Zion*Solutions*, LLC.
Technical Support Document

TSD 14-032

Conestoga-Rovers Report: Simulation of the Post-Demolition Saturation of Foundation Fill Using a Foundation Water Flow Model

Revision 0

Originator: Conestoga-Rovers & Associates Report Date: 12/12/2014
Name

Reviewer: ______________ Date: 12/14/2014
Dave Fauver

Approval: ______________ Date: 12/18/14
Robert F. Yetter

Summary of Changes in this Revision:

- Rev. 0 –Initial issuance.

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& ASSOCIATES

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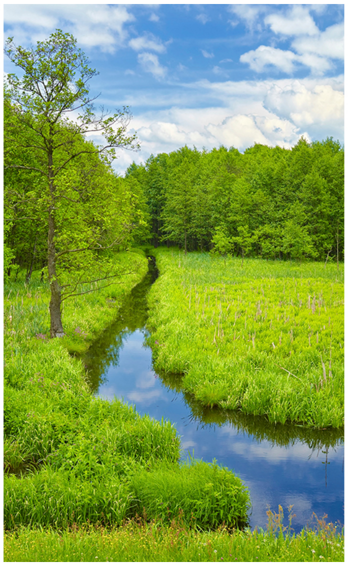

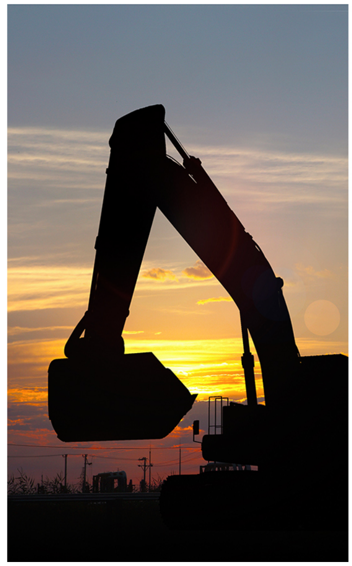

Simulation of the Post-Demolition Saturation of Foundation Fill Using a Foundation Water Flow Model

Zion Station Restoration Project
Zion, Illinois

Prepared for: Energy Solutions

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December 2014 • 054638 • Report No. 4

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Section 1.0 Introduction

This report provides estimates of the time required for rainwater infiltration to fully saturate the foundations remaining after the demolition of the Zion Nuclear Generating Station, 101 Shiloh Boulevard, Zion, Lake County, Illinois (Site). The time estimates for the different scenarios are calculated using the Foundation Water Flow Model (Flow Model) developed to simulate water movement within deep building foundations at the Site. The Flow Model evaluates the hypothetical post-demolition conditions in the largest and deepest structures at the Site, namely the Unit 1 Containment Building (C1), Unit 2 Containment Building (C2), Auxiliary Building (Aux), Turbine Building (TB), Spent Fuel Pool (FP), and Crib House (CH). The model was developed using Microsoft Excel and Visual Basic for Applications (VBA).

Zion*Solutions*, Inc. (Zion*Solutions*) provided blueprints and plans of the Facility, construction photographs from the 1970s, a spreadsheet summary of building penetrations, and details regarding the current demolition plan for the Site (including the current plan for the post-demolition disposition of the penetrations). Conestoga-Rovers & Associates, Inc. (CRA) organized the penetration data into clusters which connect two buildings or connect one building with the surrounding stratigraphy.

Section 2.0 Post-Demolition Site Conditions

The Flow Model was developed to evaluate the post-demolition flow of water between building foundations and the environment. The flow scenarios are based on draft decommissioning plans developed by Zion*Solutions* as part of the Zion Station Restoration Project. During decommissioning, foundation penetrations may be sealed, abandoned in place with certain pipe segments intact, or open to the native soil surrounding the structures. Penetrations may allow water to flow between buildings or to exit the buildings and flow into the surrounding aquifer. General model assumptions are:

- Building foundations will be cut off at an elevation of 588 feet above mean sea level (AMSL)
- Building foundations will be filled with sand
- Building foundations are water tight except for the identified penetrations
- Rainwater infiltration is daily and uniform
- Building penetrations which are not sealed will be filled with the building backfill material
- Simplified building geometries are used which assume that the building areas do not change with depth (with the exception of the Turbine Building, which has two representative areas differentiated by elevation)
- Penetrations are treated as a single elevation (equivalent to a horizontal slot)
- A hypothetical resident farmer well is located within the Aux Building foundation

The Flow Model assumes that the substructure is backfilled with sand, and the foundation walls remain intact and do not leak. The model assumes that precipitation recharges the groundwater within the foundation using average rainwater infiltration rates.

The Flow Model estimates the flow of water between the Unit 1 Containment Building, the Unit 2 Containment Building, the Auxiliary Building, and the Turbine Building (called the Main Complex herein). The Crib House will be hydraulically isolated from the Main Complex and will be evaluated separately.

The model may also be used to evaluate the potential for a hypothetical residential well to successfully operate if it is installed within the Aux Building footprint. A conceptual flow model schematic is shown on Figure 1. An elevation summary of planned post-demolition Site features is provided in the table below.

Table 2.1 Post-demolition Site features elevation summary

Feature	Elevation (feet AMSL)	Source	Feature	Elevation (feet AMSL)	Source
C1 base level	565.0	(1)†	Crib House base level	537.0	(2)
C1 incore cavity sump	541.5	(3)	Crib House sump	532.5	(2)
C2 base level	565.0	(1)†	Ground surface	591.0	(1)
C2 incore cavity sump	541.5	(3)	Fuel Pool base level	576.0	(1)
Aux base level	542.0	(1)	Foundation cutoff	588.0	
Aux sump	532.0	(3)	Lake Michigan max (1886)	582.6	(4 p. 6)
TB base level	560.0	(1)	Lake Michigan min (1964)	576.0	(4 p. 6)
Main steam tunnel base level	570.0	(1)	Lake Michigan average	579.0	(4 p. 6)
Diesel generator base level	567.5	(1)	Water table (east of TB)	579.0	(5 p. Fig 6.11)‡

Notes:

†This elevation assumes that the 3 feet of concrete above the liner will be removed during demolition.

‡Based on March 2013 water levels.

2.1. Building Properties

The decommissioning process will include the demolition of the above-ground portions of the major Site structures and removal of foundation walls to 588 feet AMSL, a depth of approximately 4 feet below ground surface (bgs). The remaining portions of the foundations will be radiologically decontaminated and remain in place. The foundation areas at the 588 feet AMSL cutoff elevation are shown below.

Table 2.2 Foundation areas			
	Foundation Area†		
Building	**(ft^2)**	**(m^2)**	**Source**
Containment Building No. 1	20,032	1,861	(6) (7)
Containment Building No. 2	20,032	1,861	(6) (7)
Auxiliary Building	29,030	2,697	(6) (7) (8)
Spent Fuel Storage Pool◊	2,502	232	(9)
Turbine Building 570-588‡	59,941	5,569	(6) (10)
Turbine Building 560-570	83,317	7,740	(11) (7) (12)
Crib House	31,355	2,913	(2) (13)

Notes:
†The foundation area is the building area at elevation 588 feet AMSL
‡The Turbine Building foundation area for the 570-588 feet AMSL elevation includes the hydraulically connected steam tunnels (7,776 ft^2 ×2) and the Diesel Generator Rooms (3,912 ft^2 ×2).
◊ The Spent Fuel Storage Pool foundation area includes the area of the transfer canal (423 ft2).

A plan showing the foundations remaining after decommissioning are shown on Figure 2.

2.2. Building Penetration Details

The building foundations have a number of openings or penetrations to accommodate piping and conduits which connect to other buildings or structures. A summary of the building penetrations was prepared by Zion*Solutions* based on construction drawings (14) (15), (16), (17), (18), (8), (19), (11), (20), (21), (22), (23), (24), (25), (26), (27), and (7). The approximate groundwater elevation at each penetration was determined by cross-referencing the March 2013 potentiometric surface (5 p. Figure 6.11) with the applicable drawing. The foundation penetrations are also shown on the 1973 construction photographs presented on Figures 3-9. General penetration locations are shown on Figure 10.

2.3. Foundation Fill Properties

For the scenarios evaluated herein it will be assumed that the building foundations will be filled with sand obtained from local sources. This sand fill will also be assumed to be of similar characteristics to the sand located at the Site. The properties of this assumed fill material are summarized in the table below.

Table 2.3 Foundation Fill Properties			
Parameter	***Value***	***Units***	***Source***
Fill Material	native sand	na	(28)
Fill Hydraulic conductivity	2.88E+03	m/y	(28)
Fill Porosity	0.353	v/v	(28)
Notes: v/v is volume per volume (e.g., L/L). m/y is meters per year.			

2.4. Flow between Buildings

The current decommissioning plan will allow certain building penetrations to remain open (although filled with the same porous material used to fill the foundations). These open penetrations allow water to flow between buildings and from buildings to the native soil.

The flow between building foundations can be estimated using Darcy's law:

$$Q = K \cdot i \cdot A$$

Where: Q is the flow in ft^3/d
K is the hydraulic conductivity of the fill material in ft/day
i is the hydraulic gradient in ft/ft
A is the cross-sectional area of the penetration in ft^2

The hydraulic gradient is calculated using the difference in head between the buildings and the wall thickness separating the buildings. The model assumes that the head within each building is flat.

2.5. Rainwater Infiltration Rate

The current decommissioning plan is to cover the building foundations with permeable surface material such as gravel or sod. This permeable material will allow rainwater to percolate through the surface material and slowly fill the building foundations. The volume of water which can enter the foundations due to precipitation can be estimated using the infiltration rates presented in the Parameters Report (28).

The average precipitation rate for the Zion area is 32.61 inches/year (in/y) (0.863 m/y) with an evapotranspiration rate of 28 in/y (0.71 m/y), as presented within the Parameters Report (28). The rainwater infiltration rate is estimated by the difference between the precipitation rate and the evapotranspiration rate.

The amount of rainfall which would potentially infiltrate into the ground was determined by the following equation:

$$Infiltration\ Rate = 32.61\frac{in}{y} - 28\frac{in}{y} = 4.61\frac{in}{y} = 0.38\frac{ft}{y}$$

$$Infiltration\ Rate = 0.863\frac{m}{y} - 0.71\frac{m}{y} = 0.12\frac{m}{y}$$

The head rise within the building foundation is calculated by dividing the infiltration rate by the fill porosity:

$$Head\ Rise = \frac{Infiltration\ Rate\ \left(\frac{ft}{y}\right)}{Porosity} = \frac{0.38\frac{ft}{y}}{0.353} = 1.1\frac{ft}{y}$$

$$Head\ Rise\ \left(\frac{m}{y}\right) = \frac{Infiltration\ Rate\ \left(\frac{m}{y}\right)}{Porosity} = \frac{0.12\frac{m}{y}}{0.353} = 0.34\frac{m}{y}$$

The volume of rainwater infiltrating each substructure was determined by the following equation:

$$Volume\ of\ infiltrating\ rainwater\ =\ Infiltration\ rate \times\ Area\ of\ structure$$

Table 2.4 Rainwater Infiltration Rates

Parameter	Unit	Unit 1 Containment	Unit 2 Containment	Auxiliary Building	Turbine Building 560-570†	Turbine Building 570-588	Crib House
Infiltration Rate	m/y	0.12	0.12	0.12	0.12	0.12	0.12
	ft/y	0.38	0.38	0.38	0.38	0.38	0.38
Fill Porosity	v/v	0.353	0.353	0.353	0.353	0.353	0.353
Head Rise Inside Foundation	m/y	0.34	0.34	0.34	0.47	0.34	0.34
	ft/y	1.1	1.1	1.1	1.6	1.1	1.1
Foundation Area	m^2	1,861	1,861	2,697	5,569	7,740	271
	ft^2	20,032	20,032	29,030	59,941	83,317	2,913
Infiltration Water Volume	m^3/y	223.32	223.32	323.64	928.8	928.8	32.52
	ft^3/y	7,612.16	7,612.16	11,031.4	31,660.46	31,660.46	1,106.94
	gal/y	56,942.92	56,942.92	82,520.61	236,836.7	236,836.7	8,280.49

†For the Turbine Building it is assumed that rain falling on the steam tunnels and diesel generator rooms will drain into the Turbine Building basement until the water level reaches the base elevation of the steam tunnels (570 feet AMSL), at which point the steam tunnels and diesel generator rooms will also begin to fill with water.

