Documentation of Initial Hazard Potential Classification Assessment

Ash Pond
Kincaid Power Station
Christian County, Illinois

Prepared for:
Dynegy

October 12, 2016

Stantec Consulting Services Inc.
Design with community in mind
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Executive Summary

This report documents the hazard potential classification assessment for the Ash Pond at the Kincaid Power Station as required per the CCR Rule in 40 C.F.R. § 257.73-(a)(2). The applicable hazard potential classifications are defined in 40 C.F.R. § 257.53 as follows:

> (1) High hazard potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.
>
> (2) Significant hazard potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.
>
> (3) Low hazard potential CCR surface impoundment means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Based on these definitions and the analysis herein, the Ash Pond is classified as a Significant hazard potential CCR surface impoundment.

This report contains supporting documentation for the hazard potential classification assessment. The hazard potential classification for this CCR unit was determined by a breach analysis conducted by Stantec in July, 2016.

1. Introduction

1.1. Background

The CCR Rule was published in the Federal Register on April 17, 2015. The Rule requires that a hazard potential classification assessment be performed for existing CCR surface impoundments that are not incised. A previously completed assessment may be used in lieu of the initial assessment provided the previous hazard assessment was completed no earlier than April 17, 2013. The applicable hazard potential classifications are defined in the CCR Rule 40 C.F.R. § 257.53 as follows:

<u>High Hazard Potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation will probably cause loss of human life.

<u>Significant Hazard Potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation results in no probable loss of human life, but can cause economic loss, environmental damage, disruption of lifeline facilities, or impact other concerns.

<u>Low Hazard Potential CCR surface impoundment</u> means a diked surface impoundment where failure or mis-operation results in no probable loss of human life and low economic and/or environmental losses. Losses are principally limited to the surface impoundment owner's property.

Dynegy has contracted Stantec Consulting Services Inc. (Stantec) to prepare hazard potential classification assessments for selected impoundments[1].

It was determined that there was no existing available hazard potential classification assessment documentation for the Ash Pond.

1.2. Location

Kincaid Power Station is located near Highway 104 and the unincorporated community of Sicily in Christian County, south of the Sangchris Lake State Park and approximately 4 miles west of Kincaid, Illinois. The Ash Pond is located northeast of the Kincaid Power Station. The Ash Pond is bounded to the northwest and southeast by Sangchris Lake and to the northeast by farm land. A site overview figure is included in Appendix C.

2. Source Data

The following information was used to perform the hazard assessment of the Ash Pond:

[1] Dynegy Administrative Services Company (Dynegy) contracted Stantec on behalf of the Kincaid Power Station owner, Kincaid Generation, LLC. Thus, Dynegy is referenced in this report.

- Aerial Imagery - 2015 NAIP Imagery Server (Reference 2)
- CCR facilities with Ash Pond outlet pipe drawings (dated 1964-1979) provided by Dynegy (Reference 3)
- Pipe Inspection Summary with drawings references - Excel file provided by Dynegy (dated 05/12/2016) (Reference 4)
- Topographic Survey and Hydrographic Survey for the area around the Ash Pond (Reference 5)
- Dam Safety Assessment (Reference 6)

3. Potential Failure Scenarios

3.1. Facility Description

Including the embankment, the Ash Pond has a footprint of approximately 185 acres with dimensions of about 3,000 by 3,000 feet. The dam crest is approximately 11,500 feet long with a typical crest width of about 12 feet. The Ash Pond is a diked facility in which the only surface runoff is generated within the interior of the dam crest. The minimum crest elevation is located near the southeastern corner of the impoundment where there is a dam height of approximately 20 feet. The maximum dam height is approximately 35 feet. The Ash Pond maintains a water volume of approximately 213 acre-feet at normal pool operating level (603.5 feet, 1.5 feet below the crest) with the capacity being approximately 322 acre-feet at the crest.

Flow typically enters the Ash Pond from the plant through the southwest embankment via eight discharge pipes. Flow circulates through the Ash Pond until reaching the normal pool which is approximately 60 acres of open water on the east side of the Ash Pond. Flow is primarily circulated through a 60 inch diameter pipe located at the base of the recycle intake screen house. The screen house intake has an approximate crest elevation of 603.5 feet. The 60 inch diameter pipe conveys flow to the recycle pump house. An emergency spillway at the same location consists of a concrete weir chamber structure with three sides. Each side is approximately 3 feet in length with an elevation of approximately 604.5 feet. Flow out of this structure is routed via a 48 inch diameter corrugated metal pipe (CMP) to the adjacent discharge channel ("hot ditch") which conveys flows to the east toward Sangchris Lake. This flow is controlled by a valve structure.

3.2. Failure Scenarios

3.2.1. "Sunny Day" Scenario

Stantec analyzed two "Sunny Day" failure scenarios (no storm water runoff draining to the facility) assuming a piping failure of the Ash Pond. Stantec assumed the primary recycle pump was not in operation; therefore, normal pool was assumed to be at 604.5 feet based on the emergency spillway elevation.

3.2.2. PMP Scenario

Probable Maximum Precipitation (PMP) values were based on *Procedural Guidelines for Preparation of Technical Data to be Included in Applications for Permits for Construction and Maintenance of Dams*, Illinois Department of Natural Resources (IDNR) (Reference 7). PMP rainfall depths for 1 square mile were used and the spatial extent of the storm was assumed to be equal to the size of the drainage basin. The rainfall depth (33.7 inches) for the 24-hour event was obtained from HMR51 (Reference 8). The SCS - Type II rainfall distribution was used as the temporal distribution for this event.

3.2.3. Breach Locations

The "Sunny Day" scenario was analyzed at two potential breach locations on the east embankment. Initial piping elevations were set to the bottom of the breach as a conservative assumption. The piping failures of the Ash Pond would discharge flow onto the adjacent farm land and then disperse over the local topography into Sangchris Lake immediately downstream. A fixed water surface elevation boundary of 585 feet was applied to represent the normal pool elevation of Sangchris Lake during "Sunny Day" conditions.

The PMP breach scenario assumes the Ash Pond begins at normal pool elevation (603.5 feet) and receives storm water runoff from a 24-hour PMP event, which is routed through the reservoir. The simulated PMP water surface elevation exceeds the crest elevation of Ash Pond, so a failure by overtopping was assumed to occur at the time of overtopping. A single breach location centered at the lowest crest elevation on the Ash Pond embankment was used for the PMP scenario. A fixed water surface elevation boundary of 593 feet was applied to represent the approximate 100-year flood elevation of Sangchris Lake.

3.3. Breach Hydrograph Development

Breach hydrographs were developed using HEC-HMS, version 4.0 (Reference 9) and HEC-RAS, version 5.0.1 (Reference 10). The dam breach function of HEC-RAS requires input of estimated breach parameters and impounded volumes. Breach parameters were determined using empirical equations. Since there is uncertainty in predicting dam breach parameters, Stantec used several empirical equations and based final breach parameters on engineering judgment (References 11 - 19).

Table 1 summarizes the breach parameters estimated for this analysis. These values are based on the assumed failure conditions, height of breach, impoundment water volume above breach, and width of the embankment. B_{avg} is the average width of a breach failure and t_f is the time for the breach to fully develop. The empirical calculations that served as the basis for the breach parameters' estimation are included in Appendix A.

