Documentation of Initial Hazard Potential Classification Assessment

Ash Pond No. 1
Coffeen Power Station
Montgomery 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 Ash Pond No. 1 (also known as Bottom Ash Recycle Pond) at the Coffeen Power Station as required per the CCR Rule (Reference 1) in 40 C.F.R. § 257.73(a)(2). The applicable hazard potential classifications are defined in the CCR Rule 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, Ash Pond No. 1 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 August, 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 (Reference 1):

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

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.

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.

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 Ash Pond No. 1.

1.2. Location

The Coffeen Power Station is located in Montgomery County, Illinois approximately 1.5 miles south of Coffeen, Illinois. The plant is located on the east bank of Coffeen Lake, which is an impoundment created by Coffeen Lake Dam. Ash Pond No. 1 is located east of the plant. A site overview figure is included in Appendix C.

2. Source Data

The following information was used to perform the hazard assessment of Ash Pond No. 1.

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

2.1. GIS DATA

Geographic Information Systems (GIS) data was collected for use in this study, including;

- Aerial Imagery obtained from 2015 NAIP Imagery Server (Reference 2);
- Streets obtained from the US Census Bureau, 2015 TIGER Roads layer (Reference 3);
- 1/3 Arc Second Digital Elevation Model (DEM) obtained from the United States Geological Service (USGS) National Map (Reference 4).

2.2. Field Survey

Topographic and bathymetric survey data of Ash Pond No. 1 was provided by Dynegy. The survey data was prepared by Weaver Consultants Group (December, 2015) (Reference 5).

Bathymetric data of Coffeen Lake was obtained from the Aquatic Ecology Technical Report 93/9(2); “Compendium of 143 Illinois Lakes: Bathymetry, physio-chemical features, and habitats” (June, 1993). This data source was available online from the University of Illinois at Urbana-Champaign Library Large-scale Digitization Project (2007) (Reference 6).

2.3. Record Drawings

Dynegy provided the following record drawings that were utilized in the hazard potential classification assessment of Ash Pond No. 1:

- Sargent & Lundy Engineers, “Earthwork & Grading Plan - Unit 1”, Dynegy File: B-35 Earthwork & Grading Plan, January 2, 1963 (Reference 7);
- Sargent & Lundy Engineers, “Miscel. Outdoor Foundations Plans & Sections – Unit 1”, Dynegy File: B-68 Misc Outdoor Foundations Plans & Sections, November 12, 1963 (Reference 8);
- Stearns-Roger Incorporated, “Civil Site Plan”, Dynegy File: S-40 rev9.0 civil site plan – ash pond 1 and 2 overall, June 16, 1978 (Reference 9);
- Stearns-Roger Incorporated, “Civil, Layout & Grading Plan Sheet 4”, Dynegy File: S-44 rev6 civil layout and grading plan.pdf, June 8, 1979 (Reference 10);
- Stearns-Roger Incorporated, “Civil, Layout & Grading Plan Sheet 5”, Dynegy File: S-45 rev9 civil layout and grading plan – recycle pond.pdf, June 9, 1978 (Reference 11);

- Stearns-Roger Incorporated, "Concrete Recycle Pump House – Intake Structure & Miscellaneous Foundations", Dynegy File: S-8 Concrete – Recycle Pump House – recycle pond.pdf, June 8, 1979 (Reference 12);

- Stearns-Roger Incorporated, "Concrete Miscellaneous Structures, Foundation Plans Sections & Details", Dynegy File: s9s+r.dgn, January 5, 1979 (Reference 13);

- Stearns-Roger Incorporated, "Civil, Miscellaneous Sections & Details Sheet 4 ", Dynegy File: S-49 rev4 civil sections and details – recycle pond.pdf, June 9, 1978 (Reference 14);

- Hanson Professional Services Inc., "Proposed Site Plan, Landfill Cell 1", Dynegy File: cc10207_04.dgn, January 5, 2011 (Reference 15);

- Hanson Professional Services Inc., "Groundwater Monitoring & Boring Plan - Landfill", Dynegy File: cc10207_05.dgn, January 5, 2011 (Reference 16).

2.4. Record Documents

Dynegy provided the following Coffeen Power Station documents that were utilized in this assessment:

- Operation & Maintenance (O&M) Manual for #1 Ash Pond (Bottom Ash Recycle Pond), initially prepared by Hanson Professional Services Inc. (February, 2008) and amended by Dynegy Operating Company (March, 2014) (Reference 17);

- Coffeen Lake Dam Emergency Action Plan (EAP), initially prepared by Hanson Professional Services Inc. (August, 2008) and amended by Dynegy Operating Company (October, 2015) (Reference 18).

Note that the Coffeen Lake Dam EAP utilizes a breach analysis of the Coffeen Lake Dam performed by Hanson Professional Services in 2007. This breach analysis contained Coffeen Lake water surface elevations (WSELs) that were calculated for various storm events analyzed. The lake WSEL calculated for the event that corresponded with a 100-year storm event was utilized in this assessment.

2.5. Other Document Reviewed

The EPA Site Assessment Report, prepared by Kleinfelder in April 2011 (Reference 19), was reviewed for background information purposes. Within the site assessment report, Kleinfelder determined that Ash Pond No. 1 should be considered a CCR impoundment and recommended that Ash Pond No. 1 be classified as a Significant Hazard dam due to potential environmental and economic impacts that would be associated with a breach.

3. Potential Failure Scenarios

3.1. Facility Description

Ash Pond No. 1 consists of a single pond with a surface area of approximately 23 acres formed by earthen embankments around the perimeter. The earthen embankment is approximately 4,300 feet long and has a maximum height of 41.5 feet above the surrounding grade. The pool level is controlled by a recycle pump system that is located at the NW corner. The intake for the recycle pump system consists of a reinforced concrete riser that connects to a 48-inch inside diameter steel pipe. A 24-inch inside diameter corrugated metal pipe connects to the top of the 48-inch inside diameter steel pipe to provide an emergency spillway that discharges into the cooling water discharge channel to the north. The Cooling Water Pond discharge channel runs along the north side of the pond into the eastern cove of Coffeen Lake (Eastern Cove).

