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Conestoga-Rovers and Associates Report: Evaluation of Hydrogeological Parameters in Support of Zion Restoration Project

Revision 5

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Evaluation of Hydrological Parameters in Support of Dose Modeling for the Zion Restoration Project

Zion Restoration Project
Zion, Illinois

Revision 5

Prepared for: ZionSolutions

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Section 1.0 Introduction

Conestoga-Rovers & Associates (CRA) was retained by ZionSolutions, LLC (ZionSolutions) for hydrogeology consulting services related to the Zion Restoration Project at the former Zion Nuclear Power Station in Zion, Lake County, Illinois (Site). This report provides an evaluation of several components of the Conceptual Site Model (CSM) and preliminary estimates of hydrogeological parameters. The parameters are considered accurate but may change as new information becomes available. These parameters are used in radionuclide release, transport, and dose modeling activities performed by ZionSolutions.

Section 2.0 Development of Conceptual Site Model Components for Existing Conditions

This section provides an evaluation of specific components of the CSM applicable to current Site conditions, decommissioning activities, and post-decommissioning use of the Site.

2.1. An Evaluation of the Transport of Groundwater to Lake Michigan

Groundwater at the Site generally flows from areas west of the Zion Station Protected Area (PA) eastward towards Lake Michigan (Lake) within the unconfined upper sand unit which underlies the Site to a depth of approximately 33 feet below ground surface (bgs) (the Shallow Aquifer). There are variations in flow directions and rates due to the presence of subsurface structures (e.g., Reactor, Containment, Auxiliary, Turbine, and Crib House buildings).

The seepage velocity (also called the specific discharge) is the average velocity of groundwater flowing through a porous medium. The average seepage velocity of 137 feet per year (ft/y) is representative of groundwater due to the natural gradient. The seepage velocity of 0 to 104 ft/y is representative of the natural velocity attenuated by the subsurface structures (e.g., building basements and the sheet pile wall) and describes conditions ranging from stagnant (0 ft/y) west of the Crib House to 58 ft/y for groundwater flowing around the edge of the sheet pile wall (see Section 5.8). The estimated travel time of groundwater from the PA to Lake Michigan is on the order of less than 1 year to over 2 years.

The volume of groundwater flowing through the Shallow Aquifer from the PA into Lake Michigan (groundwater flux) can be approximated by the following calculation:

- The saturated thickness = 21.5 ft
- The length of the area of interest = 830 ft (north to south)
- Cross section area is (21.5 ft)×(830 ft) = 1.78E+04 ft^2
- Porosity = 0.353
- **Saturated pore portion of the cross sectional area = (1.78E+04 ft^2)×(0.353) = 6.30E+03 ft^2**

- Groundwater flux into the Lake using the low end groundwater velocity (assuming structures and basements remain in place) = (6.30E+03 ft^2)×(104 ft/y) = 6.58E+05 ft^3/y × 7.48 gal/ft^3 = 4.92E+06 gal/y
- Groundwater flux into the Lake using the high end groundwater velocity (assuming structures and basements are removed) = (6.30E+03 ft^2) × (137 ft/y) = (8.60E+05 ft^3/y) × (7.48 gal/ft^3) = 6.43E+06 gal/y

2.2. Estimation of the Effects of Dilution on Contaminants Entering Lake Michigan via Groundwater

The total volume of water in Lake Michigan is estimated to be 1,180 cubic miles or about 1.3E+15 gallons (1). The stream flow entering the Lake is approximately 7.92 cubic miles per year (8.72E+12 gallons per year), and the discharge to Lake Huron is approximately 11.8 cubic miles per year (1.30E+13 gallons per year) (2). The average residence time (the time between entry and discharge/evaporation) for water in the Lake is 99 years (1), which is equivalent to an exchange of 3.6E+10 gallons per day. Also, the Lake waters undergo an annual inversion which mixes the water as part of the natural lake processes (3).

Although estimating the dilution requires release-specific information, the general scale of dilution can be illustrated using dilution factors calculated by the mixing of hypothetical Site contaminants in groundwater flux with the surface water volume of Lake Michigan. Two dilution estimation methods are evaluated below. The complete mixing approach is suitable for estimating long term mixing and dilution over a period of many years. The shoreline mixing approach is suitable for estimating the potential impact at the shoreline adjacent to the Site.

2.2.1. Complete Mixing Approach

A release of dissolved contaminants to the Lake would be diluted by mixing with the existing volume of Lake water due to the annual inversion of the Lake and currents. This dilution factor can be estimated for the volume of groundwater flux from the Site as explained above and its mixing each year with Lake Michigan surface water. A conservative dilution factor can be estimated by mixing the Site groundwater flux with the total influx of water to Lake Michigan. Using the lower range of groundwater velocity, this yields a dilution factor of:

$$\frac{Total\ Influx\ to\ Lake\ Michigan\ \left(\frac{gal}{y}\right)}{Site\ Groundwater\ Flux\ \left(\frac{gal}{y}\right)} = \frac{1.31E+13\left(\frac{gal}{y}\right)}{4.92E+06\left(\frac{gal}{y}\right)} = 2.67E+06$$

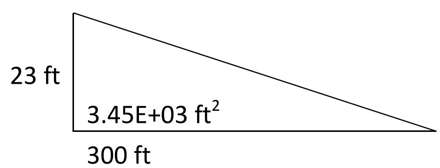
The higher range of groundwater velocity yields a dilution factor of:

$$\frac{Total\ Influx\ to\ Lake\ Michigan\ \left(\frac{gal}{y}\right)}{Site\ Groundwater\ Flux\ \left(\frac{gal}{y}\right)} = \frac{1.31E+13\left(\frac{gal}{y}\right)}{6.43E+06\left(\frac{gal}{y}\right)} = 2.04E+06$$

This estimates the dilution of a (hypothetical) continuous source of groundwater contamination entering Lake Michigan from the Site.

2.2.2. Shoreline Mixing Approach

The dilution factor was also calculated for the near-shore area of the Lake adjacent to the Site, where recreational swimmers and ecological receptors may be affected. The length along the shore of the area of concern is assumed to be 830 ft, based upon the approximate length of the PA along the shore line. The distance into Lake Michigan of the area of concern was assumed to be 100 yards (300 ft), based upon the distance a recreational swimmer is likely swim into the Lake. The depth of water at 100 yards is 23 ft, based upon the depth of water at B-81, a preconstruction borehole location. The cross-sectional area is 300 ft × 23 ft / 2 = 3,450 ft^2 (assuming the lakebed slope is linear).



Surface currents in Lake Michigan are driven by winds and are ephemeral in direction and velocity. Subsurface currents consistent with longshore drift have been described in an Illinois State Water Survey (ISWS) study at Wilmette, Illinois (approximately 30 miles south of Zion) (4). The following median current velocities were described:

- 1.137 cm/s at a station 2.1 meters (m) deep and 107 m from shore
- 1.518 cm/s at a station 5.2 m deep and 213 m from shore (4 p. 17)

Based on the average current velocity of the near shore station (1.137 cm/s or 1.18E+06 ft/y) times the cross-sectional area (3.45E+03 ft^2) yields a total volume of water of 4.06E+09 ft^3/y (or 3.04E+10 gal/y).

The volume of groundwater discharging into the Lake from the Site was estimated to be 6.43+06 gal/y, assuming the basements and sheet pile wall are removed and 4.92E+06 gal/y assuming the basements and sheet pile wall remain in place (see Section 2.1). The dilution factor for each of these scenarios was calculated to be:

$$\frac{3.04E+10\,\frac{gal}{y}}{6.43E+06\,\frac{gal}{y}} = \mathbf{4.72E+03}$$ (subsurface structures removed)

$$\frac{3.04E+10\,\frac{gal}{y}}{4.92E+06\,\frac{gal}{y}} = \mathbf{6.18E+03}$$ (subsurface structures remaining)

These dilution factors are very conservative and unlikely to represent the true dilution of groundwater into the Lake, since these values do not account for water exiting the near-shore area further into the Lake.

2.3. An Evaluation of the Effectiveness of the Silty Clay Aquitard at the Base of the Shallow Aquifer

The silty clay unit (found under the Shallow Aquifer) (also referred to herein as the Silty Clay Aquitard) is approximately 30 ft thick and overlies the lower sand unit. The silty clay unit is laterally extensive at the Site and the underlying lower sand unit has exhibited a significant confining pressure (artesian pressure at boring B-43) and a strong upward vertical gradient (5). To the extent that groundwater flow can occur through the silty clay unit, the groundwater in the lower sand unit would move upward into the upper sand unit (Shallow Aquifer).

The building foundations for the Containment Buildings, Auxiliary Building, Turbine Building, and Crib House are set in or near the upper portion of the silty clay unit. However, the silty clay unit extends approximately 15 ft below the deepest structural feature at the Site.

The silty clay unit’s low permeability and upward vertical gradient limits the potential for the migration of contaminants or radionuclides to the underlying lower sand unit or the regional bedrock aquifers.

Section 3.0 Development of CSM Components for Decommissioning Activities

Several components of the CSM require evaluation or refinement prior to their incorporation into risk assessment and dose modeling for the Site. An evaluation of these components may guide the selection of decommissioning technologies for their use in the CSM.

3.1. Basement Fill Alternatives

The CSM anticipates that the basements will generally remain in place and be filled with ‘clean’ concrete (no detectable residual radioactivity from Site operations) originating from the demolition of aboveground buildings and structures or other fill material. The scenarios described below are hypothetical.

3.1.1. Riprap Scenario

During the demolition of aboveground concrete structures, large pieces of riprap will be produced (e.g., using an excavator with a pneumatic hammer attachment) and staged at the Site. The basements would then be backfilled with large clean concrete pieces (protruding rebar must be removed), and sand would be used to fill the voids during backfilling.

This fill material would act as a framework gravel, with incomplete infilling of void spaces by sand. The resulting porosity is expected to be high, ranging from 25-40% for riprap-sand mixtures and 40 to 45% for uniform riprap. Groundwater can readily flow through this material. The area of fresh concrete surfaces would be minimized, which would reduce the pH impact due to calcium leaching.

3.1.2. 3-inch Clean Concrete Scenario

Under this scenario, during the demolition of aboveground concrete structures, large pieces of riprap will be produced and staged at the Site. A mobile concrete crusher would be used to reduce the clean concrete to 3”×3” pieces. The basements would then be backfilled with 3”×3” crushed concrete. Pea gravel may be used to top off partially demolished basement rooms and other enclosed spaces.

This fill material would act as an open framework gravel. The resulting porosity is expected to be high, ranging from 25-40% for 3”×3” concrete-sand mixtures and 40 to 50% for uniform 3”×3” concrete. Groundwater can readily flow through this material. The area of fresh concrete surfaces would be maximized, which would generally increase the pH impact due to calcium leaching.

3.1.3. Sand Scenario

Under this scenario, sand backfill is used as an alternative fill material and may be selected based on the sorption characteristics of the radionuclides of concern. The resulting porosity is expected to be typical of sand, ranging from 25-40%. Groundwater can readily flow through this material. The use of sand backfill would minimize the pH impacts from fresh concrete surfaces. The sand backfill would also minimize the potential for settling over time. However, sand cannot be compacted if it is placed in a room below grade that is not open at the top due to load bearing or similar considerations for the remaining structure.

3.1.4. Riprap and Flowable Fill Scenario

Under this scenario, during demolition of above ground concrete structures, large pieces of riprap are produced and staged at the Site. The basements would then be backfilled with large clean concrete pieces (protruding rebar must be removed), and flowable fill (grout fill) would be used to fill the voids during backfilling.

The flowable fill may be composed of a blend of cement, fly ash, sand and gravel, slag, and/or water. The flowable fill will solidify upon standing. Water in contact with the flowable fill is expected to exhibit an elevated pH due to the chemical makeup of the concrete and fly ash. However, the building foundations and low permeability of the flowable fill will limit the amount of groundwater that can be exposed to the fill.

3.1.5. Surface Cover

The surface cover for the filled building basements is currently proposed to consist of approximately 3 feet of sand/soil.

3.2. Final Disposition of the Sheet Pile Wall

The current decommissioning scenario allows the sheet pile wall to remain intact at the end of the project. It is assumed that the sheet pile wall will not be cut off below grade or damaged during the decommissioning, but will continue in its current use for shoreline erosion control.

3.3. An Evaluation of the Risk of Compromising the Silty Clay Aquitard at the Base of the Shallow Aquifer During Decommissioning Activities

The current decommissioning plan for the Site will allow the deeper building foundations to remain in place. Excavation activities for foundation removal will be limited to slab-on-grade and shallow building foundations.

As previously stated in Section 2.3, the silty clay unit is approximately 30 ft thick and extends at least 15 ft below the deepest building foundations at the Site. Since there will not be any excavation to a depth that the silty clay unit could be affected, the unit is expected to remain intact during and after the decommissioning process. The silty clay unit will continue to act as a laterally extensive aquitard which limits the potential for the vertical movement of groundwater at the Site.

Section 4.0 Development of Post-Decommissioning CSM Components

Several components of the post-decommissioning CSM require evaluation or refinement prior to their incorporation into risk assessment and dose modeling for the Site. An evaluation of these components may guide the selection of decommissioning technologies or their use in the CSM.

4.1. An Evaluation of Groundwater Flow Through and Around Subsurface Structures Left in Place

If the basements and sheet wall are perforated but left in place, the impediment on groundwater flow will be reduced but not completely eliminated. There will be some restrictions and retardation of the overall flow of groundwater from areas to the west toward Lake Michigan. However, the primary flow of groundwater will continue to be toward the Lake. Some vertical migration of groundwater will occur within the Shallow Aquifer as groundwater flows through and around these subsurface structures.

If the buildings and sheet pile wall are left intact (not perforated for flow), then a localized stagnation of groundwater around these barriers will occur since groundwater is prevented from flowing through these structures toward the Lake.

4.1.1. Deterioration of the Sheet Pile Wall Over Time

During construction of the Site in 1968, a cofferdam (also called a sheet pile wall) was built along the Lake side of the Crib House to allow the first sections of circulating water pipe and their easements to be installed dry. The cofferdam was constructed of sheet piling installed parallel to the Lake with sections (called walers) extending about 415 feet north and south of the Crib House. There is no indication that protective coatings or cathodic protection were used. The sheet piling was left in place at the completion of the construction for shore erosion protection. “Should the sheet piling deteriorate there can be no deleterious effect on the Crib House or any other safety-related structures. The Crib House and safety-related structures are self-contained and do not depend on the sheeting for protection” (6 pp. 2.4-14).

The sheet pile wall was constructed of U.S. Steel MZ27 sheet piling (new standard designation PZ27) (7). MZ27 sheet piling is 0.375-inches [9.5 millimeters (mm)] thick.

Corrosion rates for sheet pile walls have been estimated based on available literature.

Table 4.1 presents the estimated loss of thickness due to corrosion, and Table 4.2 presents the loss of thickness due to pitting.

Table 4.1 Loss of Thickness in the Sheet Pile Wall Due to Corrosion (mm)

	Years from Installation				
Installation	5	25	50	75	100
Undisturbed natural soils (sand, silt, clay, schist, etc.) (8)	0.00	0.30	0.60	0.90	1.20
Common fresh water (river, ship canal, etc.) in the zone of high attack (water line) (8)	0.15	0.55	0.90	1.15	1.40

Table 4.1 Loss of Thickness in the Sheet Pile Wall Due to Corrosion (mm)					
	Years from Installation				
Installation	5	25	50	75	100
Duluth-Superior Harbor accelerated fresh water corrosion (maximum of 0-3 meters) (9)	0.50	2.50	5.00	7.50	10.00
Duluth-Superior Harbor accelerated fresh water corrosion (greater than 3 meters) (9)	0.20	1.00	2.00	3.00	4.00

Pitting, or localized corrosion, will occur at a more rapid rate (2 to 3 times that of the average corrosion rate) (10).

Table 4.2 Loss of Thickness in the Sheet Pile Wall Due to Pitting (mm)					
	Years from Installation				
Installation	5	25	50	75	100
Undisturbed natural soils (sand, silt, clay, schist, etc.)†	0	0.9	1.8	2.7	3.6
Common fresh water (river, ship canal, etc.) in the zone of high attack (water line) †	0.45	1.65	2.7	3.45	4.2
Duluth-Superior Harbor accelerated fresh water corrosion (maximum of 0-3 meters) ‡	1.5	7.5	15	22.5	30
Duluth-Superior Harbor accelerated fresh water corrosion (greater than 3 meters) ‡	0.6	3	6	9	12
Notes: 1. Loss due to pitting is based on 3 times the corrosion rate. † ArcelorMittal 2008 (8 p. 3/6 to 3/7) ‡ Clark et al. 2009 (9)					

The sheet pile wall is approximately 45 years old (2013-1968=45). Based on its age and the expected corrosion rates, perforations may be present in the upper 10 ft of the saturated zone if accelerated corrosion rates apply. If normal corrosion rates apply, the upper 10 ft is expected to remain intact for >100 years. The remaining depth, although structurally weakened by corrosion, is generally expected to remain intact for 30 to >100 years. The sheet pile wall will act as a significant barrier to groundwater flow while intact and is expected to slowly pit and corrode over a period of decades or centuries, with failure in the upper 10 feet significantly preceding the remainder of the wall. Once the pitting penetrates the wall, its effectiveness as a hydraulic barrier will decline.

4.2. An Assessment of the Feasibility of a Future Site Occupant Installing a Water Well at the Site

Three potential scenarios exist for the installation and use of a residential water well installed into the Shallow Aquifer at the Site:

1) A well installed within the basement of a former building filled with clean concrete pieces
2) A well installed between the former buildings and the Lake
3) A well installed closer to the Lake

Under the current decommissioning scenario, the basements would be filled with clean concrete pieces. As a practical matter, the drilling of a well through clean concrete pieces is much more difficult and expensive than drilling a well in any other nearby location. In the case where the basements are filled with a grouted mixture, drilling a well is even more difficult. The yield of such a well would be limited to the rate at which water could enter the building through perforations and may not be sufficient to provide for residential use. Additionally, the water in the former basements would exhibit undesirable taste and odor characteristics due to the elevated pH that is anticipated due to the presence of clean concrete pieces.

A hypothetical well installed between the major buildings and the sheet pile wall could easily be installed within the Shallow Aquifer. This well would be in an area of low groundwater flow or even stagnation. Its yield would be somewhat restricted by the approximately 15 to 20 ft of saturated thickness of this aquifer. However, such a well is anticipated to produce sufficient water for a single residential use scenario.

A hypothetical well installed downgradient of the buildings (near the Lake) could be installed and used easily. It would likely yield much more water as the recharge to the well would include Lake water. The quality of water of such a well (located near the Lake) may not make it appropriate for drinking water purposes without treatment due to potential biological contamination.

4.2.1. Potential Capture Zone and Drawdown

The potential capture zone and drawdown were calculated based upon the scenario of a hypothetical water well being installed within the PA, between the buildings and the sheet pile wall. The calculations were performed assuming two conditions: the sheet pile wall remains in place (gradient = 0.0039) and, the sheet pile wall is removed (gradient = 0.0051).

The steady state Todd equation (11) was used for the capture zone calculation. It can be described for an unconfined aquifer as follows:

$$T_{width} = 2Y_{\max} = \frac{2QL}{K(h_1^2 - h_2^2)}$$

Where,

T_{width} is the capture width at an infinite upgradient distance (ft)
Y_{max} is one half of the total capture width (ft)

Q is the pumping rate (ft^3/day)
h_1 is the measured groundwater elevation above the base of the aquifer upgradient of the pumping well (ft)
h_2 is the measured groundwater elevation above the base of the aquifer downgradient of the pumping well (ft)
L is the distance over the two water level measuring locations
K is the hydraulic conductivity for the aquifer (ft/day)

The steady-state Theim equation for an unconfined aquifer (12) was used to determine the drawdown. It can be described as follows:

$$K = \frac{Q}{\pi(b_2^2 - b_1^2)} \ln\left(\frac{r_2}{r_1}\right)$$

Where,
K is the hydraulic conductivity for the aquifer (ft/day)
Q is the pumping rate (ft^3/day)
b_1 is the saturated thickness at distance r_1 from the pumping well (ft)
b_2 is the saturated thickness at distance r_2 from the pumping well (ft)

The following parameters were utilized to calculate the capture zone and drawdown:

Table 4.3 Hypothetical Water Well Parameters

Parameter	Symbol	Units	Value	Source
Aquifer thickness	b	ft	21.53	Section 5.1.1
Hydraulic conductivity	K	cm/s	5 x 10^{-3}	Section 5.6
Hydraulic gradient	i	ft/ft	0.0039, 0.0051	Section 5.7
Pumping Rate	Q	m^3/yr	250	RESRAD Default

Based upon the parameters listed in Table 4.3 (above), the expected capture zone and drawdown for a well located within the Shallow Aquifer with varying pumping rates are presented in Table 4.4 below. These calculations were performed based upon a gradient of 0.0039 ft/ft to simulate the sheet pile wall in place and a gradient of 0.0051 to simulate the sheet pile wall being removed or degraded over time. The estimated width of the capture zones at the center of pumping are calculated to be 6.77 ft (based upon a gradient with the sheet pile wall in place) and 5.18 ft (based upon a gradient with sheet pile wall being removed or degraded over time). The drawdown as based upon both of these gradients is nominal under this pumping rate. These are the capture zones which can be generally expected in a well located within the Shallow Aquifer when pumped at the average rate of 250 m^3/yr [0.13 gallons per minute (gpm)], under their respective conditions.

The average pumping rate within the Shallow Aquifer was determined to be 10.9 gpm. This rate is based upon ISGS water well logs for wells located within 2 miles of the Site with pumping rates provided. The maximum pumping rate with the sheet pile wall in place or removed is expected to be approximately 20 gpm. However, the capture zone and drawdown are expected to be greater with the sheet pile wall in place. This is due to the restricted gradient in place by the sheet pile wall. These calculations do not take into account the close proximity to Lake Michigan and the likely recharge provided by the Lake. Therefore, the actual maximum pumping rate with the sheet pile wall removed is likely to be greater than the estimated rate. The capture zone and drawdown under these scenarios will be further developed with modeling in order to account for complexities outside the reach of these calculations.

Table 4.4 Hypothetical Water Well Capture Zone and Drawdown

Pumping Rate		i=0.0039 (sheet pile wall in place)		i=0.0051 (sheet pile wall removed)	
(gpm)	(m^3/yr)	Capture Zone (ft)	Drawdown (ft)	Capture Zone (ft)	Drawdown (ft)
0.13	250	10.2	0.04	8.04	0.03
0.5	995	40.4	0.20	30.9	0.19
1	1,991	80.9	0.46	61.9	0.44
5	9,955	404	3.08	309	2.96
10	19,910	809	7.20	618	6.92
15	29,865	1,213	12.4	928	11.9
20	39,820	1,618	19.3	1,237	18.4
25	49,774	*	*	*	*

Notes:
*Water well cannot support this pumping rate.

4.3. Rise in Lake Michigan Surface Water Elevation

Since the Shallow Aquifer and the Lake are directly connected, it is possible for a zone of stagnation to occur if the Lake water level rises above the groundwater level. The pressure from the Lake water entering the groundwater would prevent the groundwater from reaching the Lake.

If the water level in Lake Michigan were to rise, it could cause a reversal of flow westward. The Lake has historical, measured fluctuations of over 6 ft. Even under these extreme conditions, a groundwater flow reversal would be localized and found only near the Lake, as the regional flow would still flow eastward towards Lake Michigan. A zone of stagnation would occur where the two groundwater flow fronts meet. In order for this to occur, the Lake water level would have to be higher than the groundwater level.

Monthly average water levels in Lake Michigan/Huron have been recorded beginning in 1918. Between 1918 and 2013, the average water level in Lake Michigan was 578.8 ft above mean sea level (amsl). The lowest monthly average Lake level was 576.02 ft amsl in January 2013. The highest monthly average Lake level was 582.35 ft amsl in October 1986 (13) (14) (15).

4.4. De Minimus Scenarios

There are several scenarios that are unlikely and have been determined to have minimal consequence. These scenarios are discussed in the following sections.

4.4.1. Basement Overflow Scenario

The basement overflow scenario assumes that the basement walls and floors are left intact during the decommissioning (or alternatively that any building penetrations have been sealed over time). The basements would then fill up over time due to the infiltration of precipitation and eventually overflow.[1] Basement overflow rates were calculated based upon basement depths, precipitation rate, and evaporation rate. These calculations determine how long it will take for the substructures to fill with water assuming substructures are left in place with the superstructure roof removed. This scenario also assumes that no cracks are present in the basement walls. The average annual precipitation rate, as detailed in Section 5.8 below, of 32.61 inches/y was utilized. These calculations were performed for each structure with a significant substructure. Basement depths and dimensions for each substructure are presented in the table below. For the purpose of these calculations, 3 ft were subtracted from the building depths to account for the proposed removal of the upper 3 ft of the substructure.

[1] An additional consideration for the scenario where the walls are left intact is the buoyancy of the structure, which must be taken into consideration prior to the removal of the above ground structures and other building loads. The buoyancy of subsurface structures is not evaluated in this report.

Table 4.5 Substructure Dimensions

	Finish Grade (ft amsl)	Top of Basement Floor (ft amsl)	Adjusted depth of basement† (ft)	Adjusted depth of basement† (in)	Area (ft^2)	Volume (ft^3)
Unit 1 Containment	591	568	20	240	2.00E+04	4.01E+05
Unit 2 Containment	591	568	20	240	2.00E+04	4.01E+05
Fuel Handling Building	591	576	12	144	9.18E+03	1.10E+05
Auxiliary Building	591	542	46	552	2.90E+04	1.34E+06
Turbine Building	591	560	28	336	1.21E+05	3.38E+06
Lake Crib House	591	539	49	588	3.14E+04	1.54E+06
Wastewater Treatment Facility	591	578	10	120	9.45E+03	9.45E+04

Notes:
† Three feet were subtracted from the building depths to account for the upper 3 feet of basement that will be removed

This scenario was run under four different assumptions: 1) Assuming no evaporation, 2) Assuming a pan evaporation rate, 3) Assuming a lake evaporation rate, and 4) Assuming evapotranspiration.

This scenario only accounts for rainwater falling directly into the substructure and does not account for runoff into the substructure. Further, this scenario was also run assuming each of the following: the basements are open holes with no backfill, the basements are backfilled with sand, and the basements are backfilled with riprap. It was assumed that the sand backfill will have a porosity of 0.35, based upon the September 2013 investigation. The riprap is assumed to have a porosity of 0.45 (16). The sand and riprap backfill were accounted for by multiplying the number of years to fill the open hole by their respective porosities. The backfill to be used on Site will likely be a combination of sand and riprap. These calculations provide a likely range of the years it will take for the unperforated basements to fill with water.

The following basic calculation steps were utilized to determine the fill rates:

Step 1: *Annual Precipitation Rate – Evaporation Rate = Annual Water Accumulation*
Step 2: *(Basement Depth)/(Annual Water Accumulation) = Years to Fill Basement*
Step 3: (*Years to Fill Basement) x (Porosity) = Years to Fill Basement Considering Backfill Material*

4.4.1.1. Assumption 1 - No Evaporation

The first scenario assumes that the substructures fill based upon the average precipitation rate and does not take into account any loss of water. This scenario is highly unlikely, since evaporation of water will occur. Based upon these parameters, the expected fill time of each substructure is presented below.

Table 4.6 Time to Over Top the Foundation Assuming No Evaporation

Structure	***Average Precipitation Rate (inches/y)***	***Time to Over-Top the Foundation (Years)***		
		No Fill	***Sand Fill†***	***Riprap Fill‡***
Unit 1 Containment	32.61	7.36	2.58	3.31
Unit 2 Containment	32.61	7.36	2.58	3.31
Fuel Handling Building	32.61	4.42	1.55	1.99
Auxiliary Building	32.61	16.93	5.92	7.62
Turbine Building	32.61	10.30	3.61	4.64
Lake Crib House	32.61	18.03	6.31	8.11
Wastewater Treatment Facility	32.61	3.68	1.29	1.66

Notes:
† This calculation assumes the basements are filled with sand. The porosity of sand is assumed to be 0.35, based upon the September 2013 investigation.
‡ This calculation assumes the basements are filled with riprap. The porosity of riprap is assumed to be 0.45, based upon guidelines from the U.S. Department of the Interior (16).

4.4.1.2. Assumption 2 - Pan Evaporation

Pan evaporation rates are determined from direct loss of water from a pan over time. The pan evaporation rate utilized in this analysis was determined from an Illinois pan evaporation isoline map presented in an ISWS lake evaporation study (17). The ISWS study (17) utilized pan evaporation data from 17 stations in and near Illinois collected between May through October over a 16 year period to derive a state-wide map. This method is limited in that it only accounts for the months of May through October. Evaporation during the winter months is likely to be less.

