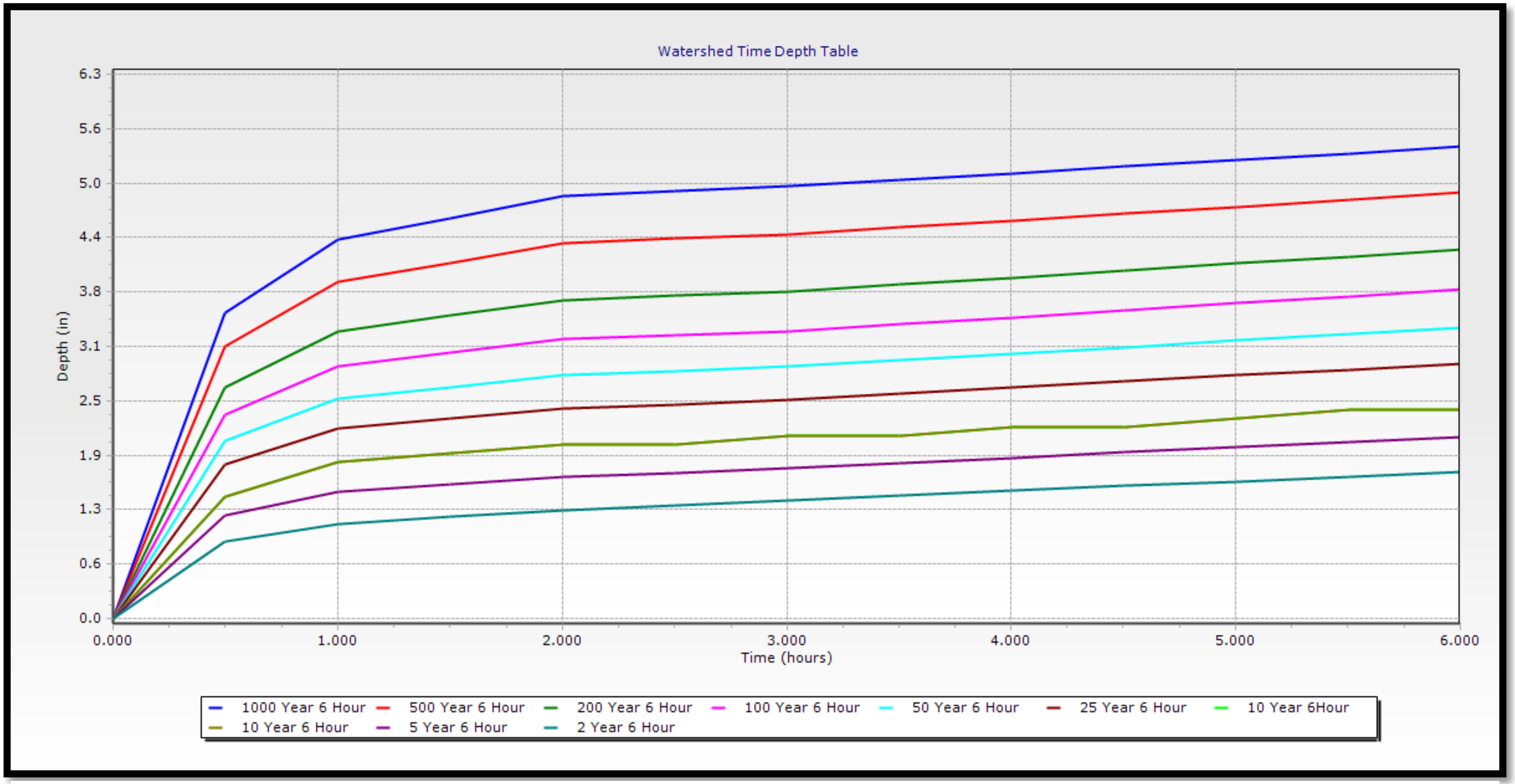


Table K-1: Graphical representation of the interpolated Time depths. Time Depth Curve.

Appendix L – Inflow Hydrographs	Figure L-1
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