Normal pool elevation used in the analysis was 630 feet based on available survey data. The stormwater capacity of Ash Pond No. 1 is approximately 215 acre-feet at a crest elevation of 637.5 feet. The stored material within the pond consists of primarily bottom ash according to the Ash Pond No. 1 O&M Manual (Reference 17) and boiler slag according to the EPA Site Assessment Report (Reference 19).

3.2. Elevation-Storage

A stage-storage curve for the pond was developed for the volume between the stored material and the embankment crest based on the 2015 survey data from elevations 624.0 feet to 637.5 feet. The corresponding volume was assumed to be water-only. The stage-storage relationship used in development of the breach hydrographs is shown as Figure A.3 in Appendix A.

The elevation-storage relationship was developed from a three-dimensional (3D) surface created in AutoCAD Civil 3D (AutoCAD) using 2015 topography (Reference 5). Data used to create the surface included an Autocad drawing, Dynegy file name "Coffeen_Topo_2015-WGC.dwg" provided to Stantec which contained two-dimensional (2D) polylines with elevation labels. In AutoCAD the 2D polylines were converted to 3D polylines by assigning them elevations based on the labels. The 3D polylines were then used in AutoCAD to create the Ash Pond No. 1 surface. The Ash Pond No. 1 elevation-storage values were calculated in AutoCAD at one-foot increments.

3.3. Failure Scenarios

3.3.1. PMP Scenario

Stantec analyzed a Probable Maximum Precipitation (PMP) event failure scenario. The PMP scenario assumes a piping failure of Ash Pond No. 1 once it has reached a peak pool elevation of 633.6 feet during a PMP event simulation. The 24-hour PMP event precipitation depth (34.0 inches) was obtained from the US Department of

Commerce National Oceanic and Atmospheric Administration (NOAA) Hydrometeorology Report No. 51, Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 ($26km^2$) (Reference 20). A Soil Conservation Service (SCS) Type-II 24-hour hyetograph was applied to the PMP depth for this simulation. Storm routing was initiated with the water surface at normal pool. During the PMP scenario, surrounding water-ways were assumed to be at the 100-year flood condition.

3.3.2. Breach Locations

The PMP scenario was analyzed at two potential breach locations. The northeast (NE) breach location is where the embankment is at its maximum height (41.5 feet) above surrounding grade and will result in discharge directly into the Eastern Cove. The northwest (NW) breach location is located where the embankment is approximately 17.5-feet above surrounding grade and will discharge towards the Coffeen Power Station facilities (parking lot, buildings, stacks, etc.).

3.4. Breach Hydrograph Development

The NE breach hydrograph was developed using the 'Dam Breach' capabilities of HEC-HMS (Reference 21) and the NW breach hydrograph was developed using the 'Dam Break' function in HEC-RAS (Reference 32). Both breach functions in HEC-HMS and HEC-RAS require 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 evaluated several empirical equations and based final breach parameters on engineering judgment (References 22 - 30).

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. It was assumed that settled bottom ash and boiler slag mobilization will be negligible during a breach event. Therefore the Ash Pond No. 1 stored material elevation at each breach analyzed was considered the breach bottom elevation and the stored material was not included within the breach volume. The empirical calculations that served as the basis for the breach parameters' estimation are included as Figures A.1 and A.2 in Appendix A.

Table 1 Summary of Estimated NE and NW Dam Breach Parameters

	PMP Scenario
Range of Breach Width Estimates (feet)	25.5 – 145.3
Range of Failure Time Estimates (hours)	0.05 – 0.69
B_{avg} (feet)	35.9
t_f (hours)	0.41

Runoff calculations for the PMP scenario were performed within the HEC-HMS model consistent with methodology described in the US Department of Agriculture (USDA) SCS *Technical Release-55* (Reference 31). The total contributing drainage area to Ash Pond No. 1 is approximately 26.7 acres (0.04 square miles) which reflects the area within the embankment crest.

For purposes of routing the PMP through Ash Pond No. 1, process inflows, recycle pump outflow, and emergency spillway outflow were considered negligible and not included within the analysis. Additionally, the majority of the impoundment watershed area is open water; therefore, a curve number of 99 was used. The resulting peak pool elevation from the PMP storm event was used to determine the elevation at which to initiate the dam breach failure. The PMP storm event volume, plus the normal pool volume, was included within the breach discharge.

3.5. Hydraulic Model Development

For the breach inundation, Stantec used HEC-RAS, Version 5.0.1 (April, 2016) (Reference 32) to develop one-dimensional/two-dimensional (1D/2D) and 2D unsteady flow models for the northeast and northwest breaches, respectively. The development of both 1D and 2D hydraulic models is discussed in the following subsections.

3.5.1. Coffeen 3D Ground Surface Creation

A 3D ground surface of Coffeen Power Station and the surrounding terrain was created for use in hydraulic modeling. The 3D ground surface was created with AutoCAD and ArcGIS.

The portion of the 3D ground surface representing the Coffeen Power Station was created in AutoCAD using contours provided on the Landfill Cell 1 Site Plan and the Landfill Groundwater Monitoring and Boring Plan drawings (References 15 and 16). These contours were included within two AutoCAD drawings, Dynegy file names "Drawing4.dwg" and "Drawing5.dwg" that were provided to Stantec, which contained 2D polylines with elevation labels. In AutoCAD the 2D polylines were converted to 3D polylines by assigning them elevations based on the labels. The 3D polylines were then used in AutoCAD to create the 3D ground surface of Coffeen Power Station.