This scenario assumes that the substructures fill with water based upon the average precipitation rate and accounts for the loss of water due to evaporation. An evaporation rate of 28 inches/y was assumed based upon “Pan Evaporation” studies performed in Illinois (17). Based upon these parameters, the expected fill time of each substructure is presented below. Actual fill times may be less, since this does not account for evaporation between November and April.

Table 4.7 Time to Over Top the Foundation Assuming Pan Evaporation

Structure	Pan Evaporation rate (inches/y)	Water Gain (inches/y)	Time to Over-Top the Foundation (Years)		
			No Fill	Sand Fill†	Riprap Fill‡
Unit 1 Containment	28	4.61	52.06	18.22	23.43
Unit 2 Containment	28	4.61	52.06	18.22	23.43
Fuel Handling Building	28	4.61	31.24	10.93	14.06
Auxiliary Building	28	4.61	119.74	41.91	53.88
Turbine Building	28	4.61	72.89	25.51	32.80
Lake Crib House	28	4.61	127.55	44.64	57.40
Wastewater Treatment Facility	28	4.61	26.03	9.11	11.71

Notes:
† This calculation assumes the basements are filled with sand. The porosity of sand is assumed to be 0.35, based upon the September 2013 investigation.
‡ This calculation assumes the basements are filled with riprap. The porosity of riprap is assumed to be 0.45, based upon guidelines from the U.S. Department of the Interior (16).

4.4.1.3. Assumption 3 - Lake Evaporation

The third scenario assumes that the substructures fill with water based upon the average precipitation rate and also accounts for the loss of water due to evaporation. An evaporation rate of 31 in/y was assumed based upon studies performed in Illinois (17). This evaporation rate is an annual average over a 52 year period between 1911 and 1962. Lake evaporation rates were computed in the ISWS study by utilizing air temperature, dew point temperature, wind movement, and solar radiation. Based upon the Lake evaporation rate near the Zion area, the expected fill time of each substructure is presented below.

Table 4.8 Time to Over Top the Foundation Assuming Lake Evaporation

Structure	Lake Evaporation rate (inches/y)	Water Gain (inches/y)	Time to Over-Top the Foundation (Years)		
			No Fill	Sand Fill†	Riprap Fill‡
Unit 1 Containment	31	1.61	149.07	52.17	67.08
Unit 2 Containment	31	1.61	149.07	52.17	67.08
Fuel Handling Building	31	1.61	89.44	31.30	40.25
Auxiliary Building	31	1.61	342.86	120.00	154.29
Turbine Building	31	1.61	208.70	73.04	93.91
Lake Crib House	31	1.61	365.22	127.83	164.35
Wastewater Treatment Facility	31	1.61	74.53	26.09	33.54

Notes:
† This calculation assumes the basements are filled with sand. The porosity of sand is assumed to be 0.35, based upon the September 2013 investigation.
‡ This calculation assumes the basements are filled with riprap. The porosity of riprap is assumed to be 0.45, based upon guidelines from the U.S. Department of the Interior (16).

4.4.1.4. Assumption 4 – Evapotranspiration

Evapotranspiration is the evaporation of water from plants, soil, and other surfaces to the atmosphere. This scenario most accurately depicts the filled basement state. The mean annual potential evapotranspiration near the Zion area is expected to be 28 inches/y, based upon a potential evapotranspiration isoline map of Illinois, as presented in an ISWS study (17). Based upon the evapotranspiration rate near the Zion area, the expected fill time of each substructure is presented below.

Table 4.9 Time to Over Top the Foundation Assuming Evapotranspiration Rates

Structure	***Evapotranspiration Rate (inches/y)***	***Water Gain (inches/y)***	***Time to Over-Top the Foundation (Years)***		
			No Fill	***Sand Fill†***	***Riprap Fill‡***
Unit 1 Containment	28	4.61	52.06	18.22	23.43
Unit 2 Containment	28	4.61	52.06	18.22	23.43
Fuel Handling Building	28	4.61	31.24	10.93	14.06
Auxiliary Building	28	4.61	119.74	41.91	53.88
Turbine Building	28	4.61	72.89	25.51	32.80
Lake Crib House	28	4.61	127.55	44.64	57.40
Wastewater Treatment Facility	28	4.61	26.03	9.11	11.71

Notes:
† This calculation assumes the basements are filled with sand. The porosity of sand is assumed to be 0.35, based upon the September 2013 investigation.
‡ This calculation assumes the basements are filled with riprap. The porosity of riprap is assumed to be 0.45, based upon guidelines from the U.S. Department of the Interior (16).

4.4.2. Hydrogeologic Feasibility of a Pond for Fish Consumption

To receive water containing radionuclides released from the basement fill CSM, a pond would have to be constructed downgradient from the major building basements. Two simple types of surface water impoundments or ponds could hypothetically be constructed at the Site in the area between the former buildings and the Lake. The first type of pond construction would rely on groundwater to seep into the pond and to provide a base level (freeboard) of surface water. The second type of pond would be constructed such that the pond is lined or has some barrier to hold and contain surface water recharge and precipitation infiltration.

Neither of these pond types is likely to be constructed by a single resident due to engineering and cost issues. In addition, if a resident wished to use surface water, Lake Michigan is nearby.

The first type of pond would have to be excavated to a depth of over 10 to 15 ft in order to intercept the groundwater table. This type of construction would require engineered side walls, shoring, and other methods to keep the pond from collapsing (as it is constructed into sands).

The second type of pond, which relies upon surface recharge, would require a liner or bottom of some sort. Without a liner or bottom in the pond, any of the surface water captured in the pond would easily recharge through the Shallow Aquifer and seep to the groundwater table. As such, an engineered liner would have to be constructed.

Given the engineering design and costs to construct either of these pond types, this exposure pathway is highly unlikely.

Section 5.0 Dose Modeling Parameters

This section provides input parameters to be used for dose pathway calculations. These include selected physical and hydraulic property parameters that may be input to the DUST-MS model where the floor of a major building such as a Containment Building includes surface contamination. This contaminated material is instantaneously released into a band of water and the radionuclides are transported in this band through the building into and through the down gradient natural system to receptor locations. The DUST-MS model uses selected parameter values to calculate the water concentration outputs which are then input into the RESRAD or RESRAD OFFSITE code for calculation of the pathway dose. Site specific parameters are based on field studies conducted in 2012 and 2013, which are described in the reports provided in Appendix A through D.

5.1. Thickness of Contaminated Zone

For the RESRAD Family of Codes, “Thickness of the Contaminated Zone” is defined as “the distance between the shallowest and the deepest depth of contamination” (18 pp. 4-25). Thickness of the contaminated zone is an important physical parameter in the RESRAD and RESRAD-OFFSITE codes. This parameter is evaluated for two scenarios: contaminated zone that extends from the water table to the bottom of the saturated zone and a contaminated zone that extends from ground surface to the bottom of the saturated zone.

5.1.1. Scenario 1 –Shallow Aquifer

This potential scenario assumes that contamination extends from the water table to the top of the Silty Clay Aquitard at the base of the Shallow Aquifer. This thickness can be estimated using the boring logs for the wells situated immediately downgradient from the central plant area, as provided in Table 5.1 below:

Table 5.1 Thickness of the Saturated Portion of the Shallow Aquifer				
Boring Location	March 13, 2013 Water Level *(ft amsl)*	Aquitard Surface *(ft amsl)*†	Thickness *(ft)*	Thickness *(meters)*
MW-ZN-01S	578.95	562.18	16.8	5.1
MW-ZN-02S	579.43	555.21	24.2	7.4
MW-ZN-03S	579.72	556.54	23.2	7.1
MW-ZN-04S	579.47	557.51	22.0	6.7
Average			**21.5**	**6.6**

Notes:
†The Shallow Aquifer includes stratigraphic units containing gravel, sand, and silt with sand.

5.1.2. Scenario 2 – Vadose Zone and Shallow Aquifer

This potential scenario assumes that contamination extends from the ground surface to the top of the Silty Clay Aquitard at the base of the Shallow Aquifer. This thickness can be estimated using the boring logs for the wells situated immediately downgradient from the central plant area, as provided in Table 5.2 below:

Table 5.2 Thickness of the Vadose Zone and Shallow Aquifer				
Boring	Ground Surface (ft amsl)	Aquitard Surface (ft amsl) †	Thickness (ft)	Thickness (meters)
MW-ZN-01S	591.43	562.18	29.3	8.9
MW-ZN-02S	591.21	555.21	36.0	11.0
MW-ZN-03S	591.54	556.54	35.0	10.7
MW-ZN-04S	591.01	557.51	33.5	10.2
Average			**33.4**	**10.2**

Notes:
† The Shallow Aquifer includes stratigraphic units containing gravel, sand, and silt with sand.

Note: The subsurface material near the Site buildings is composed of native fill material; as such, the material may be variable across the area. The MW-ZN-03S boring log indicates that a 1 foot thick silty clay till layer is present at 11 feet bgs, followed by a silt and sand layer and a silt with sand layer to a depth of 35 feet bgs. Due to the nature of the source of the soil in the area and the comparable aquifer thicknesses at nearby boring locations, the thickness of the shallow aquifer at MW-ZN-03 is estimated to be 35 feet.

5.2. Contaminated/Saturated Zone Field Capacity

Field capacity is defined as the ratio of the volume of water retained in the soil sample (after all downward gravity drainage has ceased) to the total volume of the sample (19). Laboratory measurements of field capacity typically measure the volumetric water content of a soil sample under a negative pressure of 1/10 or 1/3 bar (20) (21). A volumetric water content greater than the field capacity is not available for plant use because it drains away quickly. The wilting point is the maximum pressure that a plant can exert to overcome the tension of the water adhering to the soil. The wilting point corresponds to a negative pressure of 15 bars. The water content of a soil between the field capacity (1/10 to 1/3 bar) and the wilting point (15 bar) is called the available water content. Literature values of field capacity for different soil textures are provided in the table below:

Table 5.3 Literature Values of Field Capacity

Soil Texture	***Field Capacity at 1/3 bar in percent by volume†***	***Soil Texture***	***Field Capacity at 1/3 bar in percent by volume†***
Sand	1.8 – 16.4	Sandy Clay Loam	18.6 – 32.4
Loamy sand	6.0 – 19.0	Clay Loam	25.0 – 38.6
Sandy loam	12.6 – 28.8	Silty Clay Loam	30.4 – 42.8
Loam	19.5-34.5	Sandy Clay	24.5 – 43.3
Silt Loam	25.8 – 40.2	Silty Clay	33.2 – 44.2
Silt	- -	Clay	32.6 – 46.6

Notes:
† Source: Nachabe 1998 (21). The listed range is +/- one standard deviation about the mean

Laboratory measurements of field capacity and water retention were determined using a compression/decompression chamber method. This method places a saturated soil sample onto a porous ceramic plate which is then placed in a closed chamber. A known amount of pressure is then established in the chamber, which forces water out of the soil sample and into the porous plate and out of the chamber. The water holding capacity of the soil is determined by the amount of water held in the soil sample versus the dry weight of the sample. The amount of pressure applied during each test ranged from 0.1 bar to 15 bar. Soil water retention curves were developed using the water content at different pressure points. The soil water retention curves are included in Appendix D. The laboratory estimates of field capacity at 1/10 bar and 1/3 bar are shown in the table below:

Table 5.4 Field Capacity

Soil Boring Identifier	***Sample Identifier***	***Field Capacity (%)***	
		0.1 bar	***1/3 bar***
GT2-MW-01S	GT2-MW-01S-5	10.4	4.7
GT2-MW-01S	GT2-MW-01S-20	3.6	1.2
GT2-MW-01S	GT2-MW-01S-28	6.5	2.5
GT2-MW-02S	GT2-MW-02S-5	10.3	4.1

Table 5.4 Field Capacity			
		Field Capacity (%)	
Soil Boring Identifier	***Sample Identifier***	***0.1 bar***	***1/3 bar***
GT2-MW-02S	GT2-MW-02S-26	8.9	3.8
GT2-MW-06S	GT2-MW-06S-5	3.9	1.8
GT2-MW-06S	GT2-MW-06S-20	2.9	1.0
Arithmetic mean		**6.64**	**2.73**

Typical field capacity values for sand range from 1.8% to 16.4% by volume at 1/3 bar (21). The arithmetic mean of the laboratory values for field capacity at 1/3 bar is 2.73% by volume, which is within the range of the literature values.

The Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil (Yu et al., 1993) defines field capacity as the ratio of the volume of water retained in the soil sample (after all downward gravity drainage has ceased) to the total volume of the sample (19). To meet this narrative definition, Romano & Santini (2002) recommend using the volumetric water content at 0.1 bar as the estimate of field capacity for coarse-grained soils (e.g., sands) (20). The average field capacity of the soil samples at 0.1 bar is 6.64% by volume. This is consistent with field capacity values identified by the International Atomic Energy Agency (IAEA) for sand ranging from 6% for coarse sand to 10% for fine sand (22 p. 4).

5.3. Density of Contaminated/Saturated Zone

The proposed model scenario is based on the transport of contaminants in groundwater released from the major building basements in the down-gradient direction toward Lake Michigan. Under this scenario, the contaminants would be transported through both the disturbed sand unit to the west of the sheet pile wall and the native sand unit to the east of the sheet pile wall. Since the transport will encompass both disturbed and undisturbed sands, the average value of laboratory measurements (of saturated zone samples) is used to estimate the bulk density of native sands and fill mixture in the saturated zone[2]. These values are provided in Table 5.5 below:

Table 5.5 Dry Soil Bulk Density			
Soil Boring Identifier	***Sample Identifier***	***Bulk Density (pcf)***	***BulkDensity (gm/cm^3)***
GT2-MW-01S	GT2-MW-01S-5	112.6	1.80
GT2-MW-01S	GT2-MW-01S-20	118.0	1.89

[2] Soil samples collected in the earlier investigation on December 12, 2012 were also submitted for laboratory analysis of dry bulk density. However, a review of the laboratory report resulted in the rejection of the analytical results for dry bulk density due to inconsistency with grain size distribution. The results were comparable to a dense-graded aggregate such as MDOT 21AA rather than the fine to medium sand at the Site. As a result, the dry soil bulk density values from the December 12, 2012 investigation have been excluded from the evaluation.

Table 5.5 Dry Soil Bulk Density			
Soil Boring Identifier	***Sample Identifier***	***Bulk Density (pcf)***	***BulkDensity (gm/cm³)***
GT2-MW-01S	GT2-MW-01S-28	115.3	1.85
GT2-MW-02S	GT2-MW-02S-5	118.4	1.90
GT2-MW-02S	GT2-MW-02S-26	112.5	1.80
GT2-MW-06S	GT2-MW-06S-5	102.2	1.64
Arithmetic mean		**113.2**	**1.81**

5.4. Contaminated/Saturated Zone Total Porosity

The proposed model scenario is based on the transport of contaminants in groundwater released from the major building basements in the down-gradient direction toward Lake Michigan. Under this scenario, the contaminants would be transported through both the disturbed sand unit to the west of the sheet pile wall and the native sand unit to the east of the sheet pile wall. Since the transport will encompass both disturbed and undisturbed sands, the average value of laboratory measurements (from saturated zone samples) is used to estimate the total porosity, as provided in Table 5.6 below:

Table 5.6 Soil Porosity		
Boring Identifier	***Sample Identifier***	***Porosity (% by volume)***
GT2-MW-01S	GT2-MW-01S-5	33.2
GT2-MW-01S	GT2-MW-01S-20	29.7
GT2-MW-01S	GT2-MW-01S-28	31.6
GT2-MW-02S	GT2-MW-02S-5	33.4
GT2-MW-02S	GT2-MW-02S-26	36.9
GT2-MW-06S	GT2-MW-06S-5	39.3
GT2-MW-06S	GT2-MW-06S-20	42.7
Arithmetic mean		**35.3**

5.5. Contaminated/Saturated Zone Effective Porosity

The term “effective porosity” can refer to the retention of water against gravity drainage (also called specific retention) or the portion of porosity that is interconnected and allows the flow of groundwater. The Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil (19) defines effective porosity as the total porosity minus the field capacity. This is consistent with the specific retention-based definition of effective porosity as described by Bear (1972):

“In the case of a phreatic aquifer, water is actually drained out of the pore space, and air is substituted as the water table drops. However, not all water contained in the pore space is removed by gravity drainage (say, toward a depression in the ground water table caused by a pumping well). A certain amount of water is held in place against gravity in the interstices between grains under molecular forces and surface tension. Hence, the storativity of a phreatic aquifer is less than the porosity by a factor

called specific retention (the ratio of water retained against gravity to the bulk volume of a soil sample). Reflecting this phenomenon, the storativity of a phreatic aquifer is often referred to as specific yield. The term effective porosity is also often used in this context. However, one should be careful not to confuse this usage of the term with that effective porosity referring to flow through a porous medium" (23 p. 8).

Since the effective porosity is used to calculate transport time in groundwater (24 pp. E-19), smaller values are considered more conservative (i.e., they reduce transport time). Total porosity and field capacities determined during the September 30, 2013 investigation were utilized to calculate the effective porosity (specific yield), as described in Table 5.7 below:

Table 5.7 Effective Porosity (Specific Yield) Based on Field Capacity

Boring Identifier	***Sample Identifier***	***Porosity***	***Field Capacity at 0.1 bar (%)***	***Effective Porosity (%)***
GT2-MW-01S	GT2-MW-01S-5	33.2	10.4	22.8
GT2-MW-01S	GT2-MW-01S-20	29.7	3.6	26.1
GT2-MW-01S	GT2-MW-01S-28	31.6	6.5	25.1
GT2-MW-02S	GT2-MW-02S-5	33.4	10.3	23.1
GT2-MW-02S	GT2-MW-02S-26	36.9	8.9	28.0
GT2-MW-06S	GT2-MW-06S-5	39.3	3.9	35.4
GT2-MW-06S	GT2-MW-06S-20	42.7	2.9	39.8
Arithmetic mean		**35.3**	**6.6**	**28.6**

The average effective porosity value of 28.6% is appropriate to use for RESRAD models.

5.5.1. Effective Porosity with Respect to Flow through a Porous Medium

The second definition of the term "effective porosity" refers to the portion of porosity that is interconnected and allows the flow of groundwater. The average velocity of groundwater can be expressed as (23 pp. 121-122):

V = Q/nA = q/n

where: V is the average groundwater velocity (m/s)
Q is the volumetric flow rate (m^3/s)
q is the specific discharge (m/s)
n is the volumetric porosity
A is the cross sectional area (m^2)

However, part of the fluid in the pore space is immobile due to adhesion between the solid surface and the molecules of the fluid or when the porous medium includes a large number of dead-end pores. In this case, the effective porosity with respect to flow through a porous medium is defined as:

$V = q/\eta_e$

where: V is the average groundwater velocity (m/s)
q is the specific discharge (m/s)
η_e is the effective porosity (m^3/ m^3)

Literature values for effective porosity include $\eta_e = 0.85\eta$ for fine sand, and $\eta_e = 0.80\eta$ for coarse sand (25 p. 36). Since the average groundwater velocity is inversely proportional to the effective porosity, smaller values of effective porosity are conservative. Based on the average total porosity of 35% described above, a conservative estimate of the effective porosity with respect to flow through a porous medium is 35 × 0.80 = 28%.

The effective porosity value of 28% is appropriate to use for the Disposal Unit Source Term (DUST) models.

5.6. Contaminated/Saturated Zone Hydraulic Conductivity

Soil samples were collected in December 2012 and September 2013 for hydraulic conductivity analysis using a flexible wall permeameter. The hydraulic conductivity results are shown in Table 5.8 below.

Table 5.8 Hydraulic Conductivity Determined by Laboratory Analysis of Soil Samples

Boring Location	***Sample Identifier***	***Hydraulic Conductivity***		***Saturated Zone Hydraulic Conductivity***	
		(cm/s)	***(m/y)***	***(cm/s)***	***(m/y)***
GT MW 01s	S-121212-LP-01 (S-01)	5.10E-03	1.61E+03	- -	- -
GT MW 01s	S-121212-LP-02 (S-02)	5.60E-03	1.77E+03	5.60E-03	1.77E+03
GT MW 01s	S-121212-LP-03 (S-03)	9.10E-03	2.87E+03	9.10E-03	2.87E+03
GT MW 02s	S-121212-LP-04 (S-04)	3.30E-03	1.04E+03	- -	- -
GT MW 02s	S-121212-LP-05 (S-05)	2.40E-03	7.57E+02	2.40E-03	7.57E+02
GT2-MW-01S	GT2-MW-01S-5	5.36E-03	1.69E+03	- -	- -
GT2-MW-01S	GT2-MW-01S-20	3.94E-03	1.24E+03	3.94E-03	1.24E+03
GT2-MW-01S	GT2-MW-01S-28	3.13E-02	9.88E+03	3.13E-02	9.88E+03
GT2-MW-02S	GT2-MW-02S-5	1.26E-03	3.98E+02	- -	- -
GT2-MW-02S	GT2-MW-02S-26	1.96E-03	6.19E+02	1.96E-03	6.19E+02
GT2-MW-06S	GT2-MW-06S-5	1.04E-02	3.28E+03	- -	- -
Geometric Mean		**4.85E-03**	**1.53E+03**	**5.56E-03**	**1.75E+03**

Single well response tests were performed on monitoring wells in September 2013. The single well response tests were performed by introducing an aluminum slug into each well and recording the water level in the well as it equilibrated with the water table. The results of the slug tests are provided in Table 5.9 below.

Table 5.9 Hydraulic Conductivity Determined by Single Well Response Test

Well ID	Test Type	Analytical Method	Saturated Zone Hydraulic Conductivity (cm/s)	Saturated Zone Hydraulic Conductivity (m/y)
MW-01S	Falling Head	Hvorslev	3.51E-02	1.11E+04
MW-01S	Rising Head	Hvorslev	2.46E-02	7.77E+03
MW-02S	Falling Head	Hvorslev	4.36E-03	1.37E+03
MW-02S	Rising Head	Hvorslev	4.70E-03	1.48E+03
MW-03S	Falling Head	Hvorslev	2.51E-03	7.91E+02
MW-03S	Rising Head	Hvorslev	2.49E-03	7.86E+02
MW-04S	Falling Head	Hvorslev	7.49E-03	2.36E+03
MW-04S	Rising Head	Hvorslev	7.16E-03	2.26E+03
MW-06S	Rising Head	Hvorslev	5.18E-03	1.63E+03
MW-07S	Falling Head	Hvorslev	5.40E-02	1.70E+04
MW-07S	Rising Head	Hvorslev	2.18E-02	6.88E+03
		Geometric mean	**9.11E-03**	**2.88E+03**

The geometric mean of the single well response tests is 2.88E+03 m/y. This result is generally consistent with laboratory permeater tests on soil samples collected in December 2012 and September 2013. These data are also in the range of hydraulic conductivity for a sand material based on literature values. The single well response tests are considered to better represent in situ aquifer conditions than laboratory permeater tests.

5.7. Saturated Zone Hydraulic Gradient

Hydraulic gradients were estimated for areas in the central plant area (east of the Turbine Building), the southern plant area (which is generally unaffected by the sheet pile wall) and the western area (upgradient of the PA). The resulting hydraulic gradients are described in Table 5.10 below:

Table 5.10 Hydraulic Gradient

Date	Western Area Gradient (near MW-ZN-06s)	Southern Area Gradient (near MW-ZN-05s)	Central Area Gradient (near MW-ZN-01s)
July 2006	0.0015	0.0054	0.0000 - 0.0040
October 2007	0.0016	0.0050	0.0000 - 0.0042
September 2008	0.0020	0.0059	0.0000 - 0.0038
September 2009	0.0012	0.0027	0.0000 - 0.0038
September 2010	0.0019	0.0059	0.0000 - 0.0040
September 2011	0.0021	0.0056	0.0000 - 0.0022

Table 5.10 Hydraulic Gradient			
Date	***Western Area Gradient (near MW-ZN-06s)***	***Southern Area Gradient (near MW-ZN-05s)***	***Central Area Gradient (near MW-ZN-01s)***
September 2012	0.0022	0.0044	0.0000 - 0.0053
March 2013	0.0022	0.0056	0.0000 - 0.0042
Average	**0.0018**	**0.0051**	**0.0000 - 0.0039**

Note: The central area is that region that includes the Protected Area of the Site.

The RESRAD model may be used for scenarios where the sheet pile wall is in place (using a conservative gradient of 0.0039 ft/ft). Alternately, if the scenario assumes that the sheet pile wall has been removed or degraded over time, the natural gradient downgradient of the PA is expected to be 0.0051 ft/ft.

5.8. Groundwater Velocity

The groundwater velocity can be calculated by the equation:

$$v=\frac{K \cdot i}{\theta_T}$$

where: K is the hydraulic conductivity
i is the hydraulic gradient
θ_T is the total soil porosity

Groundwater velocities for different scenarios are provided in Table 5.11 below.

Table 5.11 Estimates of Groundwater Velocity		
Scenario	***Hydraulic Gradient***	***Groundwater Velocity (m/y)***
Assuming structures and basements remain in place	0.0039	31.8
Assuming structures and basements are removed	0.0051	41.6
Notes: 1. Using a hydraulic conductivity of 2.88E+03 m/y and a total porosity of 35.3%		

5.9. Precipitation

The average precipitation for the Site was estimated using weather information from the Waukegan Harbor station (WHRI2), located approximately 5 miles south of the Site, for the period from 2003 through 2012. Table 5.12 presents a summary of the precipitation data:

Table 5.12 10-Year Average Precipitation

Year	***Precipitation (inches)*** (26)	***Precipitation (meters)***
2012	26.87	0.682
2011	38.28	0.972
2010	30.21	0.767
2009	42.50	1.080
2008	37.69	0.957
2007	32.72	0.831
2006	32.92	0.836
2005	20.63	0.524
2004	33.98	0.863
2003	30.34	0.771
Average	**32.61**	**0.828**
Standard Deviation	6.19	0.157

Notes:
1. Waukegan Harbor Station (WHRI2)

5.10. Runoff Coefficient

A runoff coefficient value of 0.2 is identified as the RESRAD default value. Site-specific runoff coefficients can be developed based on soil type and land use based on the information provided in Table 5.13:

Table 5.13 RESRAD Runoff Coefficients

Environment		***Coefficient***	***Value***
Agricultural†	Flat land with average slopes of 0.3 to 0.9 m/mi	c_1	0.3
	Hilly land with average slopes of 46 to 76 m/mi	c_1	0.1
	Rolling land with average slopes of 4.6 to 6.1 m/mi	c_1	0.2
	Intermediate combinations of clay and loam	c_2	0.2
	Open sandy loam	c_2	0.4
	Tight, impervious clay	c_2	0.1
	Cultivated lands	c_3	0.1
	Woodlands	c_3	0.2
Urban	Flat, residential area — about 30% impervious	C_r	0.4
	Moderately steep, residential area — about 50% impervious	C_r	0.65
	Moderately steep, built-up area — about 70% impervious	C_r	0.8

Notes:
†The runoff coefficient for an agricultural environment is given by $C_r = 1 - c_1 - c_2 - c_3$ (18 pp. E-7).

A Site-specific runoff coefficient for the post-decommissioning land use of 0.2 has been estimated based on an agricultural environment with flat land, open sandy loam, and cultivated lands (1 – 0.3 – 0.4 –

0.1 = 0.2). A runoff coefficient of 0.2 is appropriate for the Site because it is consistent with the proposed post-decommissioning land use of the Site and is also the broadly applicable default value.

Additionally, the RESRAD runoff coefficient appears to be based on the "Rational Method" for calculating peak flows from small watersheds. Tables of runoff coefficients for the Rational Method should be compatible with RESRAD and may be used to develop different model scenarios (27) (12 pp. 61-62).

5.11. Well Pump Intake Depth

The model scenario includes a hypothetical well installed in the shallow sand aquifer with a pump intake at the base of the aquifer. Based on the "Thickness of Contaminated Zone" parameter (Section 5.1), the pump intake depth is 33.44 ft (10.19 meters) for this scenario.

5.12. Contaminated Fraction Below Water Table

The contaminated fraction below the water table is based on the CSM. The following two scenarios are evaluated:

- Scenario 1 – contaminated zone from water table to top of aquitard
- Scenario 2 – contaminated zone from ground surface to top of aquitard

Under the current CSM, Scenario 1 is the preferred alternative.

5.12.1. Scenario 1 – Contaminated Zone from Water Table to Top of Aquitard

This scenario assumes that contamination extends from the water table to the top of the Silty Clay Aquitard at the base of the Shallow Aquifer. The contaminated fraction below the water table under this scenario is 100%.