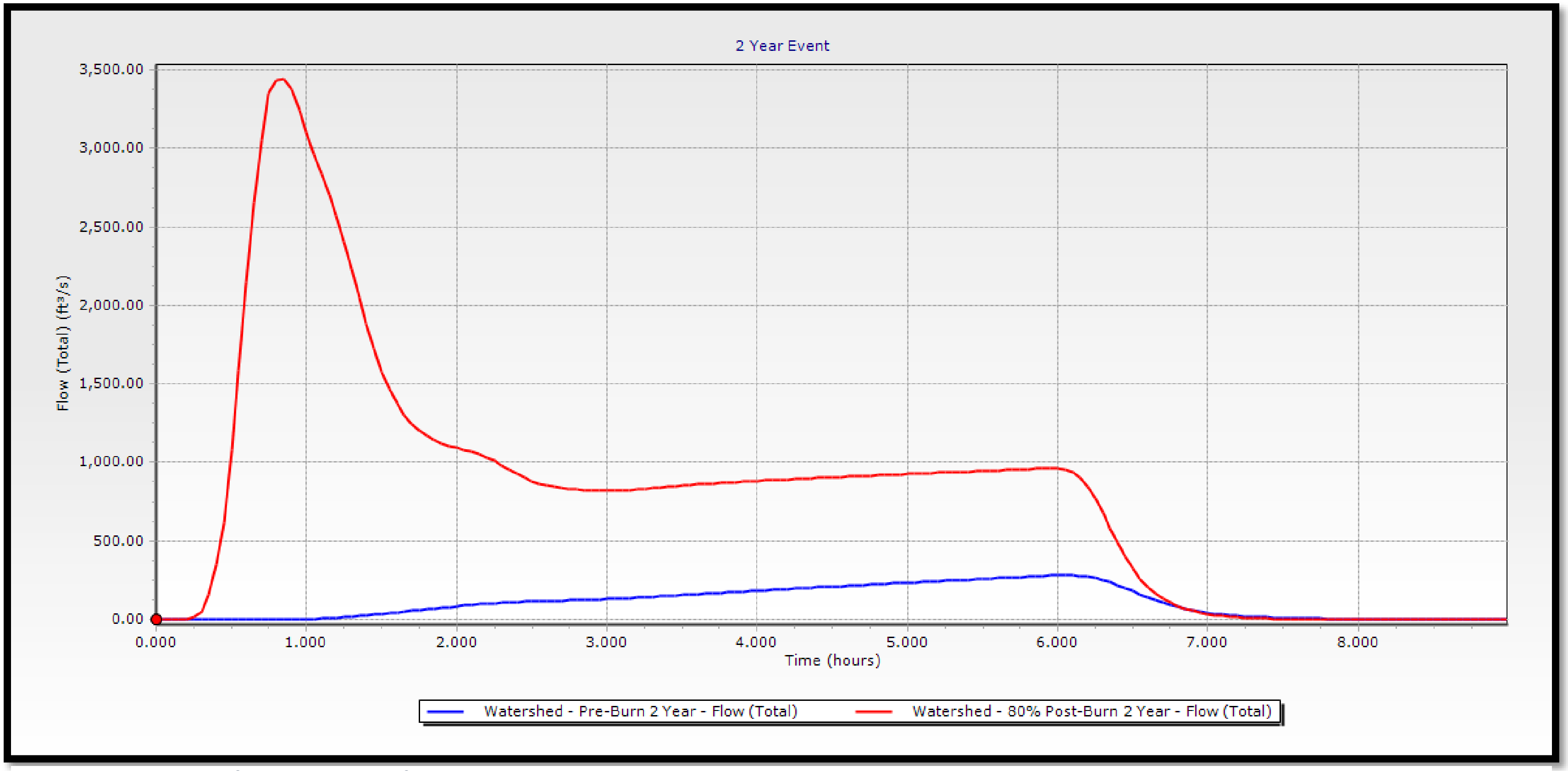


Table L-1: The 2 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-2
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

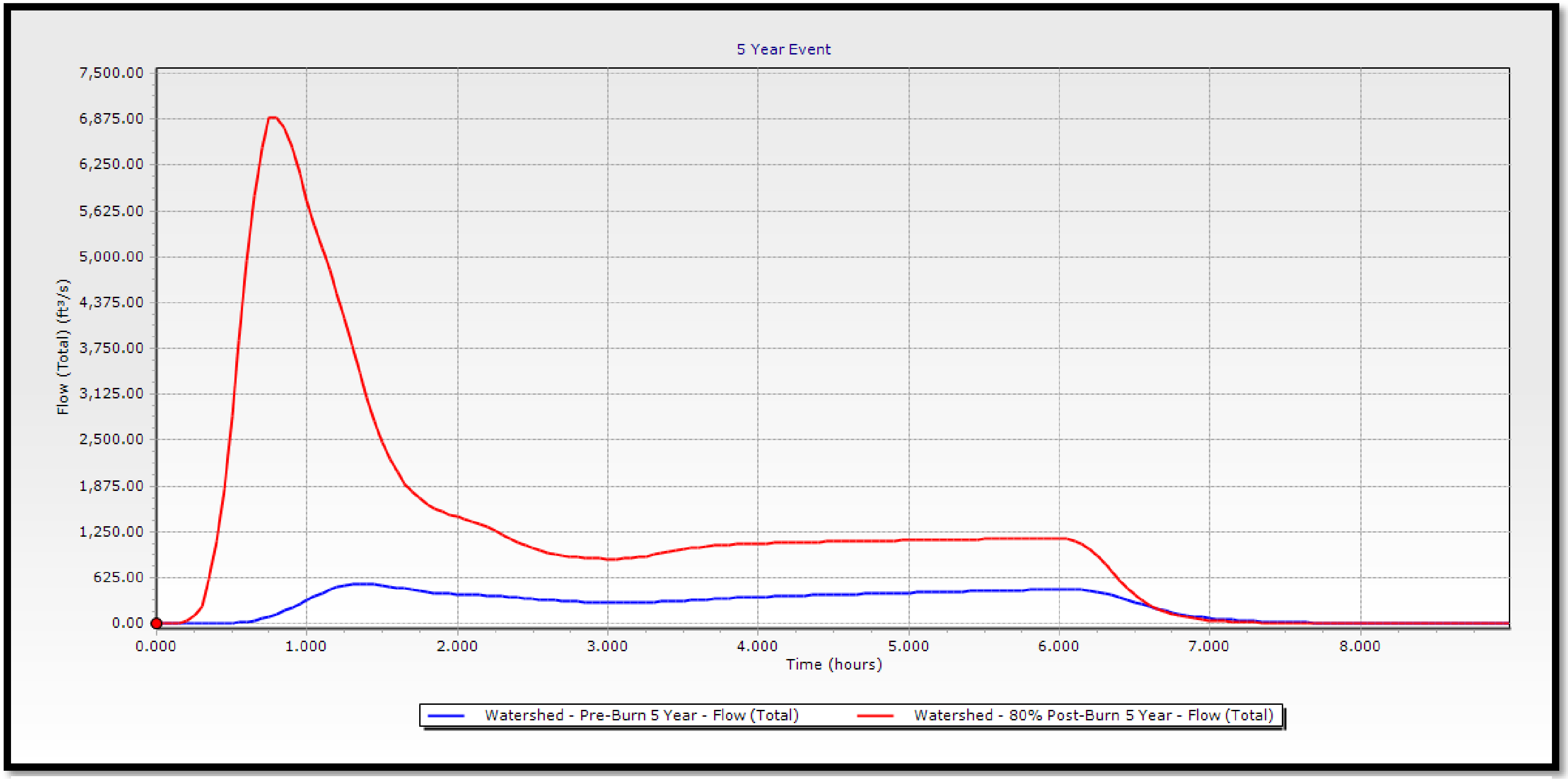


Table L-2: The 5 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-3
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