2.6. Pumping Rate for a Hypothetical Resident Farmer Well

The hypothetical future Resident Farmer scenario includes residential water use and irrigation watering. Under the Resident Farmer scenario, this water is assumed to be provided by a water well located in the center of the Aux Building.

The hypothetical well in the Aux Building can draw water from the Aux Building, Turbine Building, and Containment Buildings through building penetrations remaining after demolition. However, the penetrations to exterior soil are all above the natural water table, which prevents any contribution from exterior groundwater. The Main Complex structures is expected to receive an average of 1,186 gpd (0.82 gpm) from precipitation. If the Aux Well pumped at this rate, equilibrium conditions would exist. A greater pumping rate would eventually drain the buildings and the pump would run dry. A lesser pumping rate would allow the structures to fill and then discharge to the surrounding soil through exterior penetrations.

Section 3.0 Scenario 1 - Foundation Saturation by Rainwater Infiltration

This scenario simulates the saturation of the foundations by rainwater infiltration over time. The initial state of the simulation assumes post-demolition conditions where the foundations are filled with dry sand and clean concrete[1]. The model input parameters are listed in the table below.

Table 3.1 Scenario 1 Model Input Parameters

Parameter		Value	Units
Start date		1/15/2015	- -
Time step		730.5 and 1095.75	days
Aux well pumping rate		0	gallons/day
Initial Building Head	Containment 1	565	feet AMSL
	Containment 2	565	feet AMSL
	Spent Fuel Pool	576	feet AMSL
	Turbine Building	560	feet AMSL
	Auxiliary Building	542	feet AMSL
	Crib House	537	feet AMSL

The Flow Model was run using a time step of 730.5 days (2 years) for the Main Complex and a time step of 1095.75 days (3 years) for the Crib House. The Flow Model output is provided in Appendix A.

The Turbine Building and Containment Buildings initially drain to the deeper Auxiliary Building. Once the Auxiliary Building has filled to the base level of the Containment Buildings, water levels rise at a nearly

[1] All the scenarios described assume that sump areas are saturated with water at the beginning of the simulation.

uniform rate until exterior penetrations are reached. Equilibrium saturation is achieved at an elevation of 586 feet AMSL in approximately 26 years.

The Crib House is assumed to be isolated from the other foundations based on current Zion Station Restoration Project plans to plug the Circulating Water Intake Piping at the East and west sides of the Crib House(and the Service Water Headers). The Crib House would then fill at a uniform rate until exterior penetrations are reached. Equilibrium saturation is achieved at an elevation of 581.5 feet AMSL in approximately 42 years.

Section 4.0 Scenario 2 - Additional Penetration Requirements to Equilibrate Near Exterior Groundwater Elevations and Accelerate Foundation Saturation

This scenario estimates the minimum size of constructed penetrations that would be required for the equilibrium water levels within the foundations to be approximately equal to the exterior water level. The initial state of the simulation assumes post-demolition conditions where the foundations are filled with dry sand and concrete. An additional penetration is added to the Turbine Building (or steam tunnels) in the model and iteratively resized until the equilibrium water levels inside the Main Complex foundation are within 6 inches of the exterior water levels. The added penetration represents a breach in the foundation wall from the top of the foundation after demolition (i.e., 588 feet AMSL) to an elevation of 570 feet AMSL (i.e., the base elevation of the steam tunnels).

An additional penetration is also added to the Crib House and iteratively resized until the equilibrium water levels inside the Crib House foundation are within 6 inches of the exterior water levels. The added penetration represents a breach in the foundation wall beginning from the top of the foundation after demolition (i.e., 588 feet AMSL) and extending below the water table.

The model input parameters are listed in the table below.

Table 4.1 Scenario 2 Model Input Parameters

Parameter		Value	Units
Start date		1/15/2015	- -
Time step		90	days
Aux well pumping rate		0	gallons/day
Initial Building Head	Containment 1	565	feet AMSL
	Containment 2	565	feet AMSL
	Spent Fuel Pool	576	feet AMSL
	Turbine Building	560	feet AMSL
	Auxiliary Building	542	feet AMSL

Table 4.1 Scenario 2 Model Input Parameters

Crib House	537	feet AMSL

For the Main Complex, the additional penetration required to meet the scenario criteria is a breach in the foundation wall 20-feet wide and extending from the top of the foundation to an elevation of 570 feet AMSL (i.e., the base of the steam tunnels). The Flow Model output is provided in Appendix B.

The addition of a large penetration below the water table would also significantly reduce the time required for the Main Complex foundations to fill with water (i.e., scenario 1 with an added penetration). The equilibrium saturation would be achieved in approximately 3.2 years instead of the 28 years for rainwater infiltration alone.

For the Crib House, the additional penetration required to meet the scenario criteria is a breach in the foundation wall 2-feet wide and extending from the top of the foundation to a depth of 1 foot below the exterior water table (578 feet AMSL). The Flow Model output is provided in Appendix B.

The addition of a large penetration below the water table would also significantly reduce the time required for the Crib House foundation to fill with water (i.e., scenario 1 with an added penetration). The equilibrium saturation would be achieved in approximately 1.6 years instead of the 45 years for infiltration alone.

Section 5.0 Scenario 3 - Additional Penetration Requirements to Equilibrate at a Level above Exterior Groundwater Elevations

This scenario estimates the minimum size of constructed perforations that would be required for the equilibrium water levels within the foundations to be approximately equal to the elevation of the constructed penetrations. The initial state of the simulation assumes post-demolition conditions where the foundations are filled with dry sand and concrete. Additional penetrations are added to the Turbine Building (or steam tunnels) at an elevation of 580 feet AMSL (approximately a foot above the exterior water level) and iteratively resized until the equilibrium water levels inside the Main Complex foundation are within 6 inches of the constructed penetrations.

An additional penetration is also added to the Crib House at an elevation of 580 feet AMSL and iteratively resized until the equilibrium water levels inside the Crib House foundation are within 6 inches of the exterior water levels.

The model input parameters are listed in the table below.

Table 5.1 Scenario 3 Model Input Parameters

Parameter		Value	Units
Start date		1/15/2015	- -
Time step		30	days
Aux well pumping rate		0	gallons/day
Initial Building Head	Containment 1	579	feet AMSL
	Containment 2	579	feet AMSL
	Spent Fuel Pool	579	feet AMSL
	Turbine Building	579	feet AMSL
	Auxiliary Building	579	feet AMSL
	Crib House	579	feet AMSL

For the Main Complex, the additional penetration required to meet the scenario criteria is a breach in the foundation wall 15-feet wide and extending from the top of the foundation after demolition (i.e., 588 feet AMSL) to an elevation of 580 feet AMSL (i.e., one foot above the exterior water table) [2]. The Flow Model output is provided in Appendix C.

For the Crib House, the additional penetration required to meet the scenario criteria is a breach in the foundation wall 2-feet wide and extending from the top of the foundation to a depth of 1 foot above the exterior water table (580 feet AMSL). The Flow Model output is provided in Appendix C.

Section 6.0 Scenario 4 - Additional Penetration Requirements to Equilibrate the Spent Fuel Pool with the Transfer Canal

The Flow Model assumes that the Spent Fuel Pool and Transfer Canal water levels are equal. However, the base elevation of the Fuel Handling Transfer Canal Gate (the current connection between these two structures) is at 592.33 feet AMSL (29), which is above the foundation cutoff elevation of 588 feet AMSL.

This scenario estimates the minimum size of constructed perforations that would be required to achieve equilibrium water levels between the Spent Fuel Pool and the adjacent Transfer Canal.

The initial state of the simulation assumes post-demolition conditions described in Scenario 3 above. The penetrations from the Transfer Canal to the Containment Buildings[3] are iteratively resized in the model until the equilibrium water levels inside the Spent Fuel Pool foundation are less than 580.5 feet AMSL (i.e., within 6 inches of the constructed penetrations described in Scenario 3).

[2] This scenario is based on removing a section of the Turbine Building or steam tunnel wall using an excavator equipped with a hydraulic hammer. This is equivalent to using an anchor core drill with a 14-inch diameter bit to create 19 penetrations in the walls with penetration base elevations at 580 feet AMSL.
[3] The penetrations from the Transfer Canal to the Containment Buildings are used as a surrogate for the connection between the Transfer Canal and the Fuel Pool.

The model input parameters are listed in the table below.

Table 6.1 Scenario 4 Model Input Parameters

Parameter		Value	Units
Start date		1/15/2015	- -
Time step		60	days
Aux well pumping rate		0	gallons/day
Initial Building Head	Containment 1	579	feet AMSL
	Containment 2	579	feet AMSL
	Spent Fuel Pool	579	feet AMSL
	Turbine Building	579	feet AMSL
	Auxiliary Building	579	feet AMSL
	Crib House	579	feet AMSL

The additional penetrations required to meet the scenario criteria must be installed below an elevation of 579 feet AMSL and have a minimum area of 1.6 ft^2 (equivalent to 2 holes with 12 inch diameters). The optimal penetration area would be 6.3 ft^2 (equivalent to 2 holes with 24 inch diameters) or greater[4]. The Flow Model output is provided in Appendix D.

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[4] At which point the penetrations from the Transfer Canal to the Containment Buildings become the rate-limiting features.

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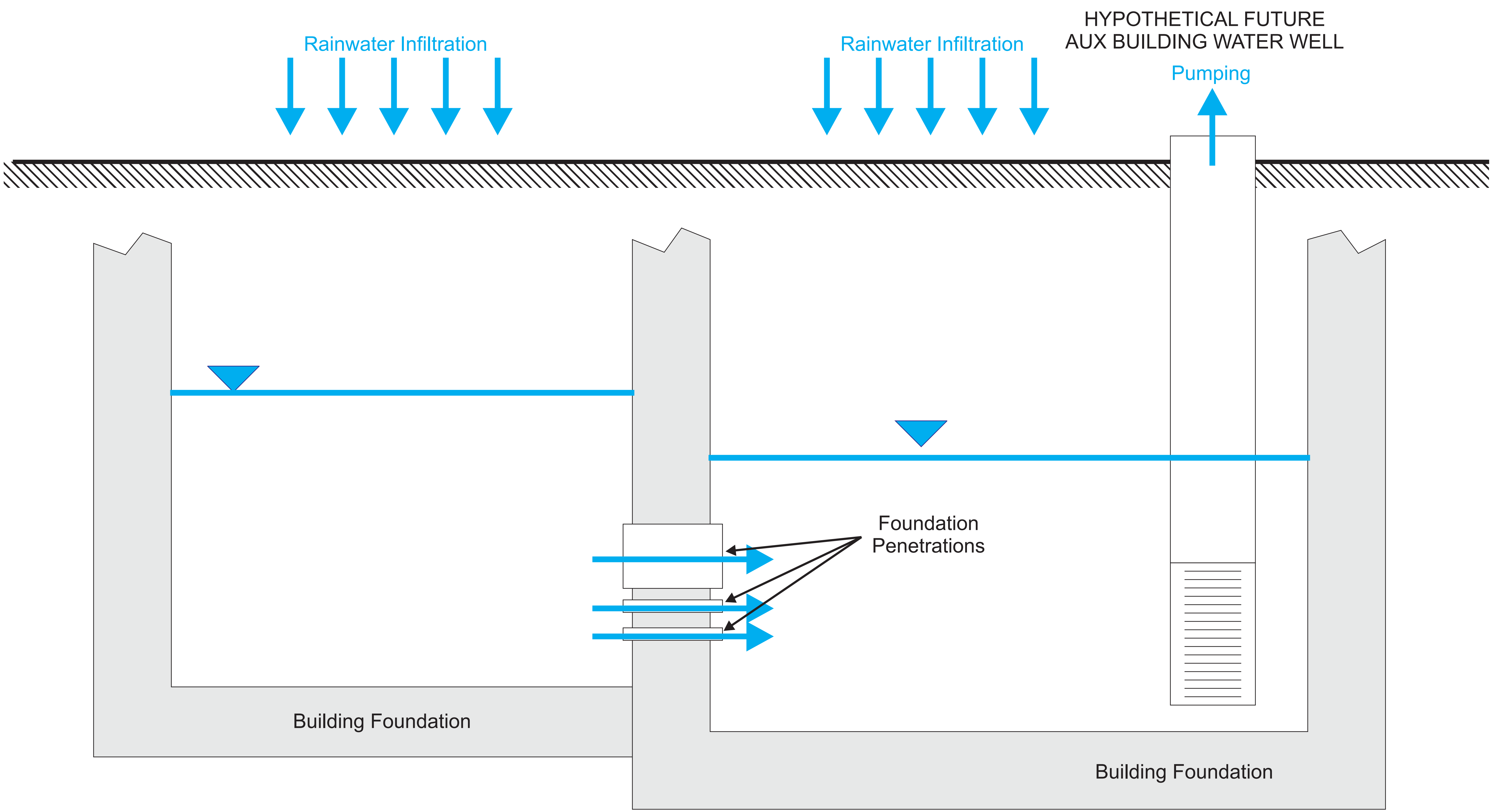