The portion of the 3D ground surface representing terrain surrounding Coffeen Power Station was created within ArcGIS using the DEM (Reference 4) and "General Lake Topo" (Reference 6). The Coffeen Power Station 3D ground surface created in AutoCAD was exported to ArcGIS, where it was then combined with the surrounding terrain 3D ground surface to create a composite 3D ground surface for use in the analysis.

3.5.2. Northeast Breach - 1D/2D Model

The northeast (NE) breach was modeled using 1D flow for the Eastern Cove and a 2D storage area (SA) to represent the main portion of Coffeen Lake. The 2D area serves as a storage that improves the accuracy of the model enabling the breach wave from the 1D portion of the model to interact with the 2D portion of the lake. The 1D/2D combination model is described further in subsections below.

3.5.2.1. 1D Cross Section Development

Cross sections were placed in the direction of flow from the NE corner of Ash Pond No. 1, along the Eastern Cove, and ending at the Coffeen Lake Dam. The 3D ground surface created, as described in Section 3.5.1, was used to obtain the elevations along the cross sections. Imagery and elevation data were used to evaluate hydraulic modeling parameters such as bank stations, ineffective areas, and to set Manning 'n' values. Table 3-1 in the HEC-RAS Reference Manual (Reference 32) was used for guidance when determining Manning 'n' values. The Manning 'n' values used within the 1D cross sections are shown below in Table 2.

Table 2. Manning 'n' Values Used for 1D Cross Sections

Channel or Overbank Type	Manning's Value, n
Woods / Brush	0.06 - 0.16
Pasture – Short Grass	0.035
Straight Channel	0.03
Winding Channel	0.033 – 0.066
Pond	0.033

3.5.2.2. 2D Lake Area Development

Development of the 2D area representing Coffeen Lake and the surrounding terrain involved creating a mesh, assigning material coverage to represent existing land use, and placement of a SA/2D connection as discussed in the following.

<u>Mesh</u>

HEC-RAS 5.0.1 utilizes a mesh based solver which requires the user to create a fixed Cartesian grid of equal x and y dimensions. The program then creates orthogonal mesh cells along the 2D boundary resulting in a hybrid mesh. HEC-RAS 5.0.1 has the capability of using large computational mesh spacing. A mesh cell size of 50 feet was used in this application since it effectively captured the important features of the DEM.

Material Cover

Land use files were obtained from the National Land Cover Data Set (2011) and utilized to develop a spatial reference for Manning's roughness values to be applied to the numerical model. Aerial imagery was compared to the land use files to verify that Manning's roughness values reflected current conditions.

Land cover GIS files were imported into HEC-RAS from ArcGIS with corresponding Manning's values. The Manning's "n" values were determined using engineering judgement. The GIS land cover file was converted to a GeoTiff file so that HEC-RAS could read in the data and apply the roughness value to the mesh cells. A table of Manning's "n" values to corresponding land cover can be seen in Table 3.

Table 3. Manning 'n' Values for 2D Storage Area

Land Cover Type	Manning's "n" Value
Barren Land	0.030
Cultivated Crops	0.040
Deciduous Forest	0.100
Developed, Low Intensity	0.060
Developed, Medium Intensity	0.080
Developed, High Intensity	0.100
Developed, Open Space	0.035
Emergent Herbaceous Wetlands	0.120
Open Water	0.035
Pasture/Hay	0.035
Woody Wetlands	0.100

SA/2D Connection

A SA/2D connection was created within HEC-RAS to link 1D flow to the 2D SA. This type of boundary condition allows the 1D river reach to pass flow each time step to the 2D flow area, while the stage in the downstream 1D cross section is based on the water surface elevation in the 2D cells that it is connected to (Reference 32). This process allows for flow to be distributed to the cells linked to the 1D cross section, instead of flow being distributed across the whole SA.

3.5.2.3. Boundary Conditions

Boundary conditions for the 1D reach of the NE corner breach analysis consisted of the breach inflow hydrograph at the upstream cross section developed in HEC-HMS and the 2D SA connection at the furthest downstream 1D cross section. The connection with the 2D SA accounts for backwater effects from the main portion of Coffeen Lake that the Eastern Cove would experience.

The lake 2D SA downstream boundary condition used an initial WSEL set equal to the 100-year, 24-hour maximum WSEL that was provided in the Coffeen Lake Dam EAP (2014) from a breach analysis study performed in 2007 by Hanson Professional Services Inc. (Reference 18). Based on imagery from the Coffeen Lake Dam breach inundation mapping figures compared to current imagery, the 100-year maximum WSEL estimated in the 2007 analysis was considered appropriate for purposes of this assessment.

3.5.3. Northwest Breach - 2D Model

The NW Breach 2D Model utilized the same type of modeling inputs and boundary conditions as shown in Sections 3.5.2.2 and 3.5.2.3, with the exception of the upstream boundary condition. Instead of utilizing the inflow hydrograph from HEC-HMS, the NW Breach 2D Model simulated the breach using the 'Dam Break' function in RAS with breach parameters as discussed in Section 3.4. The breach was located along the NW corner of the Ash Pond No. 1 embankment. A weir coefficient of 2.6 was applied to the breach because this is the HEC-RAS default value for earth dams.

3.6. Breach Modeling Results

Inundation limits for each of the two 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 at the Coffeen Power Station and surrounding area. Maximum flood depths and velocities were recorded at these areas of interest. 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 33).