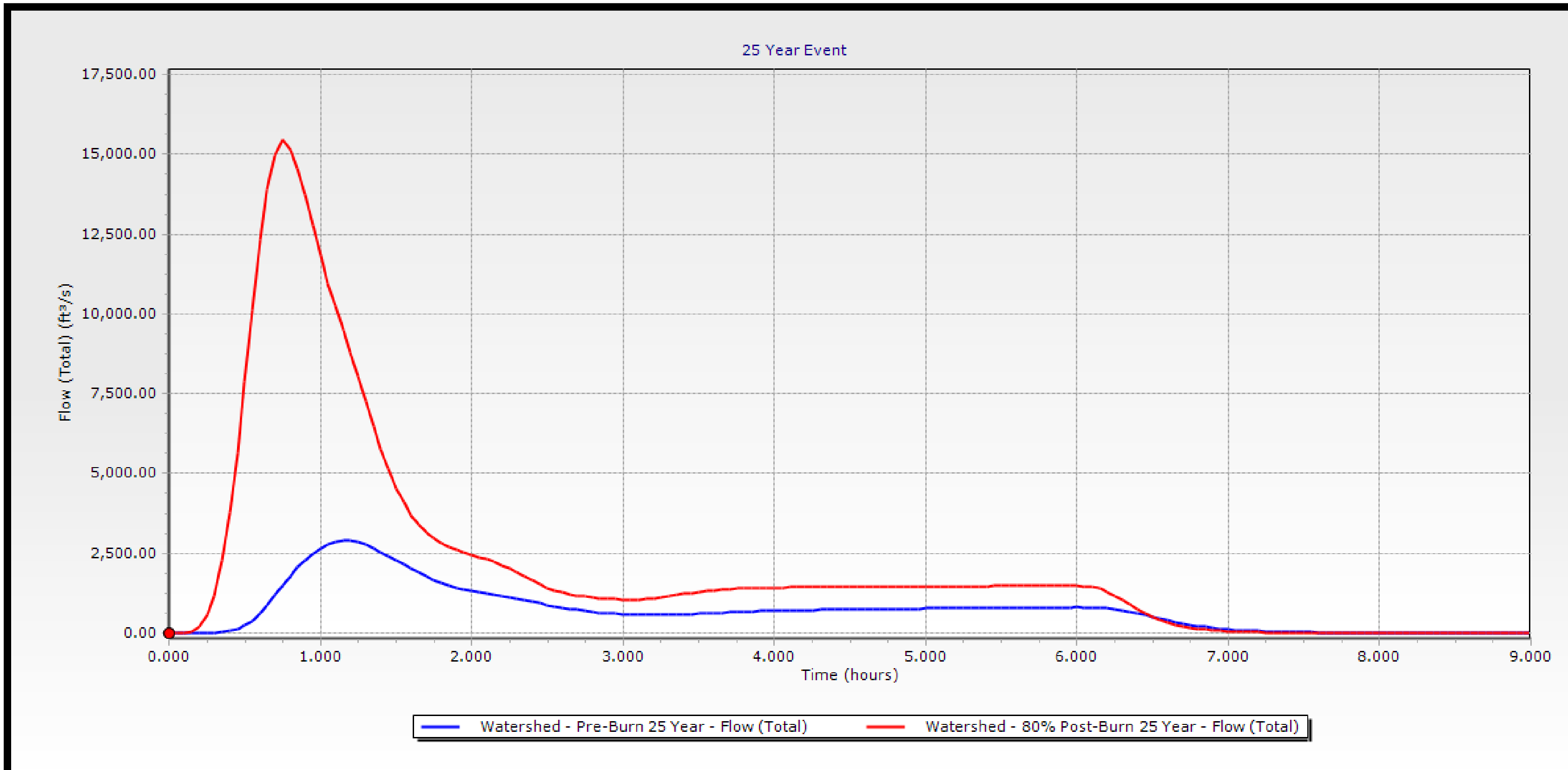


Table L-3: The 25 Year Inflow Hydrograph of pre-burn and 80% post-burn.

