Documentation of Initial Hazard Potential Classification Assessment

GMF Recycle Pond
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 the GMF Recycle Pond at the Coffeen 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) <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.
>
> (2) <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.
>
> (3) <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.

Based on these definitions and the analysis herein, the GMF Recycle Pond is classified as a <u>Significant hazard potential</u> 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:

<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 GMF Recycle Pond.

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. The GMF Recycle Pond is located northeast of the power plant and south of the GMF Pond. A site overview figure is included in Appendix C.

2. Source Data

The following information was used to perform the hazard assessment of the Gypsum Recycle Pond.

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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 the GMF Recycle Pond was provided by Dynegy. The survey data was prepared by Hanson Professional Services Inc. (July, 2016) (Reference 5).

Bathymetric data of Coffeen Lake was obtained from the Aquatic Ecology Technical Report 93/9(2); "Compendium of 143 Illinois Lakes: Bathymetry, physico-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 the GMF Recycle Pond:

- Ameren Energy Generating, "Gypsum Stack – Cell G1, Coal Combustion By-Product Management Facility", July, 2008 (Reference 7);
- Sargent & Lundy Engineers, "Earthwork & Grading Plan - Unit 1", Dynegy File: B-35 Earthwork & Grading Plan, January 2, 1963 (Reference 8);
- Hanson Professional Services Inc., "Proposed Site Plan, Landfill Cell 1", Dynegy File: cc10207_04.dgn, January 5, 2011 (Reference 9);
- Hanson Professional Services Inc., "Groundwater Monitoring & Boring Plan - Landfill", Dynegy File: cc10207_05.dgn, January 5, 2011 (Reference 10).

2.4. Record Documents

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

- Operation & Maintenance (O&M) Manual for Coffeen Power Station – Gypsum Management Facility, initially prepared by Hanson Professional

Services Inc. (February, 2008) and amended by Dynegy Operating Company (March, 2014) (Reference 11);

- Emergency Action Plan (EAP) for Gypsum Stack Dam, initially prepared by Hanson Professional Services Inc. (October, 2010) and amended by Dynegy Operating Company (March, 2014) (Reference 12).

- Coffeen Lake Dam EAP, initially prepared by Hanson Professional Services Inc. (August, 2008) and amended by Dynegy Operating Company (February, 2015) (Reference 13).

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, created by Kleinfelder in April 2011 (Reference 14), was reviewed for background information purposes. Within the site assessment report, Kleinfelder determined that the GMF Recycle Pond should be considered a CCR impoundment and recommended that the GMF Recycle Pond be classified as a Significant Hazard dam due to potential environmental and economic impacts that a failure of this impoundment would present.

3. Potential Failure Scenarios

3.1. Facility Description

The GMF Recycle Pond consists of a single pond with a surface area of approximately 17 acres formed by earthen embankments around the perimeter. The earthen embankment is approximately 3,600-feet long and has a maximum height of approximately 20 feet above the surrounding grade. The pool level is controlled by a recycle pump system that is located at the southeast corner. There is an emergency spillway located at the northeast corner that consists of three precast 6-feet by 6-feet reinforced concrete risers with crest elevations at 624.11 feet, 624.13 feet and 624.15 feet. The risers are connected to 48 inch inside diameter high-density polyethylene (HDPE) pipes that convey flow from the risers and discharge into the creek to the east of the pond. The creek runs along the east side of the pond, underneath a nearby downstream road, and finally discharges into the eastern cove of Coffeen Lake (Eastern Cove).

Normal pool elevation used in the analysis was 610 feet based on available survey data and as-built drawings. The stormwater capacity of the GMF Recycle Pond is approximately 324 acre-feet at a crest elevation of 629.0 feet. The pond is used to dewater, store and dispose of flue gas desulphurization sludge (gypsum) (Reference 11). Currently, the stored material resides along the western embankment from approximate elevations 605 feet to 615 feet, and was estimated to be approximately 18.3 acre-feet in volume given the design total storage volume of 342 acre-feet (Reference 11).