Table 1 Summary of Estimated of Dam Breach Parameters

	Sunny Day 1	Sunny Day 2	PMP
Range of Breach Width Estimates (feet)	8.3 - 63.0	11.5 – 57.5	8.8 – 61.9
Range of Failure Time Estimates (hours)	0.0 - 0.6	0.0 - 0.7	0.0 -2.0
B_{avg} (feet)	42.9	40.2	58.8
t_f (hours)	0.4	0.4	0.5

Runoff calculations were performed within the HEC-HMS model consistent with methodology described in the US Department of Agriculture (USDA) Soil Conservation Service (SCS) *Technical Release-55* (Reference 20). The total contributing drainage area to the Ash Pond is 167.5 acres which consists of a single watershed. The hydrologic parameters for the area are summarized in Table 2 and a watershed figure is included in Appendix B.

Table 2 Summary of Hydrologic Parameters

	Area (acres)	Weighted CN	T_c (minutes)
Ash Pond	167.5	92.1	42.4

A stage-storage curve for the pond was developed based on topographic survey and hydrographic survey for the area around the Ash Pond from December of 2015. The stage-storage relationship used in development of the breach hydrographs is shown in Appendix A.

To route the storm hydrograph through the pond, a rating curve was developed for the Ash Pond emergency spillway. Based on record drawings and survey data, the pond has an emergency spillway consisting of a concrete weir chamber structure with three sides; each side approximately 3 feet in length. The riser weir was assigned a crest elevation of 604.5 feet (based on information from the 2011 Dam Safety Assessment). Flow out of this structure is controlled by a 36 inch diameter gated orifice which is then discharged to the adjacent "hot ditch" via a 48 inch diameter CMP outlet pipe. An orifice invert of 597.5 feet was applied based on the Dynegy provided drawing #869D4-C37. The rating curve used for discharge through the emergency spillway is shown in Appendix A.

The resulting breach hydrographs developed from HEC-RAS are presented in Appendix A.

3.4. Hydraulic Model Development

For the breach inundation, Stantec used HEC-RAS, version 5.0.1, computer program (Reference 10) to perform hydraulic routing calculations. The HEC-RAS breach simulation was configured as an unsteady flood routing model. A two-dimensional flood routing model was selected for simulating potential breach impacts from the Ash Pond.

3.4.1. Hydraulic Parameters

For the breach analysis in the hydraulic model, the initial water elevations within the Ash Pond were set at the lowest crest elevation for the PMP overtopping event based on the WSE identified from the hydrologic model and reservoir routing. Additionally, the remaining runoff inflow hydrograph after the start of breach was included as part of the breach analysis. The Sunny Day breach simulation had a normal pool initial elevation set to 604.5 feet; the crest of the emergency spillway.

The PMP breach scenario was set to overtopping failure mode with a final bottom elevation of 600 feet; the top of the stored ash on the interior embankment slope. For the two Sunny Day scenarios, a piping coefficient was set to 0.6 at initial piping elevations of 598 feet and 599 feet; the top of the stored ash on the interior embankment slope for the two Sunny Day breach locations. The three breaches were set to have 1:1 side slopes and a breach weir coefficient of 2.6.

The PMP event hydraulic model has a constant water surface elevation of 593 feet as a two-dimensional boundary condition representing the approximate 1-Percent WSE of Sangchris Lake as observed in the FEMA FIS of Christian County (Reference 21). The Sunny Day boundary condition was the normal pool of the Sangchris Lake (585 feet).

A Manning's "n" value of 0.04 was used for the downstream area, representing farmland.

3.5. Breach Modeling Results

Inundation limits for each of the breach scenarios were evaluated to determine the potential impacts on property and structures and the potential risk to human life. Model results have been summarized below for selected areas of interest. Maximum flood depths and velocities at the time they occur relative to the start of the breach are recorded. Faster moving water creates greater risk for damage to infrastructure and a greater chance of loss of life; according to the National Flood Insurance Program (NFIP), water moving at more than 5 feet per second is considered to be moving with high velocity (Reference 22).

1. Adjacent farm land ("Sunny Day 1" and "Sunny Day 2")
    a. Maximum approximate flood depth is 1.5 feet occurring 25 minutes after the breach develops.
    b. Maximum approximate flood velocity is 5 feet/second.

The PMP model results show minimal impact from the overtopping breach scenario. During the breach simulation, the WSE in the Sangchris Lake "Hot Ditch" increases by a maximum of about 1 foot immediately downstream of the breach location; however, the flow does not exceed the banks. Maximum approximate flood velocities of 10 feet/second are isolated to the breach location on the south embankment.

4. Hazard Classification

Areas of potential impact were identified with results discussed in Section 3.5 of this report. Adjacent farm land to the east of the Ash Pond is the only area identified as impacted from a breach. Discharge would ultimately flow into Sangchris Lake, located 1,500-2,500 feet downstream of the "Sunny Day" breach locations, by way of the farm land, with no structures identified in-between. Failure or mis-operation of the Ash Pond would result in no probable loss of human life. However, a potential breach event would likely result in the off-site release of CCR material onto adjacent farm land and/or into Sangchris Lake resulting in environmental damage. Therefore, the impoundment fits the definition for a Significant hazard potential CCR surface impoundment (as defined in the CCR Rule §257.53) (Reference 1).

5. References

1. US Environmental Protection Agency. (2015). *Disposal of Coal Combustion Residuals from Electric Utilities, 40 CFR § 257 and § 261* (effective April 17, 2015).

2. The National Agriculture Imagery Program (NAIP) - United States Department of Agriculture - Farm Service Agency (2015).

3. Site drawings dated 1964-1979 provided by Dynegy on 5/16/2016.

4. Pipe Inspection Summary Excel File. "Pipe_Inspection_Summary_ with Drawing References 051216 - JMFversion.xlsx" Provided by Dynegy on 6/2/2016.

5. Topographic/Bathymetric Survey - Kincaid 2015 Aerial Topography - Existing Site Conditions. Prepared for Dynegy by Weaver Consultants Group. 12/1/2015.

6. Dam Safety Assessment of CCW Impoundments - Kincaid Generation - Slag Field Prepared for United States Environmental Protection Agency by O'Brien & Gere Engineers, Inc. March 24, 2011.

7. Procedural Guidelines for Preparation of Technical Data to be included in Applications for Permits for Construction and Maintenance of Dams. State of Illinois Department of Natural Resources. Office of Water Resources. https://www.dnr.illinois.gov/WaterResources/Documents/ResmanProcedural_Guidelines.pdf Undated.

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National Oceanic and Atmospheric Administration. U.S. Department of the Army Corps of Engineers. June 1978.

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15. Federal Energy Regulatory Commission (FERC). (1987). *FERC 0119-1: Engineering Guidelines for the Evaluation of Hydropower Projects*. Office of Hydropower Licensing.

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17. US Bureau of Reclamation (USBR). (1988). *ACER Technical Memorandum No. 11: Downstream Hazard Classification Guidelines*. Assistant Commissioner-Engineering and Research, Denver, Colorado, 57.