5.12.2. Scenario 2 – Contaminated Zone from Ground Surface to Top of Aquitard

This scenario assumes that contamination extends from the ground surface to the top of the Silty Clay Aquitard at the base of the Shallow Aquifer. The contaminated fraction below the water table can be estimated using the boring logs for the wells situated immediately downgradient from the central plant area. This is summarized in Table 5.14:

Table 5.14 Contaminated Fraction Below the Water Table

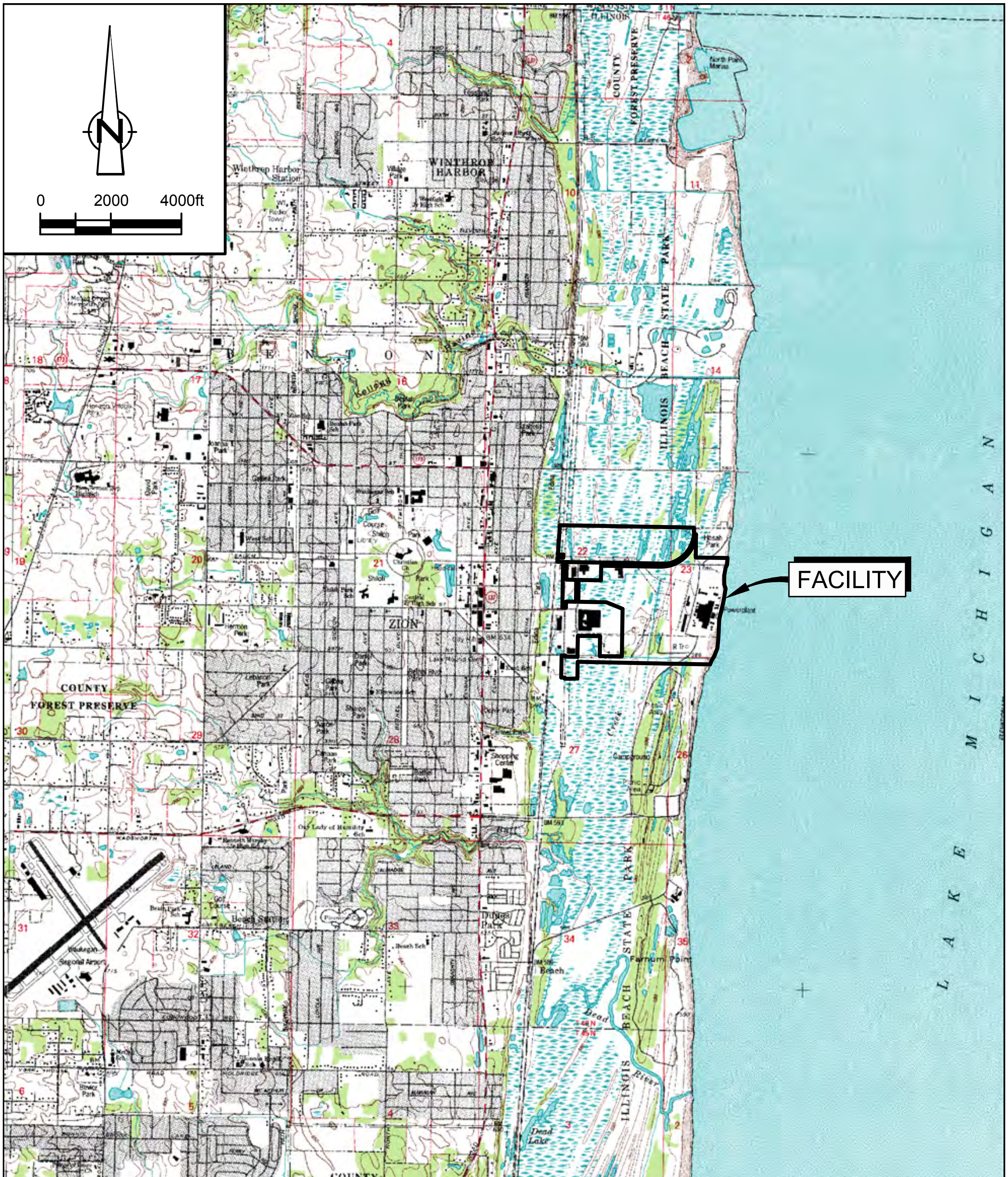
Boring	Ground Surface (ft amsl)	Groundwater Surface on March 13, 2013 (ft amsl)	Aquitard Surface (ft amsl)	Fraction Below the Water Table
MW-ZN-01S	591.43	578.95	562.18	57%
MW-ZN-02S	591.21	579.43	555.21	67%
MW-ZN-03S	591.54	579.72	556.54	66%
MW-ZN-04S	591.01	579.47	557.51	66%
Average				**64%**

Section 6.0 References

1. **Great Lakes Information Network.** Lake Michigan Facts and Figures. October 15, 2013.
2. **Klein, David H.** Fluxes, Residence Times, and Sources of Some Elements to Lake Michigan. *Water, Air, and Soil Pollution.* Dordrecht, Holland : D. Reidel Publishing Company, 1975. Vol. 4.
3. **Government of Canada and U.S. Environmental Protection Agency.** The Great Lakes: An Environmental Atlas and Resource Book, Third Edition. 1995.
4. **Bhowmik, Nani G., et al., et al.** Velocity Distribution at Two Sites Within the Southern Basin of Lake Michigan. Champaign : Illinois State Water Survey, 1991. Report of Investigation 115.
5. **Dames and Moore.** Report: Foundation Investigation, Proposed Nuclear Power Plant, Zion, Illinois (Rough Draft). October 9, 1967.
6. **Commonwealth Edision Company.** Zion Station Updated Final Safety Analysis Report (UFSAR). May 1996.
7. **Sargent & Lundy Engineers.** Drawing B-7: Crib House - Sheet Pile Wall Plan & Elevation, Zion Station Unit 1&2, Commonwealth Edison Co., Chicago, Illinois. 1969.
8. **ArcelorMittal.** Piling Handbook, 8th edition. 2008.
9. **Clark, Gene, et al., et al.** Duluth-Superior Harbor Freshwater Corrosion Update. s.l. : Minnesota Sea Grant, University of Minnesota, November 2009.
10. **Revie, R Winston.** Uhlig's Corrosion Handbook, Second Edition. New York, NY : Wiley Interscience, 2000.
11. **Grubb, Stuart.** Analytical Model for Estimation of Steadystate Capture Zones of Pumping Wells in Confined and Unconfined Aquifers. *Groundwater.* January 1993. Vol. 31, 1.
12. **Fetter, C.W.** Applied Hydrogeology, 3rd Edition. New York : Macmillan, 1994.
13. **U.S. Army Corps of Engineers.** Great Lakes Water Level Table for Lake Michigan/Huron, 1918-1950. 2004.
14. —. Great Lakes Water Level Table for Lake Michigan/Huron, 1951-1980. 2004.
15. —. Great Lakes Water Level Table for Lake Michigan/Huron, 1981-2013. 2013.
16. **Frizell, Kathleen H., Ruff, James F. and Mishra, Subhendu.** Simplified Design Guidelines for Riprap Subjected to Overtopping Flow. s.l. : U.S. Department of the Interior, Hydraulic Investigations and Laboratory Services Group , 1999.
17. **Roberts, Wyndham J. and Stall, John B.** Lake Evaporation in Illinois. Urbana, Illinois : Illinois State Water Survey, 1967. Report of Investigation 57.

18. **Yu, C., et al., et al.** User's Manual for RESRAD, Version 6. s.l. : U.S. Department of Energy, July 2001.
19. **Yu, C., et al., et al.** Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil. Argonne, Illinois : Argonne National Laboratory, April 1993.
20. **Romano, N. and Santini, A.** Field. *Methods of Soil Analysis, Part 4, Physical Methods.* Madison : Soil Science Society of America, 2002.
21. **Nachabe, M. H.** Refining the Definition of Field Capacity in the Literature. *Journal of Irrigation and Drainage Engineering.* s.l. : American Society of Civil Engineers, August 1998. Vol. 124, 4.
22. **International Atomic Energy Agency.** Field Estimation of Soil Water Content A Practical Guide to Methods, Instrumentation and Sensor Technology. Vienna : s.n., February 2008.
23. **Bear, Jacob.** Dynamics of Fluids in Porous Media. New York : Dover Publications, Inc., 1972.
24. **Yu, C., et al., et al.** User's Manual for RESRAD-OFFSITE, Version 2. s.l. : U.S. Department of Energy, July 2007.
25. **de Marsily, Ghislain.** Quantitative Hydrogeology: Groundwater Hydrology for Engineers. s.l. : Academic Press, Inc., 1986.
26. **Weather Underground.** Weather History for Waukegan, IL. April 12, 2013.
27. **Kuichling, Emil and Hering, Rudolph.** The Relation Between the Rainfall and the Discharge of Sewers in Populous Districts. With Discussion by Rudolph Hering. s.l. : American Society of Civil Engineers, 1889.
28. **USDA Natural Resources Conservation Service.** Soil Quality Indicators. June 2008.
29. **Zion Station.** Un-Fueled Safety Analysis Report. July 1995.
30. **Eid, Ratep (Boby) Abu.** Decommissioning Survey and Site Characterization Issues and Lessons Learned. *Presentation at the Workshop on Radiological Characterization for Decommissioning, Studsvik, Sweden.* s.l. : U.S. Nuclear Regulatory Commission, April 2012.
31. **U.S. Nuclear Regulatory Commission.** Standard Format and Content of License Termination Plans for Nuclear Power Reactors, Regulatory Guide 1,179, rev.1. June 2011.
32. —. NRC's Review Process and Expectations for Dose Assessment. *Slides presented at NRC Public Meeting with NASA to discuss options for demonstrating compliance with NRC Requirements for Plum Brook Sediments.* September 3, 2008. ML08259042.
33. —. Characterization, Survey, and Determination of Radiological Criteria. *Consolidated Decommissioning Guidance.* September 2006. Vol. 2. NUREG-1757 rev. 1.
34. —. Results of Evaluations for Realistic Exposure Scenarios. *Results of the License Termination Rule Analysis, Attachment 6.* May 2, 2003. SECY-03-0069.
35. —. Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM). August 2000. NUREG-1575 rev. 1.
36. —. Use of Rubblized Concrete Dismantlement to Address 10 CFR 20, Subpart E, Radiological Criteria for License Termination. February 14, 2000. SECY-00-0041.
37. **Battelle Pacific Northwest Laboratories.** Technical Basis for Translating Contamination Levels to Effective Dose Equivalent. *Residual Radioactive Contamination from Decommissioning.* s.l. : U.S. Nuclear Regulatory Commission, 1992. Vol. 1. NUREG/CR-5512, PNL-7994,.
38. **Whitman, Christine T and Meserve, Richard A.** Memorandum of Understanding Between the Environmental Protection Agency and the Nuclear Regulatory Commission: Consultation and Finality on Decommissioning and Decontamination of Contaminated Sites. s.l. : U.S. Environmental Protection Agency and U.S. Nuclear Regulatory Commission, October 9, 2002. OSWER 9295.8-06a.

39. **U.S. Environmental Protection Agency.** Example Exposure Scenarios. Washington, DC : s.n., April 2004.
40. —. Calculating Upper Confidence Limits for Exposure Point Concentrations at Hazardous Waste Sites. December 2002. OSWER 9285.6-10.
41. —. Risk Assessment Guidance for Superfund: Volume III - Part A, Process for Conducting Probabilistic Risk Assessment. December 2001. EPA 540-R-02-002.
42. **U.S. Government Printing Office.** Radiological Criteria for Unrestricted Release. *U.S. Code of Federal Regulations.* July 25, 2013. Title 10, Part 20.1402.
43. —. National Primary Drinking Water Regulations. *U.S. Code of Federal Regulations.* July 1, 2010. Title 40, Part 141.
44. —. National Secondary Drinking Water Regulations. *U.S. Code of Federal Regulations.* July 1, 2010. Title 40, Part 143.
45. **Commonwealth Edison Company.** Zion Station Historical Site Assessment. 1999.
46. **Conestoga-Rovers & Associates, Inc.** Hydrogeologic Investigation Report, Fleetwide Assessment, Zion Station, Zion, Illinois, Revision 1. September 2006. 045136(22).
47. **County Board, Lake County, Illinois.** Regional Framework Plan. February 13, 2007.
48. **Illinois Pollution Control Board.** Illinois Administrative Code Title 35 Part 742 Tiered Approach to Corrective Action Objectives. 2013.
49. **Natural Resources Conservation Service.** Urban Hydrology for Small Watersheds, TR-55. s.l. : U.S. Department of Agriculture, June 1986.
50. **Klocke, Norman L. and Hergert, Gary W.** G90-964 How Soil Holds Water. *Historical Materials from University of Nebraska-Lincoln Extension.* s.l. : University of Nebraska-Lincoln, 1990.
51. **Werner, Hal.** Measuring Soil Moisture for Irrigation Water Management. Brookings : South Dakota State University, April 2002.
52. **Karkanis, P. G.** Determining Field Capacity and Wilting Point Using Soil Saturation by Capillary Rise. *Canadian Agricultural Envineering.* 1983. Vol. 25, 1.

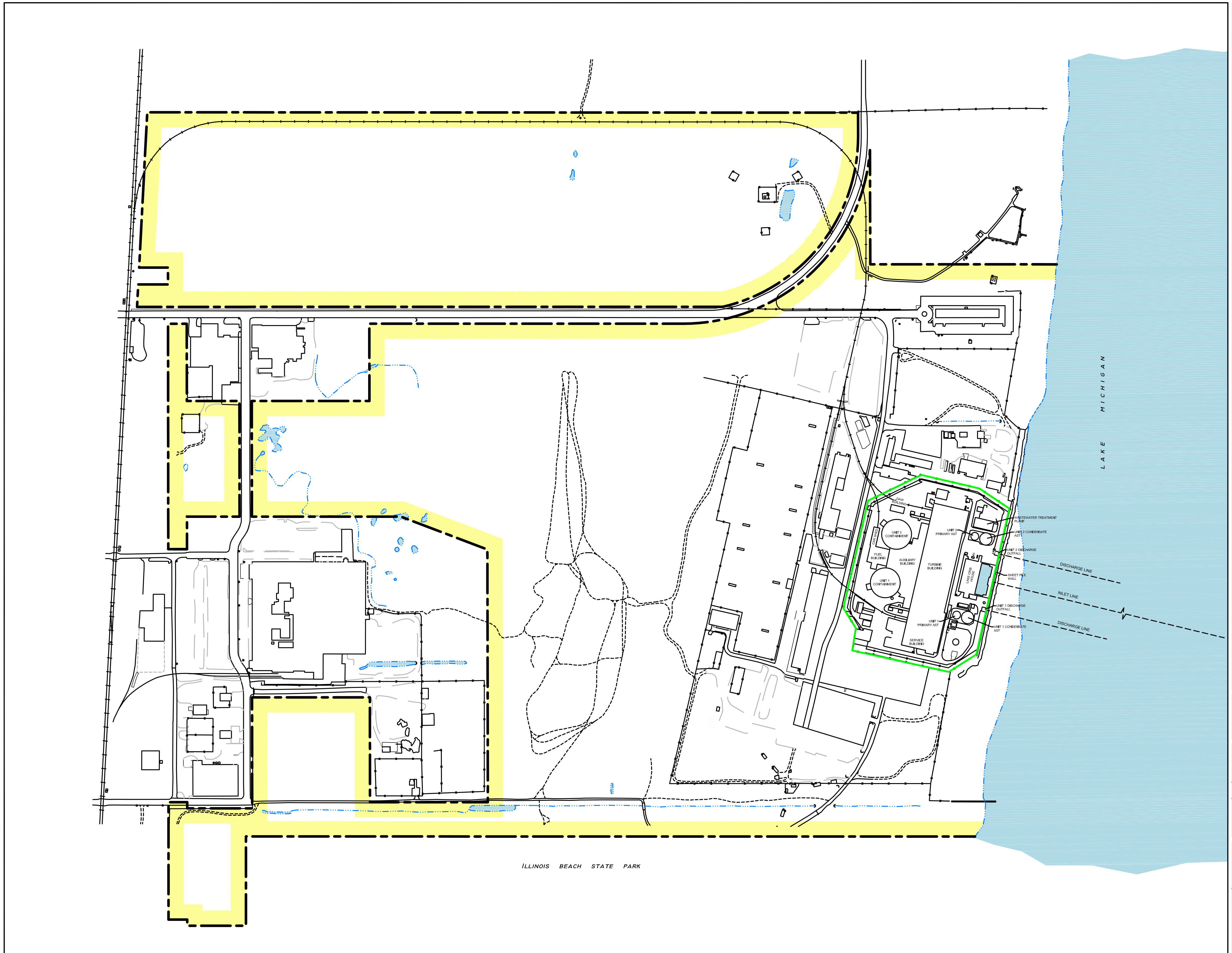


SOURCE: SOURCE: USGS QUADRANGLE MAP;
ZION, ILLINOIS (1993)

figure 4.1

SITE LOCATION
FORMER ZION NUCLEAR POWER STATION
ZIONSOLUTIONS
Zion, Illinois

54638-18(003)GN-CO001 JAN 14/2014



0 100 250ft

LEGEND

PROPERTY LINE
FENCE LINE
RAILROAD
EDGE OF WATER
TRAIL
PROTECTED AREA

SCALE VERIFICATION

THIS BAR MEASURES 1" ON ORIGINAL. ADJUST SCALE ACCORDINGLY.

ZIONSOLUTIONS

SITE PLAN
FORMER ZION NUCLEAR POWER STATION
ZION, ILLINOIS

CONESTOGA-ROVERS & ASSOCIATES

Source Reference: RUSSELL WAID DILLON SURVEYING SERVICES, ZION NUCLEAR GENERATING STATION, 5-3-2000

Project Manager:	Reviewed By:	Date: AUGUST 2013	
Scale: AS SHOWN	Project №: 54638-18	Report №: 003	Drawing №: figure 4.2

54638-18(003)GN-CO002 JAN 14/2014

Appendix A

August 2012 Subsurface Investigation to Determine Site Specific Partition Coefficient (Kd) Values Letter Report (dated September 17, 2012)

CONESTOGA-ROVERS & ASSOCIATES

8615 W. Bryn Mawr Avenue, Chicago, Illinois 60631-3501
Telephone: (773) 380-9933 Fax: (773) 380-6421
www.CRAworld.com

September 17, 2012 Reference No. 054638

Mr. Robert Decker
ZionSolutions, LLC
101 Shiloh Blvd
Zion, IL 60099

Dear Mr. Decker:

Re: Subsurface Investigation to Determine
Site-Specific Partition Coefficient (K_d) Values
Zion Nuclear Power Station Decommissioning Project

Conestoga-Rovers & Associates (CRA) was retained by ZionSolutions, LLC (ZionSolutions) for hydrogeology consulting services related to the decommissioning of the Zion Nuclear Power Station in Zion, Lake County, Illinois (Site). On August 20-21, 2012, CRA participated in a subsurface investigation to collect samples for laboratory analysis of Site-specific partition coefficients (K_d) for cobalt (^{60}Co), cesium (^{137}Cs), strontium (^{90}Sr), iron (^{55}Fe), and nickel (^{63}Ni).

The subsurface investigation included the advancement of three soil borings in the vicinity of existing monitoring wells on the eastern portion of the Site. The location of each soil boring is described in the following table:

Identifier	*Narrative Location*	*Northing*	*Easting*
Kd-SB-MW-1s	Approximately 28 feet east of MW-1s	641831.57	343806.08
Kd-SB-MW-2s	Approximately 10 feet north of MW-2s	641785.68	343788.49
Kd-SB-MW-3s	Approximately 12 feet northwest of MW-3s	641725.42	343770.03

Drilling services were provided by Direct Push Analytical Corp. of St. Charles, Illinois using a Geoprobe 7822DT track mounted rig. Samples were collected continuously using a 2.25-inch outer diameter by 48-inch probe rod equipped with polyethylene terephthalate (PETG) liners. The borings were logged by a CRA geologist. The boring logs are provided in Attachment 1.

Soil samples were selected for laboratory analysis based on the professional judgment of the field geologist to be representative of the following stratigraphic units at the Site:

- **Fill Sand** – Sand which originated as natural beach sand excavated during the construction of the facility in the early 1970s and then returned to the excavation as fill material;
- **Native Sand** – Beach sand which was not disturbed by construction activities at the facility; and,

CONESTOGA-ROVERS
& ASSOCIATES

- **Silts and Clays** – Low permeability deposits of natural lake bottom and glacial till material which underlie the upper sand units.

The following soil samples were selected for laboratory analysis:

Boring	*Depth Interval (feet bgs)*	*Sample Number*	*Stratigraphic Unit*
Kd-SB-MW-01s	12-16	L112102CJGSSB001B	fill sand (saturated)
Kd-SB-MW-01s	24-28	L112102CJGSSB001C	native sand (saturated)
Kd-SB-MW-01s	32-36	L112102CJGSSB001D	silt
Kd-SB-MW-03s	24-28	L212204CJGSSB002C	silt and clay

The samples were screened for radiological contamination in accordance with ZionSolutions' standard operating procedures prior to shipment to the Brookhaven National Laboratory via overnight courier.

If you have any questions or comment, please feel free to contact me by email (dsoutter@craworld.com) or telephone (773-380-9933).

Yours truly,

CONESTOGA-ROVERS & ASSOCIATES

Douglas G. Soutter

DS/ko/1
Encl.

cc: Phil Harvey, CRA

ATTACHMENT 1

STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

PROJECT NAME: Zion Solutions Facility	HOLE DESIGNATION: Kd-SB-MW-1S
PROJECT NUMBER: 054638	DATE COMPLETED: August 20, 2012
CLIENT: Zion Solutions	DRILLING METHOD: Geoprobe
LOCATION: Zion, Illinois	FIELD PERSONNEL: D. Soutter
DRILLING CONTRACTOR: Direct Push Analytical Corp.	DRILLER: B. Kinzer

STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS
ASPHALT	0.30
GRAVEL (paving base)	0.60
SW SAND, trace silt, trace gravel, fine to medium grained sand, poorly sorted, medium brown, dry to moist - saturated at 12.0ft BGS - dark brown at 13.5ft BGS - medium gray-brown at 16.0ft BGS - gravel from 19.2 to 19.3ft BGS	21.00
GW GRAVEL, sandy, fine grained rounded gravel, fine to coarse grained sand, poorly sorted, medium gray-brown, saturated	22.00
SW SAND, trace fine grained rounded gravel, fine to medium grained sand, poorly sorted, medium gray-brown, saturated - coarse grained sand, some fine grained gravel from 25.5 to 26.0ft BGS - fining upward sequence (native) from 27.2 to 27.4ft BGS	27.90
ML SILT, sandy, fine grained sand, low plasticity, gray, moist to saturated	36.00
END OF BOREHOLE @ 36.0ft BGS Survey Unit 12102, Northing 641831.57, Easting 343806.08	

BOREHOLE: Asphalt; Bentonite Chips. Water found at 12 ft BGS.

SAMPLE NUMBER	INTERVAL	REC (ft)	'N' VALUE
1GP	P/S		
2GP	P/S		
3GP	P/S		
4GP (12-16')	P/S		
5GP	P/S		
6GP	P/S		
7GP (24-28')	P/S		
8GP	P/S		
9GP (32-36')	P/S		

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE
WATER FOUND ⊻ 8/20/12
CHEMICAL ANALYSIS ◯

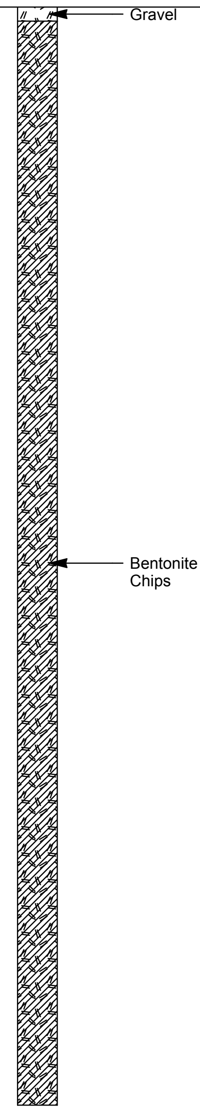
STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

Page 1 of 1

PROJECT NAME: Zion Solutions Facility | HOLE DESIGNATION: Kd-SB-MW-2S
PROJECT NUMBER: 054638 | DATE COMPLETED: August 21, 2012
CLIENT: Zion Solutions | DRILLING METHOD: Geoprobe
LOCATION: Zion, Illinois | FIELD PERSONNEL: D. Soutter
DRILLING CONTRACTOR: Direct Push Analytical Corp. | DRILLER: B. Kinzer

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS
	GW GRAVEL, sandy, fine to coarse grained gravel, poorly sorted, light brown, dry	0.40
2	SW SAND, some silt, trace clay, trace gravel, fine to medium grained sand, medium brown, dry	
12	- saturated at 12.0ft BGS	
	- dark brown at 15.0ft BGS	
	- clay, stiff, brown, saturated from 16.8 to 17.0ft BGS	
22	- concrete fragments from 21.8 to 22.0ft BGS	
	- limestone cobble from 22.0 to 22.5ft BGS	
	- little gravel at 22.5ft BGS	
	- silty at 24.5ft BGS	26.80
	ML SILT, little fine grained sand, low plasticity, medium gray, moist to wet	
	- clay from 31.0 to 31.1ft BGS	
	- gravel from 31.3 to 31.4ft BGS	
	- some organic material from 34.2 to 34.4ft BGS	
	- clay from 34.9 to 35.3ft BGS	36.00
	CL CLAY, some silt, trace gravel, stiff, moderate plasticity, dark gray, moist to wet (lake bottom)	39.00
	END OF BOREHOLE @ 39.0ft BGS	
	Survey Unit 12204, Northing 641785.68, Easting 343788.49	

Depth scale: 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, 24, 26, 28, 30, 32, 34, 36, 38, 40, 42, 44



SAMPLE NUMBER	INTERVAL	REC (ft)	'N' VALUE
1GP	P/S		
2GP	P/S		
3GP	P/S		
4GP	P/S		
5GP	P/S		
6GP	P/S		
7GP	P/S		
8GP	P/S		
9GP	P/S		
10GP	P/S		

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE
WATER FOUND ▽ 8/21/12

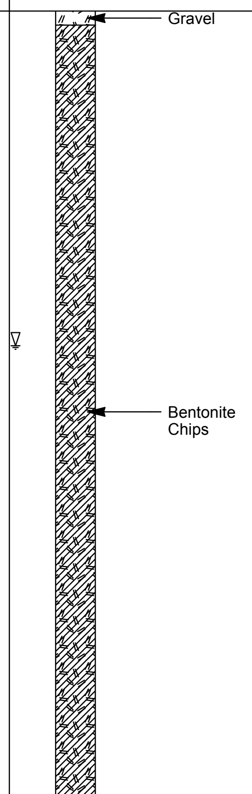
STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

PROJECT NAME: Zion Solutions Facility
PROJECT NUMBER: 054638
CLIENT: Zion Solutions
LOCATION: Zion, Illinois
DRILLING CONTRACTOR: Direct Push Analytical Corp.

HOLE DESIGNATION: Kd-SB-MW-3S
DATE COMPLETED: August 20, 2012
DRILLING METHOD: Geoprobe
FIELD PERSONNEL: D. Soutter
DRILLER: B. Kinzer

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS
	GRAVEL	0.20
	SW SAND, little silt, trace gravel, fine to medium grained sand, poorly sorted, medium brown, dry to moist	
12	- saturated at 11.9ft BGS	
20	ML SILT, clayey, little fine grained sand, trace gravel, stiff, moderate plasticity, dark gray, moist (lake bottom)	20.10
28	END OF BOREHOLE @ 28.0ft BGS	28.00
	Survey Unit 12204, Northing 641725.42, Easting 343770.03	

BOREHOLE



SAMPLE NUMBER	INTERVAL	REC (ft)	'N' VALUE
1GP	P/S		
2GP	P/S		
3GP	P/S		
4GP	P/S		
5GP	P/S		
6GP	P/S		
7GP (24-28')	P/S		

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE
WATER FOUND ∇ 8/21/12
CHEMICAL ANALYSIS ◯

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 9/6/12

Appendix B

**December 12, 2012 Geotechnical Subsurface Investigation Letter Report
(dated March 1, 2013, revised January 14, 2014)**

CONESTOGA-ROVERS
& ASSOCIATES

8615 W. Bryn Mawr Avenue, Chicago, Illinois 60631-3501
Telephone: (773) 380-9933 Fax: (773) 380-6421
www.CRAworld.com

January 14, 2014 Reference No. 054638

Mr. Robert Decker
ZionSolutions, LLC
101 Shiloh Blvd
Zion, IL 60099

Dear Mr. Decker:

Re: December 12, 2012 Geotechnical Subsurface Investigation
Zion Nuclear Power Station Decommissioning Project
Revision 1

Conestoga-Rovers & Associates (CRA) was retained by ZionSolutions, LLC (ZionSolutions) for hydrogeology consulting services related to the decommissioning of the Zion Nuclear Power Station in Zion, Lake County, Illinois (Site). On December 12, 2012, CRA participated in a subsurface investigation to collect samples for laboratory analysis of the following geotechnical parameters: porosity, bulk density, particle density, hydraulic conductivity, and grain size.