3.2. Elevation-Storage

An elevation-storage curve for the pond was developed for the volume between the stored material and the embankment crest based on the 2016 survey data from elevations 604.0 feet to 629.0 feet. The corresponding volume was assumed to be water-only. The elevation-storage relationship used in development of the breach hydrographs is shown as Figure A.2 in Appendix A.

The elevation-storage relationship was developed from a three-dimensional (3D) surface created in AutoCAD Civil 3D (AutoCAD) using 2016 topography (Reference 5). Data used to create the surface included a PDF drawing, "Bathymetric Survey 20160715 DRAFT.pdf" provided to Stantec by Dynegy, which contained contour information. The PDF was imported into AutoCAD and used to generate 3D polylines by tracing the contours and assigning elevations. The 3D polylines where then used to create the 3D surface. The GMF Recycle Pond 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) failure scenario. The PMP scenario assumes a piping failure of the GMF Recycle Pond once it has reached a peak pool elevation of 621.3 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 15). 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 the eastern embankment near the emergency spillway. The east breach location was chosen because it is where the embankment is at its maximum height (20 feet) above surrounding grade and will provide the greatest discharge volume.

3.4. Breach Hydrograph Development

Breach hydrographs were developed using the 'Dam Breach' capabilities of the hydrologic modeling software program HEC-HMS (Reference 16). The breach function of HEC-HMS 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 evaluated several empirical equations and based final breach parameters on engineering judgment (References 17 - 25).

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 presented in Figure A.1 within Appendix A.

Table 1 Summary of Estimated Dam Breach Parameters

	PMP Scenario
Range of Breach Width Estimates (feet)	25.1 – 70.0
Range of Failure Time Estimates (hours)	0.06 – 0.63
B_{avg} (feet)	45.4
t_f (hours)	0.37

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 17). The total contributing drainage area to the GMF Recycle Pond is approximately 58.5 acres (0.09 square miles) which reflects the area of the impoundment plus the area along the outer crest of the embankment in addition to the area of the upstream GMF Stack/Pond, including the emergency spillway from the Gypsum Stack/Pond to the GMF Recycle Pond.

For purposes of routing the PMP through the GMF Recycle Pond, 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 initate 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 27) to develop a one-dimensional/two-dimensional (1D/2D) unsteady flow model for the eastern embankment breach into the creek that flows into the Eastern Cove. The development of the 1D/2D hydraulic model 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 9 and 10). 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 the 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. Hydraulic Parameters

The eastern embankment breach was modeled using 1D flow for the downstream creek and Eastern Cove reaches, while a 2D storage area (SA) was used to represent the main portion of Coffeen Lake. Representing Coffeen Lake as a 2D SA improves the accuracy of the model by 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 in subsections below.

3.5.3. 1D Cross Section Development

Cross sections were placed in the direction of flow from the eastern embankment of the GMF Recycle Pond, along the creek, through the Eastern Cove, and ending at the Coffeen Lake Dam. The 3D ground surface created, as depicted 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 27) 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 - 0.20
Pasture – Short Grass	0.035
Straight Channel	0.03
Winding Channel	0.033 – 0.066
Pond	0.033
Concrete/Paved Surface	0.013

3.5.3.1. Bridge/Culvert Modeling

County Road 450 N crosses the creek just southeast of the GMF Recycle Pond, approximately 1,550-feet downstream of where the breach was modeled. Due to a lack of information about this crossing and limited elevation data within the area, approximations and assumptions were made as follows.

The 1/3 Arc Second DEM was used to approximate the road surface/deck elevation across the creek. The roadway deck was modeled to tie-in with the surrounding overbank geometry. The imagery was used to estimate the width of the roadway by taking measurements in GIS. The roadway was assumed to be paved per the imagery in GIS. The conveyance method (i.e. culvert) used at this crossing is unknown; four 48 inch inside diameter reinforced concrete pipes at the approximate invert of the creek were used in the model. It was assumed that these culverts were free from obstruction/blockage.