1. Coffeen Lake (NE and NW PMP breaches)
    a. Potential for off-site release of CCRs
    b. Reservoir level increases by approximately 0.1 feet
2. Coffeen Lake – Eastern Cove, directly East of Ash Pond No. 1 (NE PMP breach)
    a. Maximum flood wave depth is 0.5 feet
    b. Maximum flood wave velocity is 2.2 feet/second
3. Coffeen Lake Dam (NE PMP Breach)
    a. Maximum flood wave depth is 0.1 feet
    b. Maximum flood wave velocity is 0.1 feet/second
4. Coffeen Power Station – Buildings and Parking Lots West of Railroad and North of Coal Pile (NW PMP breach)

a. Maximum approximate flood depth is < 1.0 foot

b. Maximum approximate flood velocity is < 1.0 feet/second

5. Ash Pond No. 1 Recycle Pump House and surrounding area (NW PMP breach)

    a. Maximum approximate flood depth is 2.4 feet

    b. Maximum approximate flood velocity is 3.2 feet/second

6. Coal Yard Maintenance Buildings near SW corner of Ash Pond No. 1 (NW PMP breach)

    a. Maximum approximate flood depth is 1.5 feet

    b. Maximum approximate flood velocity is 1.4 feet/second

7. Abandoned Coal Mining Structures immediately south of Ash Pond No. 1 (NW PMP breach)

    a. Maximum approximate flood depth is 3.7 feet

    b. Maximum approximate flood velocity is 1.6 feet/second

4. Hazard Classification

Areas of potential impact were identified with results discussed in Section 3.6 of this report. A few Coffeen Power Station structures and access roads were found to be potentially at-risk given the PMP breach analysis performed at the northwest corner of Ash Pond No. 1. The inundated access roads are intermittently used and the at-risk populations are considered transient. In accordance with Federal guidelines, probable loss of life does not exist for scenarios where persons are only temporarily in the potential inundation area (Reference 34).

At buildings stated to have regular occupancy, per Dynegy, it was found that the depth-velocity relationship was in the Low Danger Zone according to the US Bureau of Reclamation ACER 11, Figure 2 (Reference 28). These structures include the Coffeen Power Station (main building) and the Coal Yard Maintenance Buildings near the SW corner of Ash Pond No. 1. According to ACER 11, depth-velocity relationships in the Low Danger Zone do not constitute probable loss of life. The rest of the buildings/structures in the breach inundation area are either abandoned or rarely occupied, and therefore their at-risk population was considered transient.

Due to the model results outlined above, it is Stantec's opinion that a breach of Ash Pond No. 1 does not present a probable threat to human life. Although, a breach would likely result in the off-site release of CCRs into Coffeen Lake.

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. NAIP Imagery Service. (2015). Illinois 1-meter resolution.
3. US Census Bureau. (2015). *TIGER Roads*.
4. USGS National Map. *1/3 Arc Second DEM*.
5. Weaver Consultants Group. (December, 2015). *2015 – COFFEEN TOPOGRAPHY*. Dynegy File: COFFEEN_2015 AERIAL.pdf.
6. Austen, D. J., Peterson, J. T., Newman, B., Sobaski, S. T., & Bayley, P. B. (1993). Compendium of 143 Illinois Lakes: Bathymetry, Physio-chemical Features, and Habitats. Volume 2: Lakes in Regions 2 and 5. *INHS Center for Aquatic Ecology 1993 (9: 1)*.
7. Sargent & Lundy Engineers. (January 2, 1963). *Earthwork & Grading Plan - Unit 1*. Dynegy File: B-35 Earthwork & Grading Plan.
8. Sargent & Lundy Engineers. (November 12, 1963). *Miscel. Outdoor Foundations Plans & Sections – Unit 1*. Dynegy File: B-68 Misc Outdoor Foundations Plans & Sections.pdf.
9. Stearns-Roger Incorporated. (June 16, 1978). *Civil Site Plan*. Dynegy File: S-40 rev9.0 civil site plan – ash pond 1 and 2 overall.pdf.
10. Stearns-Roger Incorporated. (June 8, 1979). *Civil, Layout & Grading Plan Sheet 4*, Dynegy File: S-44 rev6 civil layout and grading plan.pdf.
11. Stearns-Roger Incorporated. (June 9, 1978). *Civil, Layout & Grading Plan Sheet 5*. Dynegy File: S-45 rev9 civil layout and grading plan – recycle pond.pdf.
12. Stearns-Roger Incorporated. (June 8, 1979). *Concrete Recycle Pump House – Intake Structure & Miscellaneous Foundations*. Dynegy File: S-8 Concrete – Recycle Pump House – recycle pond.pdf.
13. Stearns-Roger Incorporated. (January 5, 1979). *Concrete Miscellaneous Structures, Foundation Plans Sections & Details*. Dynegy File: s9s+r.dgn.
14. Stearns-Roger Incorporated. (June 9, 1978). *Civil, Miscellaneous Sections & Details Sheet 4*. Dynegy File: S-49 rev4 civil sections and details – recycle pond.pdf.
15. Hanson Professional Services Inc. (January 5, 2011). *Proposed Site Plan, Landfill Cell 1*. Dynegy File: cc10207_04.dgn.

16. Hanson Professional Services Inc. (January 5, 2011). *Groundwater Monitoring & Boring Plan – Landfill*. Dynegy File: cc10207_05.dgn.

17. Hanson Professional Services Inc. (February, 2008). *Operation & Maintenance Manual for #1 Ash Pond (Bottom Ash Recycle Pond)*. Amended by Dynegy Operating Company. (March, 2014).

18. Hanson Professional Services Inc. (August, 2008). *Coffeen Lake Dam Emergency Action Plan*. Amended by Dynegy Operating Company. (February, 2015).

19. US Environmental Protection Agency. (April, 2011). *Coal Ash Impoundment Site Assessment Report, Coffeen Power Station, Ameren Energy Generating Company*. (Prepared by Kleinfelder).

20. US Department of Commerce National Oceanic and Atmospheric Administration and US Department of the Army Corps of Engineers. (June, 1978). *Hydrometeorology Report No. 51*. Figure 20.--All-season PMP (in.) for 24 hr 10 mi^2 ($26km^2$).

21. US Army Corps of Engineers. (2013). Hydrologic Modeling System (HEC-HMS), Version 4.0. Hydrologic Engineering Center.