18. Von Thun, Lawrence J. and D. R. Gillette. (1990). *Guidance on Breach Parameters*, unpublished internal document, USBR, Denver, Colorado, 17. (Referenced in Wahl 1998).

19. Froehlich, D. C. (1995). "Embankment Dam Breach Parameters Revisited." *Proceedings of the 1995 ASCE Conference on Water Resources Engineering*, ASCE, San Antonio, Texas, 887-891.

20. US Department of Agriculture. (1986). Technical Release – 55: *Urban Hydrology for Small Watersheds*. Soil conservation Services.

21. Federal Emergency Management Agency. Flood Insurance Study: Christian County, Illinois and Incorporated Areas.

22. Federal Emergency Management Association (FEMA). (2012). *Assessing the Consequences of Dam Failure*. A How-to-Guide.

23. Federal Emergency Management Association (FEMA). (2004). *Hazard Potential Classification System for Dams.*

Appendix A

Breach Parameters

Figure A.1 - "Sunny Day - 1" Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

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Project Data (Optional):

Dam: *Kincaid Ash Pond*
Location: *Christian County, Illinois*
Notes: *"Sunny Day" Breach of East Embankment*
Piping Failure Assumed

Inputs:

		English Units		*SI Units*	
Height of dam	h_d	18.0	feet	5.5	meters
Height of breach	h_b	18.0	feet	5.5	meters
Height/depth of water at breach	h_w	6.5	feet	2.0	meters
Storage	S	321.5	ac-feet	396502.7	m^3
Volume of water at breach	V_w	276.7	ac-feet	341353.8	m^3
Width of dam at base	W_{base}	250.0	feet	76.2	meters
Width of dam at crest	W_{crest}	12.0	feet	3.7	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	42.9	feet	13.1	meters
Breach bottom width	B_W	23.9	feet	7.3	meters
Breach formation time	t_f	0.4	hours	0.37	hours
Peak discharge	Q_p	23,841	ft^3/s	675.1	m^3/s
Breach side slope	Z	1.00		1.00	
Volume of embankment eroded	V_{er}	150878.2	ft^3	4272.6	m^3
Volume of water discharged	V_o,V_{out}	250.96	ac-feet	309558.3	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	**B** (m)	**B** (ft)	**Z**	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	9.6	31.5						
2 - Singh and Snorrason 1982, 1984	19.2	63.0						
3 - MacDonald and Langridge-Monopolis 1984	2.5	8.3		822.7				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	16.5	54.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	18.1	59.2			1.0			
8 - Froehlich 1987			0.645			39.9	1.0	
9 - USBR 1988	5.9	19.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	11.1	36.3						6.1
12 - Froehlich 1995	14.7	48.2			1.0			
13 - Froehlich 1995			1.000					

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.206
16 - FERC 1987	0.550
17 - Froehlich 1987	0.637
18 - USBR 1988	0.144
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.030
22 - Von Thun and Gillette 1990	0.186
23 - Froehlich 1995	0.470

Figure A.2 - "Sunny Day - 2" Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data (Optional):

Dam: *Kincaid Ash Pond*
Location: *Christian County, Illinois*
Notes: *"Sunny Day" Breach of East Embankment*
Piping Failure Assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	16.0	feet	4.9	meters
Height of breach	h_b	16.0	feet	4.9	meters
Height/depth of water at breach	h_w	5.5	feet	1.7	meters
Storage	S	321.5	ac-feet	396502.7	m^3
Volume of water at breach	V_w	264.5	ac-feet	326293.0	m^3
Width of dam at base	W_{base}	250.0	feet	76.2	meters
Width of dam at crest	W_{crest}	12.0	feet	3.7	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Piping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

		English Units		SI Units	
Breach width	B_{AVG}	40.2	feet	12.2	meters
Breach bottom width	B_W	23.2	feet	7.1	meters
Breach formation time	t_f	0.4	hours	0.38	hours
Peak discharge	Q_p	22,710	ft^3/s	643.1	m^3/s
Breach side slope	Z	1.00		1.00	
Volume of embankment eroded	V_{er}	89498.6	ft^3	2534.4	m^3
Volume of water discharged	V_o, V_{out}	246.82	ac-feet	304451.7	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	B (m)	B (ft)	Z	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	8.5	28.0						
2 - Singh and Snorrason 1982, 1984	17.1	56.0						
3 - MacDonald and Langridge-Monopolis 1984	3.5	11.5		727.6				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	14.6	48.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	17.5	57.5			1.0			
8 - Froehlich 1987			0.651			39.9	1.0	
9 - USBR 1988	5.0	16.5						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	10.3	33.8						6.1
12 - Froehlich 1995	14.2	46.5			1.0			
13 - Froehlich 1995			1.000					

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.197
16 - FERC 1987	0.550
17 - Froehlich 1987	0.709
18 - USBR 1988	0.135
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.025
22 - Von Thun and Gillette 1990	0.178
23 - Froehlich 1995	0.510

Figure A.3 - PMP Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Stantec

Project Data (Optional):

Dam:	*Kincaid Ash Pond*
Location:	*Christian County, Illinois*
Notes:	*PMP breach assumes dam failure is initiated when overtopping begins at dam crest.*
	Overtopping failure assumed

Inputs:

		English Units		SI Units	
Height of dam	h_d	5.0	feet	1.5	meters
Height of breach	h_b	5.0	feet	1.5	meters
Height/depth of water at breach	h_w	5.0	feet	1.5	meters
Storage	S	321.5	ac-feet	396502.7	m^3
Volume of water at breach	V_w	276.9	ac-feet	341563.5	m^3
Width of dam at base	W_{base}	150.0	feet	45.7	meters
Width of dam at crest	W_{crest}	30.0	feet	9.1	meters
Estimated breach side slope	Z	1.0		1.0	
Baseflow	Q_{base}	0.0	ft^3/s	0.00	m^3/s
Type of Failure		Overtopping			
Dam has core wall?		No			
Erosion resistant embankment?		No			

Data Convention:
- User Input Data
- Default calculation, user can change.
- Calculated value.

Average of Calculated Values:

Breach width	B_{AVG}	58.8	feet	17.9	meters
Breach bottom width	B_W	47.3	feet	14.4	meters
Breach formation time	t_f	0.50	hours	0.50	hours
Peak discharge	Q_p	26,627	ft^3/s	754.0	m^3/s
Breach side slope	Z	1.00		1.00	
Volume of embankment eroded	V_{er}	60947.6	ft^3	1725.9	m^3
Volume of water discharged	V_o, V_{out}	390.64	ac-feet	481848.6	m^3

Estimates of Breach Width & Dimensions

Source Equation (See Attached Equation Reference)	B (m)	B (ft)	Z	V_{er} (m^3)	K_o	$\overline{W}$ (m)	K_c	C_b
1 - Johnson and Illes 1976	2.7	8.8						
2 - Singh and Snorrason 1982, 1984	5.3	17.5						
3 - MacDonald and Langridge-Monopolis 1984	18.9	61.9		1816.8				
4 - MacDonald and Langridge-Monopolis 1984			0.500					
5 - FERC 1987	4.6	15.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	18.3	60.2			1.4			
8 - Froehlich 1987			6.186			27.4	1.0	
9 - USBR 1988	4.6	15.0						
10 - Von Thun and Gillette 1990			1.000					
11 - Von Thun and Gillette 1990	9.9	32.5						6.1
12 - Froehlich 1995	16.1	52.9			1.4			
13 - Froehlich 1995			1.000					