Expansion and contraction coefficients were increased to 0.3 and 0.5, respectively, at the two upstream and downstream cross sections from the modeled roadway. Finally, the pressure and/or weir method was used to model high flows at the roadway structure.

3.5.4. 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 landuse, 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 27). 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, which is typical of the traditional HEC-RAS 1D SA.

3.5.5. Boundary Conditions

Boundary conditions for the 1D reach of the 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 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 12). 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.

3.6. Breach Modeling Results

Inundation limits for the breach scenario 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 downstream of the GMF Recycle Pond. 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 20).

1. County Road 450 N (depths/velocities above roadway surface)
    a. Maximum flood wave overtopping depth is 3.0 feet
    b. Maximum flood wave overtopping velocity is 15.0 feet/second
2. Coffeen Lake – Eastern Cove, directly East of Ash Pond No.1
    a. Maximum flood wave depth is 1.1 feet
    b. Maximum flood wave velocity is 4.5 feet/second
3. Coffeen Lake Dam
    a. Maximum flood wave depth is 1.0 feet
    b. Maximum flood wave velocity is 0.1 feet/second
4. Coffeen Lake
    a. Potential for off-site release of CCRs

b. Reservoir level increases by approximately 0.2 feet

4. Hazard Classification

Areas of potential impact were identified with results discussed in Section 3.6 of this report. One transportation route (County Road 450 N) was identified. This roadway is intermittently used and the at-risk populations are considered transient. In accordance with Federal guidelines, loss of life is not considered probable for scenarios where persons are only temporarily in the potential inundation area (Reference 29).

Due to the model results outlined above, it is Stantec's opinion that a breach of the GMF Recycle Pond does not present a probable threat to human life. Although, a breach to the east 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

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15. 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 ($26km^2$).

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Appendix A

Breach Parameters

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen GMF Recycle Pond - East Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - GMF Recycle Pond*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of East 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	20.0	feet	6.1	meters
Height of dam above breach bottom elev.	h_b	20.0	feet	6.1	meters
Height of water above breach bottom elev.	h_w	13.3	feet	4.1	meters
Maximum water storage volume	S	323.7	ac-feet	399,298	m^3
Water volume above breach bottom elev.	V_w	215.5	ac-feet	265,789	m^3
Width of dam base at breach	W_{base}	140.0	feet	42.7	meters
Width of dam crest at breach	W_{crest}	20.0	feet	6.1	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}	45.4	feet	13.8	meters	48.7	feet	14.8	meters
Breach bottom width	B_W	27.4	feet	8.3	meters	32.2	feet	9.8	meters
Breach formation time	t_f	0.37	hours	0.37	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	4,845	ft^3/s	137.2	m^3/s	21,388	ft^3/s	605.7	m^3/s
Breach side slope	Z	0.90		0.90		0.82		0.82	
Volume of embankment eroded	V_{er}	72,667	ft^3	2,058	m^3	77,958	ft^3	2,208	m^3
Volume of water discharged	V_o,V_{out}	215.5	ac-feet	265,789	m^3	215.5	ac-feet	265,789	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	10.7	35.0						
2 - Singh & Snorrason 1982, 1984	21.3	70.0						
3 - MacDonald & Langridge-Monopolis 1984	7.6	25.1		1136.7				
4 - MacDonald & Langridge-Monopolis 1984			0.500					
5 - FERC 1987	18.3	60.0						
6 - FERC 1987			0.625					
7 - Froehlich 1987	18.6	60.9			1.0			
8 - Froehlich 1987			1.087			24.4	1.0	
9 - USBR 1988	12.2	39.9						
10 - Von Thun & Gillette 1990			1.000					
11 - Von Thun & Gillette 1990	16.2	53.3						6.1
12 - Froehlich 1995	13.8	45.4			1.0			
13 - Froehlich 1995			0.900					