22. Johnson, F.A and Illes, P. (1976). "A Classification of Dam Failures." *Water Power Dam Construction*, 28, 43-45.

23. Singh, Krishan P. and Snorrason, A. (1982). *SWS Contract Report 288: Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models*. Illinois Department of Energy and Natural Resources, State Water Survey Division.

24. Singh, Krishan P. and Snorrason, A. (1984). "Sensitivity of Outflow Peaks and Flood Stages to the Selection of Dam Breach Parameters and Simulation Models." *Journal of Hydrology*, 68, 295-310.

25. MacDonald, T. C., and Langridge-Monopolis, J. (1984). "Breaching Characteristics of Dam Failures." *Journal of Hydraulic Engineering*, 110 (5), 567-586.

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

27. Froehlich, D. C. (1987). "Embankment Dam Breach Parameters." *Proceedings of the 1987 National Conference on Hydraulic Engineering*, ASCE, Williamsburg Virginia, 570-575.

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

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

30. 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.

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

32. US Army Corps of Engineers. (2016). River Analysis System (HEC-RAS), Version 5.0.1. Hydrologic Engineering Center.

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

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

Appendix A

Breach Parameters

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northeast Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northeast Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		*SI Units*	
Maximum height of dam at breach	h_d	41.5	feet	12.7	meters
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3
Width of dam base at breach	W_{base}	110.0	feet	33.5	meters
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters
Estimated breach side slope	Z	0.9		0.9	
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.

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	66.0	feet	20.1	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	54.0	feet	16.5	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	26,238	ft^3/s	743.0	m^3/s
Breach side slope	Z	0.90		0.90		0.88		0.88	
Volume of embankment eroded	V_{er}	30,282	ft^3	858	m^3	55,679	ft^3	1,577	m^3
Volume of water discharged	V_o,V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	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	22.1	72.6						
2 - Singh & Snorrason 1982, 1984	44.3	145.3						
3 - MacDonald & Langridge-Monopolis 1984	7.8	25.5		610.8				
4 - MacDonald & Langridge-Monopolis 1984			0.500					
5 - FERC 1987	38.0	124.5						
6 - FERC 1987			0.625					
7 - Froehlich 1987	15.2	49.8			1.0			
8 - Froehlich 1987			1.388			19.1	1.0	
9 - USBR 1988	9.0	29.4						
10 - Von Thun & Gillette 1990			1.000					
11 - Von Thun & Gillette 1990	13.6	44.5						6.1
12 - Froehlich 1995	10.9	35.9			1.0			
13 - Froehlich 1995			0.900					

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northeast Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northeast Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		*SI Units*	
Maximum height of dam at breach	h_d	41.5	feet	12.7	meters
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3
Width of dam base at breach	W_{base}	110.0	feet	33.5	meters
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters
Estimated breach side slope	Z	0.9		0.9	
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.

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	66.0	feet	20.1	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	54.0	feet	16.5	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	26,238	ft^3/s	743.0	m^3/s
Breach side slope	Z	0.90		0.90		0.88		0.88	
Volume of embankment eroded	V_{er}	30,282	ft^3	858	m^3	55,679	ft^3	1,577	m^3
Volume of water discharged	V_o,V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh & Snorrason 1982, 1984	0.625
15 - MacDonald & Langridge-Monopolis 1984	0.209
16 - FERC 1987	0.550
17 - Froehlich 1987	0.685
18 - USBR 1988	0.120
19 - Von Thun & Gillette 1990	
20 - Von Thun & Gillette 1990	
21 - Von Thun & Gillette 1990	0.045
22 - Von Thun & Gillette 1990	0.150
23 - Froehlich 1995	0.409

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northeast Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northeast Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		SI Units	
Maximum height of dam at breach	h_d	41.5	feet	12.7	meters
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3
Width of dam base at breach	W_{base}	110.0	feet	33.5	meters
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters
Estimated breach side slope	Z	0.9		0.9	
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.

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	66.0	feet	20.1	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	54.0	feet	16.5	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	26,238	ft^3/s	743.0	m^3/s
Breach side slope	Z	0.90		0.90		0.88		0.88	
Volume of embankment eroded	V_{er}	30,282	ft^3	858	m^3	55,679	ft^3	1,577	m^3
Volume of water discharged	V_o,V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	Q_p (m^3/s)	Q_p (ft^3/s)	η	k	d
24 - Kirkpatrick 1977	24.9	877			
25 - SCS 1981	125.8	4,437			
26 - Hagen 1982	989.6	34,921			
27 - USBR 1982	144.7	5,106			
28 - Singh & Snorrason 1984	1622.6	57,258			
29 - Singh & Snorrason 1984	629.1	22,199			
30 - MacDonald & Langridge-Monopolis 1984	253.0	8,927			
31 - MacDonald & Langridge-Monopolis 1984	833.0	29,395			
32 - Costa 1985	1385.7	48,897			
33 - Costa 1985	540.3	19,067			
34 - Costa 1985	1959.4	69,142			
35 - Evans 1986	413.7	14,599			
36 - Froehlich 1995	81.0	2,858			
37 - Webby 1996	52.3	1,844			
38 - Walder & O'Connor 1997	2090.3	73,761	17.9	55	9.49

Figure A.2 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northwest Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northwest Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		SI Units		Data Convention:
Maximum height of dam at breach	h_d	17.5	feet	5.3	meters	User Input Data
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters	Default calculation, user can change.
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters	
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3	Calculated value.
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3	
Width of dam base at breach	W_{base}	60.0	feet	18.3	meters	
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters	
Estimated breach side slope	Z	0.9		0.9		
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				