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh and Snorrason 1982, 1984	0.625
15 - MacDonald and Langridge-Monopolis 1984	0.275
16 - FERC 1987	0.550
17 - Froehlich 1987	2.043
18 - USBR 1988	0.197
19 - Von Thun and Gillette 1990	
20 - Von Thun and Gillette 1990	
21 - Von Thun and Gillette 1990	0.023
22 - Von Thun and Gillette 1990	0.232
23 - Froehlich 1995	1.489

Figure A.4 - Ash Pond Stage-Storage Relationships

Facility Name: Kincaid Power Station Ash Pond

Elevation	Cumulative Water Volume (Acre-Feet)
594	0
595	0
596	0
597	1
598	6
599	18
600	45
601	84
602	130
603	182
604	244
605	321
606	414
607	515

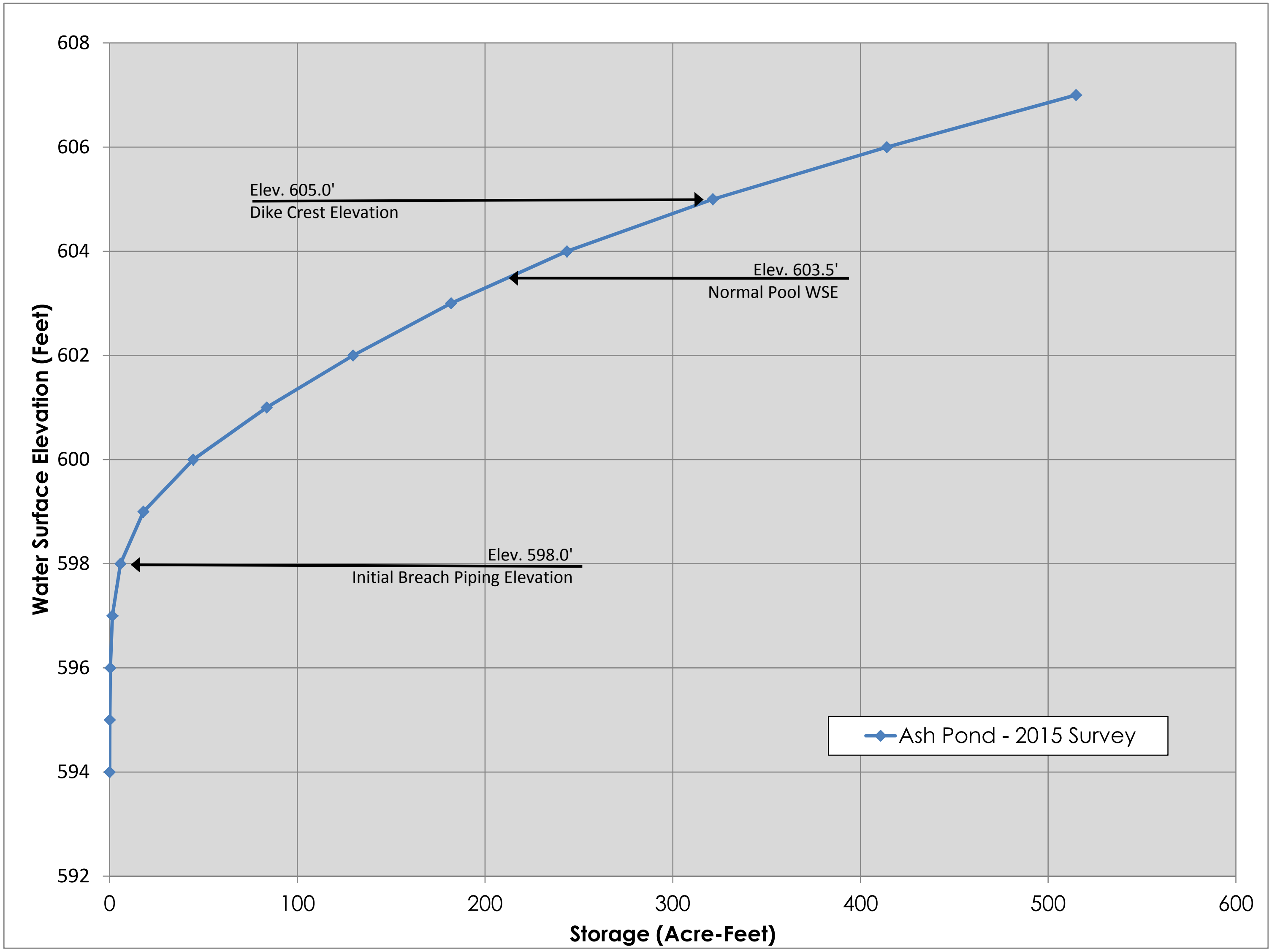
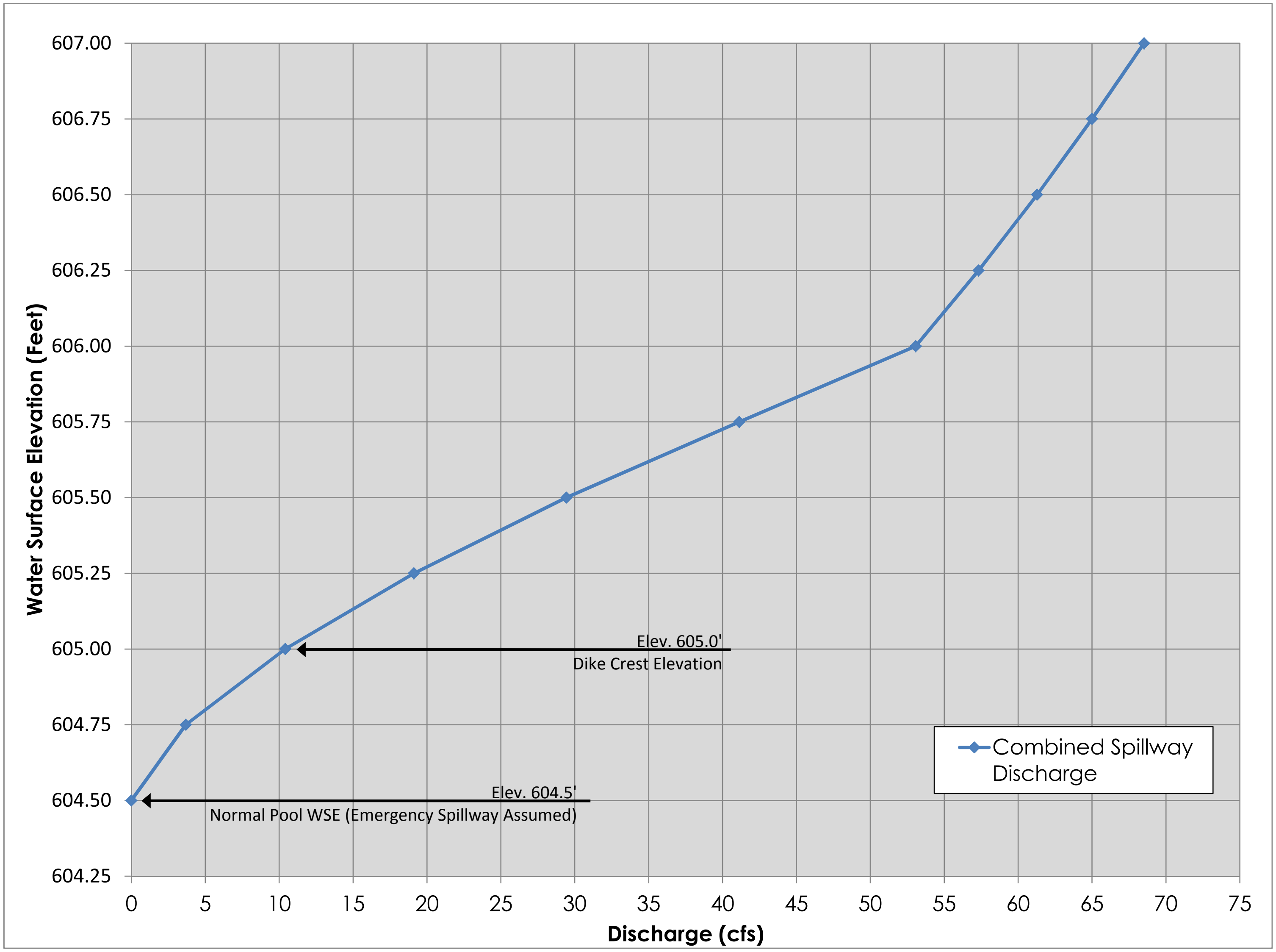


