# Assessment of Corrective Measures
# Closed Surface Impoundments

Sutherland Generating Station
3001 E Main Street Road
Marshalltown, Iowa 50158

Prepared for:

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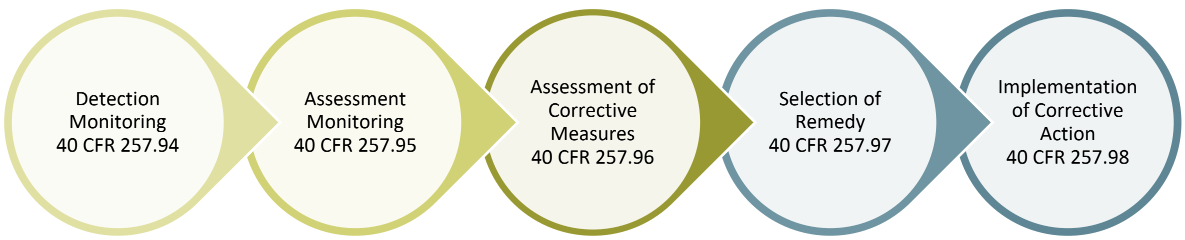
# EXECUTIVE SUMMARY

Interstate Power and Light Company (IPL), an Alliant Energy company, maintains the closed surface impoundments associated with the former Sutherland Generating Station (SGS). The closure area for the surface impoundments is monitored with a multi-unit groundwater monitoring system. Closure and capping of the surface impoundments was completed in June 2020. The multi-unit pond system was used to manage coal combustion residuals (CCR) and wastewater from the power plant, which burned coal and natural gas to generate electricity. SGS was decommissioned in 2020.

IPL samples and tests groundwater around the closed surface impoundments to comply with U.S. Environmental Protection Agency (U.S. EPA) standards for the Disposal of CCR from Electric Utilities, or the “CCR Rule” (Rule). Groundwater samples from one of the wells installed to monitor the closed impoundments contained lithium at a statistically significant level higher than the Groundwater Protection Standards (GPS) defined in the Rule. This metal occurs naturally and can be present in CCR.

IPL has prepared this Assessment of Corrective Measures (ACM) Report in response to the groundwater sampling results at SGS. The ACM process is one step in a series of steps defined in the Rule and shown below.




To prepare the ACM, IPL has worked to understand the following:

- Types of soil and rock deposits in the area of SGS.
- Depth to groundwater.
- Direction that groundwater is moving.
- Potential sources of the lithium in groundwater.
- The area where lithium levels are higher than the U.S. EPA standards.
- The people, plants, and animals that may be affected by levels of lithium in groundwater above the GPS.

IPL has been working since the ACM was initiated on January 23, 2022, to identify the nature and extent of the lithium GPS exceedances downgradient of the closed impoundment. The CCR Rule requires completion of an ACM within 150 days of initiation, but the work to understand the nature and extent of impacts is ongoing. This ACM is based on the best available information within the timeframe allowed under the rule, which has been limited by permitting processes for installing monitoring wells, weather conditions, wet floodplain soils, and downed trees from the 2020 derecho.

IPL has recently installed three new delineation monitoring wells approximately 1,200 feet downgradient from the CCR units. One initial round of groundwater samples has been collected and analyzed to date from the three new wells. There were no lithium GPS exceedances in the samples from the three delineation wells. A second phase of delineation monitoring well installation is currently underway. The groundwater quality and flow direction information from the first phase of delineation wells was used to design the number and location of the second phase of delineation well installations. IPL is currently working through the local well permitting process to install additional monitoring wells to further identify the nature and extent of impacts to groundwater. Because the time allowed by the Rule to prepare the ACM is limited, work to improve the understanding of the items listed above is ongoing. The information gathered from additional wells will be incorporated into future amendments of the ACM and the final Selection of Remedy report.