Not to Scale

figure 1
CONCEPTUAL FLOW MODEL SCHEMATIC
ZION RESTORATION PROJECT
Zion, Illinois

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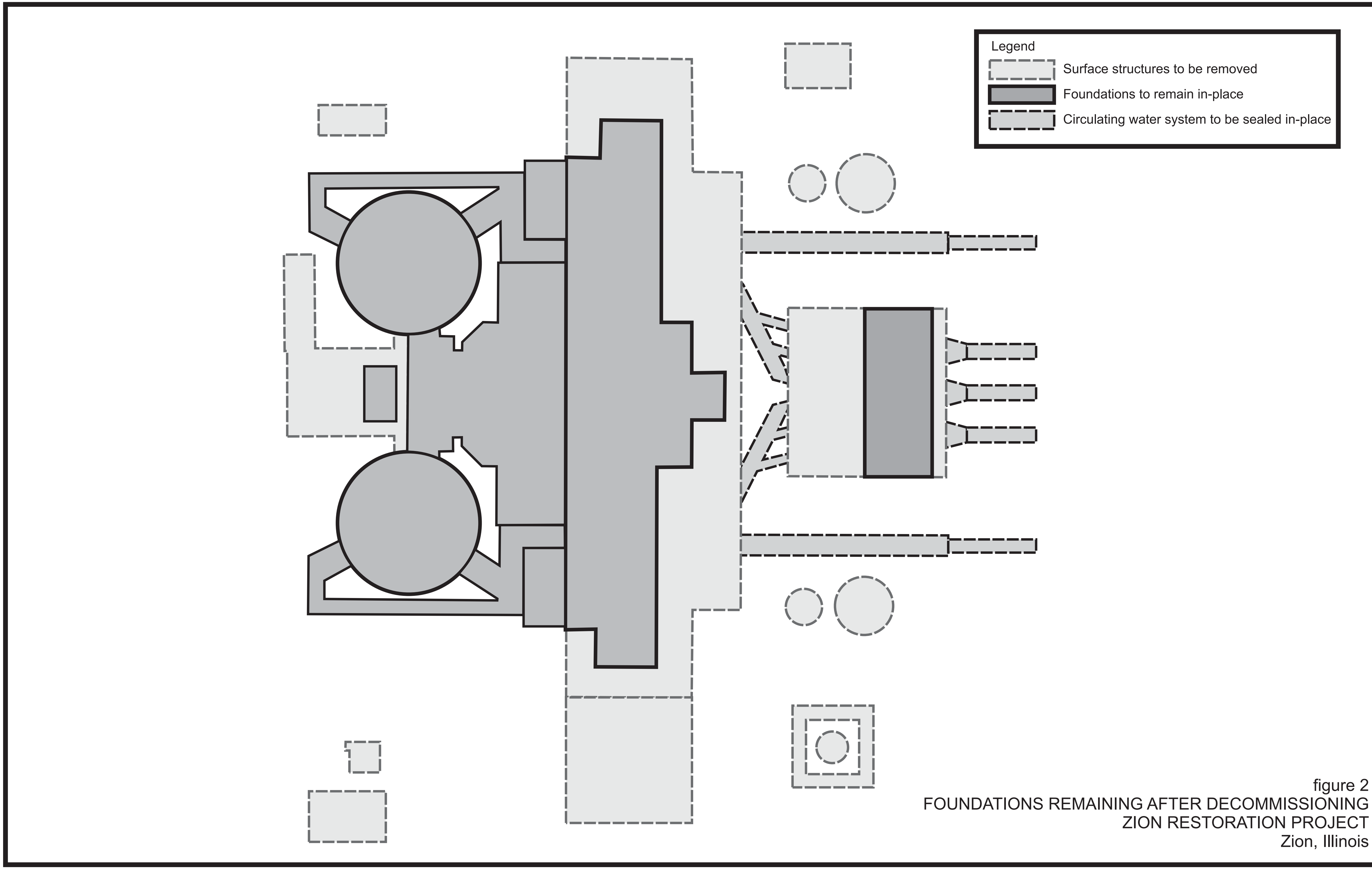

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figure 3
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

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figure 4
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

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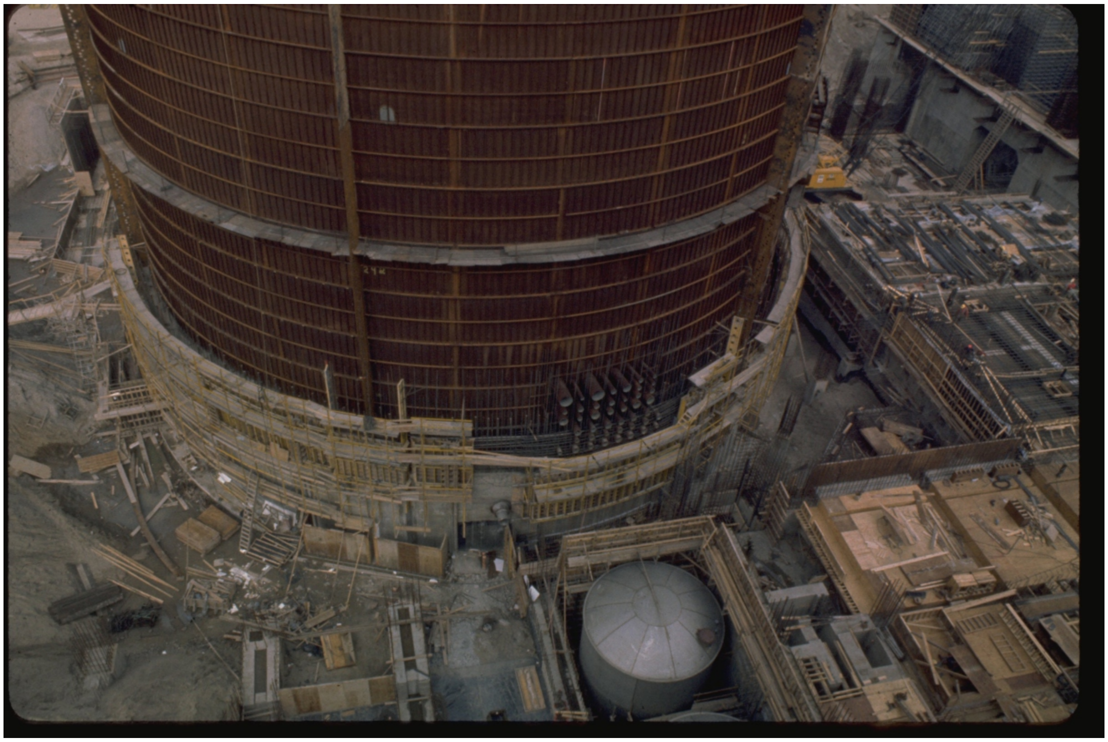

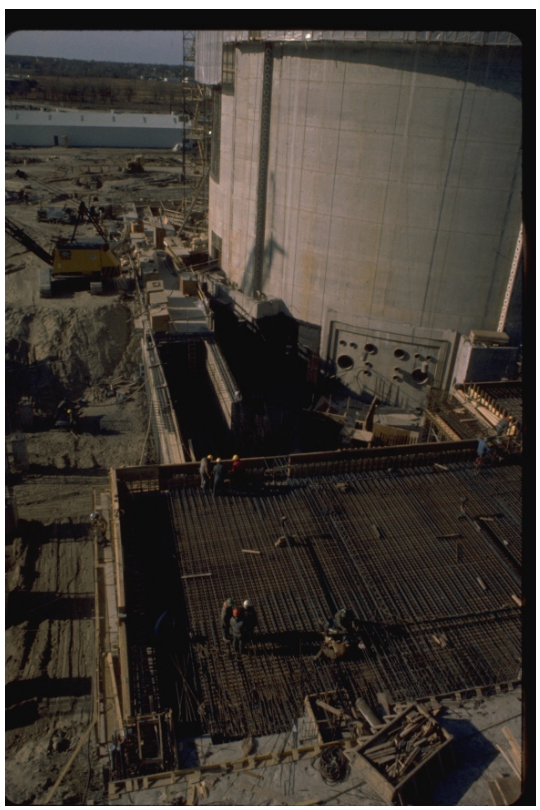

figure 5
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

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figure 6
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

054638-00(004)GIS-CO003

figure 7
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

054638-00(004)GIS-CO003

figure 8
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

054638-00(004)GIS-CO003

figure 9
Foundation Penetrations
1973 Zion Station Construction Photographs
Zion, Illinois