<u>**Appendix L – Inflow Hydrographs**</u>	Figure L-4
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

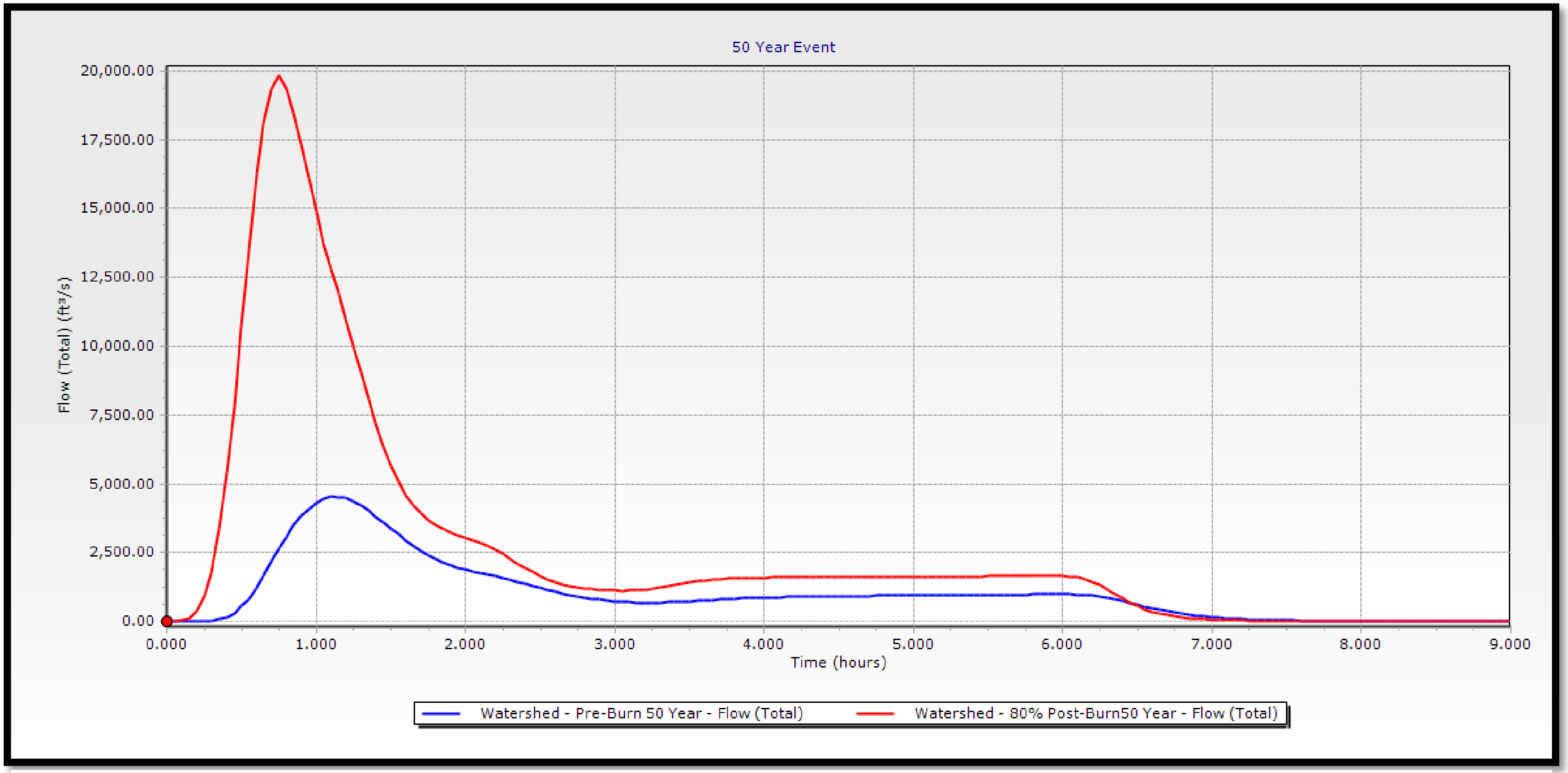


Table L-4: The 50 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-5
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