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen GMF Recycle Pond - East Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - GMF Recycle Pond*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of East 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	20.0	feet	6.1	meters
Height of dam above breach bottom elev.	h_b	20.0	feet	6.1	meters
Height of water above breach bottom elev.	h_w	13.3	feet	4.1	meters
Maximum water storage volume	S	323.7	ac-feet	399,298	m^3
Water volume above breach bottom elev.	V_w	215.5	ac-feet	265,789	m^3
Width of dam base at breach	W_{base}	140.0	feet	42.7	meters
Width of dam crest at breach	W_{crest}	20.0	feet	6.1	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}	45.4	feet	13.8	meters	48.7	feet	14.8	meters
Breach bottom width	B_W	27.4	feet	8.3	meters	32.2	feet	9.8	meters
Breach formation time	t_f	0.37	hours	0.37	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	4,845	ft^3/s	137.2	m^3/s	21,388	ft^3/s	605.7	m^3/s
Breach side slope	Z	0.90		0.90		0.82		0.82	
Volume of embankment eroded	V_{er}	72,667	ft^3	2,058	m^3	77,958	ft^3	2,208	m^3
Volume of water discharged	V_o,V_{out}	215.5	ac-feet	265,789	m^3	215.5	ac-feet	265,789	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	0.288
16 - FERC 1987	0.550
17 - Froehlich 1987	0.581
18 - USBR 1988	0.152
19 - Von Thun & Gillette 1990	
20 - Von Thun & Gillette 1990	
21 - Von Thun & Gillette 1990	0.061
22 - Von Thun & Gillette 1990	0.179
23 - Froehlich 1995	0.374

Figure A.1 - PMP Scenario Dam Breach Parameters
Coffeen GMF Recycle Pond - East Breach

Dam Breach Parameter Estimation
Earthen Embankment Comparative Spreadsheet

Project Data:

Dam: *Coffeen Power Station - GMF Recycle Pond*
Location: *Montgomery County, Illinois*
Notes: *"PMP Max. WSEL" Breach of East 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	20.0	feet	6.1	meters
Height of dam above breach bottom elev.	h_b	20.0	feet	6.1	meters
Height of water above breach bottom elev.	h_w	13.3	feet	4.1	meters
Maximum water storage volume	S	323.7	ac-feet	399,298	m^3
Water volume above breach bottom elev.	V_w	215.5	ac-feet	265,789	m^3
Width of dam base at breach	W_{base}	140.0	feet	42.7	meters
Width of dam crest at breach	W_{crest}	20.0	feet	6.1	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}	45.4	feet	13.8	meters	48.7	feet	14.8	meters
Breach bottom width	B_W	27.4	feet	8.3	meters	32.2	feet	9.8	meters
Breach formation time	t_f	0.37	hours	0.37	hours	0.35	hours	0.35	hours
Peak discharge	Q_p	4,845	ft^3/s	137.2	m^3/s	21,388	ft^3/s	605.7	m^3/s
Breach side slope	Z	0.90		0.90		0.82		0.82	
Volume of embankment eroded	V_{er}	72,667	ft^3	2,058	m^3	77,958	ft^3	2,208	m^3
Volume of water discharged	V_o, V_{out}	215.5	ac-feet	265,789	m^3	215.5	ac-feet	265,789	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	50.2	1,771			
25 - SCS 1981	221.2	7,807			
26 - Hagen 1982	842.6	29,733			
27 - USBR 1982	254.6	8,983			
28 - Singh & Snorrason 1984	408.4	14,410			
29 - Singh & Snorrason 1984	762.2	26,895			
30 - MacDonald & Langridge-Monopolis 1984	352.9	12,452			
31 - MacDonald & Langridge-Monopolis 1984	1161.0	40,968			
32 - Costa 1985	1748.8	61,710			
33 - Costa 1985	472.0	16,657			
34 - Costa 1985	1700.8	60,017			
35 - Evans 1986	539.9	19,053			
36 - Froehlich 1995	137.2	4,841			
37 - Webby 1996	96.4	3,401			
38 - Walder & O'Connor 1997	337.0	11,893	380.5	55	4.57