054638-00(004)GIS-CO003

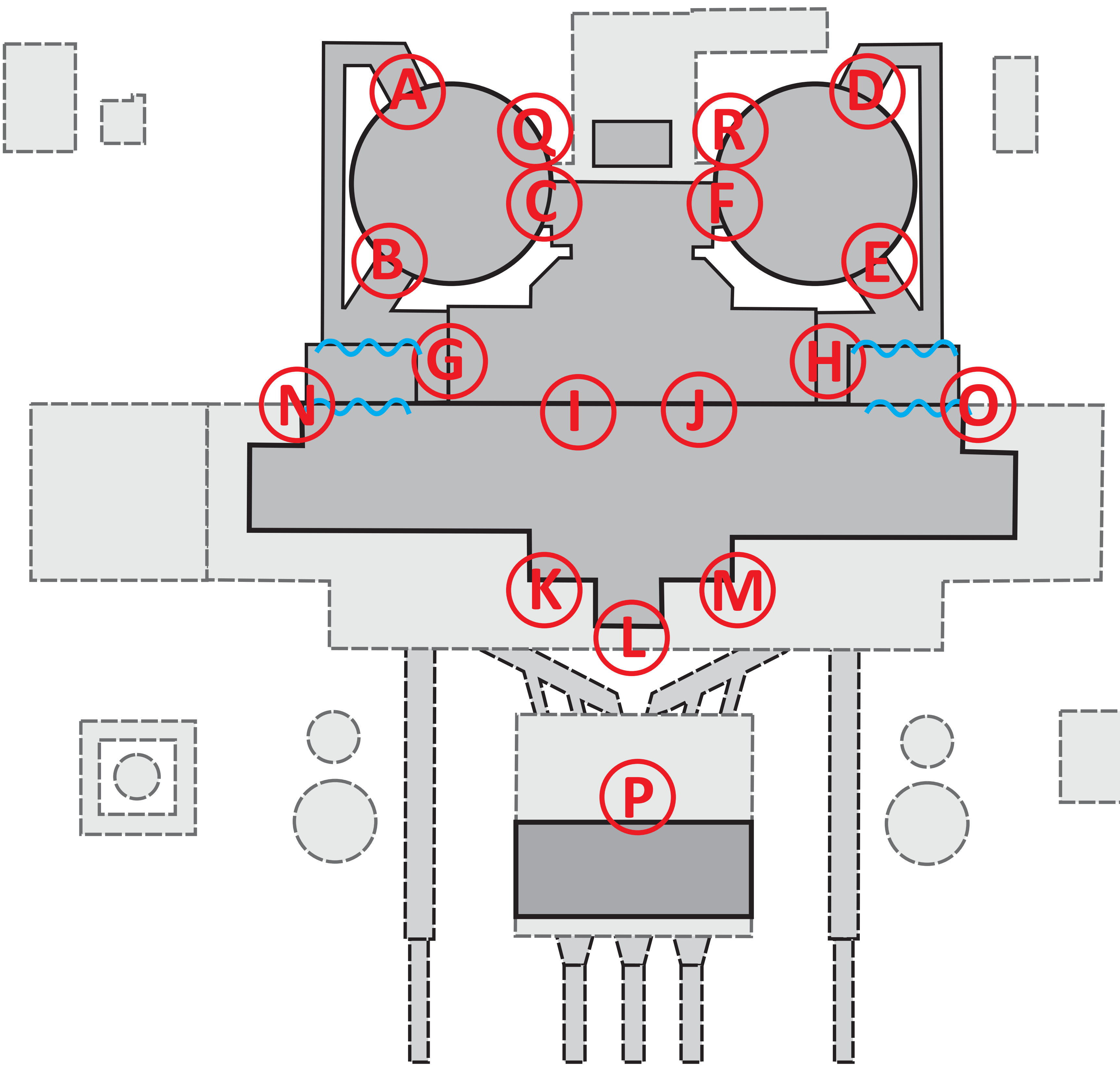


figure 10
PENETRATION CLUSTER LOCATIONS
ZION RESTORATION PROJECT
Zion, Illinois

CRA

054638-00(004)GIS-CO004

Appendix A

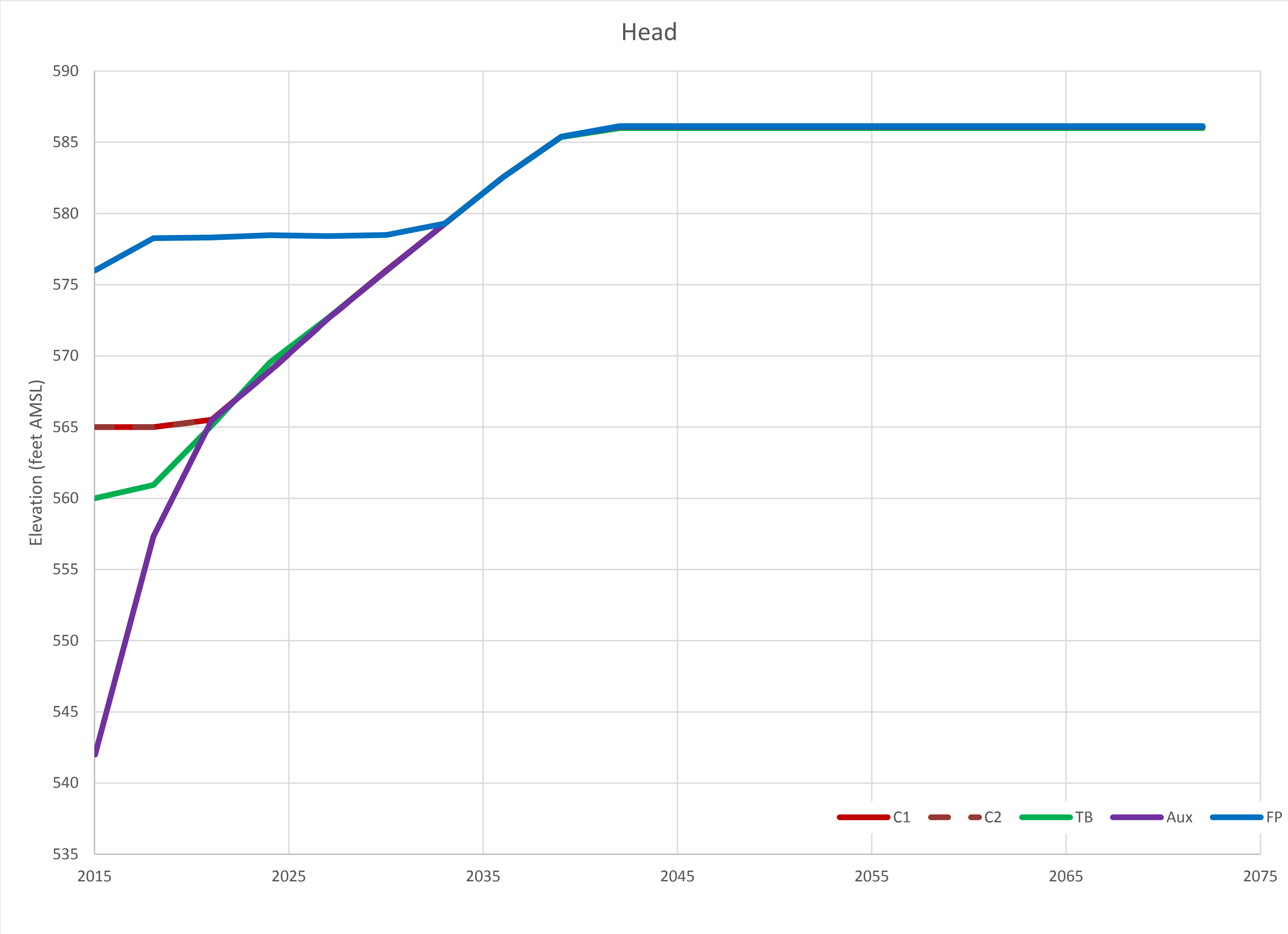
Scenario 1 Model Output

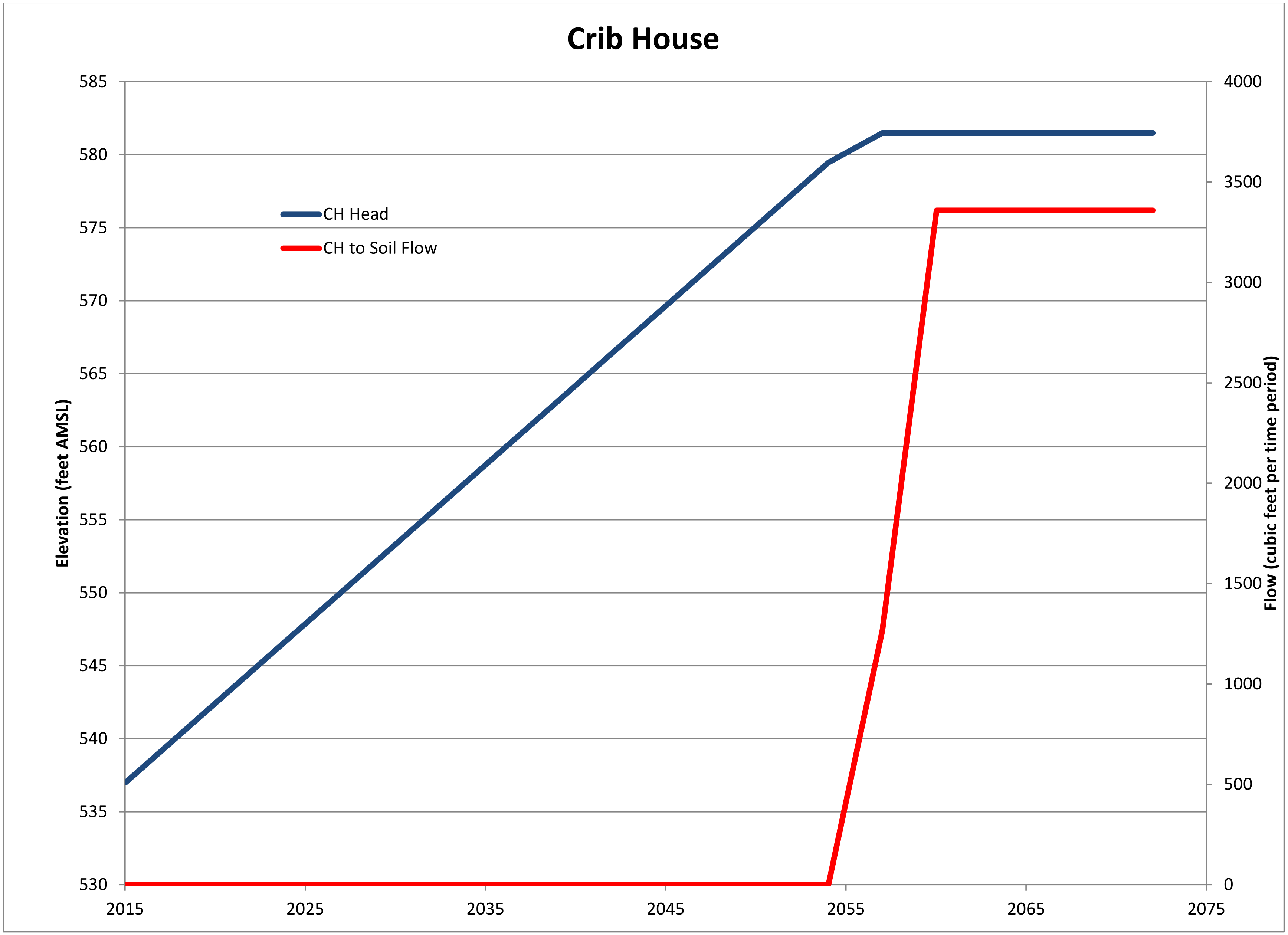
Scenario Parameters		
Start Date	1/15/2015	
Time Step (days)	1095.75	(3.0 years)
Aux Well Pumping Rate (gal/day)	0	(0 cubic feet/day)
Infiltration rate (feet/year)	0.384	(based on pan evaporation)
Total building area ($feet^2$)	152411.99	(excludes crib house)
Total infiltration inflow (gal/day)	1198.648708	(excludes crib house)
Aux infiltration inflow (gal/day)	228.3073136	(31 cubic feet/day)

General Elevations			
C1 base level	565	Spent fuel storage pool	576
C1 incore cavity sump	541.5	Crib House base level	537
C2 base level	565	Crib House sump	532.5
C2 incore cavity sump	541.5	Ground surface	591
Aux base level	542	Foundation cutoff	588
Aux sump	532	Lake Michigan max (1886)	582.6
TB base level	560	Lake Michigan min (1964)	576
Main steam tunnel base level	570	Lake Michigan average	579
Diesel generator base level	567.5	Water table (east of TB)	579

	Building Head (feet AMSL)						Building to Building Flow (cubic feet per time step)									
Date	C1	C2	FP	TB	Aux	CH	C1 to TB	C1 to Aux	C1 to FP	C2 to TB	C2 to Aux	C2 to FP	TB to Aux	TB to Soil	CH to Soil	Notes
1/15/2015	565	565	576	560	542	537	0	0	0	0	0	0	0	0	0	Initial State
1/14/2018	565	565	578.271	560.9271459	557.3197	540.2663	0	23975.393	878.65736	0	23096.7357	0	76446.19	0	0	
1/14/2021	565.511	565.475	578.316	565.0901343	565.4696	543.5325	0	22327.052	2845.2507	0	19740.0428	0	7978.444	0	0	
1/15/2024	568.943	568.919	578.476	569.5416526	568.9487	546.7988	0	1569.9871	2743.3818	0	-1261.9367	0	1873.388	0	0	
1/15/2027	572.655	572.619	578.408	572.6797559	572.6352	550.0651	0	-205.4762	2944.9986	0	-3063.2439	0	7574.658	0	0	
1/14/2030	576.012	575.983	578.496	575.966699	575.9863	553.3313	0	2168.2626	2807.2757	0	-690.11049	0	-608.1239	0	0	
1/14/2033	579.287	579.287	579.287	579.2841625	579.2866	556.5976	108.992	1945.9943	2117.9258	58.654901	-259.48794	67.7772482	-1338.108	0	0	
1/15/2036	582.552	582.552	582.552	582.5516725	582.5517	559.8639	11.4672	0.7791986	0.8819204	11.387819	0.69002559	0.87624845	-13.72395	0	0	
1/15/2039	585.384	585.385	585.402	585.3676699	585.3934	563.1301	4789.79	-1538.967	185.60338	4738.1793	-1491.9226	181.488068	-1319.964	24090.7485	0	
1/14/2042	586.062	586.063	586.139	585.9931014	586.0953	566.3964	28256.6	-8823.126	1129.7347	27916.906	-8510.6393	1104.08285	-8944.268	142787.129	0	
1/14/2045	586.062	586.063	586.139	585.9905258	586.0954	569.6627	35694.9	-11139.96	1458.8858	35266.802	-10744.851	1425.86397	-11585.67	178686.991	0	
1/15/2048	586.062	586.062	586.139	585.9971952	586.0953	572.9289	35697.6	-11140.63	1458.9347	35269.45	-10745.5	1425.91145	-11586.48	178421.221	0	
1/15/2051	586.062	586.062	586.139	585.9947069	586.0953	576.1952	35696.2	-11139.97	1458.8743	35268.011	-10744.864	1425.85258	-11585.93	178687.119	0	
1/14/2054	586.062	586.063	586.139	585.992099	586.0953	579.4615	35694.4	-11140.55	1458.9424	35266.263	-10745.425	1425.91911	-11585.78	178686.953	0	
1/14/2057	586.062	586.062	586.139	585.9896983	586.0953	581.4953	35697.3	-11140.06	1458.8798	35269.169	-10744.95	1425.85793	-11586.2	178687.151	1267.25995	
1/15/2060	586.062	586.063	586.139	585.9961791	586.0953	581.4954	35695.2	-11140.2	1458.8937	35267.053	-10745.08	1425.87146	-11585.81	178421.273	3358.57952	
1/15/2063	586.062	586.062	586.139	585.9939116	586.0952	581.4954	35698.9	-11140.48	1458.9323	35270.711	-10745.359	1425.90922	-11586.69	178686.819	3358.64239	
1/14/2066	586.062	586.063	586.139	585.9911194	586.0953	581.4954	35692.2	-11140.07	1458.8845	35264.079	-10744.96	1425.86254	-11585.15	178687.335	3358.65939	
1/14/2069	586.062	586.062	586.139	585.9979311	586.0952	581.4954	35699.5	-11140.38	1458.9111	35271.264	-10745.261	1425.88833	-11586.76	178420.983	3358.66399	
1/15/2072	586.062	586.062	586.139	585.9952862	586.0953	581.4954	35694.1	-11140.23	1458.9112	35265.947	-10745.118	1425.88875	-11585.6	178687.226	3358.66523	