Figure A.5 - Ash Pond Emergency Spillway Rating Curve

Elevation	Combined Spillway Discharge (cfs)
604.50	0
604.75	4
605.00	10
605.25	19
605.50	29
605.75	41
606.00	53
606.25	57
606.50	61
606.75	65
607.00	69

Facility Name: Kincaid Power Station Ash Pond



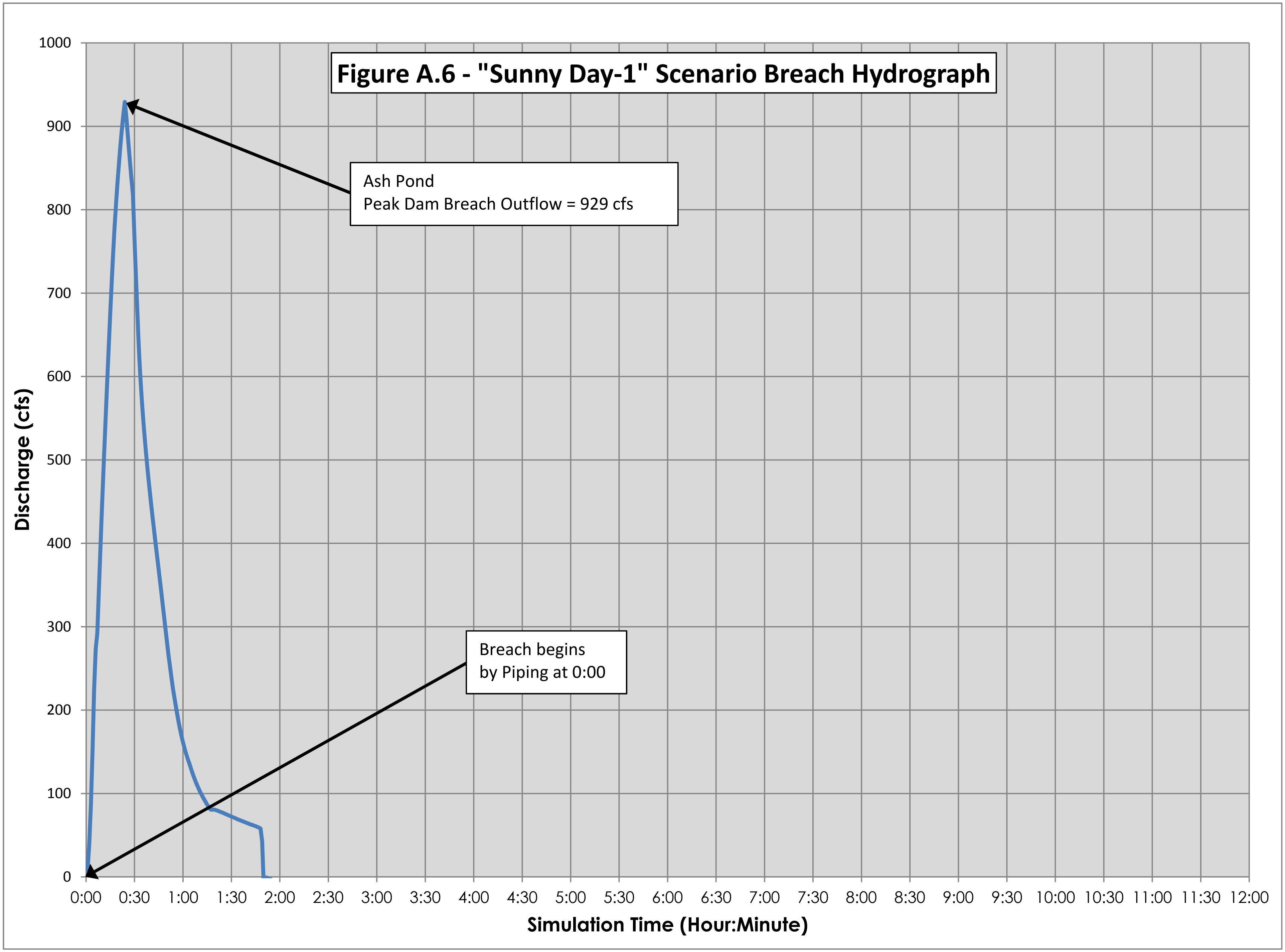


Figure A.6 - "Sunny Day-1" Scenario Breach Hydrograph
Ash Pond
Peak Dam Breach Outflow = 929 cfs
Breach begins
by Piping at 0:00
Discharge (cfs)
0
100
200
300
400
500
600
700
800
900
1000
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
Simulation Time (Hour:Minute)