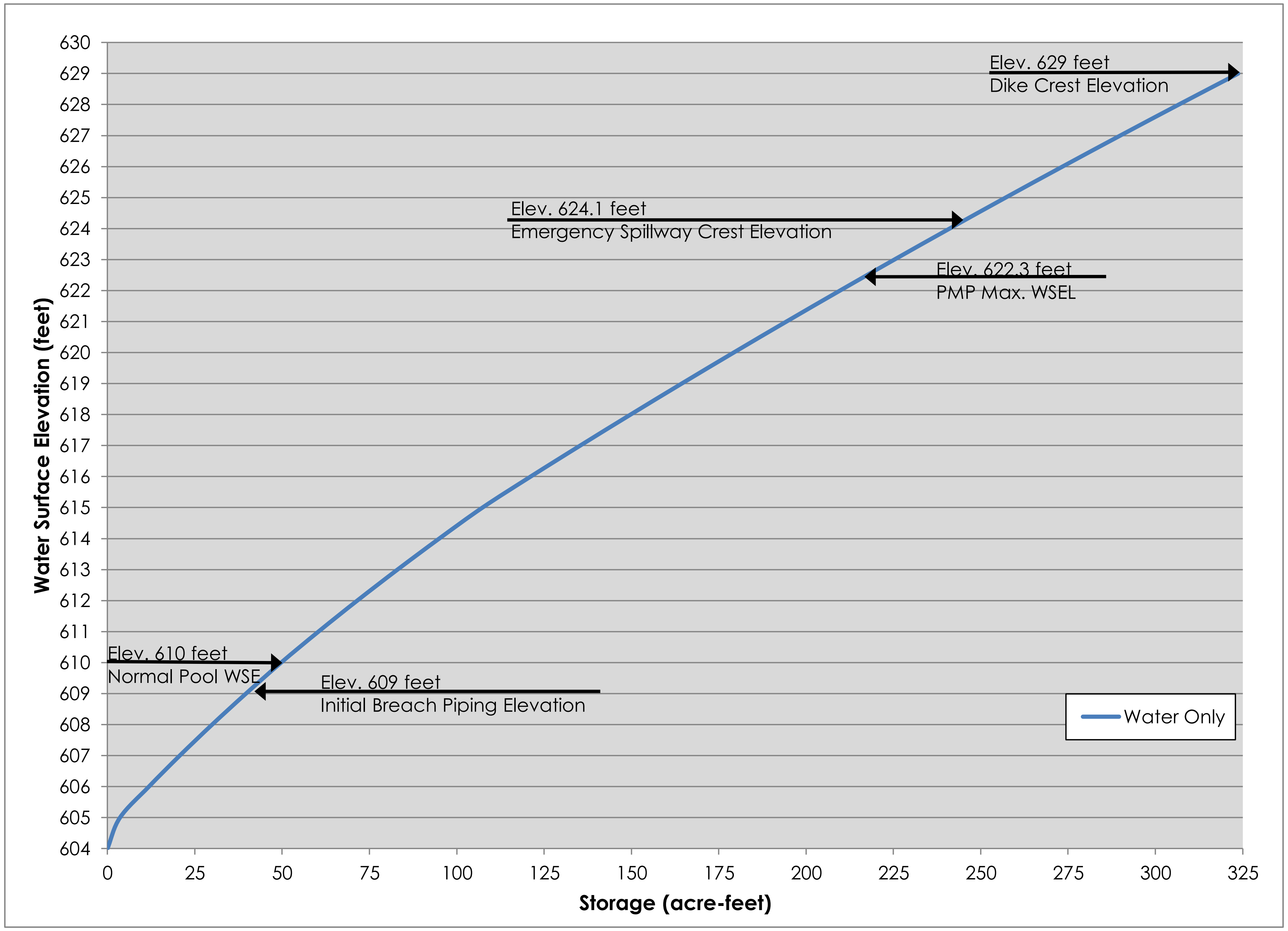
Figure A.2 - Elevation-Storage Storage Curve
Coffeen Power Station - GMF Recycle Pond