Building to Building Water Flow
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
-10000
-20000
Flow (cubic feet per time step)
200000
180000
160000
140000
120000
100000
80000
60000
40000
20000
0
TB to Soil Flow (cubic feet per time step)
2015
2025
2035
2045
2055
2065
2075
C1 to TB
C1 to Aux
C2 to TB
C2 to Aux
TB to Aux
C1 to FP
C2 to FP
TB to Soil


Head
Elevation (feet AMSL)
590
585
580
575
570
565
560
555
550
545
540
535
2015
2025
2035
2045
2055
2065
2075
C1
C2
TB
Aux
FP


Crib House
CH Head
CH to Soil Flow
Elevation (feet AMSL)
Flow (cubic feet per time period)
585
580
575
570
565
560
555
550
545
540
535
530
4000
3500
3000
2500
2000
1500
1000
500
0
2015
2025
2035
2045
2055
2065
2075

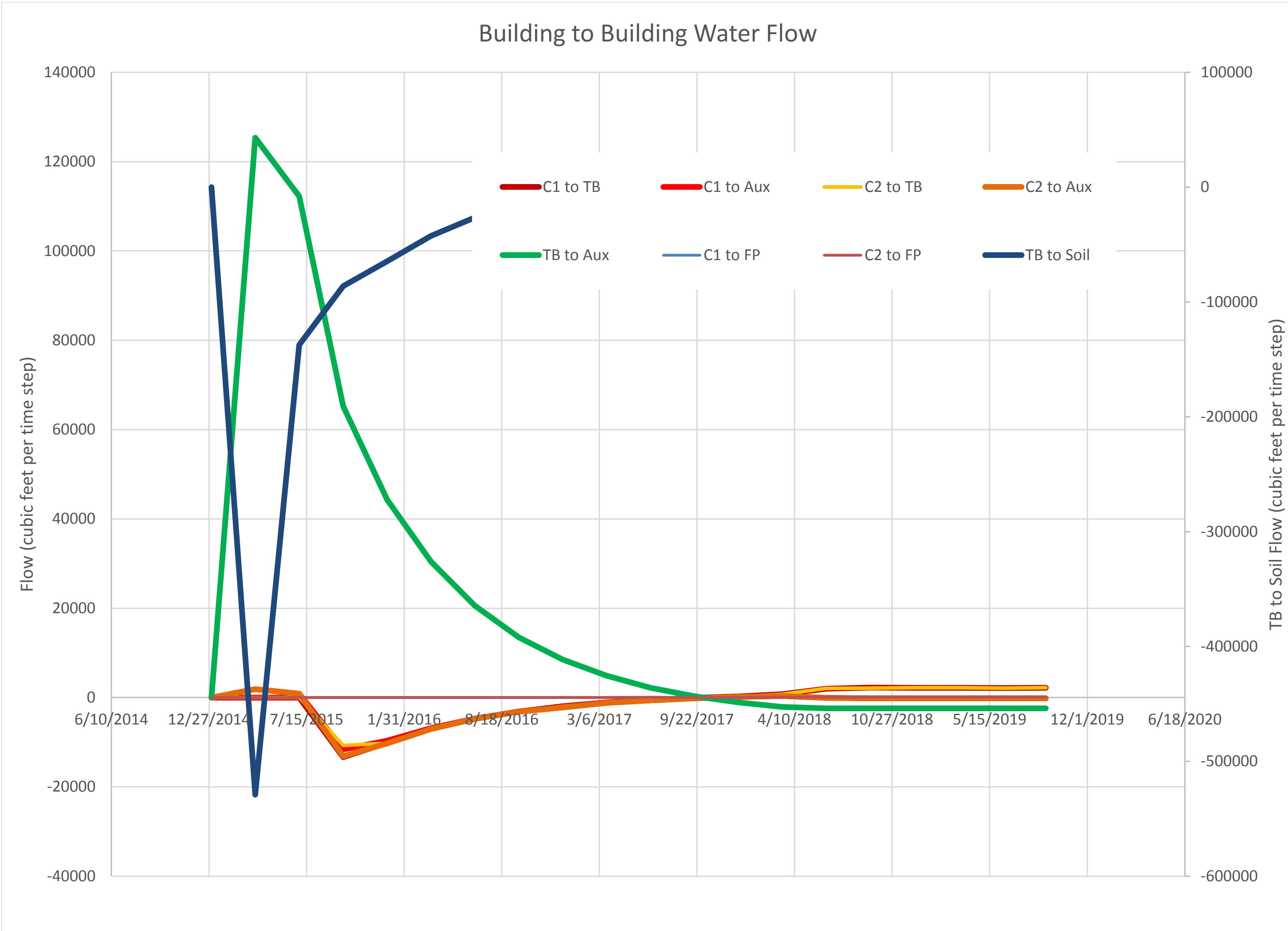
Appendix B

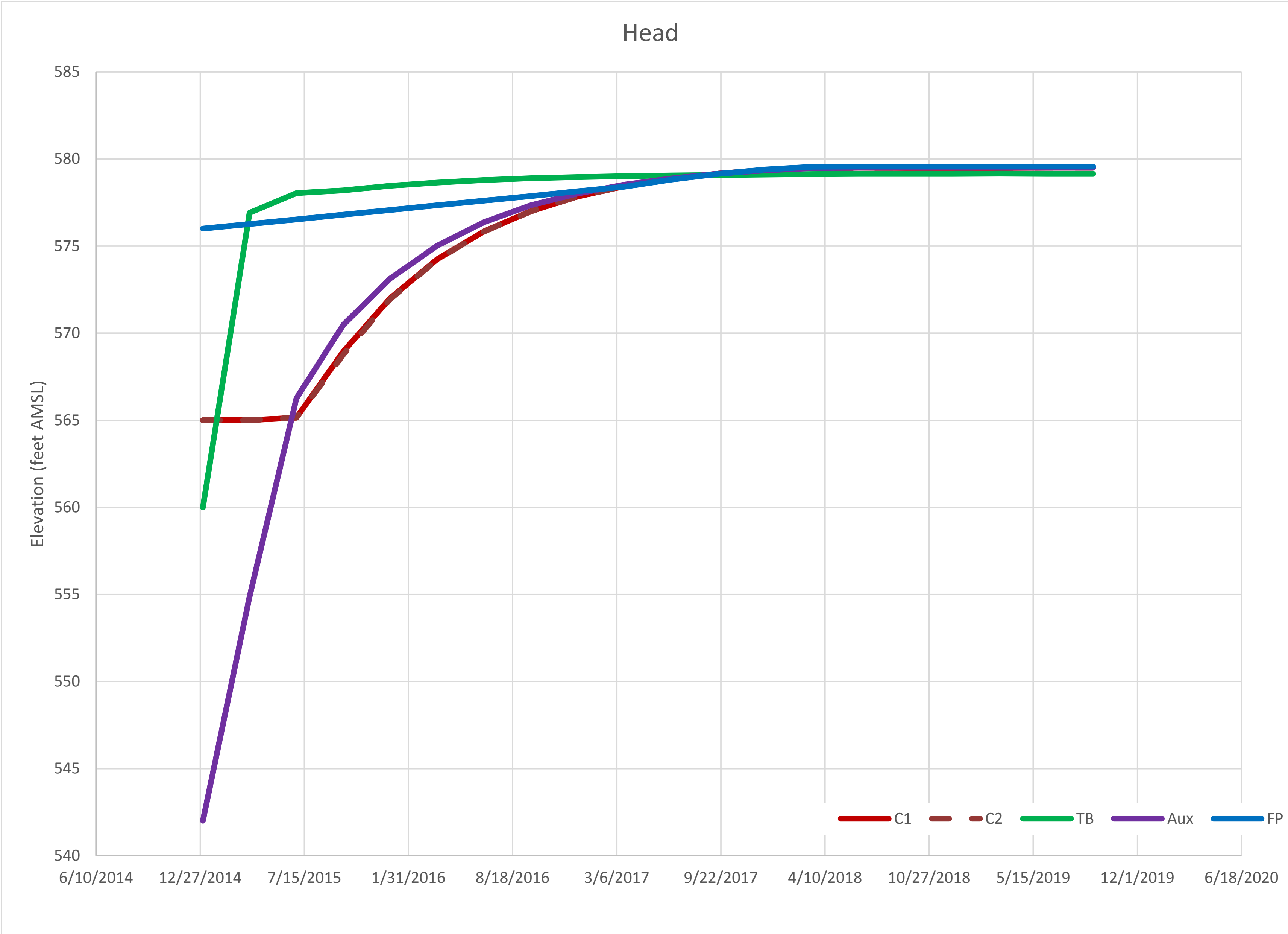
Scenario 2 Model Output

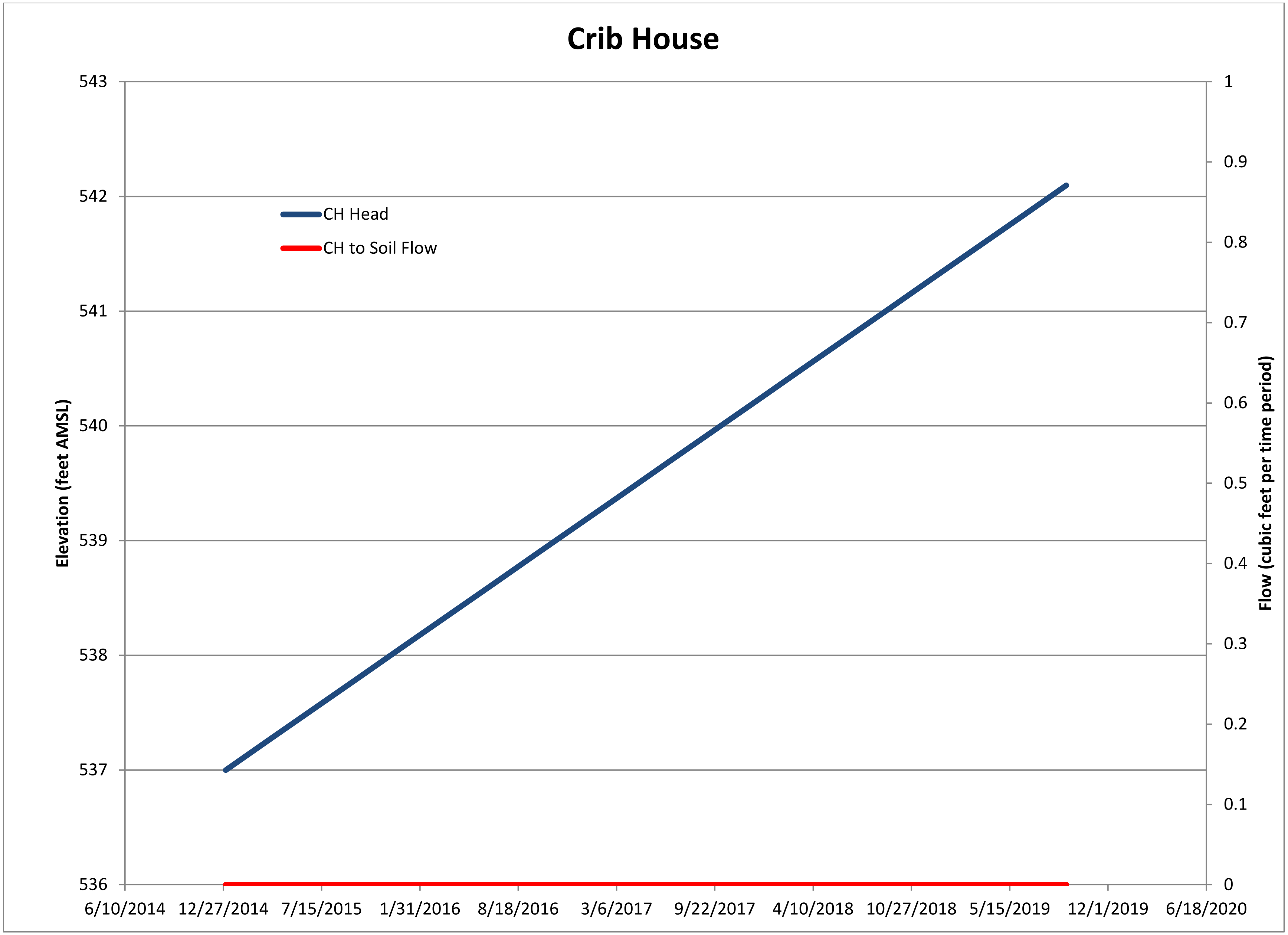
Scenario Parameters		
Start Date	1/1/2015	
Time Step (days)	90	
Aux Well Pumping Rate (gal/day)	0	(0 cubic feet/day)
Infiltration rate (feet/year)	0.384	(based on pan evaporation)
Total building area (feet^2)	152411.99	(excludes crib house)
Total infiltration inflow (gal/day)	1198.6487	(excludes crib house)
Aux infiltration inflow (gal/day)	228.30731	(31 cubic feet/day)