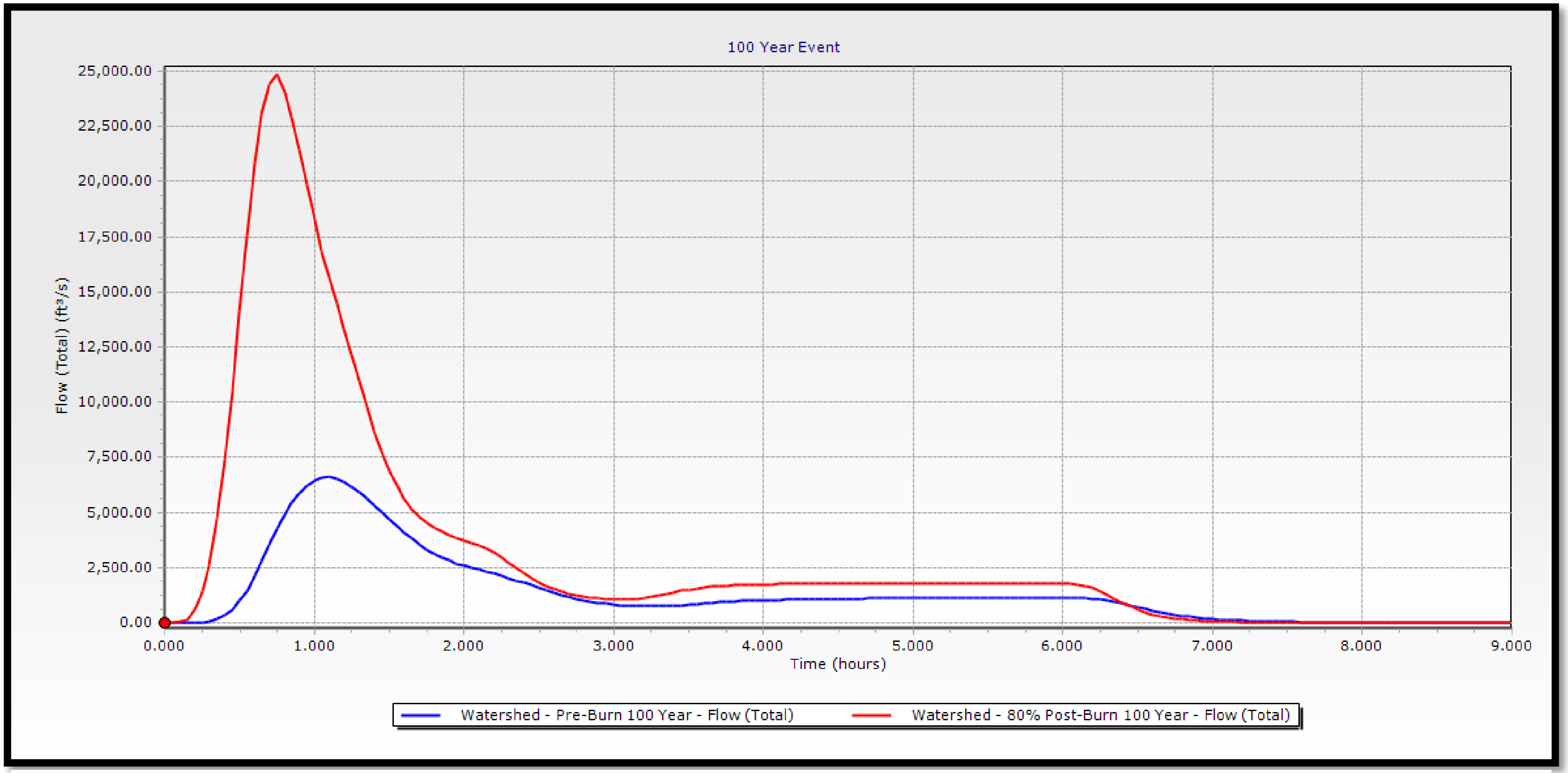


Table L-5: The 100 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-6
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

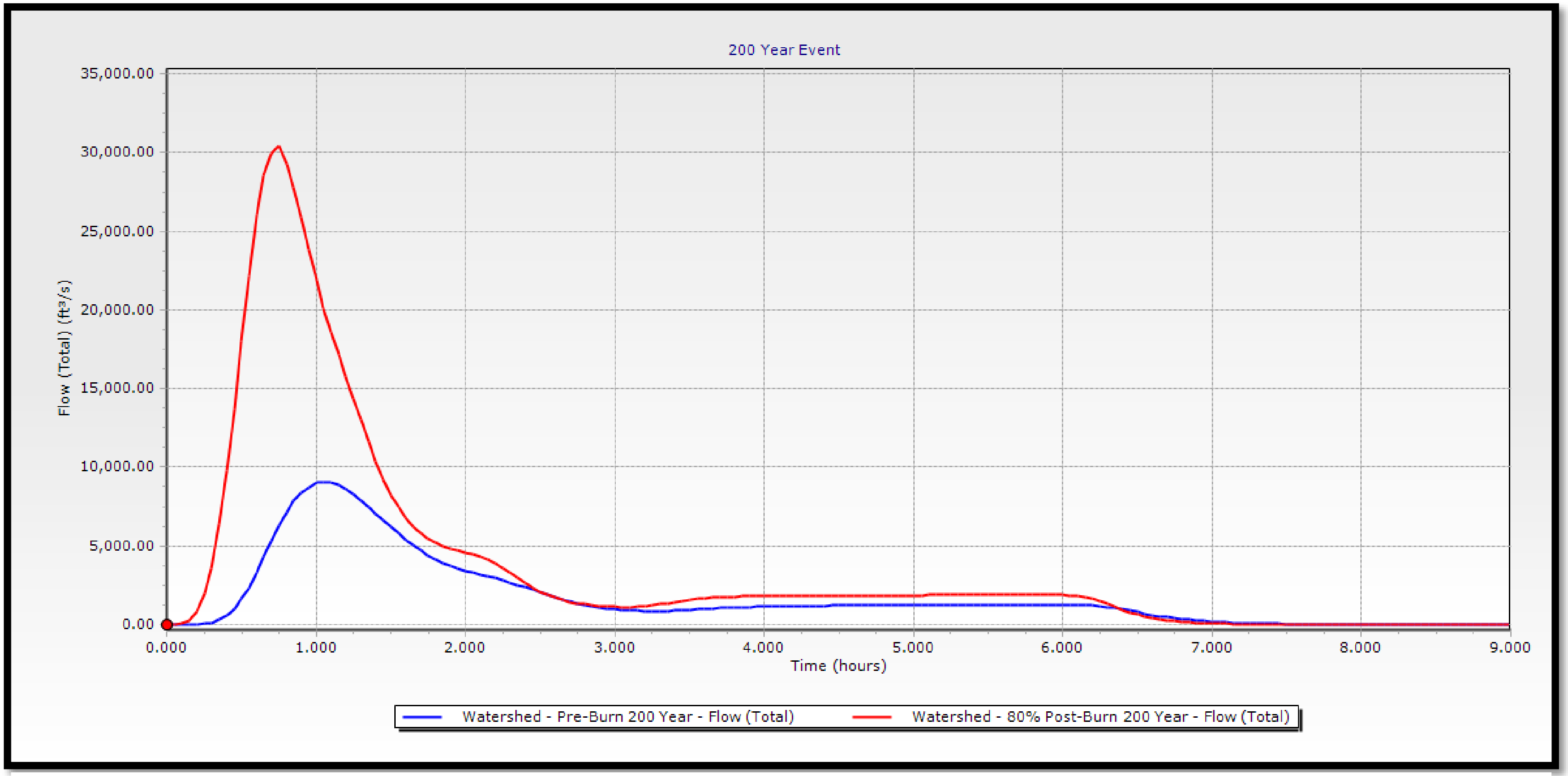


Table L-6: The 200 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-7
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