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	43.3	feet	13.2	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	32.6	feet	9.9	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.34	hours	0.34	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	16,151	ft^3/s	457.4	m^3/s
Breach side slope	Z	0.90		0.90		0.80		0.80	
Volume of embankment eroded	V_{er}	18,169	ft^3	515	m^3	21,947	ft^3	621	m^3
Volume of water discharged	V_o, V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	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	9.3	30.6						
2 - Singh & Snorrason 1982, 1984	18.7	61.3						
3 - MacDonald & Langridge-Monopolis 1984	13.0	42.6		610.8				
4 - MacDonald & Langridge-Monopolis 1984			0.500					
5 - FERC 1987	16.0	52.5						
6 - FERC 1987			0.625					
7 - Froehlich 1987	15.2	49.8			1.0			
8 - Froehlich 1987			0.956			11.4	1.0	
9 - USBR 1988	9.0	29.4						
10 - Von Thun & Gillette 1990			1.000					
11 - Von Thun & Gillette 1990	13.6	44.5						6.1
12 - Froehlich 1995	10.9	35.9			1.0			
13 - Froehlich 1995			0.900					

Figure A.2 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northwest Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northwest Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		*SI Units*	
Maximum height of dam at breach	h_d	17.5	feet	5.3	meters
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3
Width of dam base at breach	W_{base}	60.0	feet	18.3	meters
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters
Estimated breach side slope	Z	0.9		0.9	
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.

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	43.3	feet	13.2	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	32.6	feet	9.9	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.34	hours	0.34	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	16,151	ft^3/s	457.4	m^3/s
Breach side slope	Z	0.90		0.90		0.80		0.80	
Volume of embankment eroded	V_{er}	18,169	ft^3	515	m^3	21,947	ft^3	621	m^3
Volume of water discharged	V_o,V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	m^3

Estimates of Failure Time

Source Equation (See Attached Equation Reference)	t_f (hours)
14 - Singh & Snorrason 1982, 1984	0.625
15 - MacDonald & Langridge-Monopolis 1984	0.174
16 - FERC 1987	0.550
17 - Froehlich 1987	0.685
18 - USBR 1988	0.120
19 - Von Thun & Gillette 1990	
20 - Von Thun & Gillette 1990	
21 - Von Thun & Gillette 1990	0.045
22 - Von Thun & Gillette 1990	0.150
23 - Froehlich 1995	0.409

Figure A.2 - PMP Scenario Dam Breach Parameters
Coffeen Ash Pond No.1 - Northwest Corner Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - Ash Pond No. 1*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of Northwest Corner Embankment*
Piping Failure Assumed at Maximum WSEL Produced by PMP Storm Event

Inputs:

		English Units		*SI Units*	
Maximum height of dam at breach	h_d	17.5	feet	5.3	meters
Height of dam above breach bottom elev.	h_b	13.5	feet	4.1	meters
Height of water above breach bottom elev.	h_w	9.8	feet	3.0	meters
Maximum water storage volume	S	215.2	ac-feet	265,445	m^3
Water volume above breach bottom elev.	V_w	130.4	ac-feet	160,834	m^3
Width of dam base at breach	W_{base}	60.0	feet	18.3	meters
Width of dam crest at breach	W_{crest}	15.0	feet	4.6	meters
Estimated breach side slope	Z	0.9		0.9	
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.

		Froelich '95 Calculated Values:				Average Calculated Values:			
Breach width	B_{AVG}	35.9	feet	10.9	meters	43.3	feet	13.2	meters
Breach bottom width	B_W	23.7	feet	7.2	meters	32.6	feet	9.9	meters
Breach formation time	t_f	0.41	hours	0.41	hours	0.34	hours	0.34	hours
Peak discharge	Q_p	2,861	ft^3/s	81.0	m^3/s	16,151	ft^3/s	457.4	m^3/s
Breach side slope	Z	0.90		0.90		0.80		0.80	
Volume of embankment eroded	V_{er}	18,169	ft^3	515	m^3	21,947	ft^3	621	m^3
Volume of water discharged	V_o, V_{out}	130.4	ac-feet	160,834	m^3	130.4	ac-feet	160,834	m^3

Estimates of Peak Discharge

Source Equation (See Attached Equation Reference)	**Q_p (m^3/s)**	**Q_p (ft^3/s)**	η	**k**	**d**
24 - Kirkpatrick 1977	24.9	877			
25 - SCS 1981	125.8	4,437			
26 - Hagen 1982	642.6	22,677			
27 - USBR 1982	144.7	5,106			
28 - Singh & Snorrason 1984	317.3	11,196			
29 - Singh & Snorrason 1984	629.1	22,199			
30 - MacDonald & Langridge-Monopolis 1984	253.0	8,927			
31 - MacDonald & Langridge-Monopolis 1984	833.0	29,395			
32 - Costa 1985	1385.7	48,897			
33 - Costa 1985	376.0	13,267			
34 - Costa 1985	1340.0	47,287			
35 - Evans 1986	413.7	14,599			
36 - Froehlich 1995	81.0	2,858			
37 - Webby 1996	52.3	1,844			
38 - Walder & O'Connor 1997	241.4	8,517	367.4	55	4.00