The subsurface investigation included the advancement of two soil borings in the vicinity of existing monitoring wells on the eastern portion of the Site. The location of each soil boring is described in the following table:

Boring	*Narrative Location*
GT-MW-01s	Approximately 3 feet north of Kd-SB-MW-1s
GT-MW-02s	Approximately 3 feet north of Kd-SB-MW-2s

Drilling services were provided by Direct Push Analytical Corp. of St. Charles, Illinois using a Geoprobe track mounted rig. Samples were collected continuously using a 2.25-inch outer diameter by 48-inch probe rod equipped with polyethylene terephthalate (PETG) liners. The borings were logged by a CRA geologist. The boring logs are provided in Attachment 1.

Five (5) soil samples were selected for geotechnical analysis based on stratigraphic observations made during the August 2012 Site-specific partition coefficient subsurface investigation. The pre-determined soil sample depths were intended to target the following stratigraphic units at the Site:

- **Fill Sand** – Sand which originated as natural beach sand excavated during the construction of the facility in the early 1970s and then returned to the excavation as fill material.

- **Native Sand** – Beach sand which was not disturbed by construction activities at the facility.

The following soil samples were selected for laboratory analysis:

Boring	*Depth Interval (feet bgs[1])*	*Sample Identifier*	*Targeted Stratigraphic Unit*
GT-MW-01s	2-5	S-121212-LP-01 (S-01)	fill sand (vadose zone)
GT-MW-01s	16-20	S-121212-LP-02 (S-02)	fill sand (saturated zone)
GT-MW-01s	24-28	S-121212-LP-03 (S-03)	native sand (saturated zone)
GT-MW-02s	2-5	S-121212-LP-04 (S-04)	fill sand (vadose zone)
GT-MW-02s	12-16	S-121212-LP-05 (S-05)	fill sand (saturated zone)

The samples were screened for radiological contamination in accordance with ZionSolutions' standard operating procedures prior to shipment to CRA's laboratory in Plymouth, Michigan via overnight courier.

<u>Results</u>

The results of the geotechnical analyses of each sample collected are summarized in the tables below. The laboratory report is provided as Attachment 2. The dry soil bulk density results were rejected due to laboratory errors.

Boring	*Sample Identifier*	*Hydraulic Conductivity (cm/s[2])*	*Porosity (%)*	*Particle Density (unitless)*
GT-MW-01s	S-121212-LP-01 (S-01)	5.1×10^{-3}	9.25	2.64
GT-MW-01s	S-121212-LP-02 (S-02)	5.6×10^{-3}	16.69	2.67
GT-MW-01s	S-121212-LP-03 (S-03)	9.1×10^{-3}	20.40	2.71
GT-MW-02s	S-121212-LP-04 (S-04)	3.3×10^{-3}	23.97	2.74
GT-MW-02s	S-121212-LP-05 (S-05)	2.4×10^{-3}	25.66	2.66
Arithmetic mean		**- -**	**19.19**	**2.68**
Geometric mean		**4.60×10^{-3}**	**- -**	**- -**

[1] bgs – below ground surface.
[2] cm/s – centimeters per second.

Boring	*Sample Identifier*	*Grain Size Distribution*		
		% Gravel	*% Sand*	*% Silt or Clay*
GT-MW-01s	S-121212-LP-01 (S-01)	4.1	84.1	11.8
GT-MW-01s	S-121212-LP-02 (S-02)	3.1	90.3	6.6
GT-MW-01s	S-121212-LP-03 (S-03)	7.9	89.2	2.9
GT-MW-02s	S-121212-LP-04 (S-04)	5.5	73.0	21.5
GT-MW-02s	S-121212-LP-05 (S-05)	12.8	77.4	9.8

If you have any questions or comment, please feel free to contact me by email (dsoutter@craworld.com) or telephone (773-380-9933).

Yours truly,

CONESTOGA-ROVERS & ASSOCIATES

Douglas G. Soutter

DS/ko/4
Encl.

cc: Phil Harvey, CRA

ATTACHMENT 1

BORING LOGS

STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

Page 1 of 1

PROJECT NAME: Zion Solutions Facility | HOLE DESIGNATION: GT-MW-01S
PROJECT NUMBER: 054638 | DATE COMPLETED: December 12, 2012
CLIENT: Zion Solutions | DRILLING METHOD: Geoprobe
LOCATION: Zion, Illinois | FIELD PERSONNEL: L. Punch
DRILLING CONTRACTOR: Direct Push Analytical Corp. | DRILLER: Kevin

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS	BOREHOLE	SAMPLE NUMBER	SAMPLE INTERVAL	SAMPLE REC (ft)	SAMPLE DYE TEST
	ASPHALT	0.30	Asphalt				
	Sample collected for gamma spectroscopy analysis	2.00		1DPT	P/S	1.6	
2	Sample collected for geotechnical analysis	5.00		2DPT 2-5'	P/S	2.5	
6	SP SAND, fine grained, trace coarse grained sand and fine grained subangular gravel, brown, slightly moist - some fine grained subangular gravel from 7.5 to 7.9ft BGS - with coarse grained angular gravel from 8.0 to 8.2ft BGS	11.00		3DPT	P/S	3.2	
10				4DPT	P/S	2.5	
11	Not sampled	16.00	Sand	5DPT	P/S		
16	Sample collected for geotechnical analysis	20.00		6DPT 16-20'	P/S	2.3	
20	Not sampled	24.00		7DPT	P/S		
24	Sample collected for geotechnical analysis	28.00		8DPT 24-28'	P/S	3.0	
28	END OF BOREHOLE @ 28.0ft BGS						

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

GRAIN SIZE ALPHYSIS

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 1/17/13

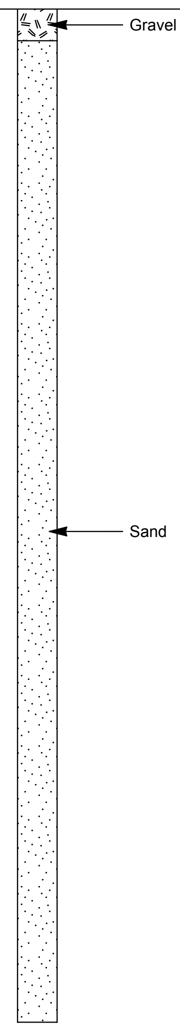
STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

Page 1 of 1

PROJECT NAME: Zion Solutions Facility
PROJECT NUMBER: 054638
CLIENT: Zion Solutions
LOCATION: Zion, Illinois
DRILLING CONTRACTOR: Direct Push Analytical Corp.

HOLE DESIGNATION: GT-MW-02S
DATE COMPLETED: December 12, 2012
DRILLING METHOD: Geoprobe
FIELD PERSONNEL: L. Punch
DRILLER: Kevin

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS
0.20	GP GRAVEL, with silt
2.00	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist
5.00	Sample collected for geotechnical analysis
6.00	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist
6.20	SW SAND, fine to coarse grained, little fine to coarse grained gravel, compact, brown, slightly moist
6.50	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist
6.70	CL CLAY, silty, firm, brown, moist
7.20	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist
7.50	CL CLAY, little fine to coarse grained sand and fine grained gravel, stiff, brown, slightly moist
10.00	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist - some fine to coarse grained gravel from 9.5 to 9.7ft BGS
10.20	CL CLAY, silty, trace fine to coarse grained gravel, stiff, brown, slight moist
12.00	SP SAND, fine grained, trace fine to coarse grained gravel, compact, brown, slightly moist
16.00	Sample collected for geotechnical analysis
	END OF BOREHOLE @ 16.0ft BGS



SAMPLE NUMBER	INTERVAL	REC (ft)	DYE TEST
1DPT	P/S	1.4	
2DPT 2-5'	P/S	2.9	
3DPT	P/S	2.2	
4DPT	P/S	2.7	
5DPT 12-16'	P/S	2.5	

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

GRAIN SIZE ANALYSIS

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 1/17/13

ATTACHMENT 2

GEOTECHNICAL LABORATORY REPORT

Sheet 1 of 1

Borehole	Depth ()	Liquid Limit	Plastic Limit	Plasticity Index	Maximum Size (mm)	%<#200 Sieve	Class-ification	Water Content (%)	Dry Density (pcf)	Satur-ation (%)	Void Ratio
S-01	2				12.5	12		6.9	149.7		
S-02	2				12.5	7		14.7	138.8		
S-03	16				18.75	3	SP	17.8	134.6		
S-04	2				18.75	21		3.6	130.0		
S-05	12				25	10		10.1	123.4		

LAB SUMMARY 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

CONESTOGA-ROVERS & ASSOCIATES

Summary of Laboratory Results

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

CONESTOGA-ROVERS & ASSOCIATES

Specific Gravity of Soil Solids
ASTM 854

Project: Zion Former Generating Facility — Project No.: 054638

Boring No.: — Sample No.: S-01

Description of Soil: (SP-SM) — Sample Depth: 2'-5'

Tested By: R. Bentley — 1/10/2013

Test No.	1	2	
Method of Air Removal	Vacuum	Vacuum	
Mass fl. + Water + Soil = M_{bws}	390.1	389.6	*after deairing
Temperature, °C	22	22	
Mass fl. + Water[b] = M_{bw}	358.8	358.8	*flask + water after deairing
Tare No.	N/A	N/A	
Tare Wt.	0	0	
Wt. Tare + Dry Soil	50	50	
Wt. Dry Soil = M_s	50	50	
$M_w = M_s + M_{bw} - M_{bws}$	18.7	19.2	*Mass of water
$\alpha = \rho_T / \rho_{20\,^\circ C}$	0.9996	0.9996	*from table below
$G_s = \alpha M_s / M_w$	2.67	2.60	
Average		***2.64***	

T (°C)	*α*
16	1.0007
18	1.0004
20	1
22	0.9996
24	0.9991
26	0.9986

CONESTOGA-ROVERS & ASSOCIATES

Specific Gravity of Soil Solids
ASTM 854

Project: Zion Former Generating Facility — Project No.: 054638

Boring No.: — Sample: S-02

Description of Soil: (SP-SM) — Sample Depth: 2'-5'

Tested By: R. Bentley — 1/10/2013

Test No.	1	2	
Method of Air Removal	Vacuum	Vacuum	
Mass fl. + Water + Soil = M_{bws}	390.2	389.9	*after deairing
Temperature, ^{o}C	22	22	
Mass fl. + Water^{b} = M_{bw}	358.8	358.8	*flask + water after deairing
Tare No.	N/A	N/A	
Tare Wt.	0	0	
Wt. Tare + Dry Soil	50	50	
Wt. Dry Soil = M_s	50	50	
$M_w = M_s + M_{bw} - M_{bws}$	18.6	18.9	*Mass of water
$\alpha = \rho_T / \rho_{20^oC}$	0.9996	0.9996	*from table below
$G_s = \alpha M_s / M_w$	2.69	2.64	
Average		***2.67***	

T (° C)	*α*
16	1.0007
18	1.0004
20	1
22	0.9996
24	0.9991
26	0.9986

CONESTOGA-ROVERS & ASSOCIATES

Specific Gravity of Soil Solids
ASTM 854

Project: Zion Former Generating Facility — Project No.: 054638

Boring No.: — Sample No.: S-03

Description of Soil: (SP) — Sample Depth: 16'-20'

Tested By: R. Bentley — 1/10/2013

Test No.	1	2	
Method of Air Removal	Vacuum	Vacuum	
Mass fl. + Water + Soil = M_{bws}	391	389.6	*after deairing
Temperature, °C	22	22	
Mass fl. + Water[b] = M_{bw}	358.8	358.8	*flask + water after deairing
Tare No.	N/A	N/A	
Tare Wt.	0	0	
Wt. Tare + Dry Soil	50	50	
Wt. Dry Soil = M_s	50	50	
$M_w = M_s + M_{bw} - M_{bws}$	17.8	19.2	*Mass of water
$\alpha = \rho_T / \rho_{20^\circ C}$	0.9996	0.9996	*from table below
$G_s = \alpha M_s / M_w$	2.81	2.60	
Average		***2.71***	

T (° C)	*α*
16	1.0007
18	1.0004
20	1
22	0.9996
24	0.9991
26	0.9986

CONESTOGA-ROVERS & ASSOCIATES

Specific Gravity of Soil Solids
ASTM 854

Project: Zion Former Generating Facility — Project No.: 054638

Boring No.: — Sample No.: S-04

Description of Soil: (SP) — Sample Depth: 2'-5'

Tested By: R. Bentley — 1/10/2013

Test No.	1	2	
Method of Air Removal	Vacuum	Vacuum	
Mass fl. + Water + Soil = M_{bws}	391.2	389.9	*after deairing
Temperature, °C	22	22	
Mass fl. + Water[b] = M_{bw}	358.8	358.8	*flask + water after deairing
Tare No.	N/A	N/A	
Tare Wt.	0	0	
Wt. Tare + Dry Soil	50	50	
Wt. Dry Soil = M_s	50	50	
$M_w = M_s + M_{bw} - M_{bws}$	17.6	18.9	*Mass of water
$\alpha = \rho_T / \rho_{20^\circ C}$	0.9996	0.9996	*from table below
$G_s = \alpha M_s / M_w$	2.84	2.64	
Average		***2.74***	

T (°C)	α
16	1.0007
18	1.0004
20	1
22	0.9996
24	0.9991
26	0.9986

CONESTOGA-ROVERS & ASSOCIATES

Specific Gravity of Soil Solids
ASTM 854

Project: Zion Former Generating Facility — Project No.: 054638

Boring No.: — Sample No.: S-05

Description of Soil: (SP) — Sample Depth: 12'-16'

Tested By: R. Bentley — 1/10/2013

Test No.	1	2	
Method of Air Removal	Vacuum	Vacuum	
Mass fl. + Water + Soil = M_{bws}	390.7	390.4	*after deairing
Temperature, °C	22	22	
Mass fl. + Water[b] = M_{bw}	359.1	359.6	*flask + water after deairing
Tare No.	N/A	N/A	
Tare Wt.	0	0	
Wt. Tare + Dry Soil	50	50	
Wt. Dry Soil = M_s	50	50	
$M_w = M_s + M_{bw} - M_{bws}$	18.4	19.2	*Mass of water
$\alpha = \rho_T / \rho_{20^\circ C}$	0.9996	0.9996	*from table below
$G_s = \alpha M_s / M_w$	2.72	2.60	
Average		***2.66***	

T (°C)	*α*
16	1.0007
18	1.0004
20	1
22	0.9996
24	0.9991
26	0.9986

CONESTOGA-ROVERS & ASSOCIATES

PERMEABILITY TEST ON GRANULAR SOILS
ASTM D 2434

PROJECT: Zion Former Generating Facility
LOCATION: Zion, IL
CLIENT : Energy Solutions
PROJECT NO.: 54638

SAMPLE DATE: 12/12/12
SAMPLE LOCATION:
SAMPLE No.: S-01
SAMPLE DEPTH: 2' - 5'
SAMPLED BY: Lisa Punch

TEST DATE: 14-Jan-13
TESTED BY: D. Kribs
LAB No. :
CHECKED BY: R. Bentley

Description of Soil: (SP-SM) SAND, trace silt and gravel

Unit Weight Determination:

Diameter D (cm): 7.62
Area A (cm^2): 45.60
Sample height H (cm): 15
Dry weight (g): 1232.2

Moisture content during compaction in the cell: 7%
Dry Density (lb/ft^3): 112.4
Ratio of standard Proctor : ---

Particle Size Summary

	Sieve Size	Percent Finer By Weight
Gravel	3"	
	3/4"	100
	#4	95.9
Sand	#10	91.4
	#40	81.1
	#200	11.8

Permeability Test Results

Test No.	Head 'h' cm	Q cm^3	t (sec)	Q/At	h/L	Permeability k (cm/sec)
1	106	200	86	0.051	7.067	7.2E-03
2	101	200	107	0.041	6.733	6.1E-03
3	96	200	130	0.034	6.400	5.3E-03
4	91	200	166	0.026	6.067	4.4E-03
5	86	200	194	0.023	5.733	3.9E-03
6	81	200	206	0.021	5.400	3.9E-03

AVERAGE 5.1E-03

CONESTOGA-ROVERS & ASSOCIATES

PERMEABILITY TEST ON GRANULAR SOILS
ASTM D 2434

PROJECT: Zion Former Generating Facility
LOCATION: Zion, IL
CLIENT : Energy Solutions
PROJECT NO.: 54638

SAMPLE DATE: 12/12/12
SAMPLE LOCATION:
SAMPLE No.: S-02
SAMPLE DEPTH: 2' -5'
SAMPLED BY: Lisa Punch

TEST DATE: 14-Jan-13
TESTED BY: D. Kribs
LAB No. :
CHECKED BY: R. Bentley

Description of Soil: (SP-SM) SAND, trace silt and gravel

Unit Weight Determination:

Diameter D (cm): 7.62
Area A (cm^2): 45.60
Sample height H (cm): 15
Dry weight (g): 1286.8

Moisture content during compaction in the cell: 15%
Dry Density (lb/ft^3): 117.4
Ratio of standard Proctor : ---

Particle Size Summary

	Sieve Size	Percent Finer By Weight
Gravel	3"	
	3/4"	100
	#4	96.9
Sand	#10	92.2
	#40	76.2
	#200	6.6

Permeability Test Results

Test No.	Head 'h' cm	Q cm^3	t (sec)	Q/At	h/L	Permeability k (cm/sec)
1	112	200	68	0.064	7.467	8.6E-03
2	107	200	94	0.047	7.133	6.5E-03
3	102	200	129	0.034	6.800	5.0E-03
4	97	200	143	0.031	6.467	4.7E-03
5	92	200	153	0.029	6.133	4.7E-03
6	87	200	187	0.023	5.800	4.0E-03

AVERAGE 5.6E-03

CONESTOGA-ROVERS
& ASSOCIATES

PERMEABILITY TEST ON GRANULAR SOILS
ASTM D 2434

PROJECT: Zion Former Generating Facility
LOCATION: Zion, IL
CLIENT : Energy Solutions
PROJECT NO.: 54638

SAMPLE DATE: 12/12/12
SAMPLE LOCATION:
SAMPLE No.: S-03
SAMPLE DEPTH: 16' - 20'
SAMPLED BY: Lisa Punch

TEST DATE: 14-Jan-13
TESTED BY: D. Kribs
LAB No. :
CHECKED BY: R. Bentley

Description of Soil: (SP) SAND, trace silt and gravel

Unit Weight Determination:

Diameter D (cm): 6.35
Area A (cm^2): 31.67
Sample height H (cm): 15
Dry weight (g): 906

Moisture content during compaction in the cell: 18%
Dry Density (lb/ft^3): 119.0
Ratio of standard Proctor : ---

Particle Size Summary

	Sieve Size	Percent Finer By Weight
Gravel	3"	
	3/4"	100
	#4	92.1
Sand	#10	89.6
	#40	85.9
	#200	2.9

Permeability Test Results

Test No.	Head 'h' cm	Q cm^3	t (sec)	Q/At	h/L	Permeability k (cm/sec)
1	112	200	52	0.121	7.467	1.6E-02
2	107	200	72	0.088	7.133	1.2E-02
3	102	200	84	0.075	6.800	1.1E-02
4	97	200	120	0.053	6.467	8.1E-03
5	92	200	219	0.029	6.133	4.7E-03
6	87	200	509	0.012	5.800	2.1E-03

AVERAGE 9.1E-03

CONESTOGA-ROVERS & ASSOCIATES

PERMEABILITY TEST ON GRANULAR SOILS
ASTM D 2434

PROJECT: Zion Former Generating Facility
LOCATION: Zion, IL
CLIENT : Energy Solutions
PROJECT NO.: 54638

SAMPLE DATE: 12/12/12
SAMPLE LOCATION:
SAMPLE No.: S-04
SAMPLE DEPTH: 2' -5'
SAMPLED BY: Lisa Punch

TEST DATE: 14-Jan-13
TESTED BY: D.Kribs D. Kribs
LAB No. :
CHECKED BY: R. Bentley

Description of Soil: (SM) Silty SAND, trace gravel

Unit Weight Determination:

Diameter D (cm): 7.62
Area A (cm^2): 45.60
Sample height H (cm): 15
Dry weight (g): 1237.3

Moisture content during compaction in the cell: 3%
Dry Density (lb/ft^3): 112.9
Ratio of standard Proctor : ---

Particle Size Summary

	Sieve Size	Percent Finer By Weight
Gravel	3"	
	3/4"	100
	#4	94.5
Sand	#10	89.7
	#40	78.6
	#200	21.5

Permeability Test Results

Test No.	Head 'h' cm	Q cm^3	t (sec)	Q/At	h/L	Permeability k (cm/sec)
1	112	200	155	0.028	7.467	3.8E-03
2	107	200	174	0.025	7.133	3.5E-03
3	102	200	193	0.023	6.800	3.3E-03
4	97	200	218	0.020	6.467	3.1E-03
5	92	200	244	0.018	6.133	2.9E-03
6	87	200	265	0.017	5.800	2.9E-03

AVERAGE 3.3E-03

CONESTOGA-ROVERS & ASSOCIATES

**PERMEABILITY TEST ON GRANULAR SOILS
ASTM D 2434**

PROJECT: Zion Former Generating Facility
LOCATION: Zion, IL
CLIENT : Energy Solutions
PROJECT NO.: 54638

SAMPLE DATE: 12/12/12
SAMPLE LOCATION:
SAMPLE No.: S-05
SAMPLE DEPTH: 12' - 16'
SAMPLED BY: Lisa Punch

TEST DATE: 14-Jan-13
TESTED BY: D. Kribs
LAB No. :
CHECKED BY: R. Bentley

Description of Soil: (SP-SM) SAND with gravel, trace silt

Unit Weight Determination:

Diameter D (cm): 7.62
Area A (cm^2): 45.60
Sample height H (cm): 15
Dry weight (g): 1352.4

Moisture content during compaction in the cell: 10%
Dry Density (lb/ft^3): 123.4
Ratio of standard Proctor : ---

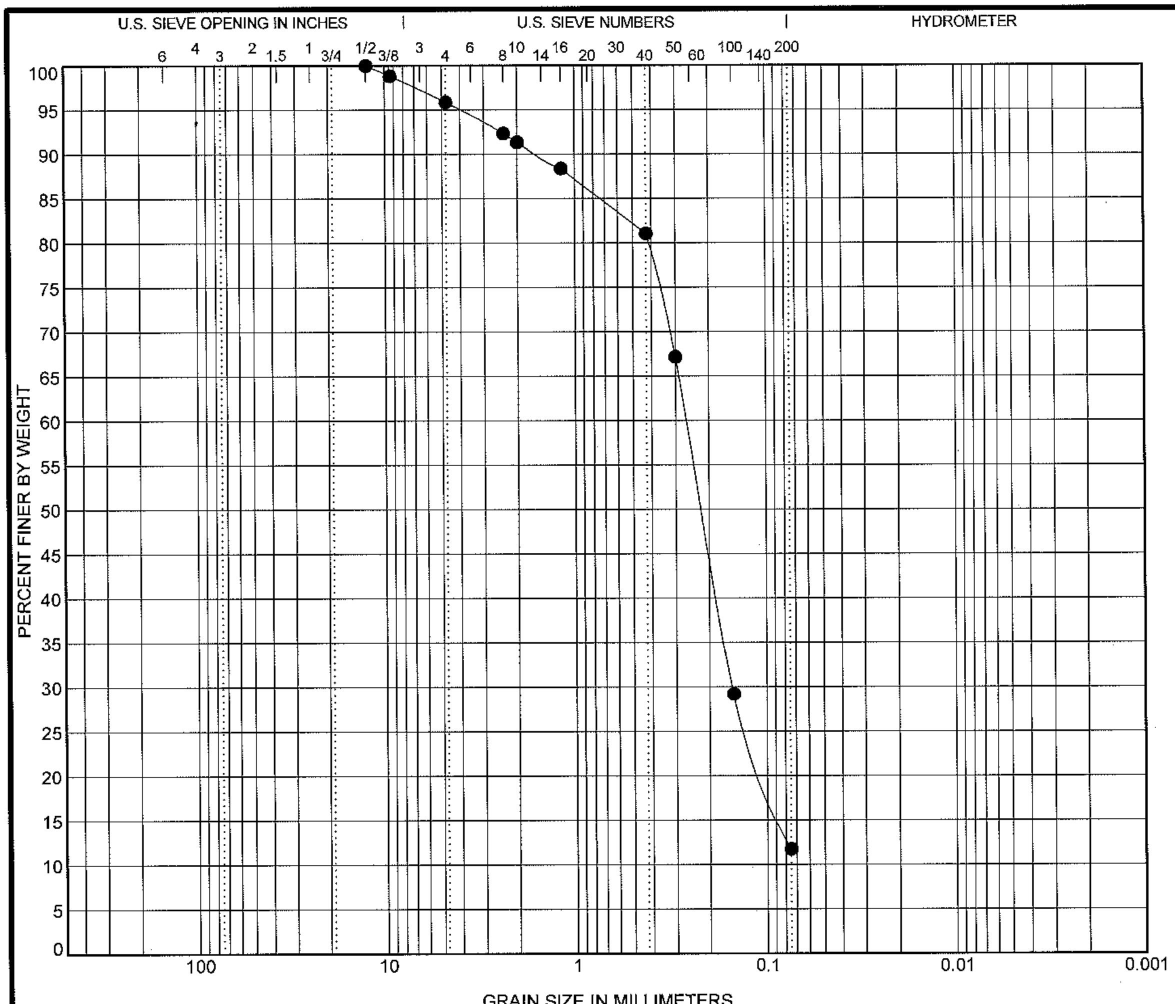
Particle Size Summary

	Sieve Size	Percent Finer By Weight
Gravel	3"	
	3/4"	96
	#4	87.2
Sand	#10	80.8
	#40	69.2
	#200	9.8

Permeability Test Results

Test No.	Head 'h' cm	Q cm^3	t (sec)	Q/At	h/L	Permeability k (cm/sec)
1	106	200	210	0.021	7.067	3.0E-03
2	101	200	264	0.017	6.733	2.5E-03
3	96	200	284	0.015	6.400	2.4E-03
4	91	200	317	0.014	6.067	2.3E-03
5	86	200	344	0.013	5.733	2.2E-03
6	81	200	369	0.012	5.400	2.2E-03

AVERAGE 2.4E-03



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	LL	PL	PI	Cc	Cu
●	**S-01**	**2**	**(SP-SM) SAND, trace silt and gravel**				**1.26**	**3.76**

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	**S-01**	**2**	**12.5**	**0.263**	**0.152**		**4.1**	**84.1**	**11.8**	