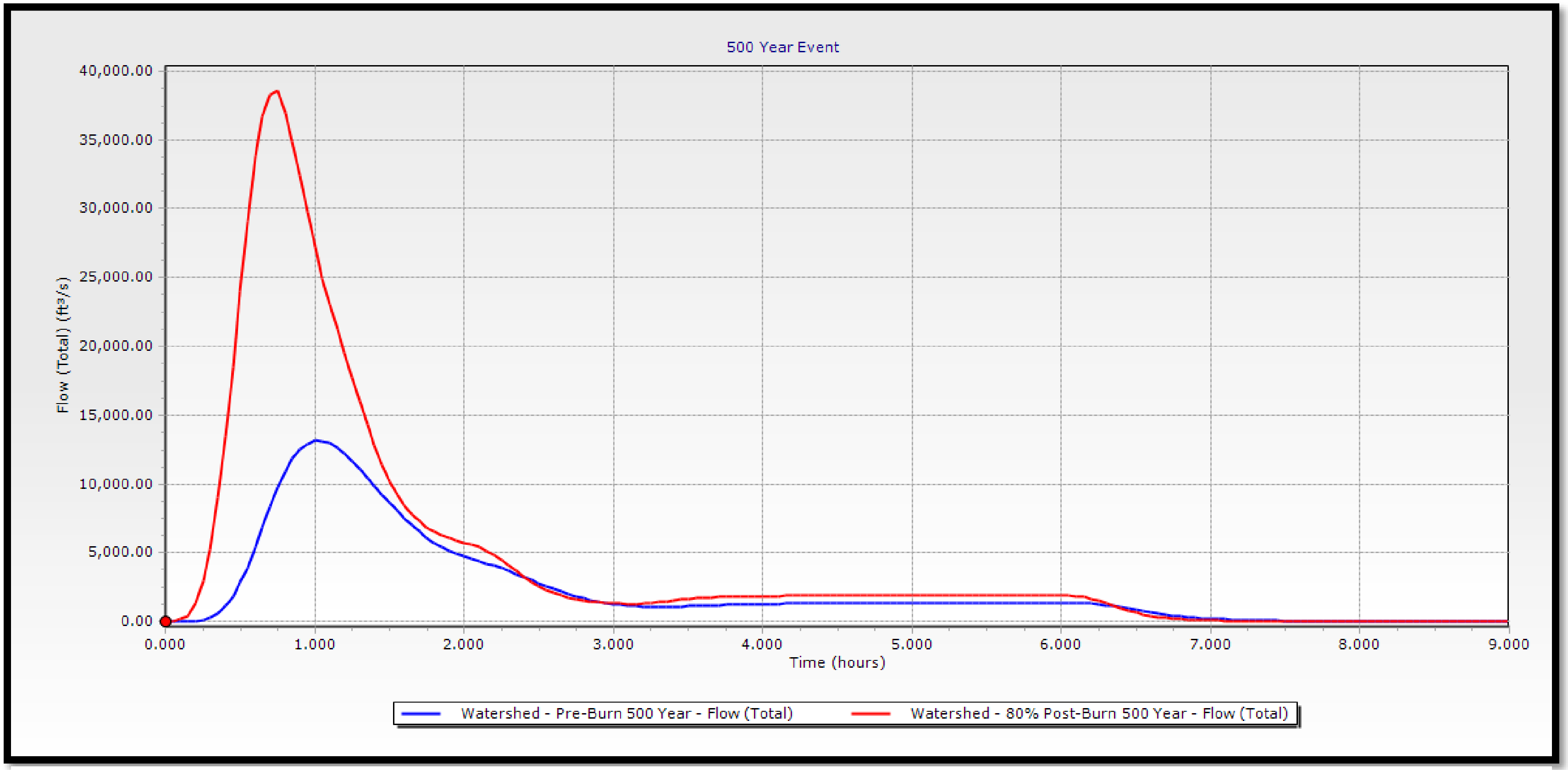


Table L-11: The 500 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix L – Inflow Hydrographs	Figure L-8
CENE 486C – Engineering Design Capstone	Source: Bentley PondPack
Odell Dam Safety Analysis	Date Created: 12-1-2014