IPL has identified appropriate options, or Corrective Measures, to bring the levels of lithium in groundwater below U.S. EPA standards. These corrective measures include:

- Alternative 1 – No Further Action (Comparison Purposes Only)
- Alternative 2 – Cover Upgrade
- Alternative 3 – Gradient Control
- Alternative 4 – In-Situ Treatment with Physical/Chemical Amendment
- Alternative 5 – Groundwater Management with Barrier Wall
- Alternative 6 – Excavate and Re-dispose

IPL has included a "No Further Action" alternative for comparison purposes only. This alternative will not be selected as a remedy because it does not meet the requirement of 40 CFR 257.96(a) to remediate the groundwater impact and restore the affected area.

The ACM includes a preliminary evaluation of all six options using factors identified in the Rule.

Based on what is currently known, the groundwater impacts at SGS are limited. IPL will continue to work on understanding groundwater impacts at SGS, and will use this information to select one of the Corrective Measures identified above.

IPL will provide semiannual updates on its progress in evaluating Corrective Measures to address the groundwater impacts at SGS. IPL may also amend this ACM prior to the Selection of Remedy to incorporate additional information relevant to the options identified in this report.

Before a remedy is selected, IPL will hold a public meeting with interested and affected parties to discuss the ACM.

For more information on Alliant Energy, please view the annual Corporate Responsibility Report at http://www.alliantenergy.com/responsibility.

# 1.0 INTRODUCTION AND PURPOSE

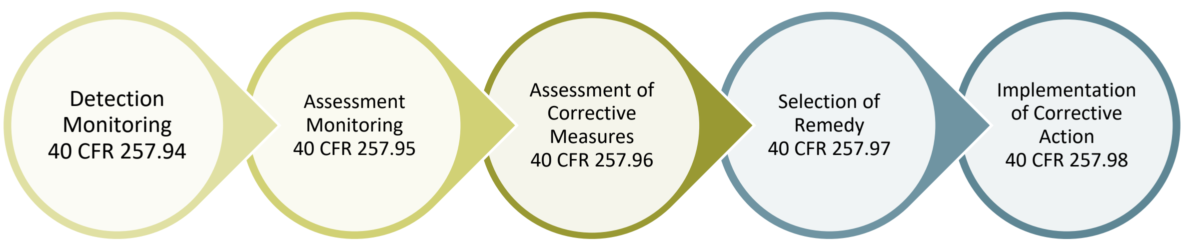
The Assessment of Corrective Measures (ACM) at the former Interstate Power and Light Company (IPL) Sutherland Generating Station (SGS) was prepared to comply with U.S. Environmental Protection Agency (U.S. EPA) regulations regarding the Disposal of Coal Combustion Residuals (CCR) from Electric Utilities [40 CFR 257.50-107], or the "CCR Rule" (Rule). Specifically, the ACM was initiated and this report was prepared to fulfill the requirements of 40 CFR 257.96, including:

- Prevention of further releases
- Remediation of release
- Restoration of affected areas

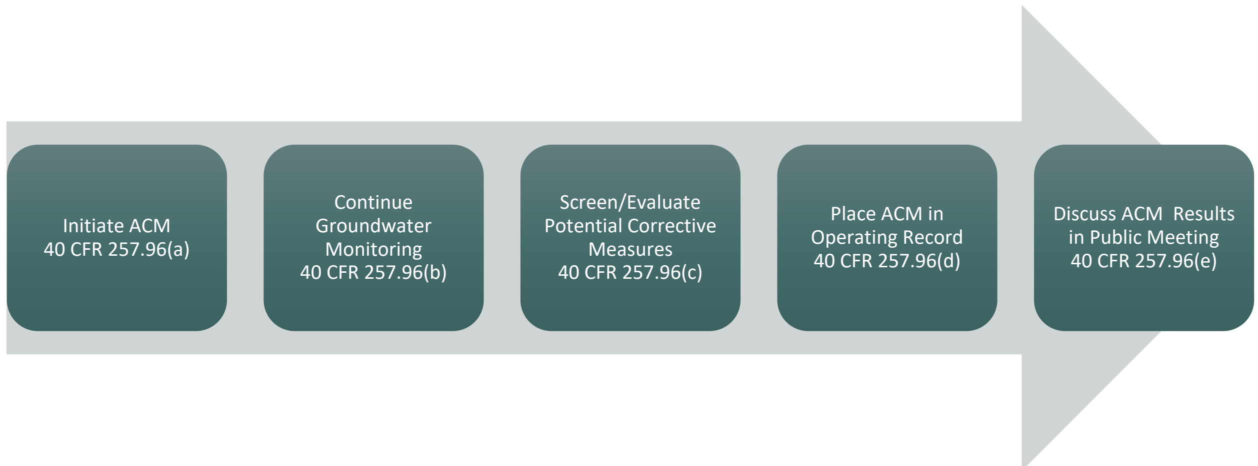
This ACM Report summarizes the remedial alternatives for addressing the Groundwater Protection Standard (GPS) exceedances identified in the Notification of Groundwater Protection Standard Exceedance dated November 17, 2021.