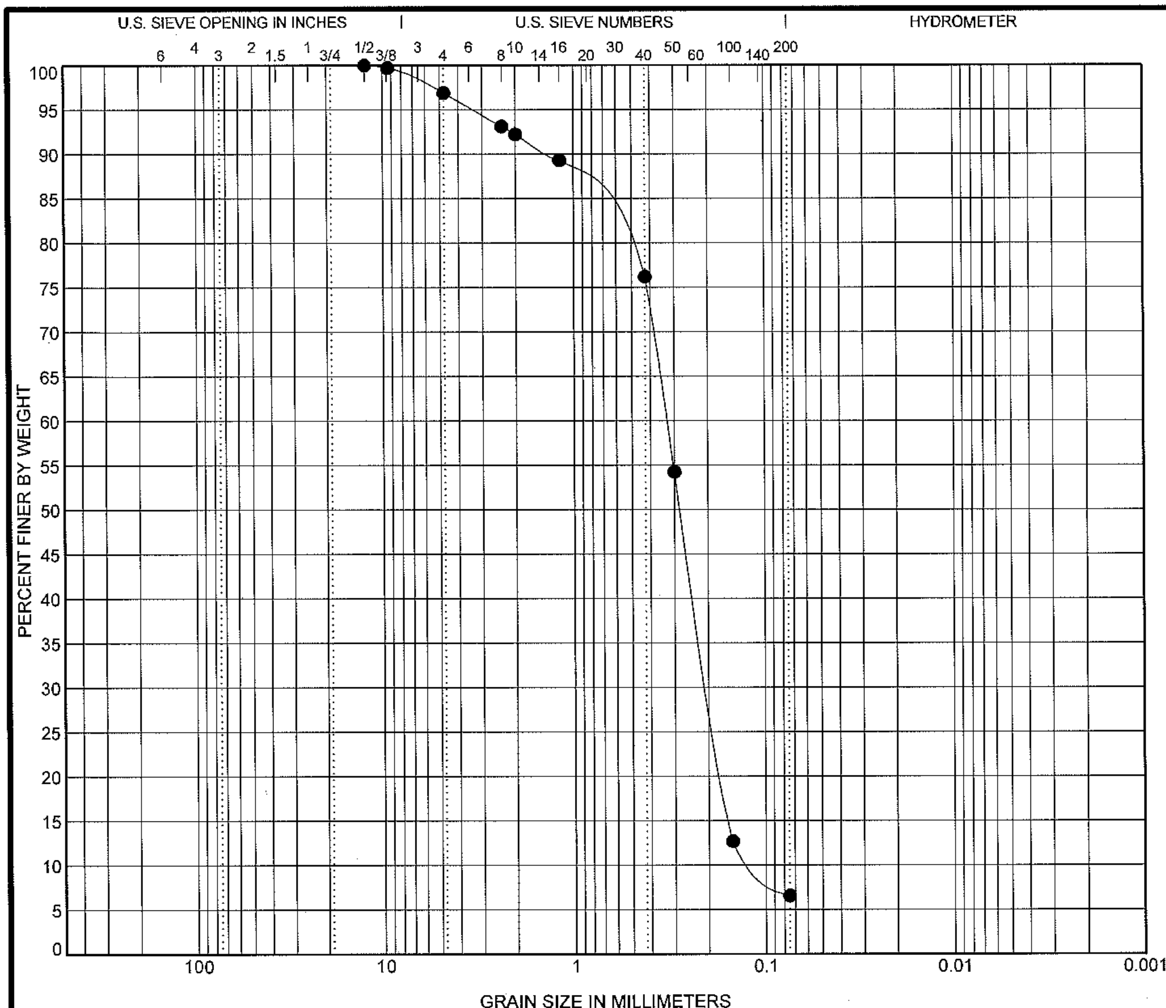
CONESTOGA-ROVERS
& ASSOCIATES

GRAIN SIZE DISTRIBUTION

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

GRAIN SIZE 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

Test by: ________ **Checked by:** ________



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

	Specimen Identification		Classification	LL	PL	PI	Cc	Cu
●	S-02	2	(SP-SM) SAND, trace silt and gravel				1.10	2.98

	Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
●	S-02	2	12.5	0.329	0.2	0.11	3.1	90.3	6.6	

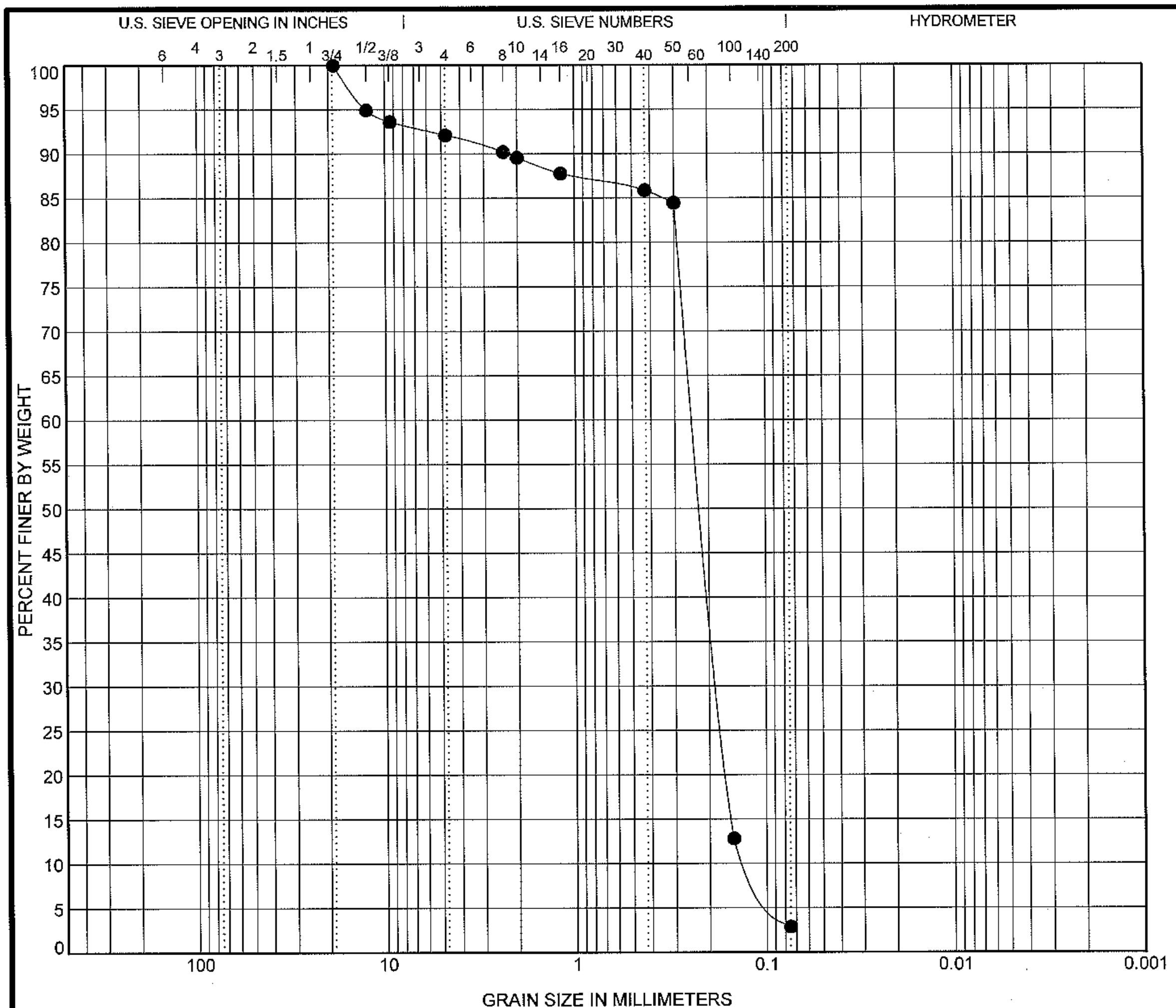
GRAIN SIZE 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

CONESTOGA-ROVERS
& ASSOCIATES

GRAIN SIZE DISTRIBUTION

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

Test by: DK **Checked by:** RG3



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	LL	PL	PI	Cc	Cu
● S-03	16	**(SP) SAND, trace silt and gravel**				**1.08**	**1.92**

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● S-03	16	**18.75**	**0.237**	**0.177**	**0.123**	**7.9**	**89.2**	**2.9**	

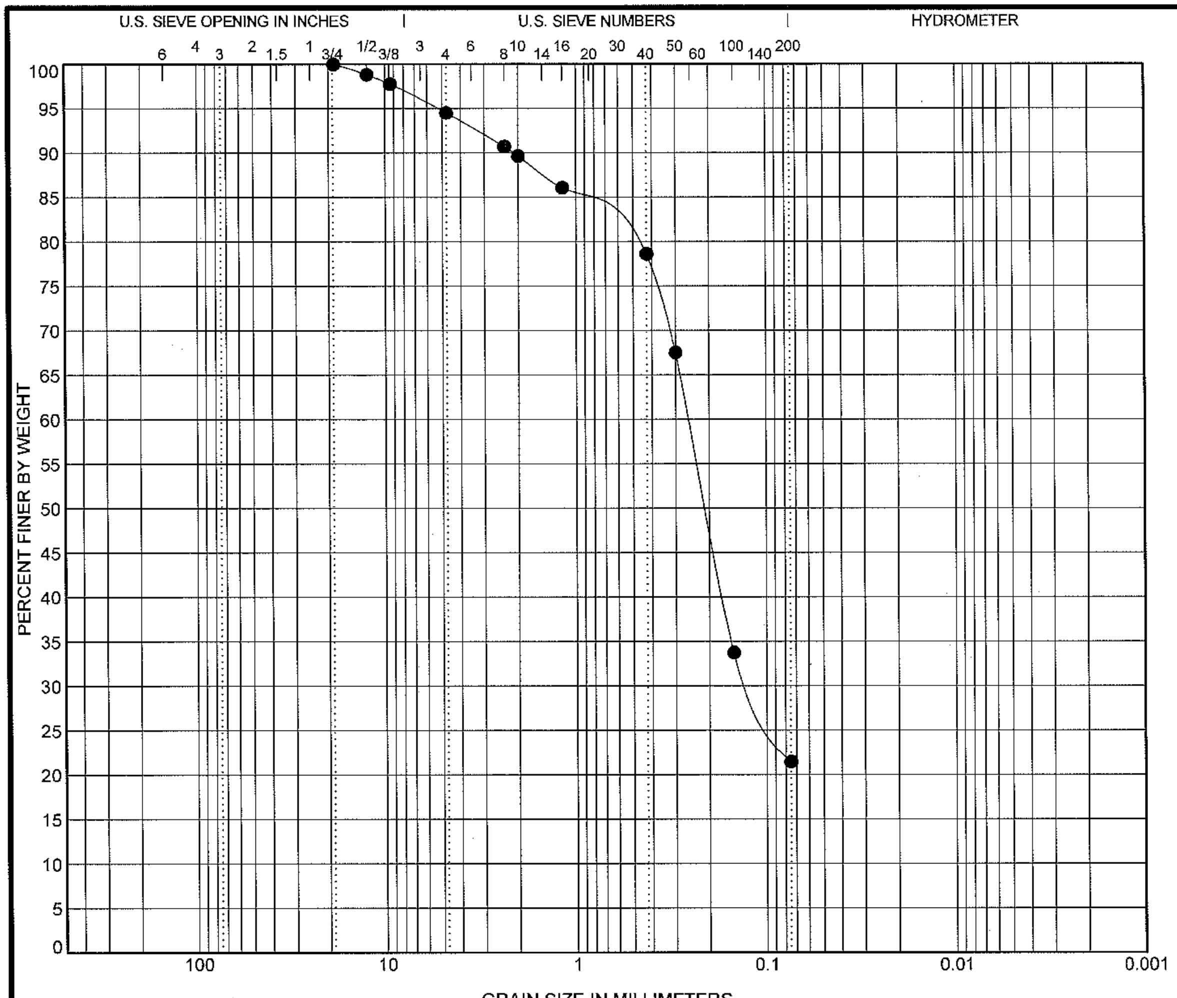
GRAIN SIZE 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

CONESTOGA-ROVERS
& ASSOCIATES

GRAIN SIZE DISTRIBUTION

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

Test by: DK **Checked by:** [illegible]



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	LL	PL	PI	Cc	Cu
● **S-04**	**2**	**(SM) Silty SAND, trace gravel**					

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● **S-04**	**2**	**18.75**	**0.257**	**0.121**		**5.5**	**73.0**	**21.5**	

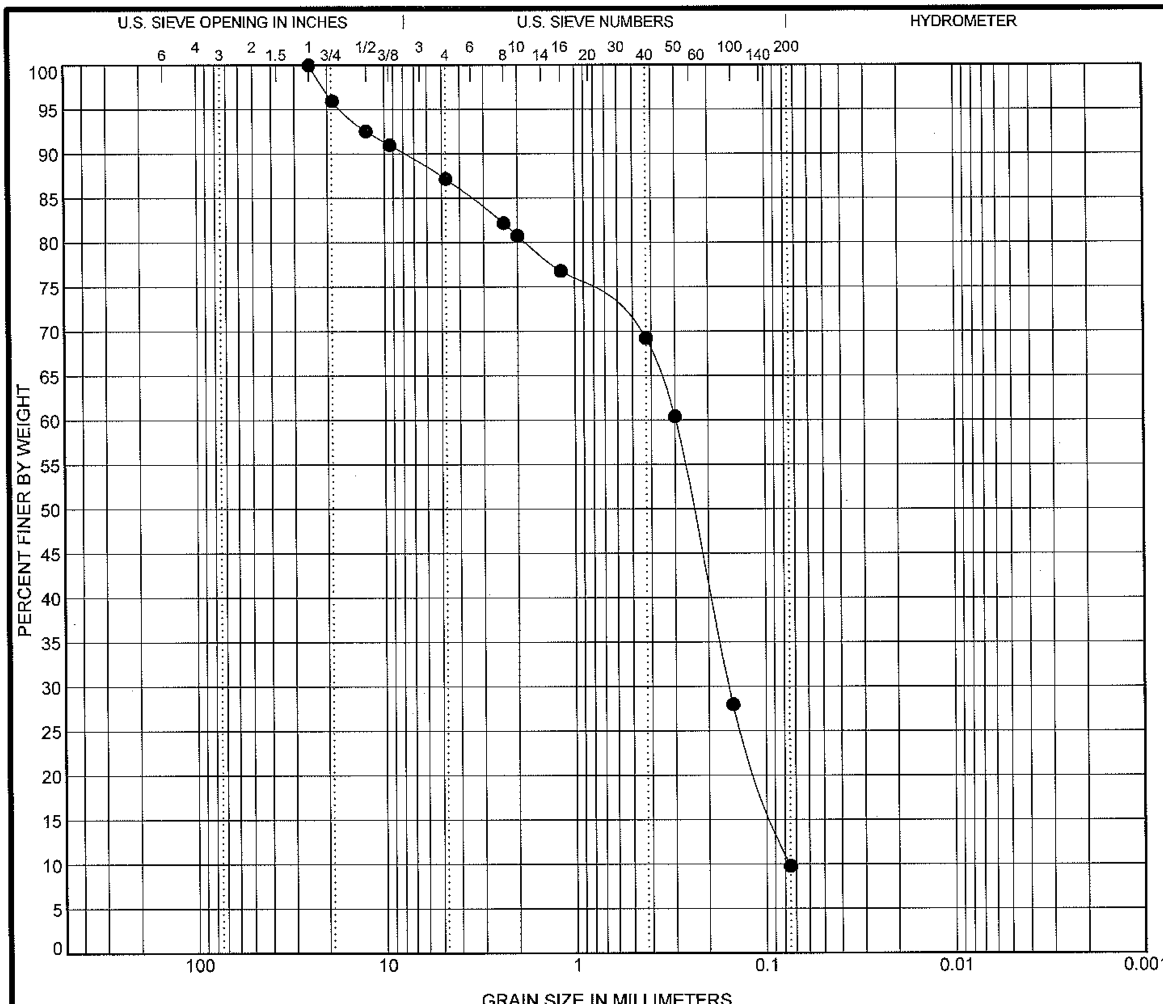
GRAIN SIZE 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

CONESTOGA-ROVERS
& ASSOCIATES

GRAIN SIZE DISTRIBUTION

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

Test by: DK **Checked by:** BCB



COBBLES	GRAVEL		SAND			SILT OR CLAY
	coarse	fine	coarse	medium	fine	

Specimen Identification		Classification	LL	PL	PI	Cc	Cu
● S-05	12	(SP-SM) SAND with gravel, trace silt				1.09	3.93

Specimen Identification		D100	D60	D30	D10	%Gravel	%Sand	%Silt	%Clay
● S-05	12	25	0.297	0.157	0.076	12.8	77.4	9.8	

GRAIN SIZE 054638 ZION.GPJ CRA PLYMOUTH.GDT 1/17/13

CONESTOGA-ROVERS & ASSOCIATES

GRAIN SIZE DISTRIBUTION

Project Name: Zion Former Generating Facility
Project Number: 054638
Client: Energy Solutions
Location: Zion, IL

Test by: DK **Checked by:** PAB

CONESTOGA-ROVERS & ASSOCIATES

CRA Project No. 054638
Zion Former Generating Facility
Zion, IL
Soil Porosity

Sample Date	Sample ID	Dry Unit Weight (pcf)	Specific Gravity	Water Unit Weight (pcf)	Void Ratio	Porosity (%)
12/12/2012	S-01	149.5	2.64	62.4	0.102	9.248737374
12/12/2012	S-02	138.8	2.67	62.4	0.200	16.69067512
12/12/2012	5-03	134.6	2.71	62.4	0.256	20.40401173
12/12/2012	S-04	130	2.74	62.4	0.315	23.96593674
12/12/2012	S-05	123.4	2.66	62.4	0.345	25.65548487

Appendix C

September 30, 2013 Single Well Response Test Letter Report
(dated November 13, 2013)

CONESTOGA-ROVERS
& ASSOCIATES

8615 W. Bryn Mawr Avenue, Chicago, Illinois 60631-3501
Telephone: (773) 380-9933 Fax: (773) 380-6421
www.CRAworld.com

November 13, 2013 Reference No. 054638-21

DRAFT

Mr. Robert Decker
ZionSolutions, LLC
101 Shiloh Blvd
Zion, IL 60099

Dear Mr. Decker:

Re: September 30, 2013 Single Well Response Tests
Zion Nuclear Power Station Decommissioning Project

Conestoga-Rovers & Associates (CRA) was retained by ZionSolutions, LLC (ZionSolutions) for hydrogeology consulting services related to the decommissioning of the Zion Nuclear Power Station in Zion, Lake County, Illinois (Site). On September 30, 2013, CRA performed single well response tests (commonly referred to as slug tests) on four onsite monitoring wells located to the east of the Protected Area (PA) (MW-ZN-01S, MW-ZN-02S, MW-ZN-03S, MW-ZN-04S) and two monitoring wells located to the west of the PA (MW-ZN-06S, MW-ZN-07S) to determine the hydraulic conductivity of the shallow sand aquifer. Figure 1 presents the monitoring well locations where single well response tests were conducted. The tests were performed using a slug to rapidly change the water level within the monitoring well. The water level within the well during the test was monitored using a pressure transducer and data logger.

CRA evaluated the data collected by the pressure transducer and data logger to determine the hydraulic conductivity using AQTESOLV software. Groundwater level response data and results from the aquifer test analyses are presented in Attachment A. The Hvorslev method was utilized for analysis. This method is appropriate for unconfined conditions in sand. The calculated hydraulic conductivities for each test and the geometric mean of these values are presented below:

Well ID	***Test***	***Method***	***Hydraulic Conductivity (ft/sec)***[1]	***Hydraulic Conductivity (cm/sec)***[2]	***Hydraulic Conductivity (m/y)***[3]
MW-01S	Test 1- Falling	Hvorslev	1.15E-03	3.51E-02	1.11E+04
MW-01S	Test 1- Rising	Hvorslev	8.08E-04	2.46E-02	7.77E+03
MW-02S	Test 2- Falling	Hvorslev	1.43E-04	4.36E-03	1.37E+03
MW-02S	Test 2- Rising	Hvorslev	1.54E-04	4.70E-03	1.48E+03
MW-03S	Test 1- Falling	Hvorslev	8.22E-05	2.51E-03	7.91E+02

[1] ft/sec – feet per second.
[2] cm/sec – centimeters per second.
[3] m/y – meters per year.

Table Continued

Well ID	*Test*	*Method*	*Hydraulic Conductivity (ft/sec)[1]*	*Hydraulic Conductivity (cm/sec)[2]*	*Hydraulic Conductivity (m/y)[3]*
MW-03S	Test 1- Rising	Hvorslev	8.17E-05	2.49E-03	7.86E+02
MW-04S	Test 1- Falling	Hvorslev	2.46E-04	7.49E-03	2.36E+03
MW-04S	Test 1- Rising	Hvorslev	2.35E-04	7.16E-03	2.26E+03
MW-06S	Test 2-2- Rising	Hvorslev	1.70E-04	5.18E-03	1.63E+03
MW-07S	Test 2- Rising	Hvorslev	7.16E-04	2.18E-02	6.88E+03
MW-07S	Test 3- Falling	Hvorslev	1.77E-03	5.40E-02	1.70E+04
Geometric mean			**2.99E-04**	**9.11E-03**	**2.88E+03**

The geometric mean of the single well response tests is 2.88E+03 m/y. This result is generally consistent with laboratory permeater tests on soil samples collected in December 2012 and September 2013. The December 2012 hydraulic conductivity laboratory data resulted in a geometric mean of 1.45E+03 m/y and the September 2013 laboratory data resulted in a geometric mean of 1.73E+03 m/y. These data are also in the range of hydraulic conductivity for a sand material based on literature values. The single well response tests are considered to better represent in situ aquifer conditions than laboratory permeater tests.

If you have any questions or comment, please feel free to contact me by email (dsoutter@craworld.com) or telephone (773-380-9933).

Yours truly,

CONESTOGA-ROVERS & ASSOCIATES

Douglas G. Soutter

DS/ko/13
Encl.

cc: Phil Harvey, CRA

[1] ft/sec – feet per second.
[2] cm/sec – centimeters per second.
[3] m/y – meters per year.

N

0 50 100ft

LEGEND

PROPERTY LINE
FENCE LINE
RAILROAD
EDGE OF WATER
TRAIL
MW-ZN-09S MONITORING WELL LOCATION
MONITORING WELL LOCATION UTILIZED FOR SINGLE WELL RESPONSE TEST

DRAFT

SCALE VERIFICATION
THIS BAR MEASURES 1" ON ORIGINAL. ADJUST SCALE ACCORDINGLY.

ZIONSOLUTIONS

SINGLE WELL RESPONSE TEST MONITORING WELL LOCATION, SEPTEMBER 2013
FORMER ZION NUCLEAR POWER STATION

CONESTOGA-ROVERS & ASSOCIATES

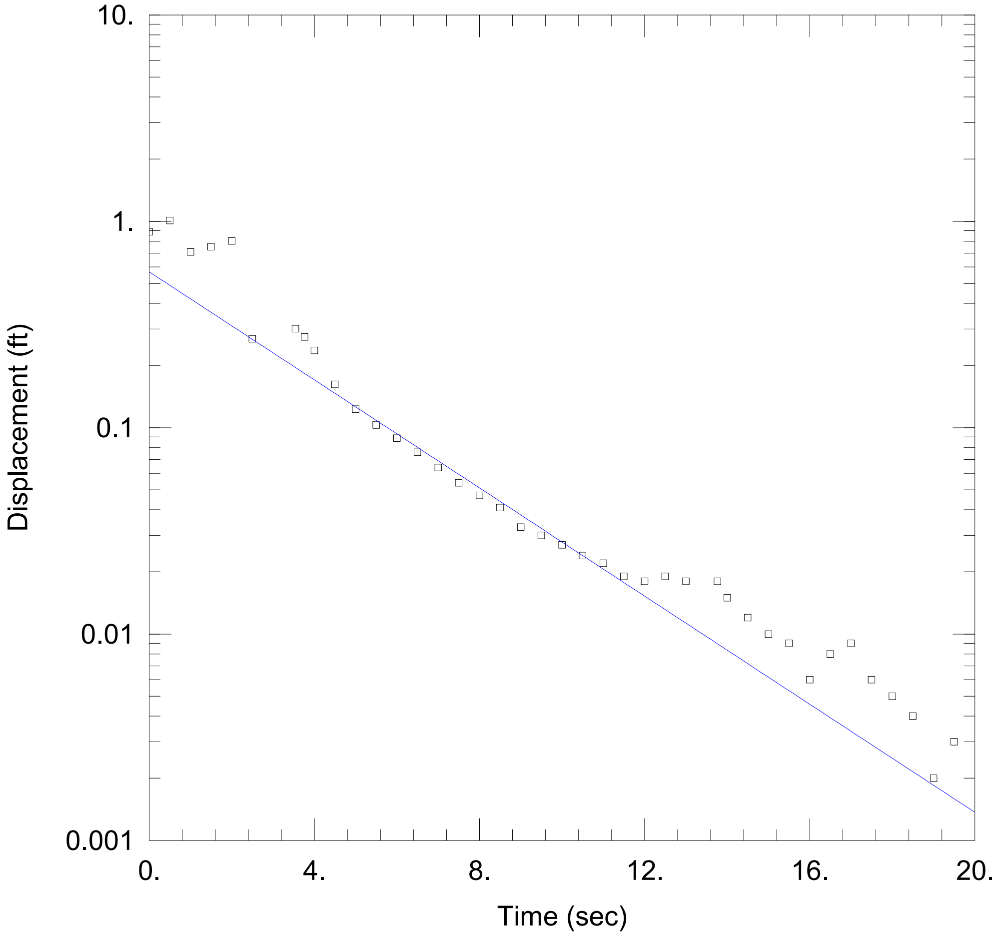
Source Reference: RUSSELL WAID DILLON SURVEYING SERVICES, ZION NUCLEAR GENERATING STATION, 5-3-2000

Project Manager:	Reviewed By:	Date:	
Scale: AS SHOWN	Project Nº: 54638-21	Report Nº: DECK013	Drawing Nº: figure 1

54638-21(DECK013)GN-CO001 NOV 13/2013

ATTACHMENT 1

AQTESOLV ANALYSIS



WELL TEST ANALYSIS

Data Set: I:\...\MW-1S test1 Falling.aqt
Date: 10/15/13   Time: 12:07:11

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-1S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft   Anisotropy Ratio (Kz/Kr): 1.