General Elevations			
C1 base level	565	Spent fuel storage pool	576
C1 incore cavity sump	541.5	Crib House base level	537
C2 base level	565	Crib House sump	532.5
C2 incore cavity sump	541.5	Ground surface	591
Aux base level	542	Foundation cutoff	588
Aux sump	532	Lake Michigan max (1886)	582.6
TB base level	560	Lake Michigan min (1964)	576
Main steam tunnel base level	570	Lake Michigan average	579
Diesel generator base level	567.5	Water table (east of TB)	579

	Building Head (feet AMSL)						Building to Building Flow (cubic feet per time step)									
Date	C1	C2	FP	TB	Aux	CH	C1 to TB	C1 to Aux	C1 to FP	C2 to TB	C2 to Aux	C2 to FP	TB to Aux	TB to Soil	CH to Soil	Notes
1/1/2015	565	565	576	560	542	537	0	0	0	0	0	0	0	0	0	Initial State
4/1/2015	565	565	576.268	576.91679	554.8732	537.2682	0	1896.6298	0	0	1896.62976	0	125377	-529001.08	0	
6/30/2015	565.144	565.143	576.536	578.0387	566.2676	537.5364	0	880.57287	0	0	885.56517	0	112251.1	-137359.07	0	
9/28/2015	568.942	568.783	576.805	578.19605	570.4883	537.8046	-13352.5	-11608.82	0	-10723.06	-13117.633	0	65229.53	-86044.321	0	
12/27/2015	572.01	571.957	577.073	578.45716	573.134	538.0729	-10143.2	-9657.4	0	-10263.92	-10286.179	0	44306.9	-64505.226	0	
3/26/2016	574.239	574.219	577.341	578.65259	575.0202	538.3411	-7012.71	-6849.293	0	-7053.301	-7042.1712	0	30471.94	-42397.263	0	
6/24/2016	575.844	575.835	577.609	578.79296	576.3729	538.6093	-4750.99	-4704.215	0	-4766.553	-4767.3756	0	20584.9	-26342.209	0	
9/22/2016	576.998	576.993	577.878	578.89366	577.3433	538.8775	-3123.59	-3136.875	0	-3130.665	-3160.3387	0	13493.11	-14820.597	0	
12/21/2016	577.849	577.846	578.146	578.96492	578.0153	539.1457	-1936.09	-2184.678	0	-1939.847	-2195.7725	0	8517.883	-6601.1363	0	
3/21/2017	578.438	578.437	578.414	579.01724	578.5272	539.4139	-1087.44	-1184.458	0	-1089.473	-1191.0134	0	4873.453	-700.81917	0	
6/19/2017	578.856	578.855	578.818	579.05459	578.889	539.6822	-493.405	-623.0736	60.758565	-494.4237	-626.23695	58.8125111	2208.353	3593.83878	0	
9/17/2017	579.154	579.154	579.15	579.08145	579.1527	539.9504	-74.7246	-167.851	29.016384	-75.11045	-169.40174	28.0072445	290.6018	6657.86882	0	
12/16/2017	579.37	579.37	579.39	579.1009	579.3436	540.2186	227.825	155.11735	13.657666	227.70884	153.219636	13.3649126	-1100.944	8872.89911	0	
3/16/2018	579.489	579.49	579.55	579.1293	579.4746	540.4868	760.404	342.50451	48.036622	757.4061	341.102388	46.7906708	-2089.497	10660.5834	0	
6/14/2018	579.499	579.487	579.57	579.149	579.502	540.755	1972.54	-38.99927	110.80734	2061.8514	-36.222751	108.454026	-2392.287	13735.8199	0	
9/12/2018	579.493	579.495	579.571	579.15095	579.5047	541.0232	2219.2	-158.5238	119.26423	2114.9288	-157.58506	117.189233	-2404.502	14569.7409	0	
12/11/2018	579.49	579.492	579.571	579.15257	579.5048	541.2914	2210.33	-171.356	119.5248	2206.7649	-171.63877	117.627753	-2404.612	14662.3193	0	
3/11/2019	579.487	579.488	579.571	579.15427	579.505	541.5597	2211.94	-172.9471	119.576	2206.4854	-168.43042	117.042679	-2405.24	14662.3072	0	
6/9/2019	579.497	579.499	579.571	579.14921	579.5052	541.8279	2112.97	-173.0164	119.58071	2108.0095	-168.77212	117.083623	-2405.278	14663.4374	0	
9/7/2019	579.495	579.496	579.571	579.15055	579.505	542.0961	2211.26	-174.6509	119.79893	2205.5639	-170.55667	117.320343	-2404.776	14670.5423	0	


Building to Building Water Flow
140000
120000
100000
80000
60000
40000
20000
0
-20000
-40000
Flow (cubic feet per time step)
100000
0
-100000
-200000
-300000
-400000
-500000
-600000
TB to Soil Flow (cubic feet per time step)
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
C1 to TB
C1 to Aux
C2 to TB
C2 to Aux
TB to Aux
C1 to FP
C2 to FP
TB to Soil


Head
Elevation (feet AMSL)
585
580
575
570
565
560
555
550
545
540
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
C1
C2
TB
Aux
FP


Crib House
CH Head
CH to Soil Flow
Elevation (feet AMSL)
Flow (cubic feet per time period)
543
542
541
540
539
538
537
536
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020