## 1.1 ASSESSMENT OF CORRECTIVE MEASURES PROCESS

As discussed above, this ACM Report has been prepared in response to GPS exceedances observed in groundwater samples collected at SGS. The ACM process is one step in a series of steps defined in the CCR Rule and depicted in the graphic below. To date, IPL has implemented a detection monitoring program per 40 CFR 257.94 and completed assessment monitoring at SGS per 40 CFR 257.95. An ACM is now required based on the groundwater monitoring results obtained through October 2021. With the ACM completed, IPL is required to select a corrective measure (remedy) according to 40 CFR 257.97. The remedy selection process must be completed as soon as feasible, and, once selected, IPL is required to start the corrective action process within 90 days.




The process for developing the ACM is defined in 40 CFR 257.96 and is shown in the graphic below. IPL is required to discuss the ACM results in a public meeting at least 30 days before selecting a remedy. To facilitate the selection of a remedy for the GPS exceedances at SGS, IPL continues to investigate and assess the nature and extent of the groundwater impacts. Information about the site, the groundwater monitoring completed, the groundwater impacts as they are currently understood, and the ongoing assessment activities are discussed in the sections that follow.




## 1.2 SITE INFORMATION AND MAP

SGS is located at 3001 E. Main Street Road in Marshalltown, Marshall County, Iowa (**Figure 1**). Four inactive CCR surface impoundments are present at SGS. Closure and capping of the surface impoundments was completed in 2020. A Notification of Completion of Closure pursuant to 40 CFR 257.102(d) was issued by Alliant Energy on June 12, 2020.

The groundwater monitoring network at Sutherland Generating Station (SGS) is a multi-unit system that monitors the closure area for the following inactive CCR units:

- SGS North Primary Pond (inactive surface impoundment – closed June 2020)
- SGS South Primary Pond (inactive surface impoundment – closed June 2020)
- SGS Main Pond (inactive surface impoundment – closed June 2020)
- SGS Polishing Pond (inactive surface impoundment – closed June 2020)

The system is designed to detect monitored constituents at the waste boundary of the SGS CCR units as required by 40 CFR 257.91(d). The groundwater monitoring system consists of two upgradient, four downgradient monitoring wells at the waste boundary, and five additional delineation monitoring wells.

A map showing the limits of the former CCR Units, the closure area, and all background (or upgradient), downgradient monitoring wells, and delineation wells with identification numbers for the CCR groundwater monitoring program is provided as **Figure 2**.

# 2.0 BACKGROUND

## 2.1 REGIONAL GEOLOGIC INFORMATION

For the purposes of groundwater monitoring, the surficial alluvium aquifer, composed of glacial drift, sand, and gravel, is considered to be the uppermost aquifer unit, as defined under 40 CFR 257.53, at SGS. Immediately underlying the surficial alluvium aquifer are the Pennsylvanian and Mississippian shale and limestone units. Devonian aged units underlie the Mississippian limestone and are composed of shale, dolomite, and limestone. Silurian dolomite underlies the Devonian shale, dolomite, and limestone (**Appendix A**).

The Iowa River and associated alluvial aquifers are a major source of surface water and shallow groundwater in the area.

Unconsolidated deposits at the site consist of clays overlain by loess, which are not productive sources of groundwater (U.S. Department of Agriculture and Soil Conservation Service [USDA], 1981). The uppermost Pennsylvanian bedrock unit is considered to be a regional aquitard.