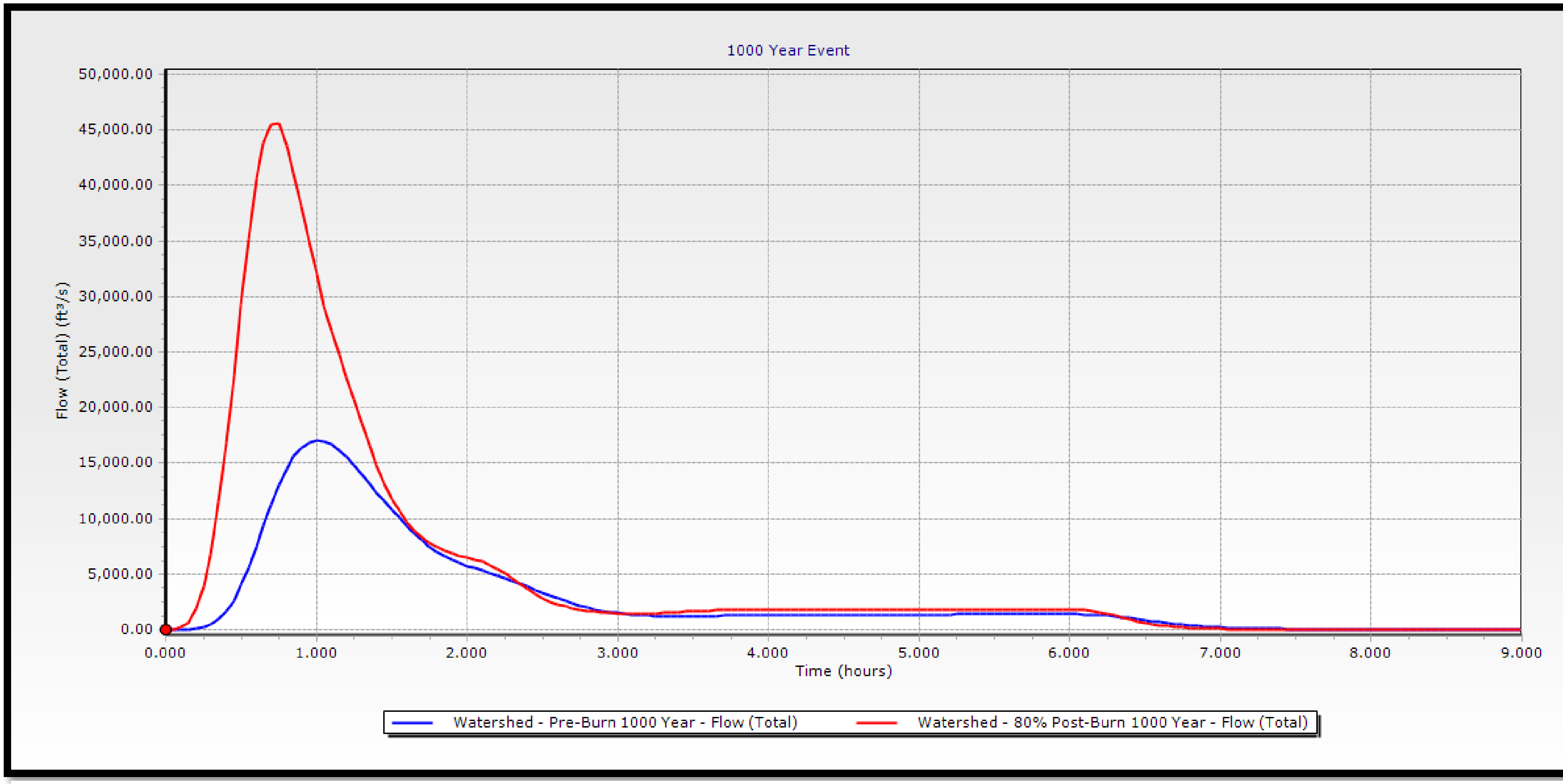


Table L-8: The 1000 Year Inflow Hydrograph of pre-burn and 80% post-burn.

Appendix M – Gantt Chart – Final	Figure M-1
CENE 486C – Engineering Design Capstone	Source: Gantt Project
Odell Dam Safety Analysis	Date Created: 12-1-2014