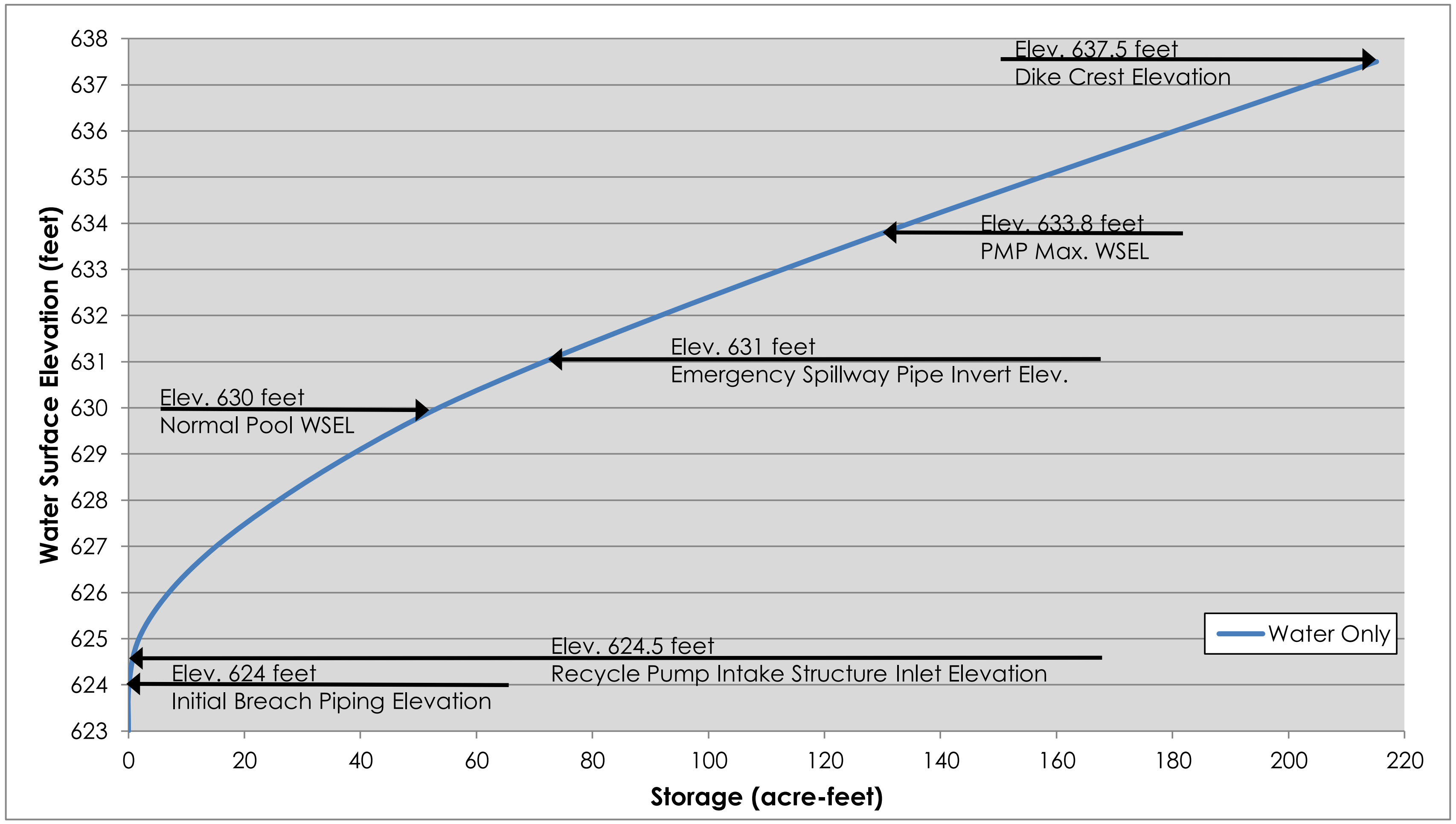
Figure A.3 - Elevation-Storage Storage Curve
Coffeen Power Station - Ash Pond No.1

Water Elevation-Storage Volume		
Elevation (ft)	Storage (CY)	Storage (ac-ft)
623.0	0	0.0
624.0	162	0.1
625.0	2,928	1.8
626.0	11,268	7.0
627.0	24,413	15.1
628.0	41,758	25.9
629.0	62,275	38.6
630.0	86,294	53.5
631.0	115,669	71.7
632.0	147,962	91.7
633.0	182,059	112.8
634.0	217,440	134.8
635.0	253,951	157.4
636.0	291,088	180.4
637.0	328,416	203.6
637.5	347,142	215.2

Notes:

1. Volumes calculated in AutoCAD 2014 using surface created from 2015 topography provided by Dynegy

2. The volume of stored material was not included within the storage volume shown



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

$$Z = 0.75K_c(h_w{}^*)^{1.57}\left(\overline{W^*}\right)^{0.73}$$

$$h_w{}^* = \frac{h_w}{h_b}$$

$$\left(\overline{W^*}\right) = \frac{\overline{W}}{h} = \frac{W_{crest} + W_{bottom}}{2h}$$

(8) $Z = 0.75K_c\left(\frac{h_w}{h_b}\right)^{1.57}\left(\frac{\overline{W}}{h_b}\right)^{0.73}$ 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) $\overline{B} = 2.5h_w + C$

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

Froehlich 1995

(12) $\overline{B} = 0.1803K_oV_w{}^{0.32}h_b{}^{0.19}$ 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) $$Q_p = \begin{cases} 1.51(g^{0.5}d^{2.5})^{0.06}\left(\frac{kV_o}{d}\right)^{0.94} & \eta < \sim 0.6 \\ 1.94g^{0.5}d^{2.5}\left(\frac{h_d}{d}\right)^{0.75} & \eta \gg 1 \end{cases}$$

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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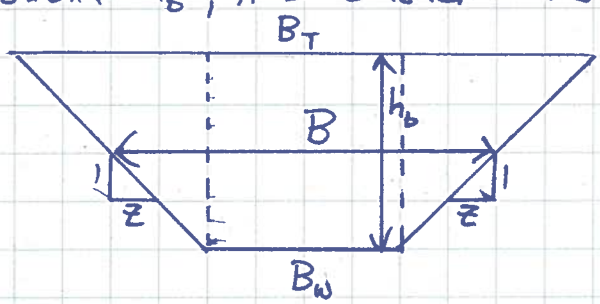
DAM BREACH EQUATIONS