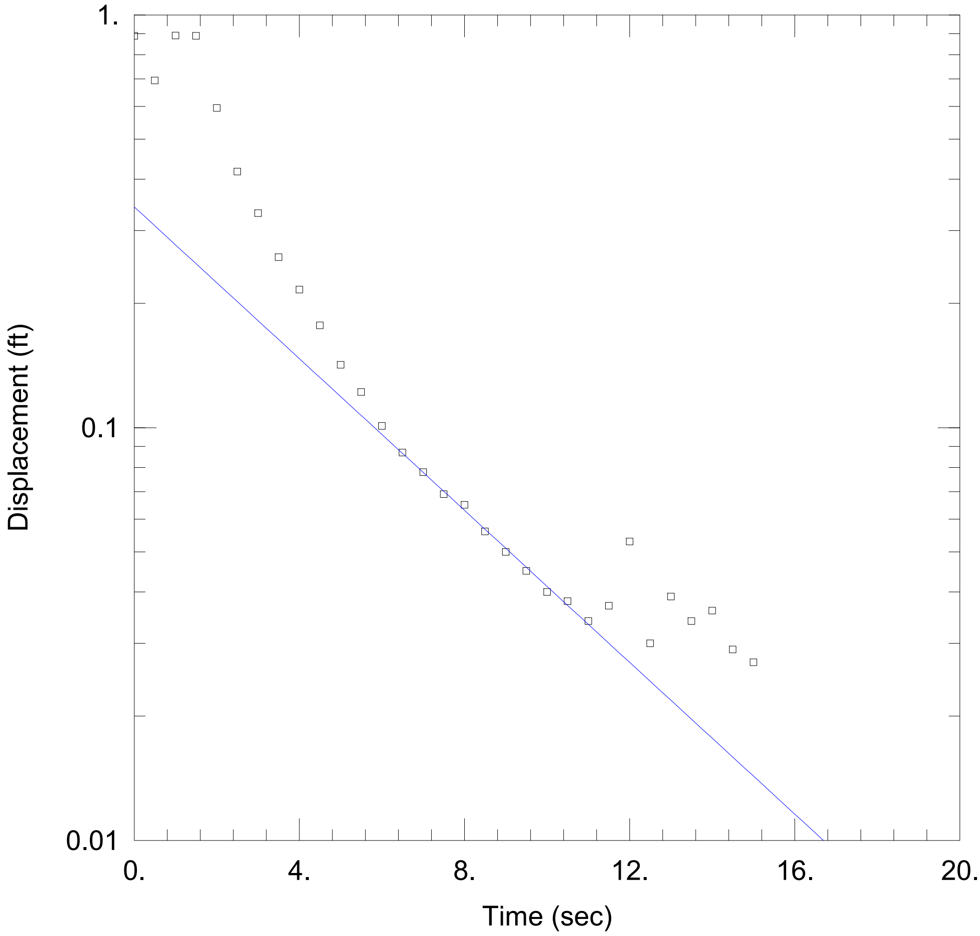
WELL DATA (MW-1S)

Initial Displacement: 0.889 ft   Static Water Column Height: 26.64 ft
Total Well Penetration Depth: 26.64 ft   Screen Length: 20. ft
Casing Radius: 0.167 ft   Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined   Solution Method: Hvorslev

K = 0.001151 ft/sec   y0 = 0.5687 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-1S test1 Rising.aqt
Date: 11/04/13
Time: 11:03:30

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-1S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

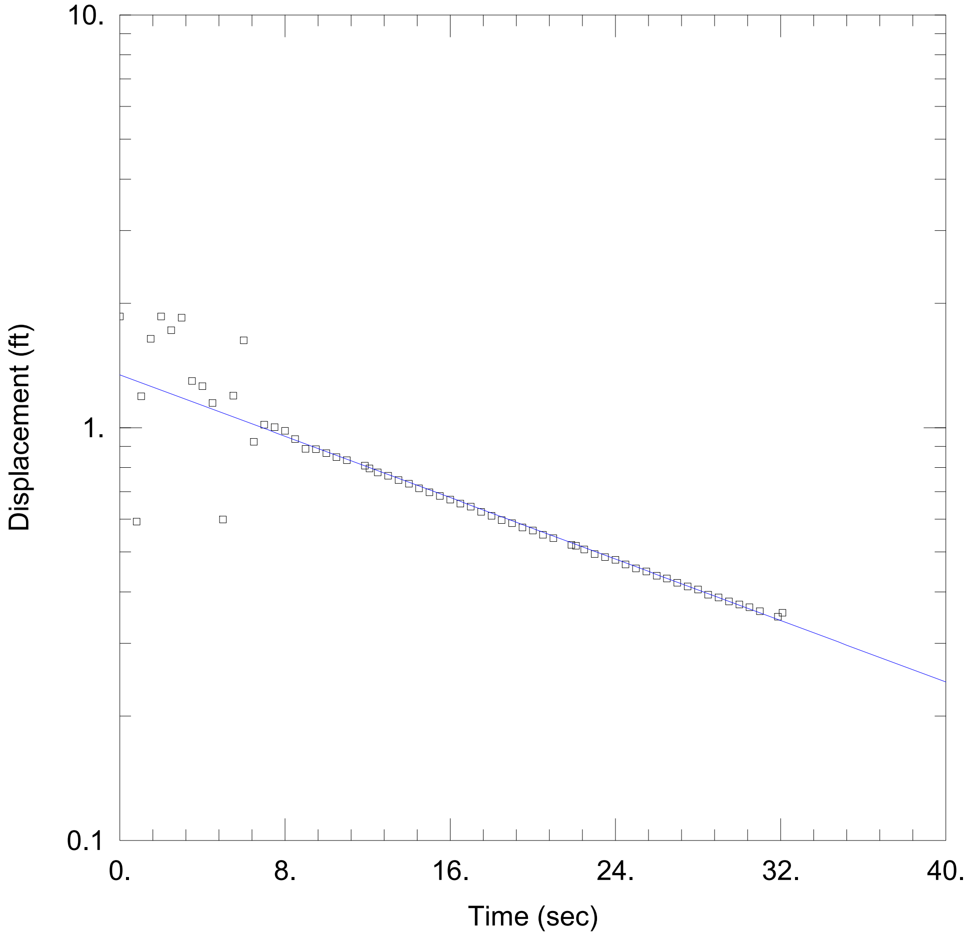
WELL DATA (MW-1S)

Initial Displacement: 0.889 ft
Total Well Penetration Depth: 26.64 ft
Casing Radius: 0.167 ft
Static Water Column Height: 26.64 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 0.0008082 ft/sec
y0 = 0.3425 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-2S test2 Falling.aqt
Date: 10/15/13 Time: 13:36:08

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-2S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

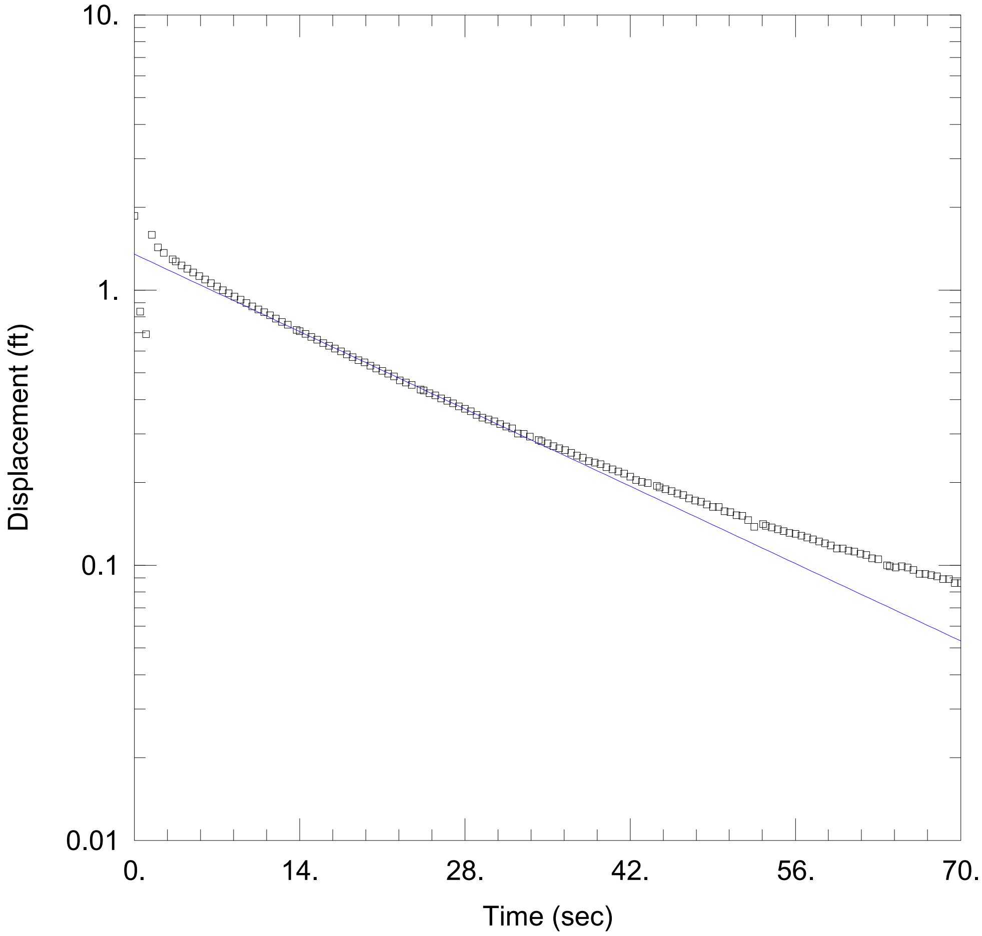
WELL DATA (MW-2S)

Initial Displacement: 1.86 ft
Total Well Penetration Depth: 20.59 ft
Casing Radius: 0.167 ft
Static Water Column Height: 20.59 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 0.0001429 ft/sec
y0 = 1.343 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-2S test2 Rising.aqt
Date: 11/04/13
Time: 10:52:19

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-2S
Test Date: 9/30/2013

AQUIFER DATA

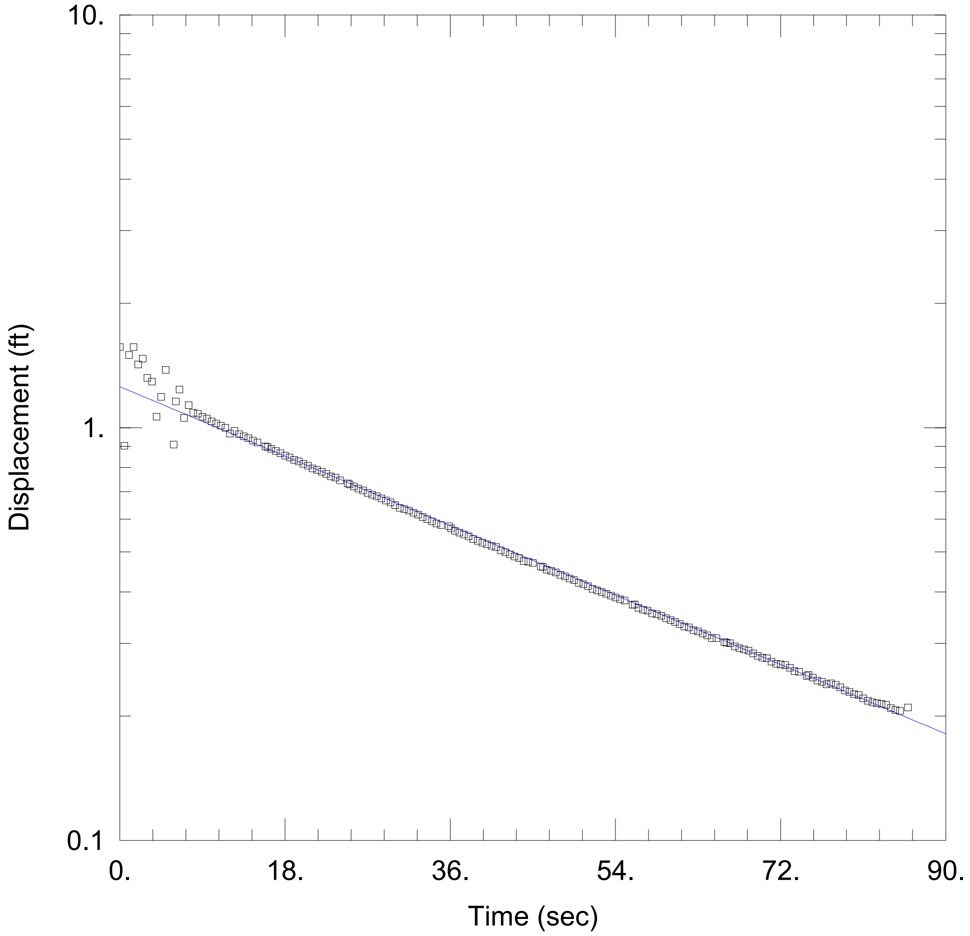
Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-2S)

Initial Displacement: 1.86 ft
Total Well Penetration Depth: 20.59 ft
Casing Radius: 0.167 ft
Static Water Column Height: 20.59 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.0001543 ft/sec
y0 = 1.351 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-3S test1 Falling.aqt
Date: 10/15/13 Time: 13:53:59

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-3S
Test Date: 9/30/2013

AQUIFER DATA

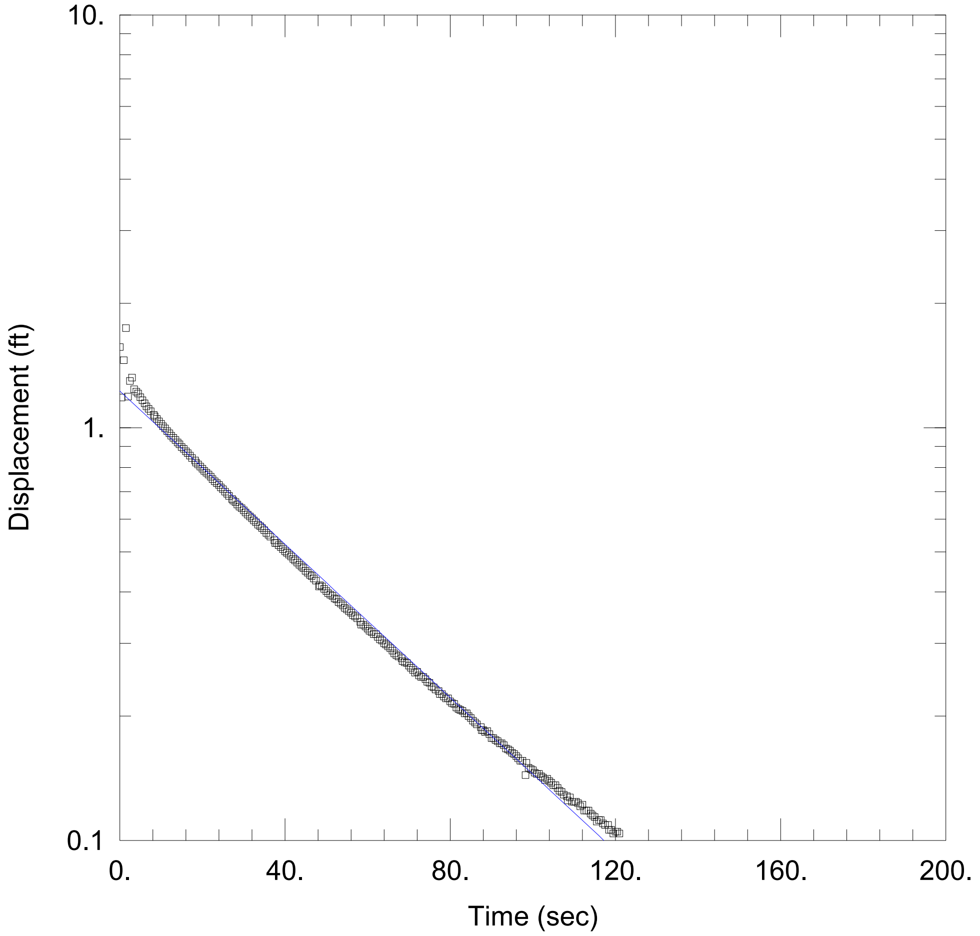
Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-3S)

Initial Displacement: 1.567 ft
Total Well Penetration Depth: 31.25 ft
Casing Radius: 0.167 ft
Static Water Column Height: 22.3 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 8.219E-5 ft/sec
y0 = 1.256 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-3S test1 Rising.aqt
Date: 11/04/13 Time: 10:56:55

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-3S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft Anisotropy Ratio (Kz/Kr): 1.

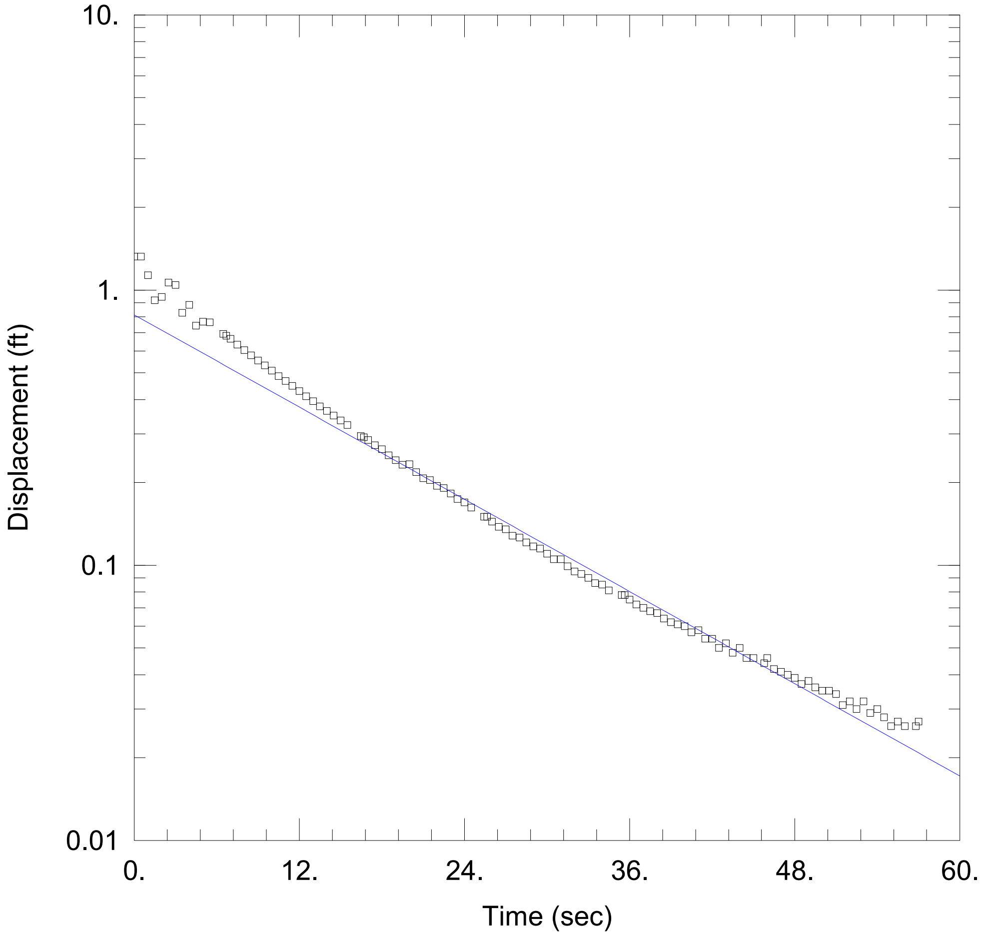
WELL DATA (MW-3S)

Initial Displacement: 1.567 ft
Total Well Penetration Depth: 21.86 ft
Casing Radius: 0.167 ft
Static Water Column Height: 22.3 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 8.169E-5 ft/sec y0 = 1.227 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-4S test1 Falling.aqt
Date: 10/15/13 Time: 14:13:54

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-4S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft Anisotropy Ratio (Kz/Kr): 1.

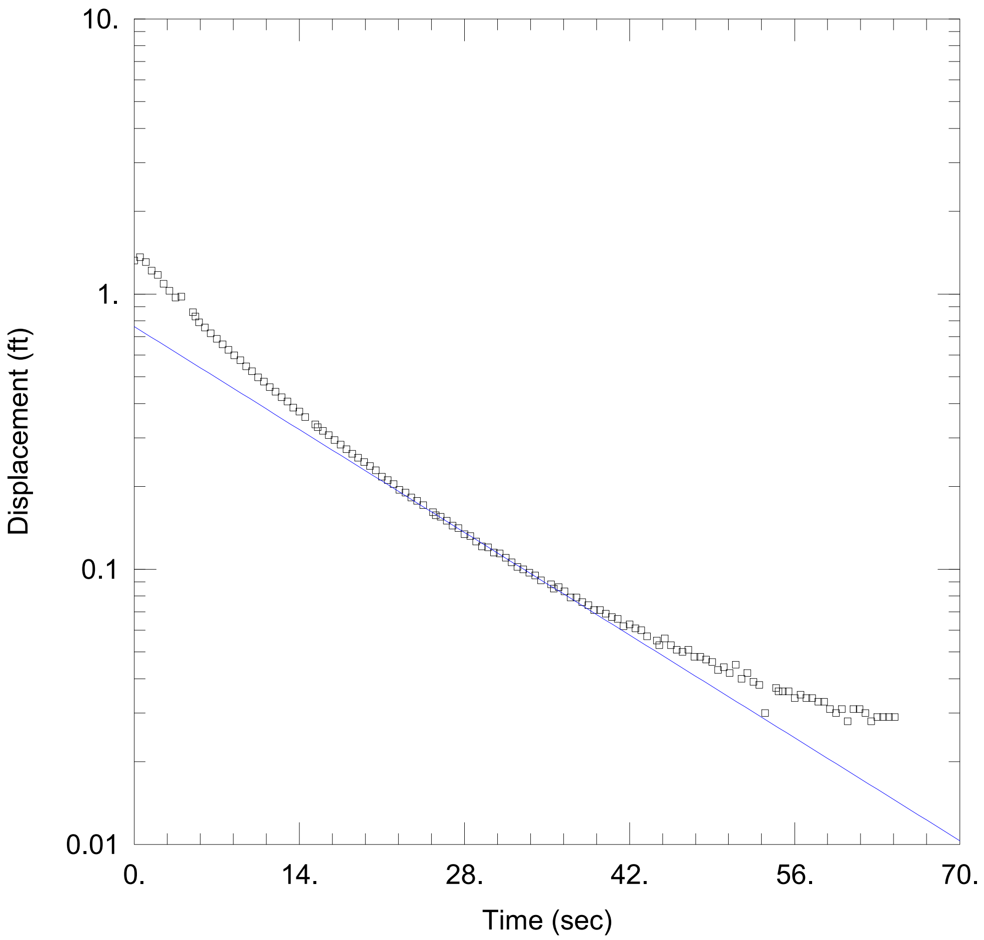
WELL DATA (MW-4S)

Initial Displacement: 1.323 ft
Total Well Penetration Depth: 23.48 ft
Casing Radius: 0.167 ft
Static Water Column Height: 23.48 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.0002457 ft/sec y0 = 0.8126 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-4S test1 Rising.aqt
Date: 11/04/13 Time: 10:33:43

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-4S
Test Date: 9/30/2013

AQUIFER DATA

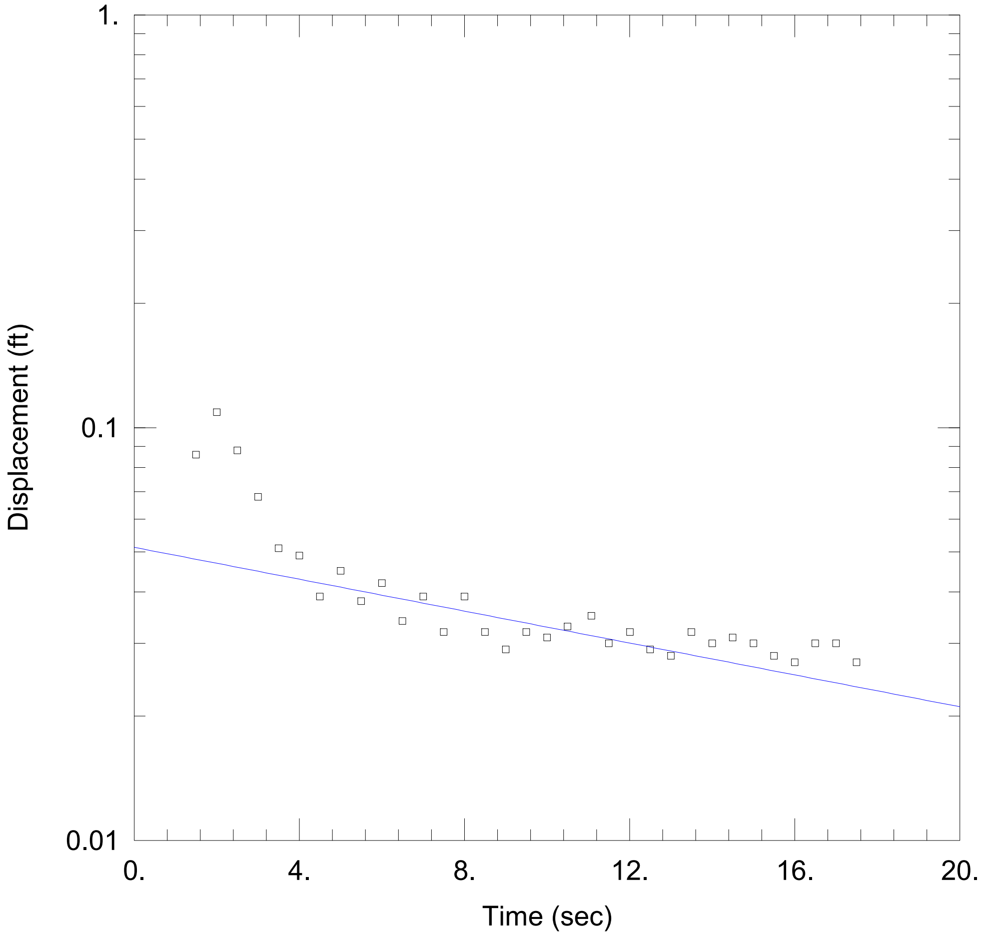
Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-4S)

Initial Displacement: 1.323 ft
Static Water Column Height: 23.48 ft
Total Well Penetration Depth: 23.48 ft
Screen Length: 20. ft
Casing Radius: 0.167 ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev
K = 0.0002348 ft/sec
y0 = 0.7615 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-6S test2-2 Rising.aqt
Date: 11/04/13
Time: 10:59:10

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-7S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft
Anisotropy Ratio (Kz/Kr): 1.

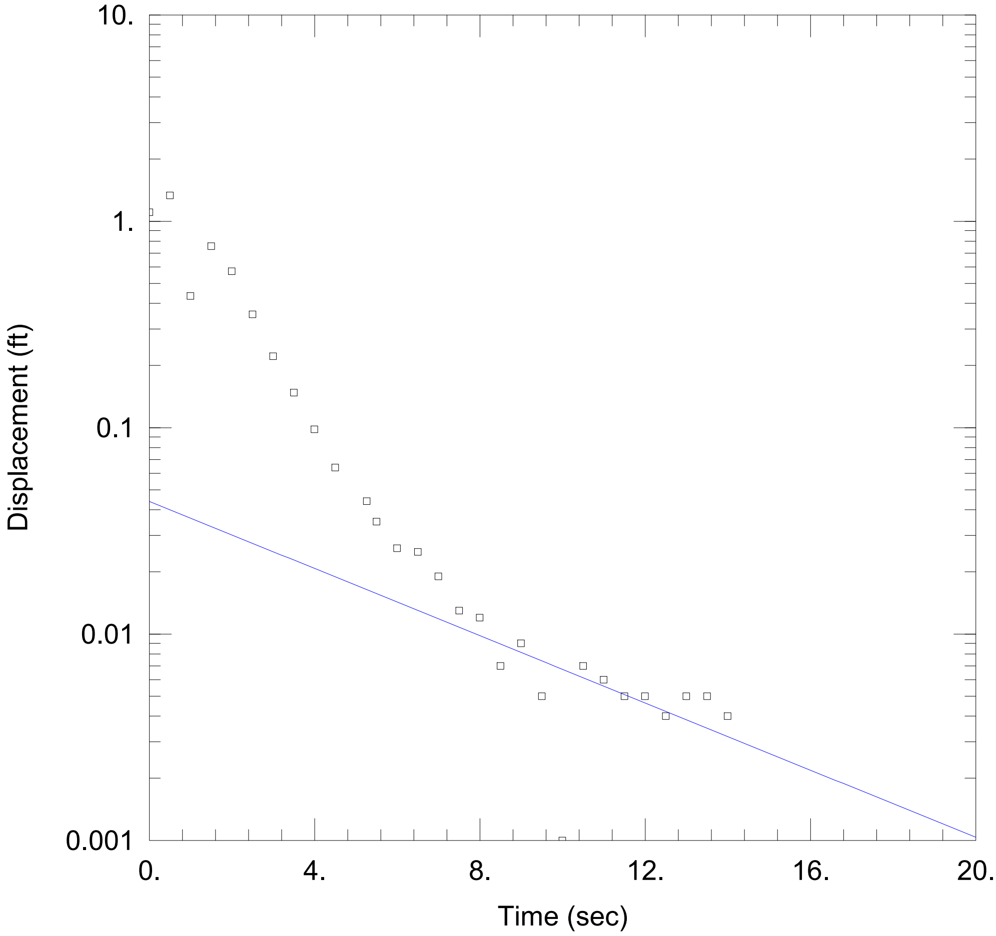
WELL DATA (MW-6S)

Initial Displacement: 1.5 ft
Total Well Penetration Depth: 22.86 ft
Casing Radius: 0.167 ft
Static Water Column Height: 22.86 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined
Solution Method: Hvorslev

K = 0.0001698 ft/sec
y0 = 0.05127 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-7S test2 Rising.aqt
Date: 11/04/13 Time: 11:00:23

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-7S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft Anisotropy Ratio (Kz/Kr): 1.

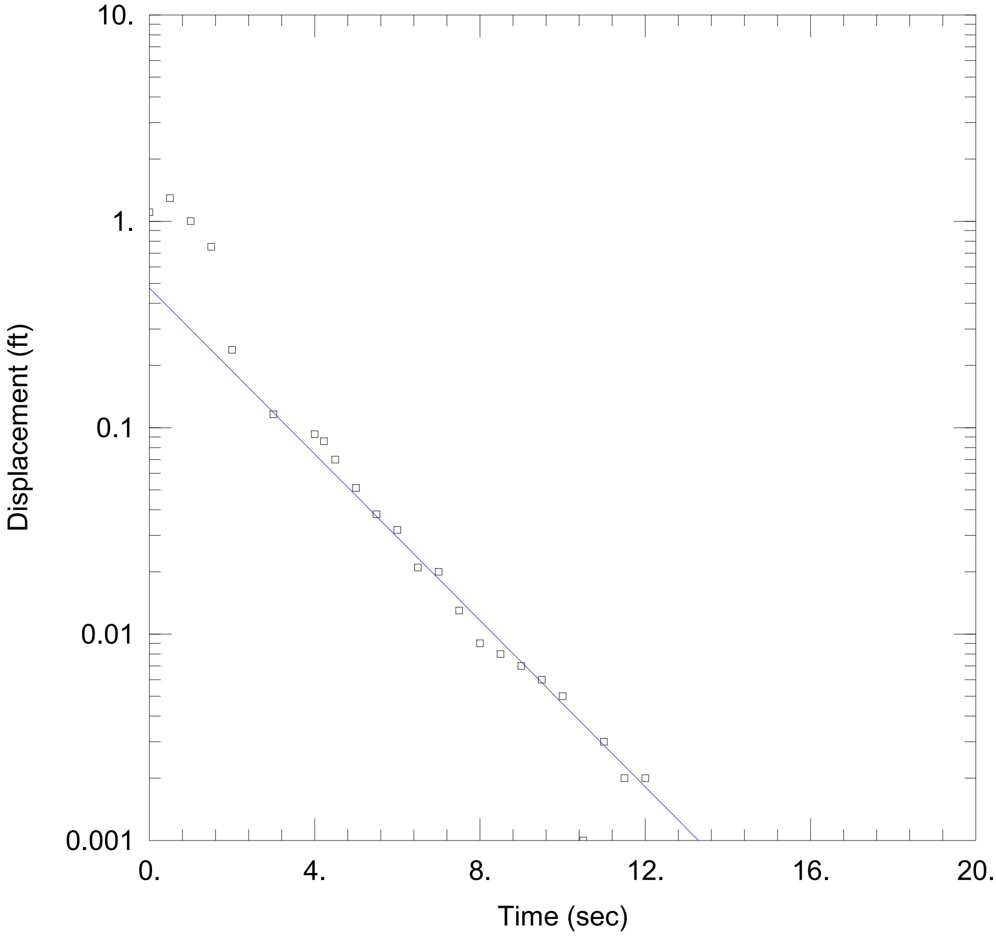
WELL DATA (MW-6S)

Initial Displacement: 1.104 ft
Total Well Penetration Depth: 25.04 ft
Casing Radius: 0.167 ft
Static Water Column Height: 25.04 ft
Screen Length: 20. ft
Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.0007157 ft/sec y0 = 0.04391 ft



WELL TEST ANALYSIS

Data Set: I:\...\MW-7S test3 Falling.aqt
Date: 10/15/13 Time: 15:12:28

PROJECT INFORMATION

Company: CRA
Client: ZionSolutions
Project: 54638
Location: Zion, IL
Test Well: MW-7S
Test Date: 9/30/2013

AQUIFER DATA

Saturated Thickness: 21.53 ft Anisotropy Ratio (Kz/Kr): 1.