Regional information indicates that groundwater flow within the Mississippian limestone is to the south-southeast.

## 2.2 SITE GEOLOGIC INFORMATION

Soils at the site are primarily sand, silt, and clay to a depth of approximately 16 to 21 feet below ground surface (bgs). During drilling of monitoring wells MW-301 through MW-306, the unconsolidated materials were identified as consisting primarily of sand, lean clay, and sandy silt. The boring logs for the recently installed monitoring wells MW-307 through MW-311, show alternating deposits of sand, lean clay, and silt to 21 feet bgs. Boring logs for the SGS monitoring wells MW-301 through MW-311 are provided in **Appendix B.**

The shallow groundwater flow at the water table is generally to the east, as shown on the October 2021 and May 2022 shallow water table maps (**Figure 3** and **Figure 4**). This flow direction is consistent with previous water table maps, and the regional groundwater flow. The groundwater monitoring well network summary is provided in **Table 1**. The groundwater elevation data for the CCR monitoring wells are provided in **Table 2**. The complete results for these sampling events during the assessment monitoring program are summarized in **Table 3**.

Geologic cross sections were prepared using information from on-site monitoring well borings. The cross section locations are provided on **Figure 5** and the cross sections are shown on **Figure 6** and **Figure 7.** Water levels measured at site monitoring wells are identified on the cross section.

## 2.3 CCR RULE MONITORING SYSTEM

The original groundwater monitoring system established in accordance with the CCR Rule consists of two upgradient (background) monitoring wells and four downgradient monitoring wells. The background wells are MW-301 and MW-302. The four downgradient compliance wells are MW-303, MW-304, MW-305, and MW-306. These wells were installed in November 2017. Additional upgradient wells MW-307 and MW-308 were installed in November 2021 to provide information on groundwater quality at locations expected to be downgradient from the former coal pile and upgradient from the pond closure area. Three additional delineation monitoring wells, MW-309, MW-310, and MW-311, were installed in May 2022. The delineation wells were installed to evaluate the nature and extent of lithium-impacted groundwater and groundwater flow direction downgradient from the pond closure area (**Figure 2**).

Plans for the installation of additional delineation wells are described in Section 3.2.3 below.

# 3.0 NATURE AND EXTENT OF GROUNDWATER IMPACTS

## 3.1 POTENTIAL SOURCES

The potential sources of groundwater impacts are the material disposed in the former CCR units at SGS and the former SGS coal yard material consolidated in the closure area. The surface impoundments stopped receiving CCR in April of 2012 when the plant was converted to natural gas. The impoundments were closed with a final cover system in June 2020 (**Figure 2**). The impoundment closure is described in a Construction Documentation Report dated June 2020.

## 3.2 GROUNDWATER ASSESSMENT

### 3.2.1 Groundwater Depth and Flow Direction

Depth to groundwater as measured in the site monitoring wells varies from 6 to 21 feet bgs due to topographic variations across the facility and seasonal variations in water levels. Groundwater flow at the site is generally to the east toward the Iowa River.

### 3.2.2 Groundwater Protection Standard Exceedances Identified

The ACM process was triggered by the detection of lithium at a statistically significant level (SSL) exceeding the GPS in samples from monitoring well MW-306.

The determination that lithium was at an SSL above the GPS was made based on the statistical evaluation of the assessment monitoring results following the July 2021 supplemental monitoring event. The statistical evaluation was completed on October 25, 2021, and was based on evaluation of the lower confidence limit for the mean, as described below. The complete results for the assessment monitoring sampling events are summarized in **Table 3.**

U.S. EPA's Unified Guidance for Statistical Analysis of Groundwater Monitoring Data at Resource Conservation and Recovery Act (RCRA) Facilities (EPA 530-R-09-007, March 2009) recommends the use of confidence intervals for comparison of assessment monitoring data to fixed GPS values. Specifically, the suggested approach for comparing assessment groundwater monitoring data to GPS values based on long-term chronic health risk, such as drinking water Maximum Contaminant Levels (MCLs), is to compare the lower confidence limit around the arithmetic mean with the fixed GPS.