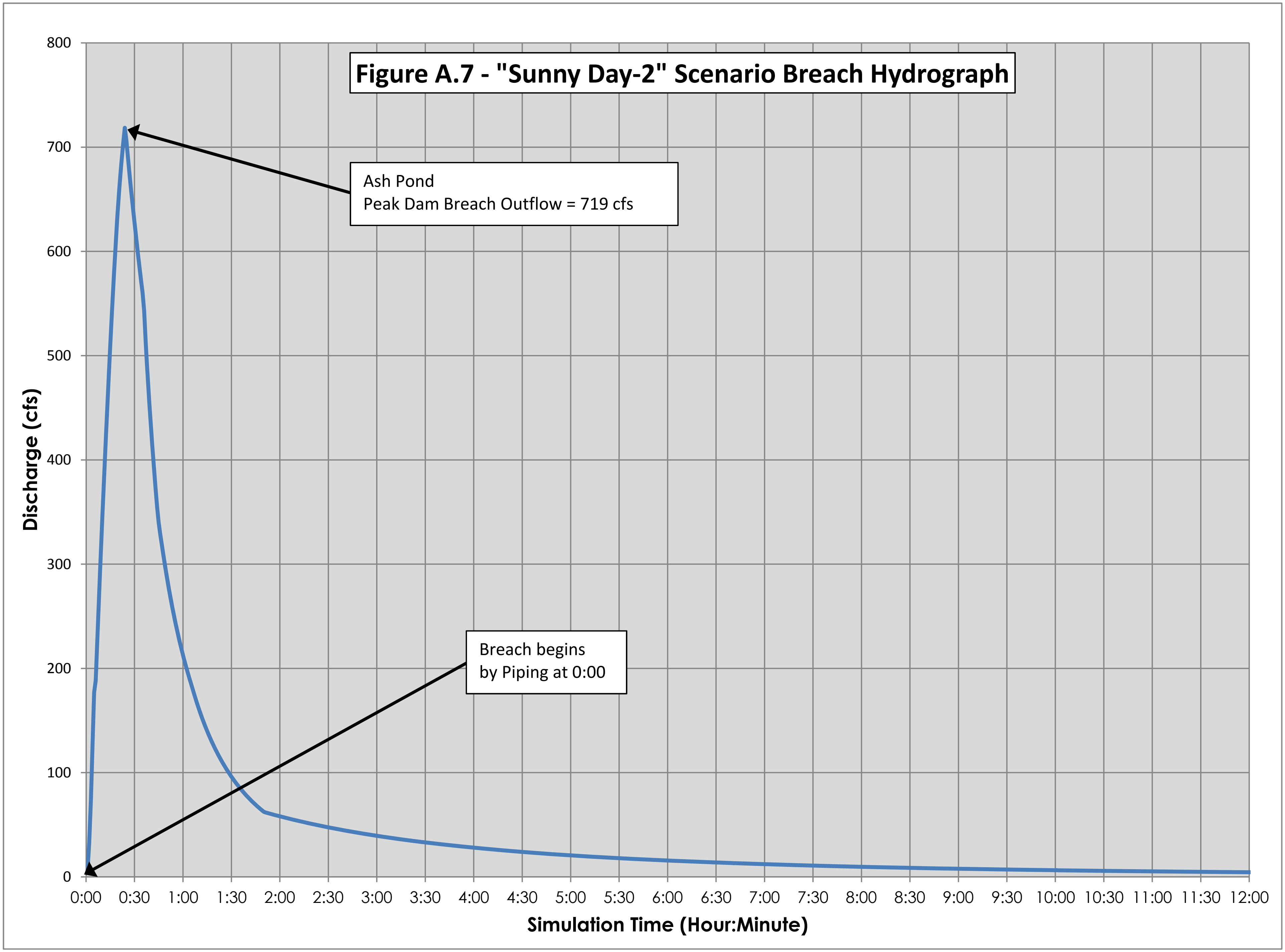


Figure A.7 - "Sunny Day-2" Scenario Breach Hydrograph
Ash Pond
Peak Dam Breach Outflow = 719 cfs
Breach begins
by Piping at 0:00
Discharge (cfs)
800
700
600
500
400
300
200
100
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00
Simulation Time (Hour:Minute)

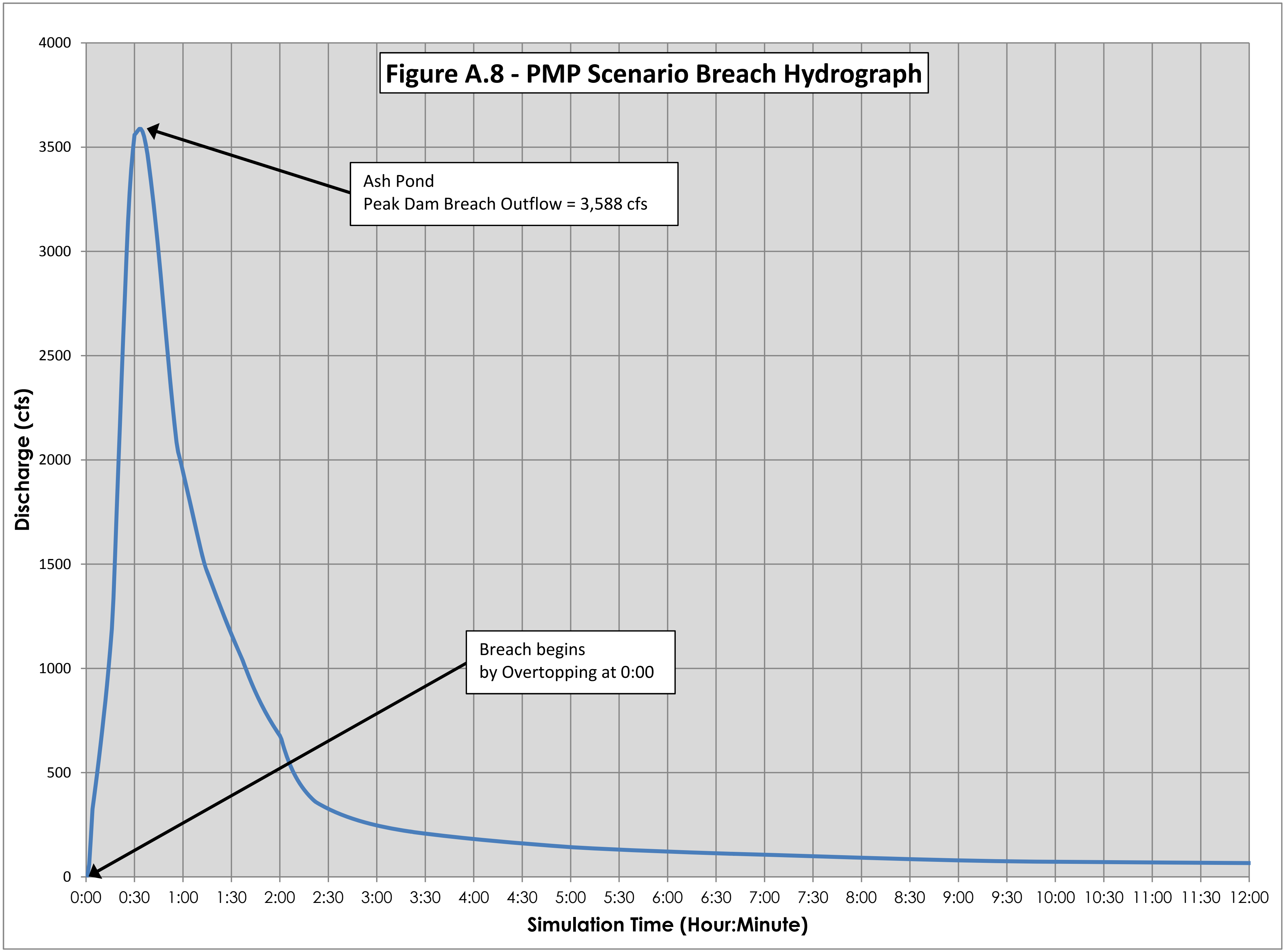


Figure A.8 - PMP Scenario Breach Hydrograph
Ash Pond
Peak Dam Breach Outflow = 3,588 cfs
Breach begins
by Overtopping at 0:00
Discharge (cfs)
Simulation Time (Hour:Minute)
4000
3500
3000
2500
2000
1500
1000
500
0
0:00
0:30
1:00
1:30
2:00
2:30
3:00
3:30
4:00
4:30
5:00
5:30
6:00
6:30
7:00
7:30
8:00
8:30
9:00
9:30
10:00
10:30
11:00
11:30
12:00