WELL DATA (MW-7S)

Initial Displacement: 1.104 ft Static Water Column Height: 25.04 ft
Total Well Penetration Depth: 25.04 ft Screen Length: 20. ft
Casing Radius: 0.167 ft Well Radius: 0.167 ft

SOLUTION

Aquifer Model: Unconfined Solution Method: Hvorslev

K = 0.001771 ft/sec y0 = 0.4751 ft

Appendix D

September 30, 2013 Geotechnical Subsurface Investigation Letter Report (dated November 15, 2013)

CONESTOGA-ROVERS
& ASSOCIATES

8615 W. Bryn Mawr Avenue, Chicago, Illinois 60631-3501
Telephone: (773) 380-9933 Fax: (773) 380-6421
www.CRAworld.com

November 15, 2013 Reference No. 054638-21

DRAFT

Mr. Robert Decker
ZionSolutions, LLC
101 Shiloh Blvd
Zion, IL 60099

Dear Mr. Decker:

Re: September 30, 2013 Geotechnical Subsurface Investigation
Zion Nuclear Power Station Decommissioning Project

Conestoga-Rovers & Associates (CRA) was retained by ZionSolutions, LLC (ZionSolutions) for hydrogeology consulting services related to the decommissioning of the Zion Nuclear Power Station in Zion, Lake County, Illinois (Site). On September 30, 2013, CRA completed a subsurface geotechnical investigation at the Site. The purpose of the investigation was to collect soil samples for laboratory analysis in an effort to determine Site-specific values for the following geotechnical parameters: bulk density, hydraulic conductivity, porosity, and field capacity.

The subsurface investigation included the advancement of three soil borings in the vicinity of existing monitoring wells on the eastern and western portions of the Site. Figure 1 presents the locations of the three soil borings. The soil boring identifier and the approximate location of each soil boring is described in the following table:

Table 1 – Boring identifiers and approximate locations			
Soil Boring Identifier	***Easting***	***Northing***	***Narrative Location***
GT2-MW-01s	343,798	641,834	Approximately 5 feet north of MW-01s
GT2-MW-02s	343,789	641,782	Approximately 5 feet north of MW-02s
GT2-MW-06s	343,287	641,724	Approximately 7 feet north of MW-06s

Drilling services were provided by Testing Services Corporation (TSC) of Carol Stream, Illinois using a drill rig equipped with 4.25-inch inside diameter hollow stem augers. Samples were collected at select intervals using Shelby tubes when possible. Samples that could not be contained within the Shelby tubes were collected as bagged samples and remolded by the laboratory. Soil samples were also collected for field capacity analysis. The borings were logged by a CRA geologist. The boring logs are provided in Attachment 1.

A total of seven soil samples from the three soil boring locations were selected for geotechnical analysis to confirm the results of prior analyses at the east side of the Site and to acquire geotechnical data from the west side of the Site. The pre-determined soil sample depths were intended to target the following stratigraphic units at the Site:

- **Fill Sand** – Sand which originated as natural beach sand excavated during the construction of the facility in the early 1970s and then was returned to the excavation as fill material.
- **Native Sand** – Beach sand which was not disturbed by construction activities at the facility.

The following soil samples were selected for laboratory analysis:

Table 2 – Selection of samples for analysis			
Soil Boring Identifier	***Target Depth Interval (feet bgs)[1]***	***Sample Identifier***	***Target Stratigraphic Unit***
GT2-MW-01s	2-5	GT2-MW-01S-5	fill sand (vadose zone)
	16-20	GT2-MW-01S-20	fill sand (saturated zone)
	24-28	GT2-MW-01S-28	native sand (saturated zone)
GT2-MW-02s	2-5	GT2-MW-02S-5	fill sand (vadose zone)
	12-26	GT2-MW-02S-26	fill sand (saturated zone)
GT2-MW-06s	2-5	GT2-MW-06S-5	native sand (vadose zone)
	16-20	GT2-MW-06S-20	native sand (saturated zone)

The samples were screened for radiological contamination in accordance with ZionSolutions' standard operating procedures prior to hand delivery to TSC's laboratory in Carol Stream. Soil samples were shipped to Agvise Laboratory (Agvise) in Northwood, North Dakota via overnight courier.

<u>Results</u>

The laboratory reports are provided as Attachment 2. Hydraulic conductivity, porosity, and bulk density values were determined by TSC. Field capacity values were determined by Agvise.

The following presents an overview of the results compared to literature values.

Hydraulic Conductivity

The hydraulic conductivity for sand is expected to be between 3E-04 to 3E-03 centimeters per second (cm/s) or 1E+02 and 1E+05 meters per year (m/y) based upon the Argonne National Laboratory (ANL) Data Collection Handbook (Yu, et al., 1993). The geometric mean of the laboratory results is 1.73E+03 m/y, which falls within the expected range. The laboratory results are summarized in Table 3 below.

[1] bgs – below ground surface

Soil Porosity

The Illinois Tiered Approach to Corrective Action Objectives (TACO) default value for the total porosity of sand is 32% by volume. Fetter (Fetter, 1994) lists a range of 25 to 50% for well sorted sand or gravel. The arithmetic mean of the laboratory porosity values is 35.3%, which falls within the range of literature values.

Bulk Density

The Illinois TACO default value for the dry bulk density of sand is 1.8 kg/L or 112.4 pounds per cubic foot (pcf). The arithmetic mean of the laboratory bulk density values is 1.82 g/cm^3 (113.6 pcf), which is similar to the literature value.

Table 3 – Hydraulic conductivity, bulk density, and porosity

Soil Boring Identifier	*Sample Identifier*	*Hydraulic Conductivity (cm/s)*	*Hydraulic Conductivity (m/y)*	*Porosity (%)*	*Bulk Density (pcf)*
GT2-MW-01S	GT2-MW-01S-5	5.36E-03	1.69E+03	33.2	112.6
GT2-MW-01S	GT2-MW-01S-20	3.94E-03	1.24E+03	29.7	118
GT2-MW-01S	GT2-MW-01S-28	3.13E-02	9.88E+03	31.6	115.3
GT2-MW-02S	GT2-MW-02S-5	1.26E-03	3.98E+02	33.4	118.4
GT2-MW-02S	GT2-MW-02S-26	1.96E-03	6.19E+02	36.9	112.5
GT2-MW-06S	GT2-MW-06S-5	1.04E-02	3.28E+03	39.3	102.2
GT2-MW-06S	GT2-MW-06S-20	8.77E-03	2.77E+03	42.7	116.2
Arithmetic mean		- -	- -	35.3	113.6
Geometric mean		5.48E-03	1.73E+03	- -	- -

Soil Water Retention Curves and Field Capacity

Field capacity is defined as the ratio of the volume of water retained in the soil sample, after all downward gravity drainage has ceased, to the total volume of the sample. For most soils, the field capacity corresponds to a negative pressure of 0.1 bar (sand), 0.2 bar (silty clay loam), or 0.3 bar (loam) (Klocke & Hergert, 1990). Laboratory measurements of field capacity typically use a negative pressure of 1/3 bar (Nachabe, 1998). A volumetric water content greater than the field capacity is not available for plant use because it drains away quickly. The wilting point is the maximum pressure that a plant can exert to overcome the tension of the water adhering to the soil. The wilting point corresponds to a negative pressure of 15 bars.

Typical field capacity values range from 2.8% to 3.9%[1] for sand and loamy sand, respectively (USDA Natural Resources Conservation Service, 2008). The arithmetic mean of the laboratory values for field capacity is 2.7% by volume. Soil water retention curves were developed using the water content under negative pressures of 0-15 bar. The soil water retention curves are included in Attachment 3.

Table 4 – Field Capacity			
Soil Boring Identifier	***Sample Identifier***	***Field Capacity (%)***	
		0.1 bar	***1/3 bar***
GT2-MW-01S	GT2-MW-01S-5	10.4	4.7
GT2-MW-01S	GT2-MW-01S-20	3.6	1.2
GT2-MW-01S	GT2-MW-01S-28	6.5	2.5
GT2-MW-02S	GT2-MW-02S-5	10.3	4.1
GT2-MW-02S	GT2-MW-02S-26	8.9	3.8
GT2-MW-06S	GT2-MW-06S-5	3.9	1.8
GT2-MW-06S	GT2-MW-06S-20	2.9	1.0
	Arithmetic mean	6.64	2.73

References

Fetter, C. (1994). Applied Hydrogeology, 3rd Edition. New York: Macmillan.

Klocke, N. L., & Hergert, G. W. (1990). G90-964 How Soil Holds Water. *Historical Materials from University of Nebraska-Lincoln Extension*. University of Nebraska-Lincoln.

Nachabe, M. H. (1998, August). Refining the Definition of Field Capacity in the Literature. *Journal of Irrigation and Drainage Engineering, 124(4)*. American Society of Civil Engineers.

USDA Natural Resources Conservation Service. (2008, June). Soil Quality Indicators.

Yu, C., Loureiro, C., Cheng, J. J., Jones, L. G., Wang, Y. Y., Chia, Y. P., & Faillace, E. (1993, April). Data Collection Handbook to Support Modeling Impacts of Radioactive Material in Soil. Argonne, Illinois: Argonne National Laboratory.

[1] 1 to 1.4 inches of water per foot of soil assuming a soil porosity of 30% (1/(12×3)=2.8% or 1.4/(12×3)=3.9%).

If you have any questions or comment, please feel free to contact me by email (dsoutter@craworld.com) or telephone (773-380-9933).

Yours truly,

CONESTOGA-ROVERS & ASSOCIATES

Douglas G. Soutter

DS/ko/12
Encl.

cc: Phil Harvey, CRA

N

0 50 100ft

LEGEND

PROPERTY LINE

FENCE LINE

RAILROAD

EDGE OF WATER

TRAIL

MW-ZN-09S MONITORING WELL LOCATION

GT2-MW-01S SOIL BORING LOCATION FOR GEOTECHNICAL ANALYSIS

DRAFT

SCALE VERIFICATION

THIS BAR MEASURES 1" ON ORIGINAL. ADJUST SCALE ACCORDINGLY.

ZIONSOLUTIONS

SOIL BORING LOCATIONS
SEPTEMBER 2013
FORMER ZION NUCLEAR POWER STATION

CONESTOGA-ROVERS & ASSOCIATES

Source Reference: RUSSELL WAID DILLON SURVEYING SERVICES, ZION NUCLEAR GENERATING STATION, 5-3-2000

Project Manager:	Reviewed By:	Date:	
Scale: AS SHOWN	Project Nº: 54638-21	Report Nº: DECK012	Drawing Nº: figure 1

54638-21(DECK012)GN-CO001 NOV 13/2013

ATTACHMENT 1

BORING LOGS

STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

PROJECT NAME: Zion Solutions Facility
PROJECT NUMBER: 054638
CLIENT: Zion Solutions
LOCATION: Zion, Illinois
DRILLING CONTRACTOR: TSC

HOLE DESIGNATION: GT2-MW-01S
DATE COMPLETED: September 30, 2013
DRILLING METHOD: 4¼" ID HSA
FIELD PERSONNEL: K. White
DRILLER: Francisco

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS	BOREHOLE
0–6	SP SAND, some gravel, few stones about 1 inch in diameter, fine to medium grained sand, brown, moist	6.00	Soil Cuttings
6–14	Blind drilled	14.00	Soil Cuttings
14–28	SP SAND, with gravel, trace silt, loose to compact, fine to medium grained sand, brown, wet		Soil Cuttings
24	- increase in gravel, grayish brown at 24.0ft BGS		
27	- stone about 2 inches in diameter at 27.0ft BGS		
27.5	- gray at 27.5ft BGS	28.00	
28	END OF BOREHOLE @ 28.0ft BGS		

DEPTH ft BGS	SAMPLE NUMBER	INTERVAL	REC (ft)	'N' VALUE
0–2	1SS	X		10
2–4	ST	■		12
4–6	2SS	X		27
14–16	14-16'	X	1.2	
16–18	ST	■	1.2	
18–20	18-20'	X		
20–22	20-22'	X		
22–24	22-24'	X		
24–26	24-26'	X		
26–28	26-28'	X		

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

GRAIN SIZE ANALYSIS ☐

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 10/7/13

STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

Page 1 of 1

PROJECT NAME: Zion Solutions Facility
PROJECT NUMBER: 054638
CLIENT: Zion Solutions
LOCATION: Zion, Illinois
DRILLING CONTRACTOR: TSC

HOLE DESIGNATION: GT2-MW-02S
DATE COMPLETED: September 30, 2013
DRILLING METHOD: 4¼" ID HSA
FIELD PERSONNEL: K. White
DRILLER: Francisco

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS
0–0.20	FILL, gravel	0.20
0.20–8.00	SP SAND, trace gravel, loose to compact, fine to medium grained sand, brown	8.00
8.00–12.00	Blind drill	12.00
12.00–20.00	SW SAND, some gravel, compact, fine to medium grained sand, brown, wet - some clay from 17.0 to 17.5ft BGS - some clay, with gravel from 18.0 to 18.5ft BGS	20.00
20.00–22.00	SM SILT and SAND, trace gravel and clay, loose, fine grained sand, gray/brown, wet	22.00
22.00	END OF BOREHOLE @ 22.0ft BGS	

BOREHOLE: Soil Cuttings

SAMPLE

NUMBER	INTERVAL (ft BGS)	REC (ft)	'N' VALUE
1SS 0-2'	0–2		13
ST	2–4	2.0	
2SS 4-8'	4–8		12
3SS 12-14'	12–14		14
ST	14–16	0.8	
16-19'	16–19		
18-22'	18–22		

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

GRAIN SIZE ANALYSIS ☐

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 10/7/13

STRATIGRAPHIC AND INSTRUMENTATION LOG (OVERBURDEN)

Page 1 of 1

PROJECT NAME: Zion Solutions Facility
PROJECT NUMBER: 054638
CLIENT: Zion Solutions
LOCATION: Zion, Illinois
DRILLING CONTRACTOR: TSC

HOLE DESIGNATION: GT2-MW-06S
DATE COMPLETED: September 30, 2013
DRILLING METHOD: 4¼" ID HSA
FIELD PERSONNEL: K. White
DRILLER: Francisco

DEPTH ft BGS	STRATIGRAPHIC DESCRIPTION & REMARKS	DEPTH ft BGS	BOREHOLE	SAMPLE NUMBER	SAMPLE INTERVAL	REC (ft)	'N' VALUE
0–6	SM SAND, with silt, trace gravel, loose, fine grained sand, brown, dry - fine to coarse grained sand at 4.0ft BGS	6.00	Soil Cuttings	1SS 0-2'	0-2	1.7	24
				ST	2-4		27
				2SS 4-6'	4-6		10
6–14	Blind drilled	14.00					
14–26	SP SAND, gravelly, some silt, coarse grained sand, brown, wet	26.00		3SS 14-16	14-16		54
				20-23'	20-23		
				23-26'	23-26		
26	END OF BOREHOLE @ 26.0ft BGS						

NOTES: MEASURING POINT ELEVATIONS MAY CHANGE; REFER TO CURRENT ELEVATION TABLE

GRAIN SIZE ANALYSIS ☐

OVERBURDEN LOG 54638 CHI.GPJ CRA_CORP.GDT 10/7/13

ATTACHMENT 2

GEOTECHNICAL LABORATORY REPORTS

TSC

CLIENT: Conestoga Rovers & Associates
8615 W. Bryn Mawr Ave.
Chicago, IL 60631

PROJECT: L-80,843
Exploratory Soil Borings
Zion Solutions
Zion, Illinois

SOIL TESTING SUMMARY

Boring Location	Sample Number	Depth (Feet)	Soil Type	MC %	Density (Bulk) pcf	Specific Gravity (Est)	Porosity (N)	Hydraulic Conductivity cm/sec
GT 2 MW-01S	1	5	SM	4.8	112.6	2.7	33.2	5.36×10^{-3}
GT 2 MW-01S	2	20	SP	10.9	118.0	2.7	29.7	$3.94\ 10^{-3}$
GT 2 MW-01S	3	28	SP - SM	13.7	115.3	2.7	31.6	3.13×10^{-2}
GT 2 MW-02S	1	5	SP - SM	5.5	118.4	2.7	33.4	1.26×10^{-3}
GT 2 MW-02S	2	26	SP - SM	5.8	112.5	2.7	36.9	1.96×10^{-3}
GT 2 MW-06S	1	5	SM	4.3	102.2	2.7	39.3	1.04×10^{-2}
GT 2 MW-06S	2	20	SP - SM	20.6	116.2	2.7	42.7	8.77×10^{-3}

MC Moisture Content
Est Estimated Specific Gravity
N Porosity

AGVISE

AGVISE LABORATORIES

RECEIVED
OCT 21 2013
CRA INC.
CHICAGO

604 Highway 15 West
P.O. Box 510
Northwood, ND 58267
(701) 587-6010
FAX (701) 587-6013
email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-06S-5
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-17-2013

AGVISE Lab No	13-2181
% Moisture at 0 bar	28.8
% Moisture at 1 cm of Water	28.5
% Moisture at 1/10 Bar	3.9
% Moisture at 1/3 Bar	1.8
% Moisture at 1.0 Bar	1.5
% Moisture at 5.0 Bar	1.1
% Moisture at 10 Bar	0.9
% Moisture at 15 Bar	0.8

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

10/18/13
Date

Agricultural Testing

AGVISE LABORATORIES

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Northwood, ND 58267

(701) 587-6010
FAX (701) 587-6013

email: agvise@polarcomm.com
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AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-06S-20
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-17-2013

AGVISE Lab No	13-2182
% Moisture at 0 bar	24.1
% Moisture at 1 cm of Water	23.8
% Moisture at 1/10 Bar	2.9
% Moisture at 1/3 Bar	1.0
% Moisture at 1.0 Bar	0.7
% Moisture at 5.0 Bar	0.6
% Moisture at 10 Bar	0.5
% Moisture at 15 Bar	0.5

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

AGVISE LABORATORIES

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email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-01S-5
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-17-2013

AGVISE Lab No	13-2183
% Moisture at 0 bar	24.7
% Moisture at 1 cm of Water	22.6
% Moisture at 1/10 Bar	10.4
% Moisture at 1/3 Bar	4.7
% Moisture at 1.0 Bar	3.5
% Moisture at 5.0 Bar	2.0
% Moisture at 10 Bar	2.1
% Moisture at 15 Bar	2.0

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

Agricultural Testing

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email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-01S-20
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-17-2013

AGVISE Lab No	13-2184
% Moisture at 0 bar	25.0
% Moisture at 1 cm of Water	23.5
% Moisture at 1/10 Bar	3.6
% Moisture at 1/3 Bar	1.2
% Moisture at 1.0 Bar	0.8
% Moisture at 5.0 Bar	0.6
% Moisture at 10 Bar	0.5
% Moisture at 15 Bar	0.5

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

Agricultural Testing

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email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm = CONESTOGA-ROVERS & ASSOC
Protocol or Study No = REF# 54638-21
Sample ID. = GT2-MW-01S-28
Trial ID. = ZION
Date Received = 10-3-13
Date Reported = 10-17-2013

AGVISE Lab No	13-2185
% Moisture at 0 bar	24.8
% Moisture at 1 cm of Water	24.4
% Moisture at 1/10 Bar	6.5
% Moisture at 1/3 Bar	2.5
% Moisture at 1.0 Bar	1.7
% Moisture at 5.0 Bar	1.1
% Moisture at 10 Bar	0.9
% Moisture at 15 Bar	0.8

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

Agricultural Testing

AGVISE LABORATORIES

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Northwood, ND 58267
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FAX (701) 587-6013
email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-02S-5
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-18-2013

AGVISE Lab No	13-2186
% Moisture at 0 bar	24.7
% Moisture at 1 cm of Water	24.0
% Moisture at 1/10 Bar	10.3
% Moisture at 1/3 Bar	4.1
% Moisture at 1.0 Bar	2.7
% Moisture at 5.0 Bar	1.8
% Moisture at 10 Bar	1.5
% Moisture at 15 Bar	1.5

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

Agricultural Testing

AGVISE LABORATORIES

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Northwood, ND 58267
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FAX (701) 587-6013
email: agvise@polarcomm.com
Homepage: www.agvise.com

AGVISE Soil Characterization Report

Submitting firm	=	CONESTOGA-ROVERS & ASSOC
Protocol or Study No	=	REF# 54638-21
Sample ID.	=	GT2-MW-02S-26
Trial ID.	=	ZION
Date Received	=	10-3-13
Date Reported	=	10-18-2013

AGVISE Lab No	13-2187
% Moisture at 0 bar	24.4
% Moisture at 1 cm of Water	23.2
% Moisture at 1/10 Bar	8.9
% Moisture at 1/3 Bar	3.8
% Moisture at 1.0 Bar	2.5
% Moisture at 5.0 Bar	1.7
% Moisture at 10 Bar	1.4
% Moisture at 15 Bar	1.4

These tests were completed in compliance of 40 CFR Part 160.

Larry Wikoff
Analytical Investigator

Date 10/18/13

Agricultural Testing

METHOD SUMMARY FOR SOIL ANALYSIS

TESTING LABORATORY: **AGVISE LABORATORIES, INC.**
P.O. Box 510; 604 Highway 15 West
Northwood, ND 58267-0510
(701) 587-6010

The following is a summary of analytical methods used by AGVISE Laboratories, Inc. in the determination of soil characteristics and nutrient content. Analytical data of some or all of these analytical methods are presented based upon the testing requested by the firm submitting the soil specimens.

Chemical Properties

Carbonates – Determined by gravimetric loss of Carbon Dioxide (NUT.02.14).

Cation Exchange Capacity – Determined by summing cations and hydrogen (NUT.02.03). The cations of Magnesium, Potassium, Calcium, and Sodium are determined by extraction with 1.0 N Ammonium Acetate (NUT.02.12) or (NUT.02.93). Hydrogen is determined by measuring the pH of the soil in Adams-Evans Buffer Solution (NUT.02.11).

Free Iron Oxide in Soil – Determined by measuring Sodium Citrate/Sodium Bicarbonate/Sodium dithionate extractable Fe (NUT.02.106).

Nitrogen, % Total – Determined by the Kjeldahl method (NUT.02.15) or Combustion Method (NUT.02.107).

Nitrogen, Nitrate and/or Nitrite – Determined using an autoanalyzer with Cadmium Reduction (NUT.02.101).

Nitrogen, Ammoniacal – Determined by the Steam Distillation method (NUT.02.47).

Organic Carbon % - Determined by the Walkley-Black procedure (NUT.02.20) or by Combustion using an Elementar Carbon Analyzer (NUT.02.107).

Organic Matter % - Determined by the Walkley-Black procedure (NUT.02.09) or by the Loss of Weight on Ignition procedure (NUT.02.04).

pH – Determined with a pH electrode in a 1:1 soil:water suspension (NUT.02.05). Alternative procedures include: pH in a 1:1 soil: 1 N KCl suspension (NUT.02.55), pH in a 1:2 soil: 0.01M $CaCl_2$ suspension (NUT.02.80), pH in a 1:1 soil: 0.01M $CaCl_2$ suspension (NUT.02.98), or pH in a saturated paste (NUT.02.39).

Phosphorus – Determined by the Olsen method (NUT.02.07). Alternative procedure includes determination by the Bray method (NUT.02.52).

Silver, Total – Determined by ICP analysis (NUT.02.114) of an acid digestion following EPA Method 3050B (NUT.02.102).

Microbial

Soil Microbial Biomass – Determined by the fumigation extraction method (MIC.02.01).

Soil Microbial Count – Determined by the plate count method (MIC.02.03).

Soil and Sediment Anaerobic Microbial Count – Determined by the anaerobic plate count method (MIC.02.06).

Soil Biomass by Solvita – Determined by measuring the CO2 produced during the Haney-Brinton Method Solvita Test (MIC.02.07).

All of the above methods are detailed in the current analytical SOPs used by AGVISE Laboratories, Inc. Characterization testing laboratory.

NUT.05.01 – Long Term Storage of Soil and Water Characterization Specimens: According to this SOP, soil characterization samples will be retained by AGVISE Laboratories, Inc. for at least two years before disposal and water characterization samples will be retained for a period of 60 days before disposal.

ADM.05.01 – Archivist Duties and Archiving Procedures: This SOP states that copies of soil and water characterization reports, original COC's, original raw data and hard copies generated by computer will be archived within 60 days after the signature by the Analytical Investigator. Supplemental data will be archived annually.

QAU.08.01 – Quality Assurance Inspections of Facilities, Studies, and Processes for GLP Compliance: Method inspections will be performed on a regular basis at AGVISE Laboratories, Inc. For soil characterization, two methods will be inspected per month and one water characterization inspection will be conducted per month. An annual facility audit will be performed by AGVISE Laboratories, Inc. Quality Assurance Unit.

All of the above methods are detailed in the current analytical SOP's used in AGVISE Laboratories, Inc. Characterization laboratory.

APPROVED BY
ANALYTICAL INVESTIGATOR: [signature] 7/11/12
Larry Wikoff, Analytical Investigator **Date**

COPY OF ORIGINAL
AGVISE Laboratories, Inc.
Initial EW Date 10-16-13

CONESTOGA-ROVERS & ASSOCIATES
8615 W. Bryn Mawr Avenue
Chicago, Illinois 60631
(773)380-9933 phone
(773)380-6421 fax

CHAIN-OF-CUSTODY RECORD

SHIPPED TO (Laboratory Name): Agvise, 604 Highway 15 West, P.O. Box 510, Northwood, ND 58267

REFERENCE NUMBER: 59638-21

PROJECT NAME: Zion

SAMPLER'S SIGNATURE: K White
PRINTED NAME: Kristine White

SEQ. No.	DATE	TIME	SAMPLE IDENTIFICATION No.	SAMPLE MATRIX	No. OF CONTAINERS	PARAMETERS: Feldcap(?)	REMARKS (Lab #)
	9/30/13	907	GT2-MW-06S-5	>	1	X	13-2181
	↓	936	GT2-MW-06S(*) 20 (*) As per bag EW 10-4-13	↓	1	X	13-2182
	↓	1310	GT2-MW-01S-5	↓	1	X	13-2183
	↓	1328	GT2-MW-01S-20	↓	1	X	13-2184
	↓	1355	GT2-MW-01S-25	↓	1	X	13-2185
	↓	1450	GT2-MW-02S-5	↓	1	X	13-2186
	↓	1515	GT2-MW-02S-26	↓	1	X	13-2187

Parameters note: Run analysis under CLP guideline as per Doug @ Conestoga Rovers. ejh 10/4/13

Remarks: 0 Bar, 1/10 bar, 1/3 bar, 1 bar, 5 bar, 10 bar, 15 bar + 1 cm.