Water Elevation-Storage Volume		
Elevation (ft)	Storage (CY)	Storage (ac-ft)
604.0	0	0.0
605.0	5,792	3.6
606.0	19,154	11.9
607.0	33,403	20.7
608.0	48,359	30.0
609.0	63,985	39.7
610.0	80,229	49.7
611.0	97,468	60.4
612.0	115,384	71.5
613.0	133,980	83.0
614.0	153,228	95.0
615.0	173,222	107.4
616.0	195,459	121.2
617.0	218,350	135.3
618.0	241,609	149.8
619.0	265,237	164.4
620.0	289,236	179.3
621.0	313,609	194.4
622.0	338,358	209.7
623.0	363,482	225.3
624.0	388,984	241.1
625.0	414,868	257.1
626.0	441,135	273.4
627.0	467,789	290.0
628.0	494,830	306.7
629.0	522,262	323.7

Notes:

1. Volumes calculated in AutoCAD 2014 using surface created from 2016 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

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

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

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

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

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

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) $t_f = \frac{\overline{B}}{4h_w}$

Highly Erodible

(21) $t_f = 0.015h_w$

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

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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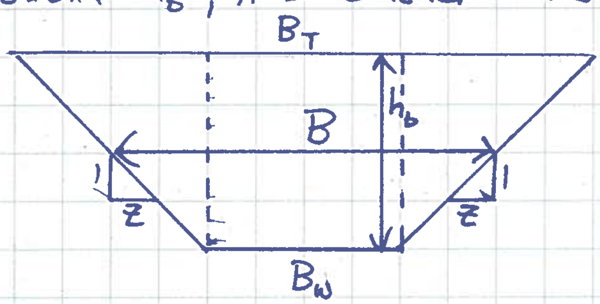
DAM BREACH EQUATIONS

DERIVATIONS NOT SHOWN

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



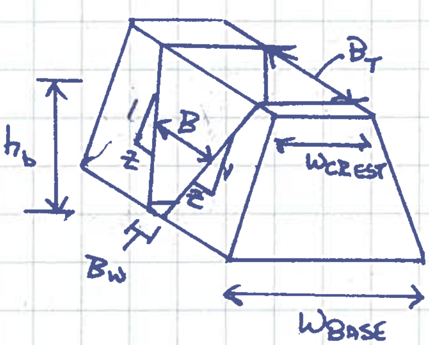
$$B = \frac{B_T + B_W}{2}$$

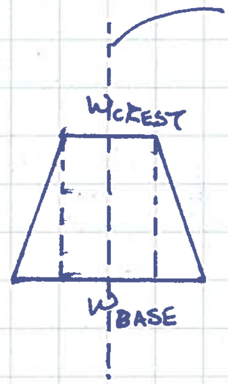
$$B_T = B_W + 2 h_b Z$$

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

$$B_W = B - h_b Z$$

2. VOLUME OF EMBANKMENT ERODED





AREA AT CENTER

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

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

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

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

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

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

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

Designed by:

Checked by:

Appendix B

Watershed Figure

Legend

GMF Pond Subwatershed Area
GMF Recycle Pond Subwatershed Area

0 750 Feet

1:9,000 (At original document size of 11x17)

Notes

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

Stantec DYNEGY

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

175666013
Prepared by PV on 2016-10-11
Technical Review by NS on 2016-10-11
Independent Review by MH on 2016-10-11

Client/Project
Dynegy
Coffeen Power Station
Hazard Potential Classification Assessment

Figure No.
B.1

Title
Watershed Figure
GMF Recycle Pond
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)

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)

Stantec DYNEGY

Project Location 175666013
Latitude: 39.059113 Prepared by PV on 2016-10-07
Longitude: -89.403293 Technical Review by NS on 2016-10-07
Montgomery County, Illinois Independent Review by MH on 2016-10-07

Client/Project
Dynegy
Coffeen Energy Center
Hazard Potential Classification Assessment

Figure No.
C.1

Title
Site Overview Figure
GMF Recycle Pond
Coffeen Power Station

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