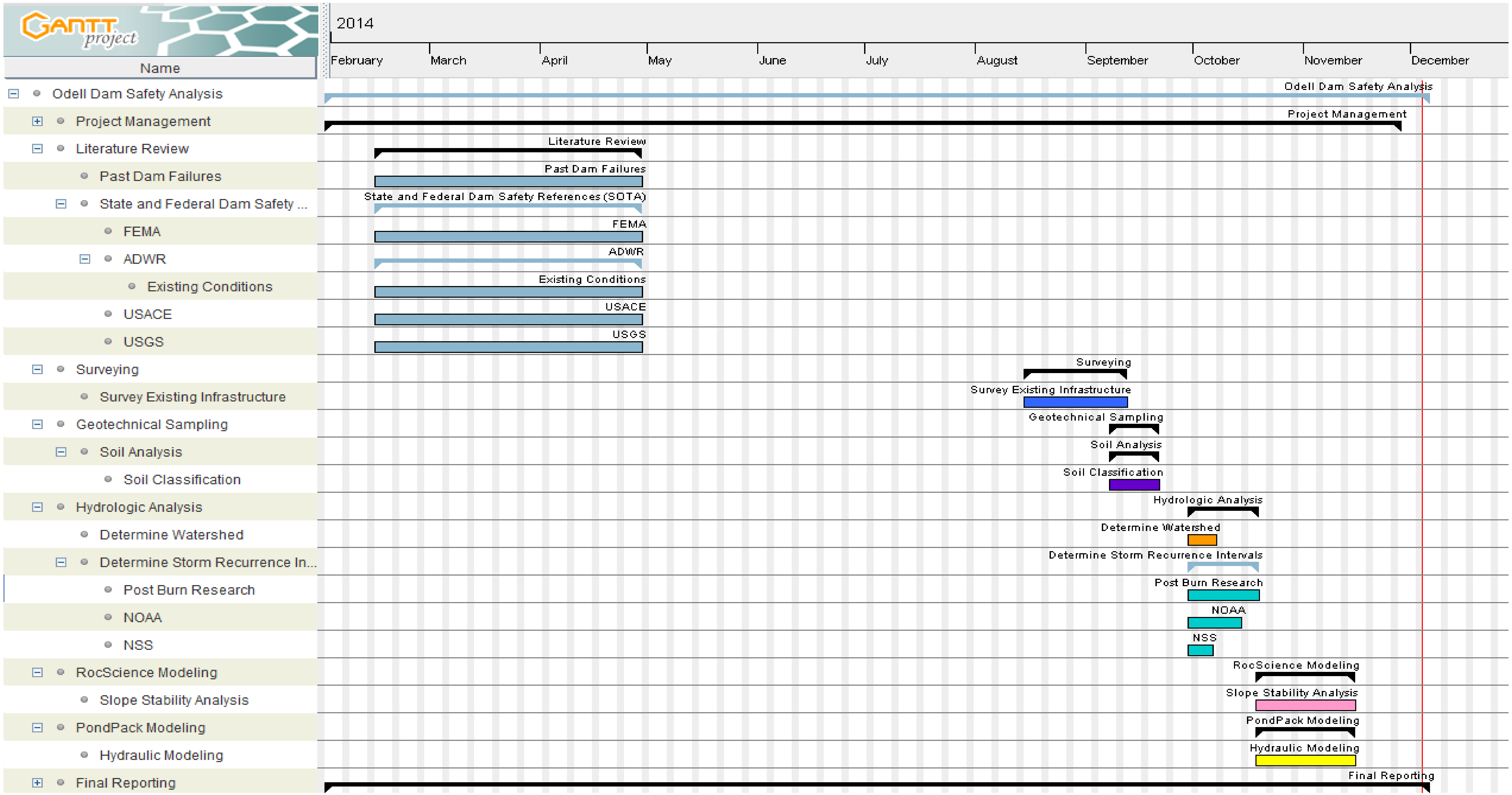


Figure M-1: Final Project Gantt Chart: 12-1-2014

Appendix N – Gantt Chart – Proposal	Figure N-1
CENE 486C – Engineering Design Capstone	Source: Gantt Project
Odell Dam Safety Analysis	Date Created: 4-14-2014

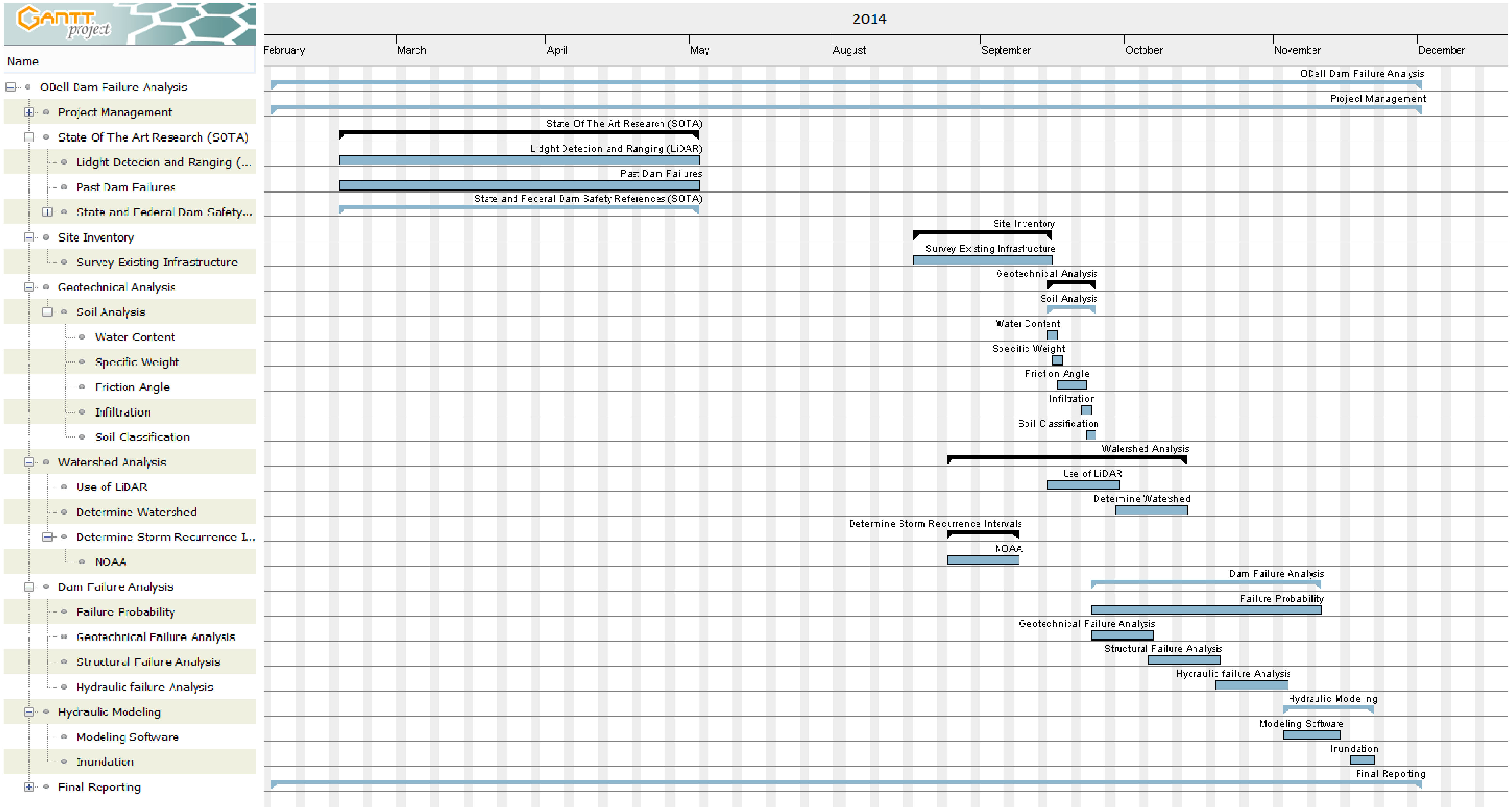


Figure N-1: Project Proposal Gantt Chart: 4-14-2014