DERIVATIONS NOT SHOWN

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



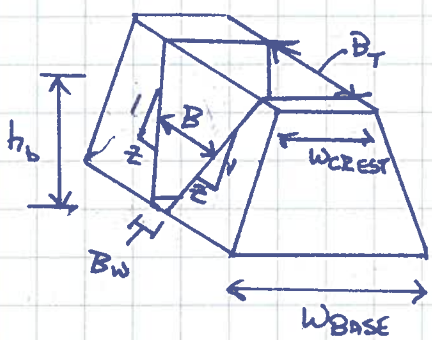
$$B = \frac{B_T + B_W}{2}$$

$$B_T = B_W + 2 h_b Z$$

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

$$B_W = B - h_b Z$$

2. VOLUME OF EMBANKMENT ERODED



AREA AT CENTER

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

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

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

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

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

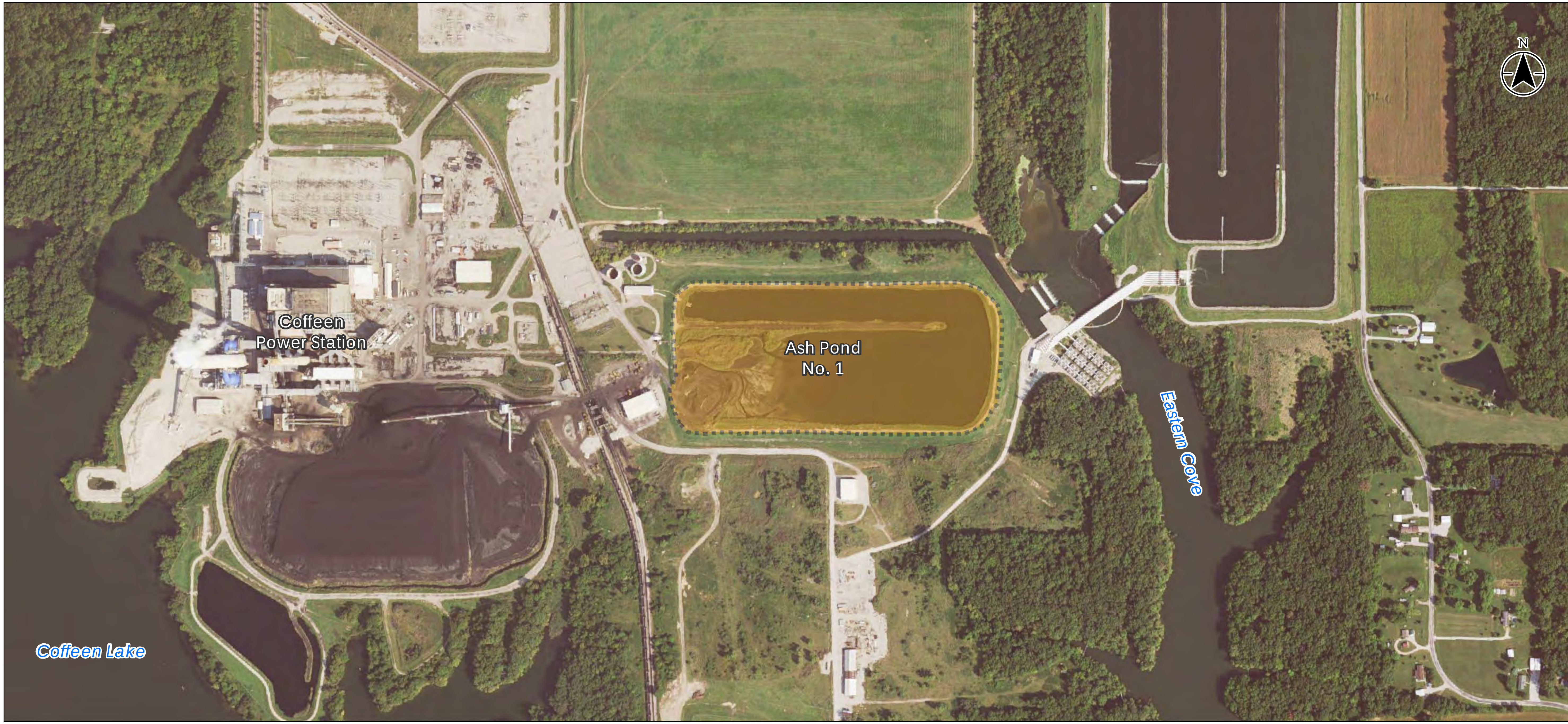
$$\forall = (B_W h_b + Z h_b^2)\left(\frac{W_c + W_B}{2}\right)$$

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

Designed by: Checked by:

Appendix B

Watershed Figure



Legend

Ash Pond No. 1 Watershed Area

0 500 Feet

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

Notes
1. Coordinate System: NAD 1983 StatePlane Illinois West FIPS 1202 Feet
2. Aerial Source: NAIP Illinois, 1m resolution dated 2015
3. Impoundment Boundaries Provided by Client (Dated 9/9/2015)

Project Location 175666013
Latitude: 39.059113
Longitude: -89.403293
Montgomery County, Illinois

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

Client/Project
Dynegy
Coffeen Power Station
Hazard Potential Classification Assessment

Figure No.
B.1

Title
Watershed Figure
Ash Pond No.1
Coffeen Power Station

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Appendix C

Site Overview Figure

0 2,000 Feet

1:24,000 (At original document size of 11x17)

Stantec DYNEGY

Project Location 175666013
Latitude: 39.059113 Prepared by PV on 2016-10-06
Longitude: -89.403293 Technical Review by NS on 2016-10-06
Montgomery County, Illinois Independent Review by MH on 2016-10-06

Client/Project
Dynegy
Coffeen Power Station
Hazard Potential Classification Assessment

Figure No.
C.1

Title
Site Overview Figure
Ash Pond No. 1
Coffeen Energy Center

Notes
1. Coordinate System: NAD 1983 StatePlane Illinois West FIPS 1202 Feet
2. Aerial Source: 2015 NAIP Imagery
3. Impoundment Boundaries Provided by Client (Dated 9/9/2015)

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