Dam Breach Parameter Spreadsheet

Equations, Procedures, and Notes

Last Updated/By: 8-24-12 – Erman Caudill (Stantec)

Assumptions:

- Equations here were extracted from the USBR Report "Prediction of Embankment Dam Breach Parameters" and the Journal of Hydraulic Engineering article "Uncertainty of Predictions of Embankment Dam Breach Parameters" by the same author (Tony L. Wahl, USBR). Citation for that reference is included below, but recursive references have been omitted.
- All earthen embankments.
- Measurements are in SI units (meters, m^3/s, hours) unless otherwise noted. Spreadsheet is set up to do the English-SI input conversions, then convert answers back to English units.

Input Parameters, Constants, and Variables:

h_d = height of dam: input
h_b = height of breach: input, generally = h_d
h_w = height (depth) of water at failure above breach bottom: input
S = storage: input parameter
V_w = volume of water above breach invert at time of breach: input, generally = S
W = Embankment width: input
Z = breach opening side slope: input or calculated

g = acceleration of gravity = 9.8 m/s^2 =127,008,000 m/hr^2

B = average breach width: calculated (see below)
B_W = breach bottom width: calculated using B, h_b, and Z (see equation 39)
t_f = breach formation time, hours: calculated (see below)
Q_p = peak breach outflow: calculated (see below)
Z = breach opening side slope: input or calculated (see below)
V_{er} = volume of embankment material eroded: generally calculated (see Equation 40)
V_o,V_{out} = volume of water discharged: calculated = S + inflow during breach

Breach Width & Dimension Equations:

Johnson and Illes 1976

(1) $0.5h_d \le B \le 3h_d$

Singh and Snorrason 1982, 1984

(2) $2h_d \le B \le 5h_d$

MacDonald and Langridge-Monopolis 1984

(3) $V_{er} = 0.0261(V_{out}h_w)^{0.769}$

(4) $Z = 1H{:}2V$

FERC 1987

(5) $2h_d \le B \le 4h_d$

(6) $0.25 \le Z \le 1.0$

Froehlich 1987

$$\overline{B^*} = \frac{\overline{B}}{h} = 0.47K_o(S^*)^{0.25}$$

$$S^* = \frac{S}{{h_b}^3}$$

(7) $\overline{B} = 0.47 h_b K_o \left(\frac{S}{h_b{}^3}\right)^{0.25}$ Ko = 1.4 overtopping; 1.0 otherwise

$$Z = 0.75 K_c (h_w{}^*)^{1.57} \left(\overline{W^*}\right)^{0.73}$$
$$h_w{}^* = \frac{h_w}{h_b}$$
$$\left(\overline{W^*}\right) = \frac{\overline{W}}{h} = \frac{W_{crest} + W_{bottom}}{2h}$$

(8) $Z = 0.75 K_c \left(\frac{h_w}{h_b}\right)^{1.57} \left(\frac{\overline{W}}{h_b}\right)^{0.73}$ Kc = 0.6 with corewall; 1.0 without a corewall

USBR 1988

(9) $B = 3h_w$

Von Thun and Gillette 1990

(10) $Z = 1H{:}1V$

(11) $\overline{B} = 2.5h_w + C$

$$C_b = f(\text{reservoir size}, m^3) = \left\{\begin{array}{cc} \textit{Size} & C_b \\ < 1.23x10^6 & 6.1 \\ 1.23x10^6 - 6.17x10^6 & 18.3 \\ 6.17x10^6 - 1.23x10^7 & 42.7 \\ > 1.23x10^7 & 54.9 \end{array}\right\}$$

Froehlich 1995

(12) $\overline{B} = 0.1803 K_o V_w{}^{0.32} h_b{}^{0.19}$ Ko = 1.4 overtopping; 1.0 otherwise

(13) $Z = 1.4$ for overtopping, 0.9 otherwise

Failure Time Equations:

Singh and Snorrason 1982, 1984

(14) $0.25\text{ hr} \le t_f \le 1.0\text{ hr}$

MacDonald and Langridge-Monopolis 1984

(15) $t_f = 0.0179(V_{er})^{0.364}$

FERC 1987

(16) $0.10\text{ hr} \le t_f \le 1.0\text{ hr}$

Froehlich 1987 (t_f* equation was corrected from the report)

$$S^* = \frac{S}{h_b{}^3}$$
$$t_f{}^* = 79(S^*)^{0.47} = 79\left(\frac{S}{h_b{}^3}\right)^{0.47}$$
$$t_f{}^* = t_f\sqrt{\frac{g}{h}}$$

(17) $t_f = \dfrac{79\left(\frac{S}{h_b{}^3}\right)^{0.47}}{\sqrt{\frac{g}{h_b}}}$

USBR 1988

(18) $t_f = 0.011B$

Von Thun and Gillette 1990

Erosion Resistant

(19) $t_f = 0.020h_w + 0.25$

(20) $t_f = \frac{\bar{B}}{4h_w}$

Highly Erodible

(21) $t_f = 0.015h_w$

(22) $t_f = \frac{\bar{B}}{4h_w + 61.0}$

Froehlich 1995

(23) $t_f = 0.00254{V_w}^{0.53}{h_b}^{(-0.90)}$

Peak Flow Equations:

Kirkpatrick 1977

(24) $Q_p = 1.268(h_w + 0.3)^{2.5}$

SCS 1981

(25) $Q_p = 16.6(h_w)^{1.85}$

Hagen 1982

(26) $Q_p = 0.54(S \times h_d)^{0.5}$

USBR 1982

(27) $Q_p = 19.1(h_w)^{1.85}$

Singh and Snorrason 1984

(28) $Q_p = 13.4(h_d)^{1.89}$

(29) $Q_p = 1.776(S)^{0.47}$

MacDonald and Langridge-Monopolis 1984

(30) $Q_p = 1.154(V_w h_w)^{0.412}$

(31) $Q_p = 3.85(V_w h_w)^{0.411}$

Costa 1985

(32) $Q_p = 1.122(S)^{0.57}$

(33) $Q_p = 0.981(S \times h_d)^{0.42}$

(34) $Q_p = 2.634(S \times h_d)^{0.44}$

Evans 1986

(35) $Q_p = 0.72(V_W)^{0.53}$

Froehlich 1995

(36) $Q_p = 0.607{V_w}^{0.295}{h_w}^{1.24}$

Webby 1996

(37) $Q_p = 0.0443g^{0.5}{V_w}^{0.367}{h_w}^{1.40}$

Walder and O'Connor 1997

$$\eta = \frac{kV_o}{g^{0.5}d^{3.5}}$$

k = vertical erosion rate = 10 m/hr – 100 m/hr
d = 50-100% of dam height

(38) $$Q_p = \begin{Bmatrix} 1.51(g^{0.5}d^{2.5})^{0.06}\left(\frac{kV_o}{d}\right)^{0.94} & \eta < \sim 0.6 \\ 1.94g^{0.5}d^{2.5}\left(\frac{h_d}{d}\right)^{0.75} & \eta \gg 1 \end{Bmatrix}$$