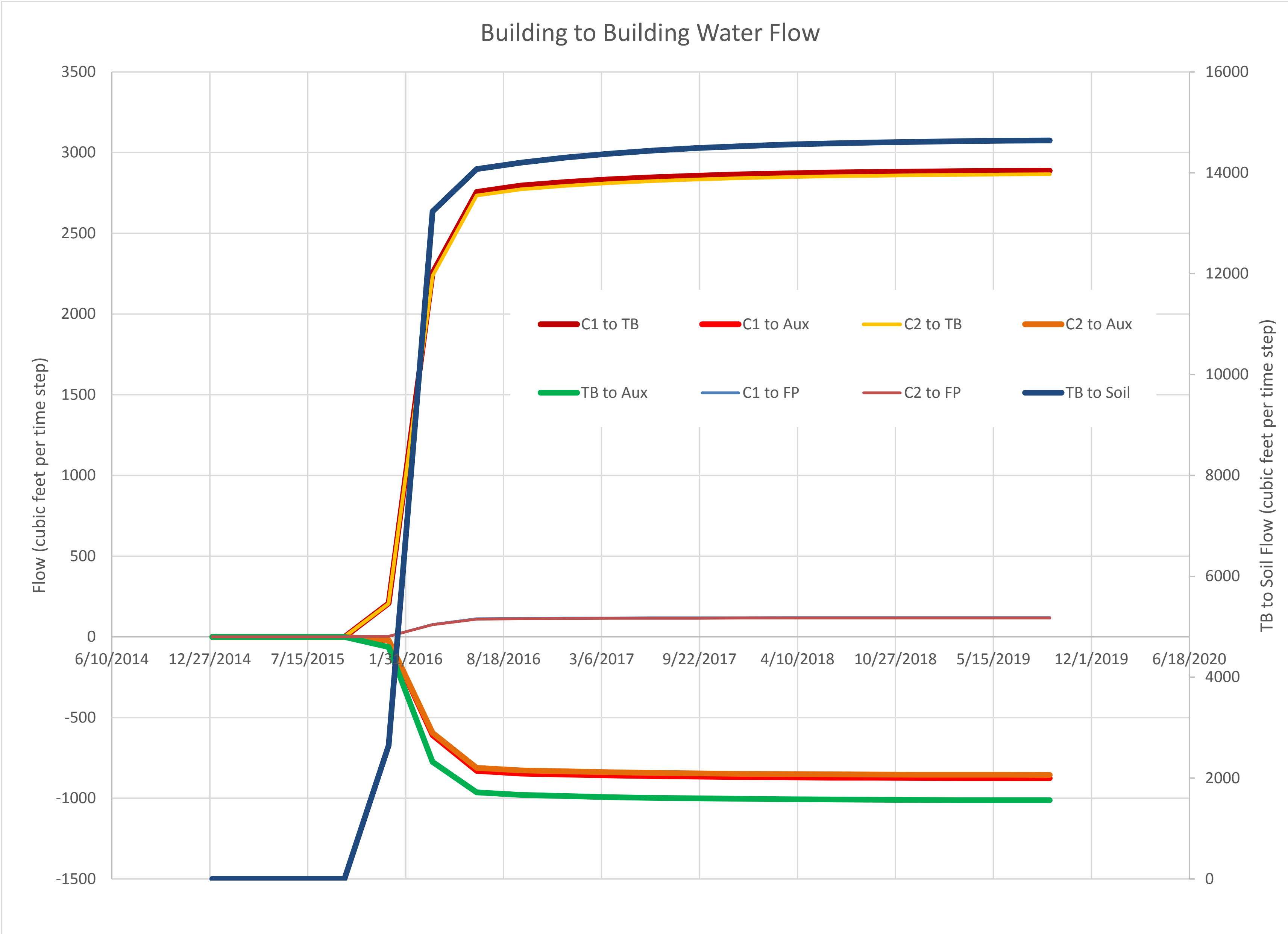
Appendix C

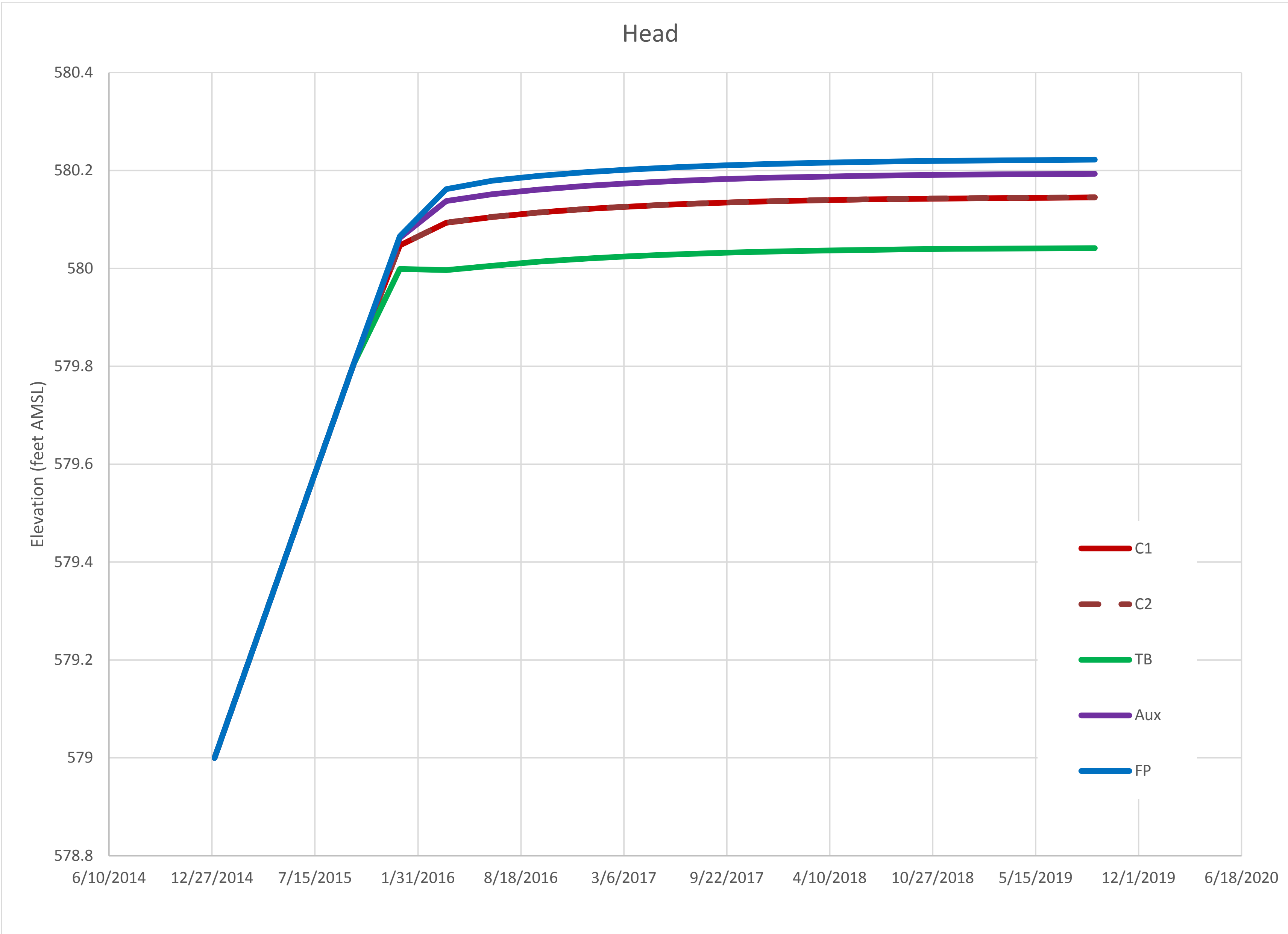
Scenario 3 Model Output

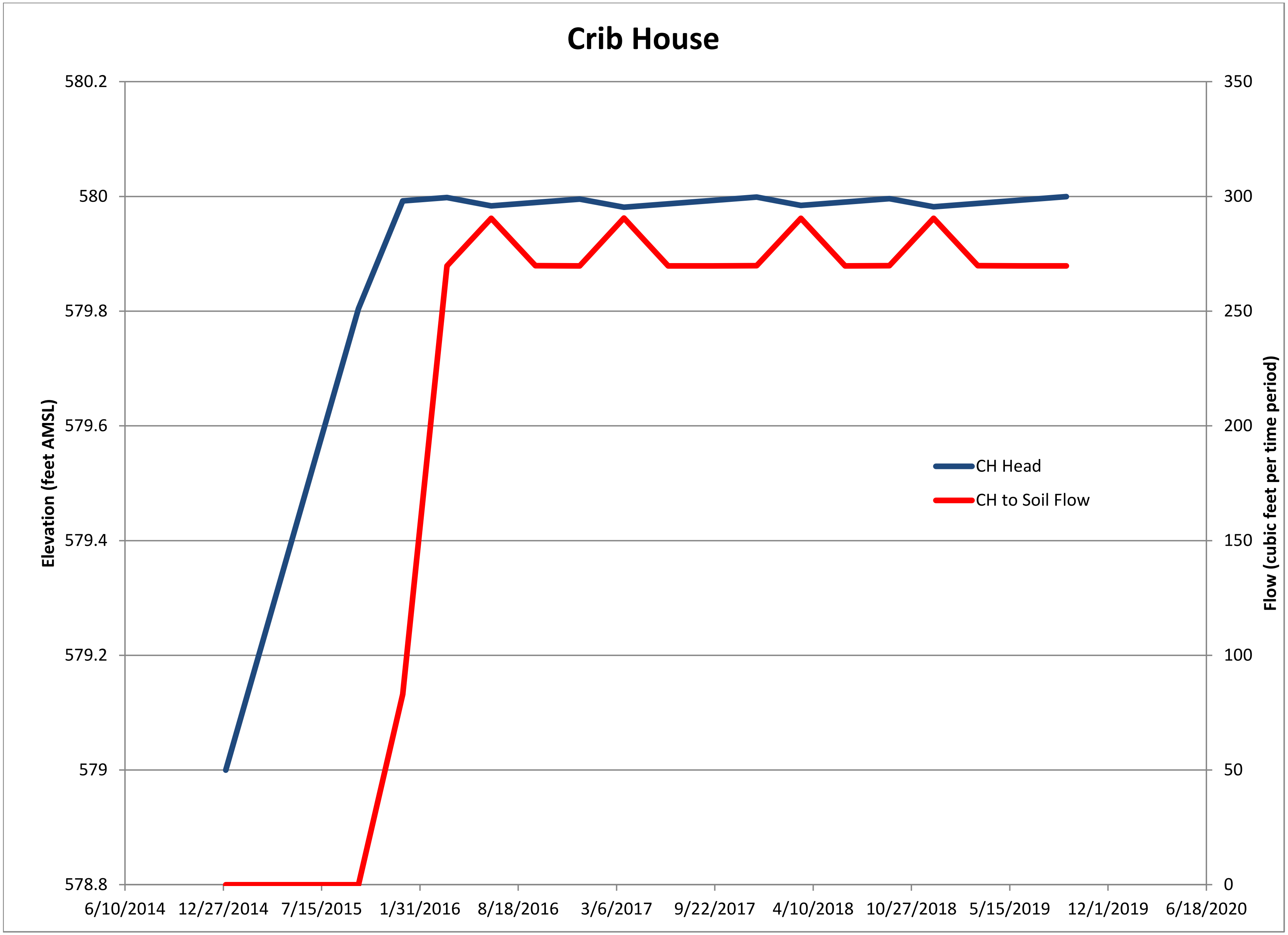
Scenario Parameters		
Start Date	1/1/2015	
Time Step (days)	90	
Aux Well Pumping Rate (gal/day)	0	(0 cubic feet/day)
Infiltration rate (feet/year)	0.384	(based on pan evaporation)
Total building area (feet^2)	152411.99	(excludes crib house)
Total infiltration inflow (gal/day)	1198.6487	(excludes crib house)
Aux infiltration inflow (gal/day)	228.30731	(31 cubic feet/day)

General Elevations			
C1 base level	565	Spent fuel storage pool	576
C1 incore cavity sump	541.5	Crib House base level	537
C2 base level	565	Crib House sump	532.5
C2 incore cavity sump	541.5	Ground surface	591
Aux base level	542	Foundation cutoff	588
Aux sump	532	Lake Michigan max (1886)	582.6
TB base level	560	Lake Michigan min (1964)	576
Main steam tunnel base level	570	Lake Michigan average	579
Diesel generator base level	567.5	Water table (east of TB)	579

	Building Head (feet AMSL)						Building to Building Flow (cubic feet per time step)									
Date	C1	C2	FP	TB	Aux	CH	C1 to TB	C1 to Aux	C1 to FP	C2 to TB	C2 to Aux	C2 to FP	TB to Aux	TB to Soil	CH to Soil	Notes
1/1/2015	579	579	579	579	579	579	0	0	0	0	0	0	0	0	0	Initial State
4/1/2015	579.268	579.268	579.268	579.26822	579.2682	579.2682	0	0	0	0	0	0	0	0	0	
6/30/2015	579.536	579.536	579.536	579.53643	579.5364	579.5364	0	0	0	0	0	0	0	0	0	
9/28/2015	579.805	579.805	579.805	579.80465	579.8046	579.8046	0	0	0	0	0	0	0	0	0	
12/27/2015	580.047	580.047	580.066	579.99905	580.0626	579.9921	207.315	-21.36571	3.2927682	205.67365	-20.895915	3.20352787	-62.7786	2646.54847	83.0129505	
3/26/2016	580.093	580.094	580.162	579.99649	580.1378	579.998	2255.47	-609.2245	76.8416	2238.1884	-594.43327	75.0570087	-774.4277	13231.9505	269.762194	
6/24/2016	580.105	580.105	580.179	580.00559	580.1518	579.9837	2755.89	-830.732	112.05768	2733.8229	-811.13069	109.57377	-963.618	14074.1904	290.480726	
9/22/2016	580.114	580.114	580.189	580.01365	580.1612	579.9896	2795.23	-846.5473	115.37795	2772.7593	-826.64136	112.830898	-978.967	14198.3216	269.775232	
12/21/2016	580.121	580.121	580.196	580.02	580.1685	579.9955	2816.73	-853.3566	116.39233	2794.0915	-833.29424	113.82352	-986.619	14299.1202	269.751669	
3/21/2017	580.127	580.127	580.202	580.02498	580.1743	579.9811	2833.37	-858.5741	117.12107	2810.5879	-838.39053	114.536377	-992.5161	14378.318	290.541474	
6/19/2017	580.131	580.131	580.207	580.0289	580.1788	579.987	2846.41	-862.6659	117.69033	2823.5274	-842.38728	115.093209	-997.1414	14440.4756	269.764283	
9/17/2017	580.134	580.135	580.211	580.03197	580.1824	579.9929	2856.65	-865.8771	118.13698	2833.6821	-845.52388	115.530114	-1000.771	14489.2573	269.743266	
12/16/2017	580.137	580.137	580.213	580.03438	580.1851	579.9988	2864.68	-868.3972	118.48751	2841.6516	-847.9855	115.872996	-1003.62	14527.5415	269.781785	
3/16/2018	580.139	580.139	580.216	580.03627	580.1873	579.9845	2870.99	-870.3751	118.76261	2847.9062	-849.9174	116.142092	-1005.856	14557.5872	290.511205	
6/14/2018	580.141	580.141	580.217	580.03775	580.189	579.9904	2875.94	-871.9273	118.97851	2852.8147	-851.43356	116.353279	-1007.61	14581.1672	269.736164	
9/12/2018	580.142	580.142	580.219	580.03892	580.1904	579.9962	2879.82	-873.1455	119.14795	2856.667	-852.62346	116.519021	-1008.987	14599.6729	269.771045	
12/11/2018	580.143	580.143	580.22	580.03983	580.1914	579.9819	2882.87	-874.1015	119.28092	2859.6903	-853.5573	116.649096	-1010.068	14614.1963	290.512289	
3/11/2019	580.144	580.144	580.221	580.04055	580.1923	579.9878	2885.26	-874.8518	119.38528	2862.063	-854.29018	116.75118	-1010.916	14625.5944	269.788056	
6/9/2019	580.144	580.145	580.221	580.04111	580.1929	579.9936	2887.14	-875.4407	119.46719	2863.9251	-854.86535	116.831295	-1011.582	14634.5397	269.761511	
9/7/2019	580.145	580.145	580.222	580.04155	580.1934	579.9995	2888.61	-875.9028	119.53146	2865.3865	-855.31674	116.894171	-1012.104	14641.56	269.741138	


Building to Building Water Flow
Flow (cubic feet per time step)
TB to Soil Flow (cubic feet per time step)
3500
3000
2500
2000
1500
1000
500
0
-500
-1000
-1500
16000
14000
12000
10000
8000
6000
4000
2000
0
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
C1 to TB
C1 to Aux
C2 to TB
C2 to Aux
TB to Aux
C1 to FP
C2 to FP
TB to Soil


Head
580.4
580.2
580
579.8
579.6
579.4
579.2
579
578.8
Elevation (feet AMSL)
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
C1
C2
TB
Aux
FP


Crib House
Elevation (feet AMSL)
Flow (cubic feet per time period)
580.2
580
579.8
579.6
579.4
579.2
579
578.8
350
300
250
200
150
100
50
0
6/10/2014
12/27/2014
7/15/2015
1/31/2016
8/18/2016
3/6/2017
9/22/2017
4/10/2018
10/27/2018
5/15/2019
12/1/2019
6/18/2020
CH Head
CH to Soil Flow