TOTAL NUMBER OF CONTAINERS: 7

RELINQUISHED BY: ① Kristine White	DATE: 9/30/13 TIME: 1600	RECEIVED BY: ② [signature]	DATE: 9/30/13 TIME: 1600
RELINQUISHED BY: ② [signature]	DATE: 10/1/13 TIME: 1535	RECEIVED BY: ③ [signature]	DATE: 10/30/13 TIME: 1535
RELINQUISHED BY: ③ Kristine White	DATE: 10/2/13 TIME: 10:00	RECEIVED BY: ④	DATE: TIME:

METHOD OF SHIPMENT: Federal Express **AIR BILL No.** 0201 9053 4273 7800 ejh 10/4/13

White -Fully Executed Copy
Yellow -Receiving Laboratory Copy
Pink -Shipper Copy
Goldenrod -Sampler Copy

SAMPLE TEAM: K. White

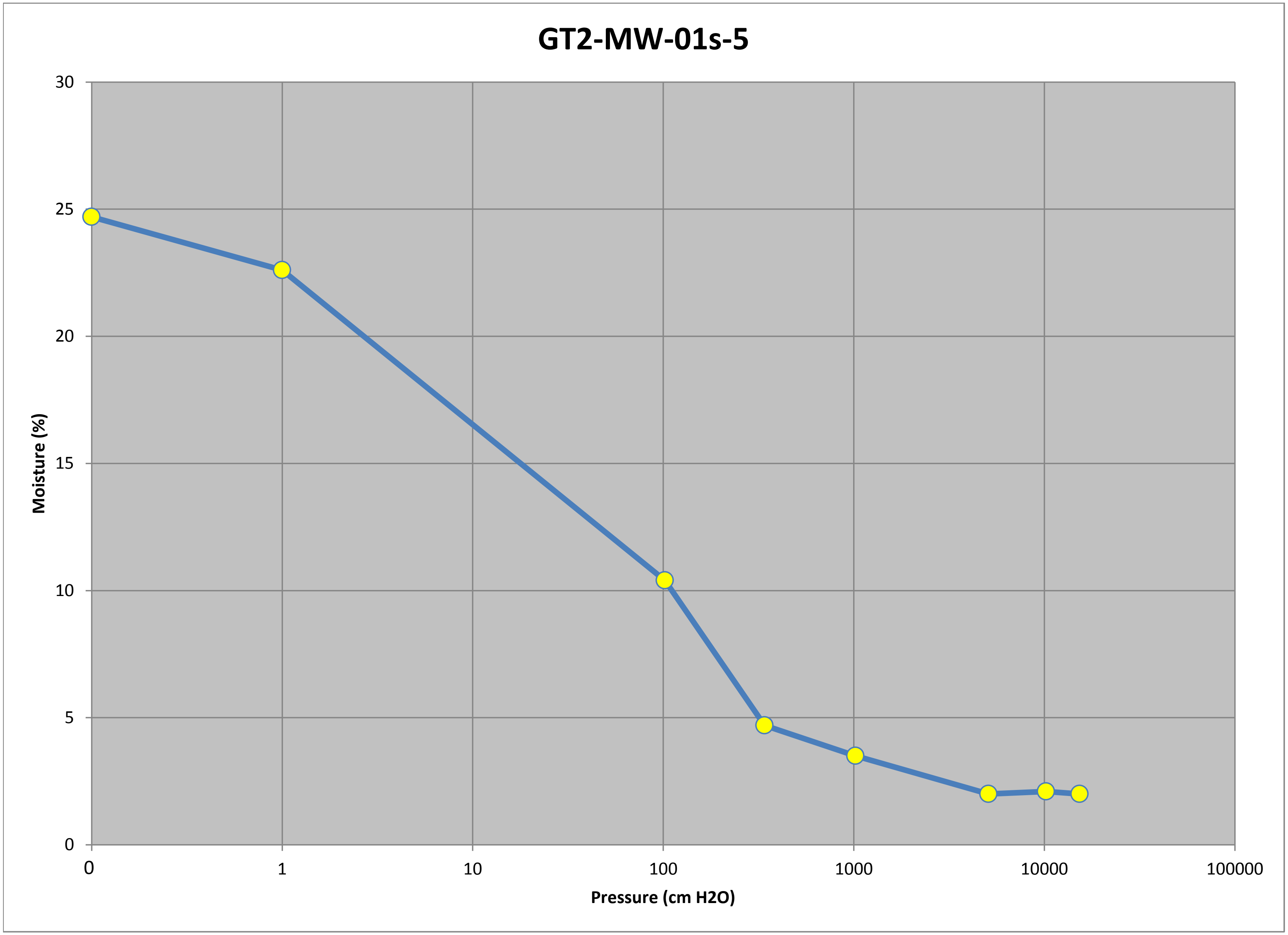
COPY OF ORIGINAL
AGVISE Laboratories, Inc.
Initial EW Date 10-4-13

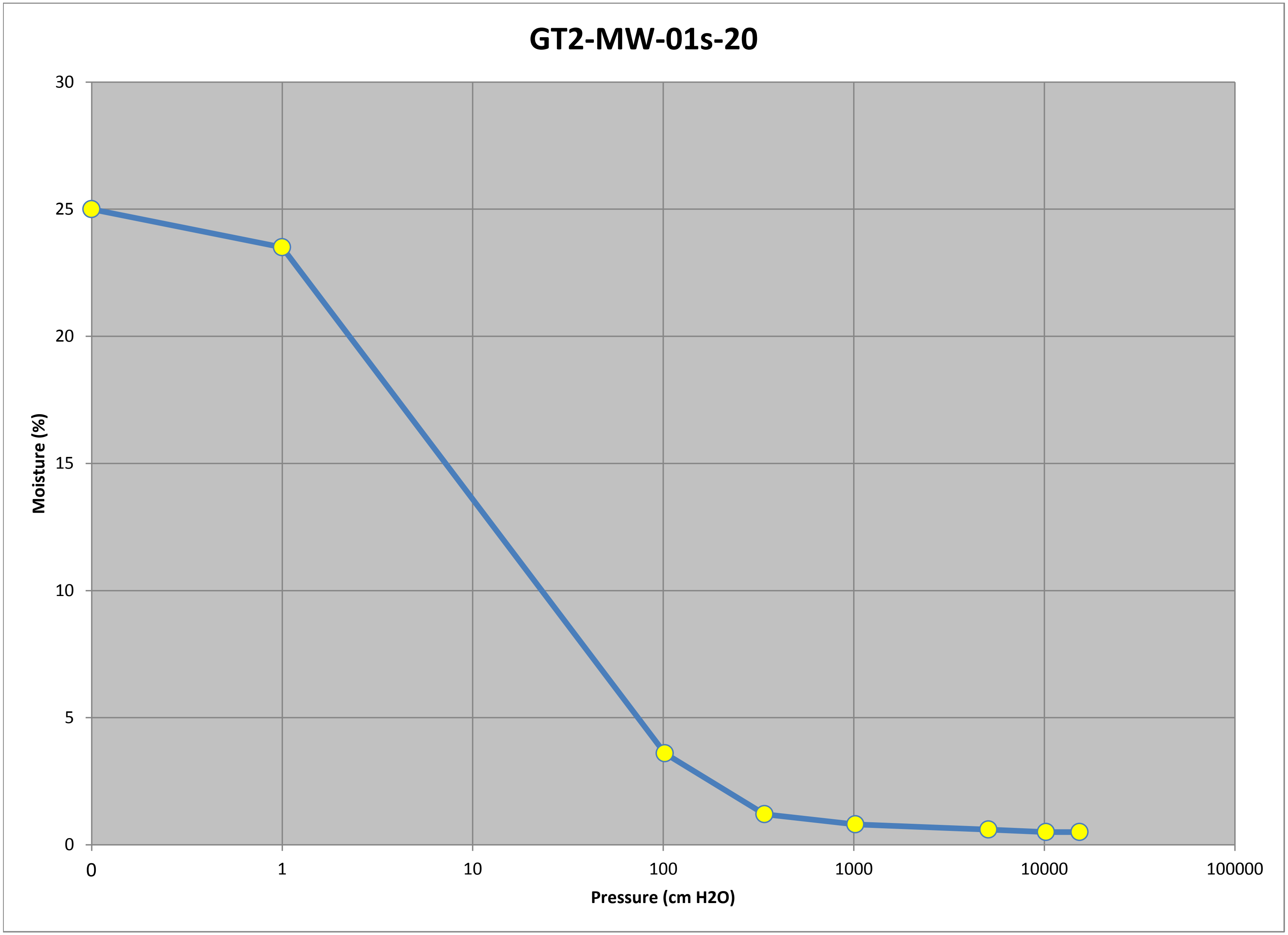
RECEIVED FOR LABORATORY BY: Sherry Hagen AGVISE 10/4/13
DATE: 10-3-13 TIME: 10:00A

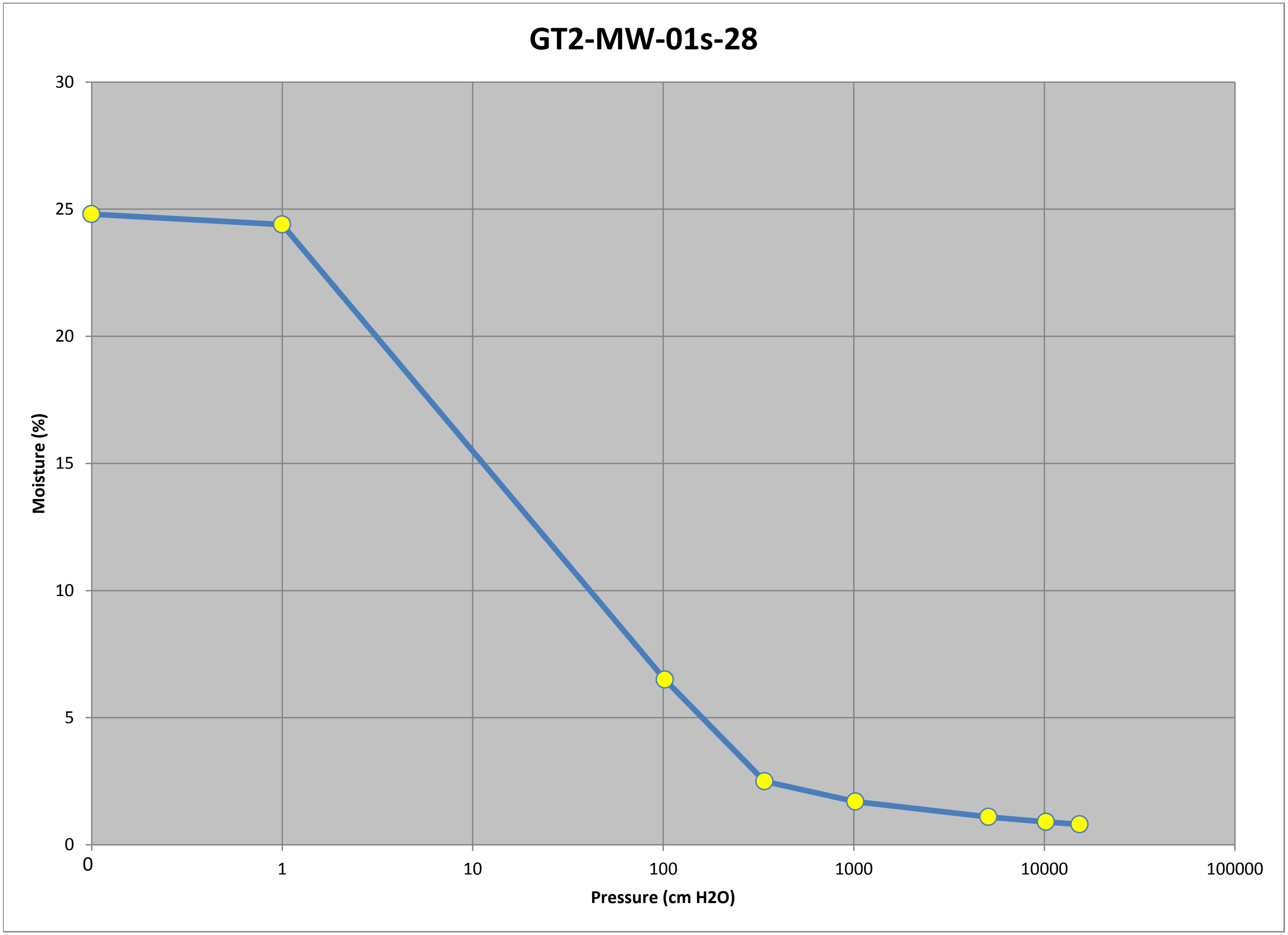
1001-00(SOURCE)GN-CO004

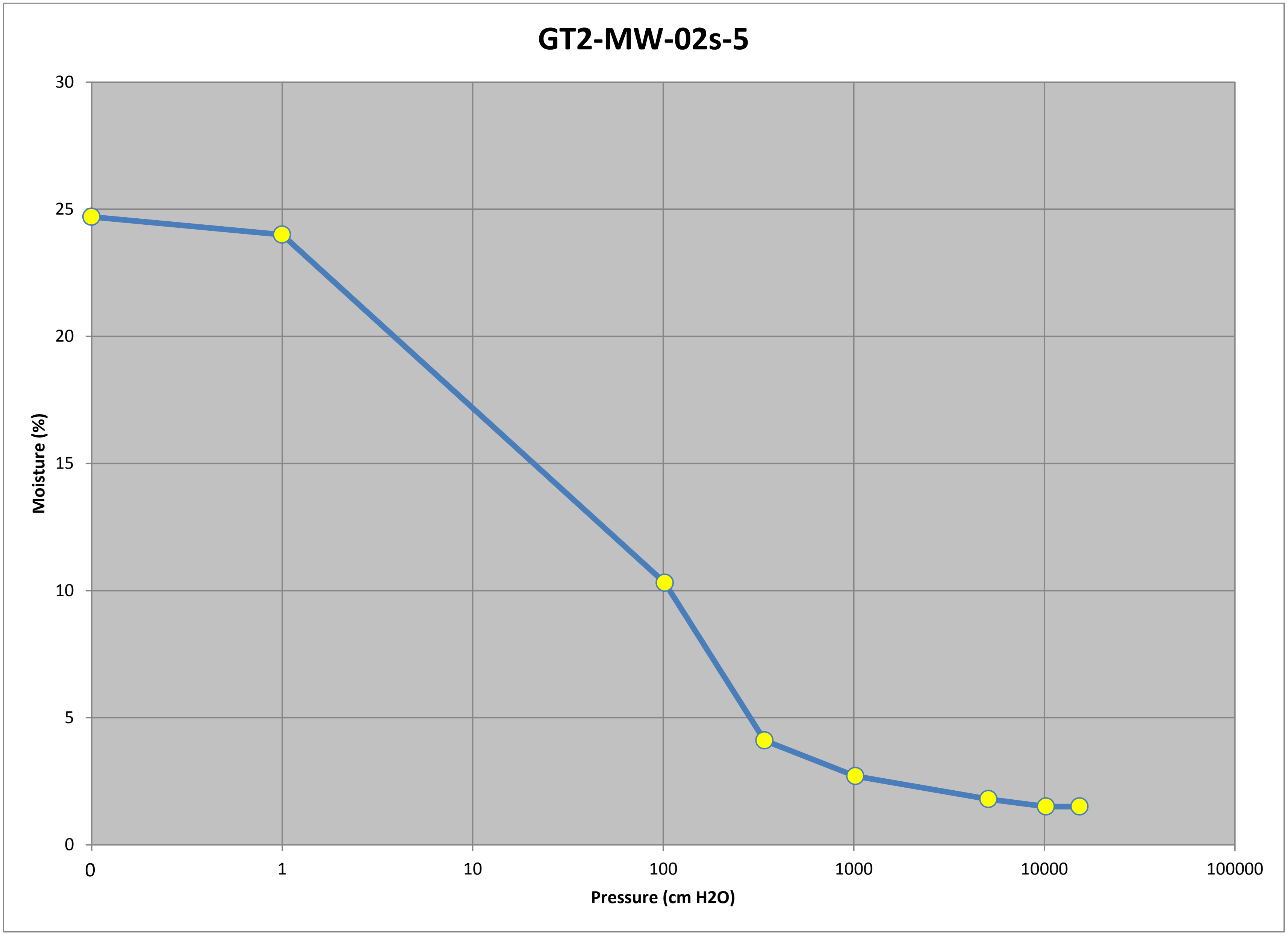
ATTACHMENT 3

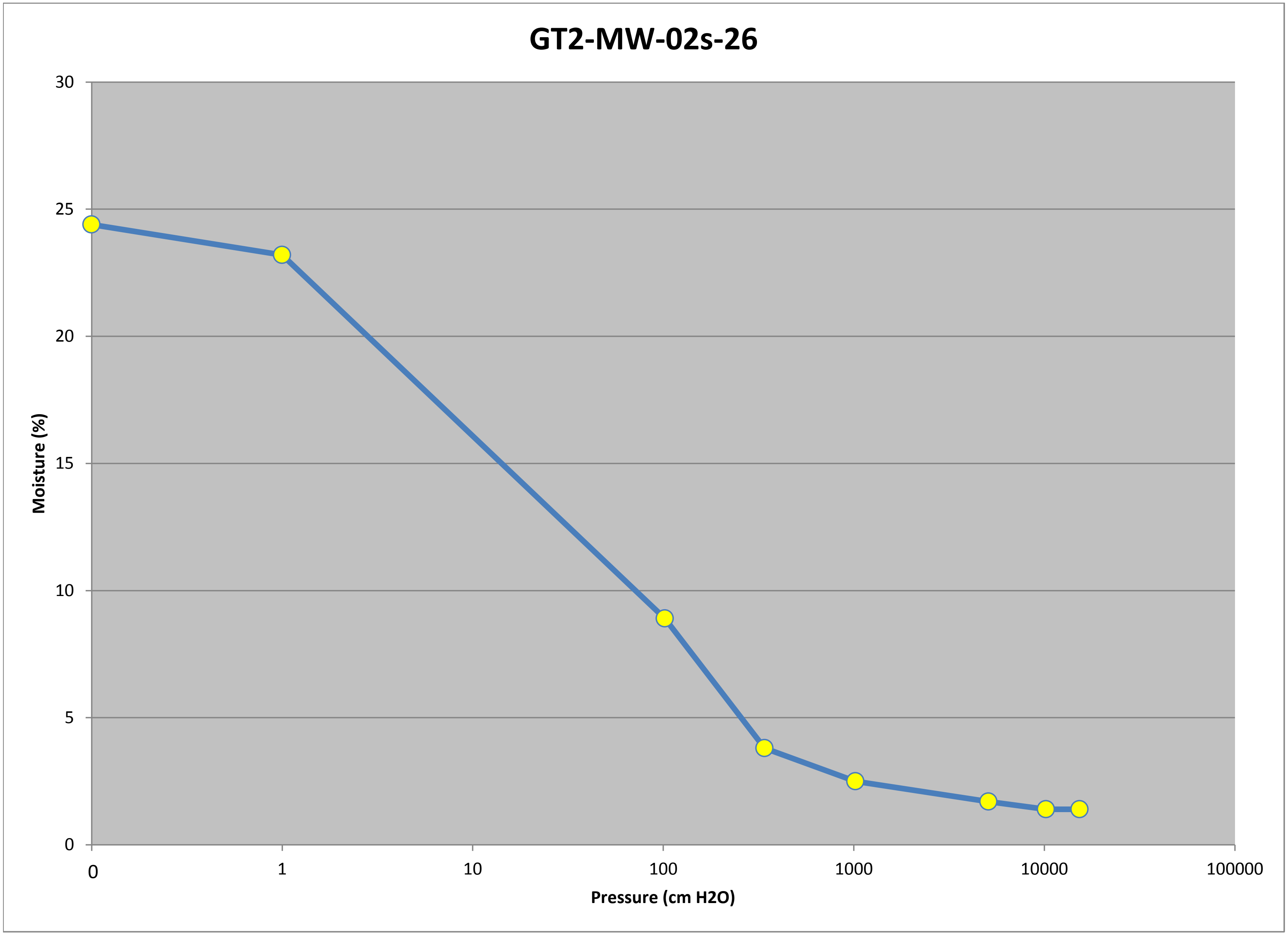
SOIL WATER RETENTION CURVES

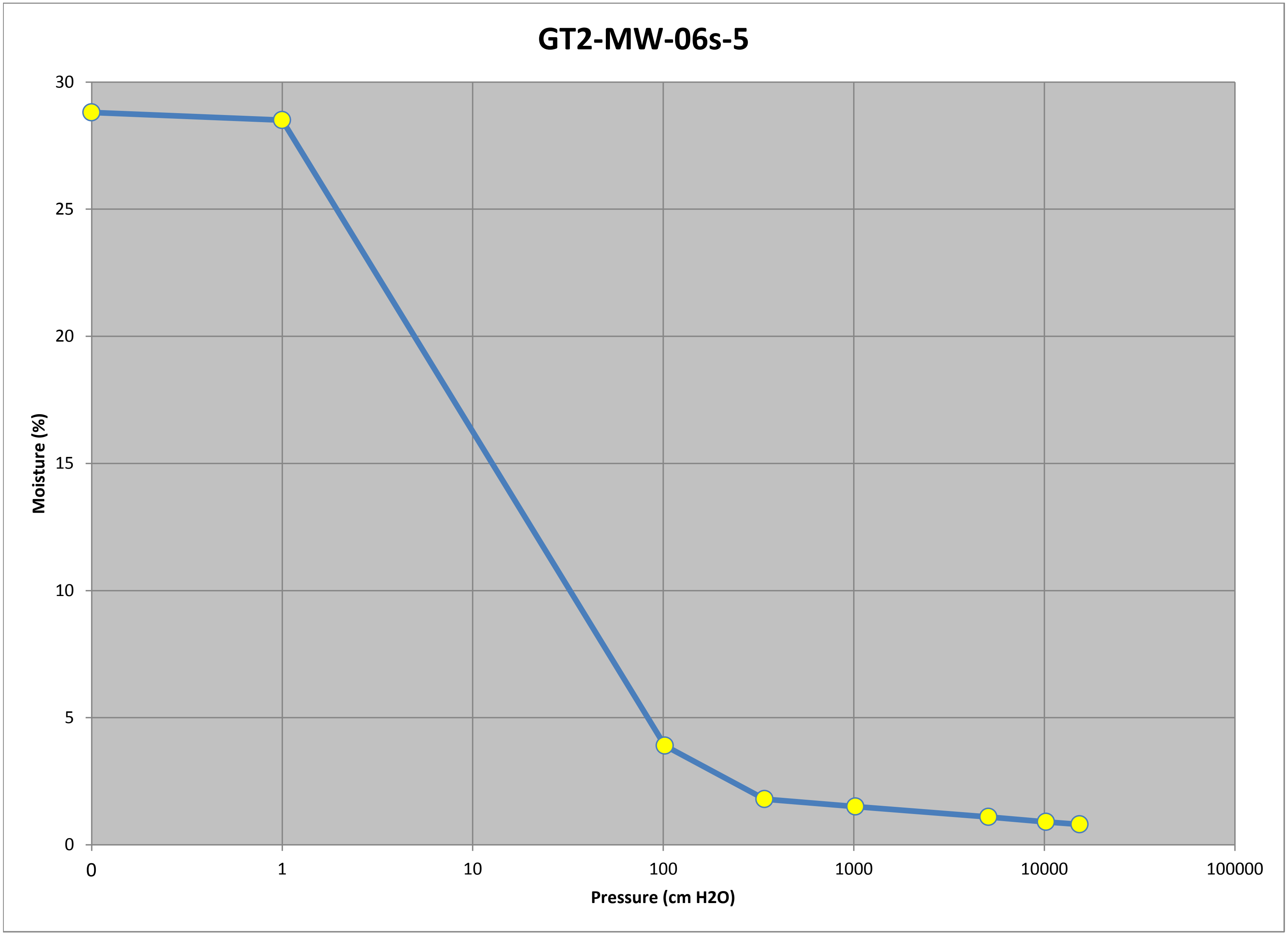

GT2-MW-01s-5
30
25
20
15
10
5
0
Moisture (%)
0
1
10
100
1000
10000
100000
Pressure (cm H2O)

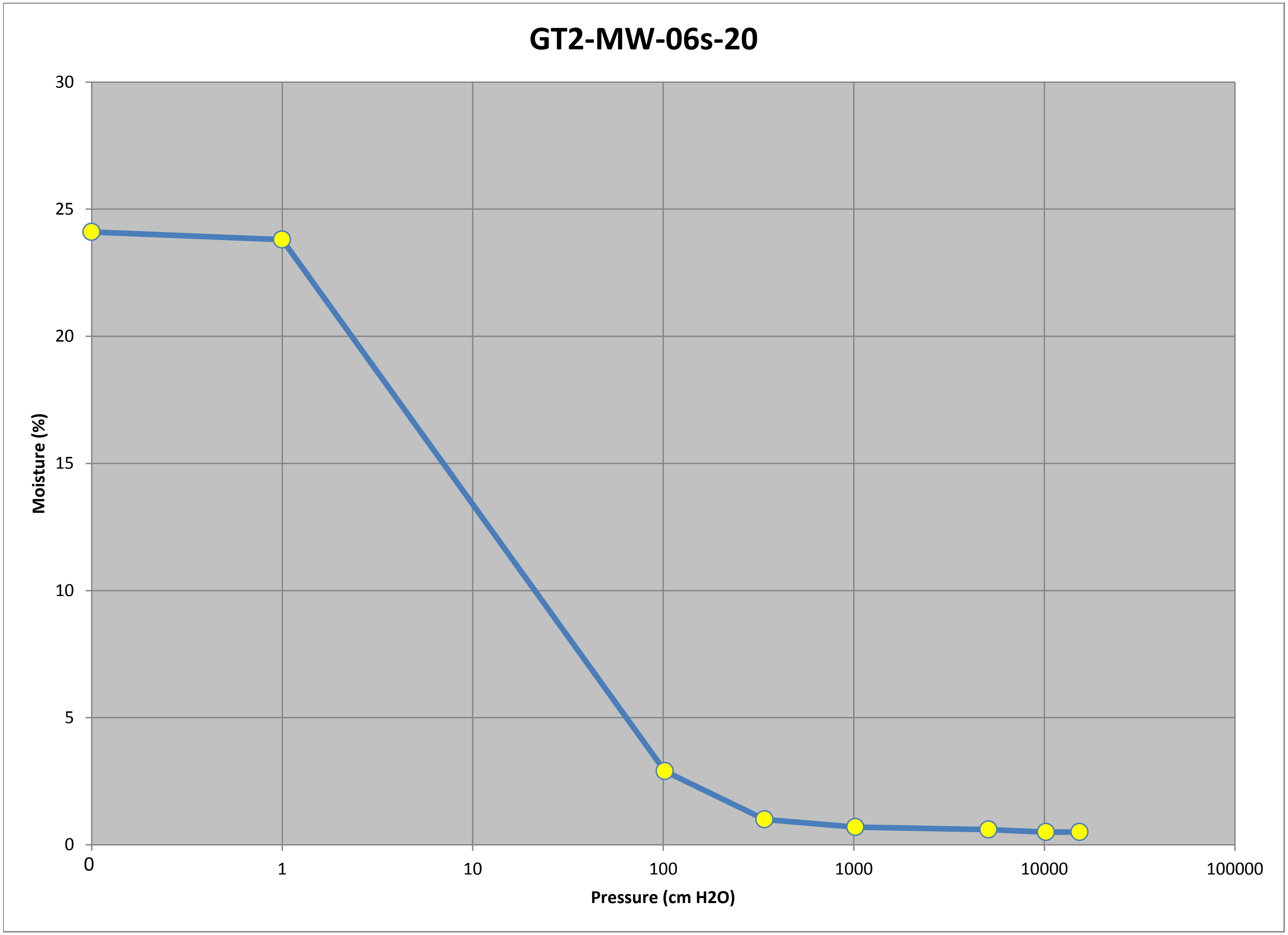

GT2-MW-01s-20
Moisture (%)
30
25
20
15
10
5
0
0
1
10
100
1000
10000
100000
Pressure (cm H2O)


GT2-MW-01s-28
Moisture (%)
30
25
20
15
10
5
0
0
1
10
100
1000
10000
100000
Pressure (cm H2O)


GT2-MW-02s-5
30
25
20
15
10
5
0
Moisture (%)
0
1
10
100
1000
10000
100000
Pressure (cm H2O)


GT2-MW-02s-26
Moisture (%)
30
25
20
15
10
5
0
0
1
10
100
1000
10000
100000
Pressure (cm H2O)


GT2-MW-06s-5
Moisture (%)
30
25
20
15
10
5
0
0
1
10
100
1000
10000
100000
Pressure (cm H2O)


GT2-MW-06s-20
30
25
20
15
10
5
0
Moisture (%)
0
1
10
100
1000
10000
100000
Pressure (cm H2O)