Other Equations:

Breach Bottom Width

(39) $$B_W = B - h_b Z$$

Embankment Volume

(40) $$V_{er} = \left(B_w h_b + Z{h_b}^2\right)\left(\frac{W_{crest} + W_{base}}{2}\right) = (Bh_b)\left(\frac{W_{crest} + W_{base}}{2}\right)$$

$$B = \frac{V_{er}}{h_b\left(\frac{W_{crest} + W_{base}}{2}\right)}$$

References:

U.S. Department of the Interior, Bureau of Reclamation, Dam Safety Office. July 1998. "Prediction of Embankment Dam Breach Parameters, A Literature Review and Needs Assessment, DSO-98-004, Dam Safety Research Report", Tony L. Wahl, Water Resources Research Laboratory. 67 pp.

"Uncertainty of Predictions of Embankment Dam Breach Parameters", Tony L. Wahl. Journal of Hydraulic Engineering, Vol. 130, No. 5, May 1, 2004. 9 pp.

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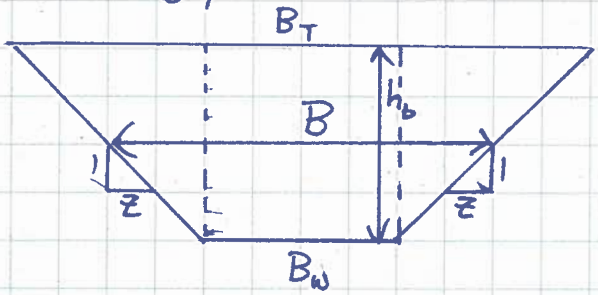
DAM BREACH EQUATIONS

DERIVATIONS NOT SHOWN

1. BREACH BOTTOM WIDTH GIVEN AVG. BREACH WIDTH B, BREACH HEIGHT H_b, AND BREACH SIDE SLOPES Z



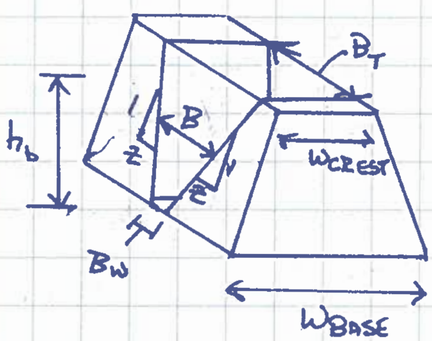
$$B = \frac{B_T + B_W}{2}$$

$$B_T = B_W + 2 h_b Z$$

$$B = \frac{(B_W + 2h_b Z) + B_W}{2} = \frac{2B_W + 2h_b Z}{2} = B_W + h_b Z$$

$$B_W = B - h_b Z$$

2. VOLUME OF EMBANKMENT ERODED



AREA AT CENTER

$$A_c = B_w h_b + Z h_b^2$$

$$\forall = A_c W_{CREST} + 2 \frac{A_c}{2} \frac{\cancel{(W_{CREST} - W_{BASE})}\ (W_{BASE} - W_{CREST})}{2}$$

$$= A_c W_c + \frac{A_c W_B}{2} - \frac{A_c W_c}{2}$$

$$= \frac{A_c W_c}{2} + \frac{A_c W_B}{2}$$

$$= A_c \left(\frac{W_c + W_B}{2} \right)$$

$$\forall = (B_w h_b + Z h_b^2) \left(\frac{W_c + W_B}{2} \right)$$

$$\forall = B h_b \left(\frac{W_c + W_B}{2} \right) \rightarrow B = \frac{\forall}{h_b \left(\frac{W_c + W_B}{2} \right)}$$

Designed by: Checked by:

Appendix B

Watershed Figure

Figure No.
B.1

Title
Watershed Figure
Ash Pond
Kincaid Power Station

Client/Project
Dynegy
Kincaid Power Station
Hazard Potential Classification Assessment

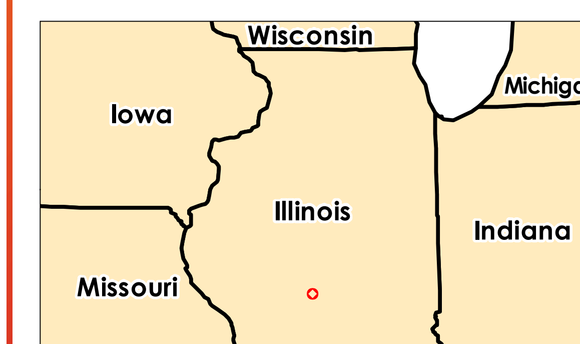
Project Location
Latitude: 38.877193
Longitude: -84.229495
SE. of Cincinnati, Clermont Co., OH

175666013
Prepared by NS on 2016-10-05
Technical Review by PV on 2016-10-05
Independent Review by MH on 2016-10-05

0 500 Feet
1:6,000 (At original document size of 11x17)

Legend

Ash Pond Watershed Area



Notes

1. Coordinate System: NAD 1983 StatePlane Illinois West FIPS 1202 Feet
2. Base features: produced from project design elements.
3. Base Imagery: Orthoimagery - Clermont County, 2015.

Stantec DYNEGY

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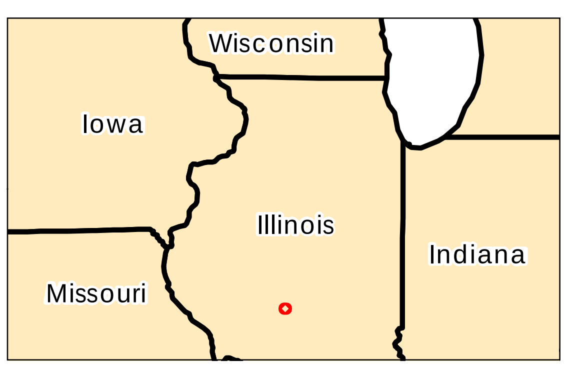
Appendix C

Site Overview Figure



0 1,000 Feet

1:12,000 (At original document size of 11x17)

Stantec DYNEGY

Project Location
Latitude: 39.592011
Longitude: -89.497012
Christian County, Illinois

175605019
Prepared by WSW on 2016-10-06
Technical Review by NS on 2016-10-06
Independent Review by MH on 2016-10-06

Client/Project
Dynegy
Kincaid Power Station
Hazard Potential Classification Assessment

Figure No.
C.1

Title
Site Overview Figure
Ash Pond
Kincaid Power Station

Notes
1. Coordinate System: WGS 1984 Web Mercator Auxiliary Sphere
2. Aerial Source: 2015 NAIP Imagery
3. Impoundment Boundaries Provided by Client (Dated 9/9/2015)

V:\1735\temporary\users\NSottes\Work\Dynegy\1_Dynegy_Review_Updates\MXD\015_appen_c_site_overview_fig_20161006.mxd Revised: 2016-10-06 By: nsottes