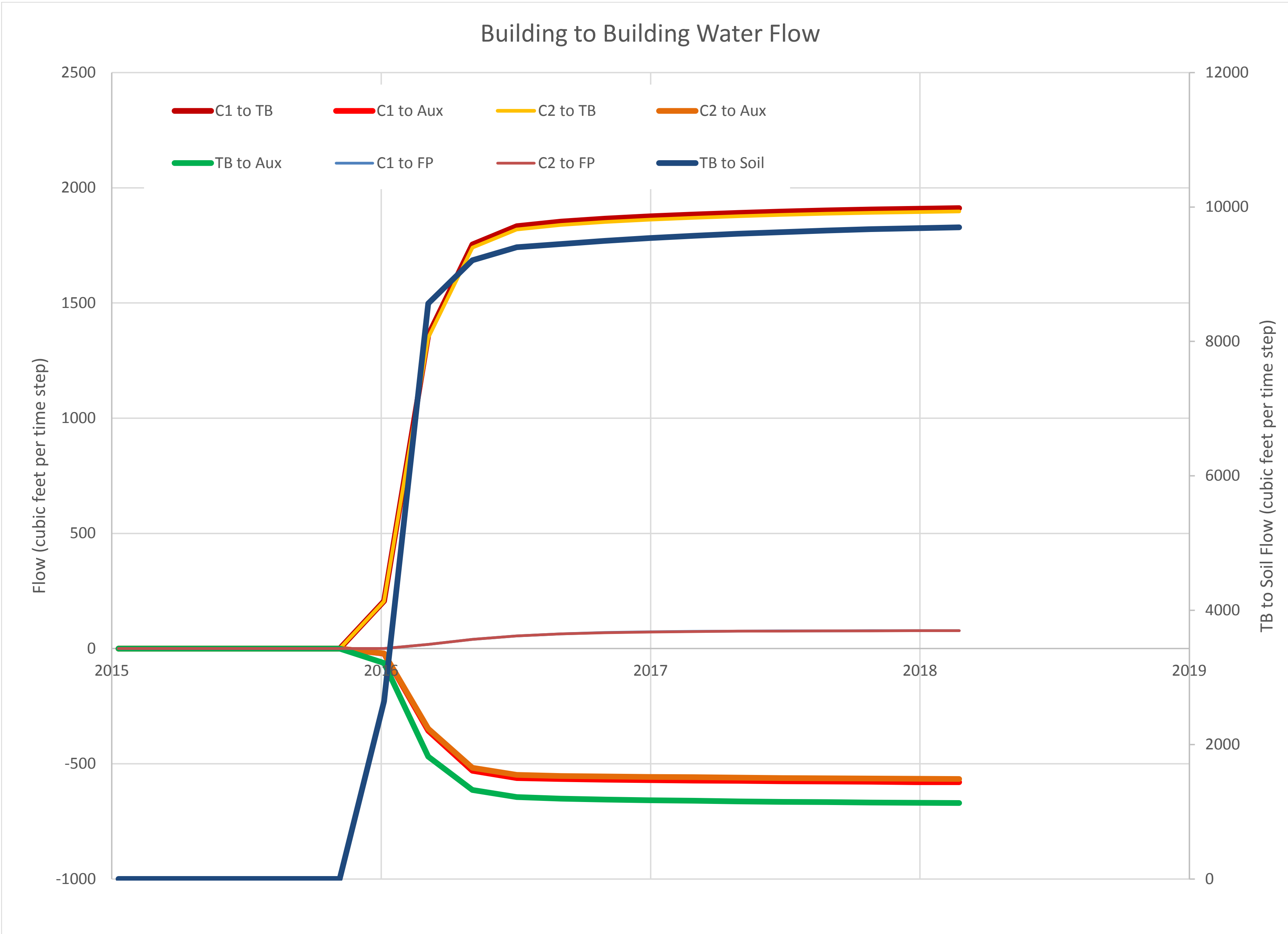
Appendix D

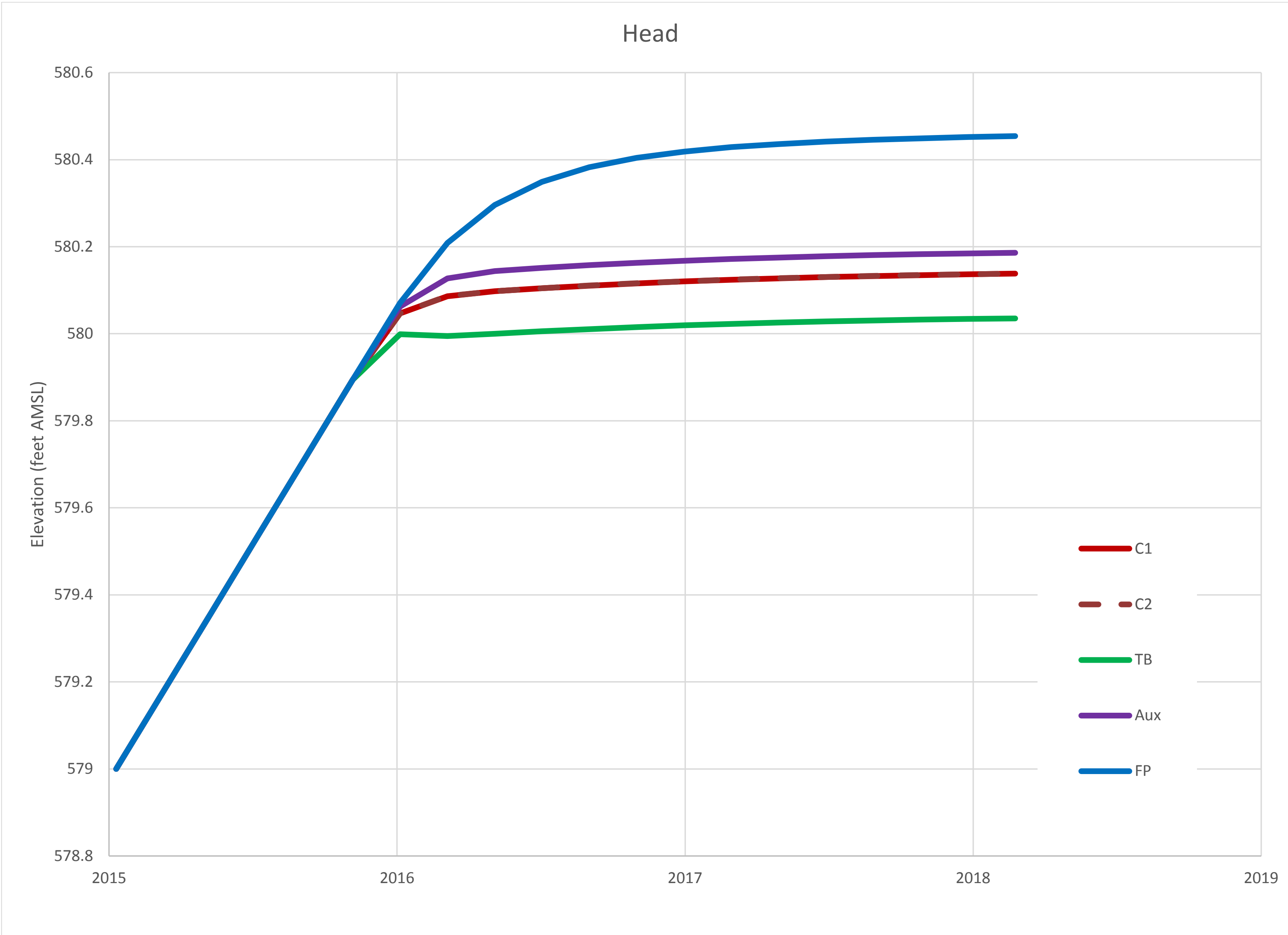
Scenario 4 Model Output

Scenario Parameters		
Start Date	1/15/2015	
Time Step (days)	60	
Aux Well Pumping Rate (gal/day)	0	(0 cubic feet/day)
Infiltration rate (feet/year)	0.384	(based on pan evaporation)
Total building area (feet^2)	152411.99	(excludes crib house)
Total infiltration inflow (gal/day)	1198.64871	(excludes crib house)
Aux infiltration inflow (gal/day)	228.307314	(31 cubic feet/day)

General Elevations			
C1 base level	565	Spent fuel storage pool	576
C1 incore cavity sump	541.5	Crib House base level	537
C2 base level	565	Crib House sump	532.5
C2 incore cavity sump	541.5	Ground surface	591
Aux base level	542	Foundation cutoff	588
Aux sump	532	Lake Michigan max (1886)	582.6
TB base level	560	Lake Michigan min (1964)	576
Main steam tunnel base level	570	Lake Michigan average	579
Diesel generator base level	567.5	Water table (east of TB)	579

	Building Head (feet AMSL)						Building to Building Flow (cubic feet per time step)									
Date	C1	C2	FP	TB	Aux	CH	C1 to TB	C1 to Aux	C1 to FP	C2 to TB	C2 to Aux	C2 to FP	TB to Aux	TB to Soil	CH to Soil	Notes
1/15/2015	579	579	579	579	579	579	0	0	0	0	0	0	0	0	0	Initial State
3/16/2015	579.179	579.179	579.179	579.17881	579.1788	579.1788	0	0	0	0	0	0	0	0	0	
5/15/2015	579.358	579.358	579.358	579.35762	579.3576	579.3576	0	0	0	0	0	0	0	0	0	
7/14/2015	579.536	579.536	579.536	579.536431	579.5364	579.5364	0	0	0	0	0	0	0	0	0	
9/12/2015	579.715	579.715	579.715	579.715241	579.7152	579.7152	0	0	0	0	0	0	0	0	0	
11/11/2015	579.894	579.894	579.894	579.894051	579.8941	579.8941	0	0	0	0	0	0	0	0	0	
1/10/2016	580.047	580.047	580.071	579.999023	580.0626	579.9921	206.86	-21.57792	0.9700468	205.23898	-21.098363	0.95824135	-62.77289	2646.52831	83.0129505	
3/10/2016	580.086	580.086	580.208	579.994752	580.1271	579.9893	1360.03	-356.1439	18.174422	1350.1844	-347.25492	18.0292372	-468.0737	8562.87838	186.756734	
5/9/2016	580.098	580.098	580.296	580.000184	580.1438	579.9865	1753.96	-530.0638	40.548413	1740.6635	-517.1075	40.285593	-613.4954	9207.3358	186.725742	
7/8/2016	580.105	580.105	580.349	580.005484	580.1514	579.9837	1833.29	-561.7006	55.513085	1819.3036	-548.06945	55.1789371	-644.4373	9400.09771	186.760443	
9/6/2016	580.11	580.111	580.383	580.010642	580.1576	579.9809	1852.97	-566.1773	64.399005	1838.8248	-552.43147	64.0231448	-650.8245	9449.89908	186.789335	
11/5/2016	580.116	580.116	580.404	580.015235	580.1629	579.9983	1865.67	-568.311	69.652259	1851.4417	-554.49792	69.2515462	-654.6418	9495.62181	166.013138	
1/4/2017	580.12	580.12	580.419	580.019249	580.1676	579.9955	1875.74	-570.3311	72.805466	1861.4368	-556.45901	72.3897196	-657.7867	9535.89389	186.724429	
3/5/2017	580.124	580.124	580.429	580.022723	580.1716	579.9927	1884	-572.26	74.740075	1869.6445	-558.33544	74.3150162	-660.4701	9570.90424	186.75935	
5/4/2017	580.127	580.128	580.436	580.025714	580.1751	579.9898	1890.88	-574.0288	75.961071	1876.4712	-560.05804	75.5300665	-662.7636	9601.12175	186.788425	
7/3/2017	580.13	580.13	580.441	580.028279	580.1781	579.987	1896.65	-575.6073	76.758549	1882.193	-561.59642	76.3236082	-664.7218	9627.08365	186.757983	
9/1/2017	580.133	580.133	580.446	580.030474	580.1806	579.9842	1901.5	-576.9927	77.300009	1887.0137	-562.94713	76.8623571	-666.3924	9649.32283	186.728001	
10/31/2017	580.135	580.135	580.449	580.032349	580.1828	579.9814	1905.61	-578.1958	77.682901	1891.0894	-564.1205	77.243304	-667.8168	9668.33572	186.762324	
12/30/2017	580.136	580.137	580.452	580.033949	580.1846	579.9988	1909.09	-579.2337	77.964536	1894.5436	-565.13286	77.5234888	-669.0308	9684.56923	166.034725	
2/28/2018	580.138	580.138	580.454	580.035314	580.1862	579.996	1912.04	-580.1251	78.179131	1897.4756	-566.00245	77.7369667	-670.0651	9698.41771	186.757611	


Building to Building Water Flow
C1 to TB
C1 to Aux
C2 to TB
C2 to Aux
TB to Aux
C1 to FP
C2 to FP
TB to Soil
Flow (cubic feet per time step)
TB to Soil Flow (cubic feet per time step)
2500
2000
1500
1000
500
0
-500
-1000
12000
10000
8000
6000
4000
2000
0
2015
2016
2017
2018
2019


Head
580.6
580.4
580.2
580
579.8
579.6
579.4
579.2
579
578.8
Elevation (feet AMSL)
2015
2016
2017
2018
2019
C1
C2
TB
Aux
FP