An updated Lower Confidence Limit (LCL) evaluation was completed for lithium, which is the only Appendix IV parameter that has been detected at a concentration exceeding the GPS in at least one sample result since assessment monitoring was initiated. The updated LCLs were calculated with Sanitas™ statistical software using historical concentrations measured from the initiation of assessment monitoring through October 2021. The evaluation is provided in **Appendix D.**

Based on the LCL evaluation, the only SSL above the GPS continues to be for lithium at MW-306.

Elevated lithium concentrations at MW-306 were previously identified in April 2020 after assessment monitoring was initiated at SGS in February 2020. While elevated Lithium concentrations were observed throughout 2020 and 2021, an upward trend was identified following the July 2021 sampling event. At that time the LCL evaluation using all data since the initiation of assessment monitoring did not indicate that lithium results for MW-306 represented an SSL; however, an upward shift in lithium concentrations at MW-306 was observed beginning with the October 2021 event. The shift may be related to changes in groundwater flow following completion of closure for the impoundments in July 2020. To account for the observed upward shift in lithium concentrations, an LCL calculation based on the most recent four rounds of groundwater sampling through July 2021 was performed. The calculations indicated an SSL for lithium at MW-306.

In summary, as of the July and October 2021 sampling events, the following SSL exceeding the GPSs has been identified:

| Assessment Monitoring Appendix IV Parameter | Location of GPS Exceedance | Historic Range of Detections at Well Exceeding GPS | Groundwater Protection Standards (GPS) |
|---|---|---|---|
| Lithium (µg/L) | MW-306 | 40 - 59 | 40 |

µg/L = micrograms per liter
Note: Historic range includes results from assessment monitoring beginning in February 2020.

### 3.2.3 Expanding the Groundwater Monitoring Network

Additional background monitoring wells, MW-307 and MW-308, were installed in November 2021 downgradient of the former coal pile and upgradient from the pond closure area. Delineation monitoring wells, MW-309, MW-310, and MW-311 were installed in May 2022 to define the nature and extent of lithium GPS exceedances downgradient of monitoring wells MW-306.

Groundwater samples were collected following installation of the new background monitoring wells, MW-307 and MW-308, in December 2021. The results indicated that the coal yard did not appear to be a major source of the lithium concentrations in well MW-306.

Groundwater samples were collected from the new delineation wells, MW-309, MW-310, and MW-311, in May 2022. No lithium GPS exceedances were identified in the new delineation wells. For analytical results see **Table 3**.

A second phase of delineation monitoring well installations is currently underway. IPL is working through the local well permitting process to install additional monitoring wells to further identify the nature and extent of impacts to groundwater. Work to improve the understanding of the lithium impacts and hydrogeologic conditions is ongoing. The information gathered from additional wells will be incorporated into future amendments of the ACM and the final Selection of Remedy report.

## 3.3 CONCEPTUAL SITE MODEL

The following conceptual site model describes the compounds and nature of constituents above the GPS, discusses potential exposure pathways affecting human health and the environment, and presents a cursory review of their potential impacts. The conceptual site model for SGS has been prepared in general conformance with the Standard Guide for Developing Conceptual Site Models for Contaminated Sites (ASTM E1689-20). This conceptual site model is the basis for assessing the efficacy of likely corrective measures to address the source, release mechanisms, and exposure routes.

### 3.3.1 Nature of Constituents Above GPS

To describe the nature of the constituents in groundwater at SGS, IPL reviewed information regarding lithium in groundwater, and how that groundwater may impact potential receptors through the exposure pathways discussed in **Section 3.3.2**.

*Lithium*
Lithium (Li) is an alkali metal that is naturally present in soil and water. Lithium is naturally present in coal and is present in CCR after the coal is combusted.

Lithium has numerous industrial and commercial uses, including as an additive in aluminum production, a catalyst of chemical reactors, a component of fluxes and brazing alloys, a component of batteries, specialized glass and ceramics, and a sanitizing agent for swimming pools, hot tubs, and spas (U.S. EPA, 2008). Primary food sources of lithium are grains and vegetables, and, in some areas, drinking water also contains lithium. Human intake varies depending on location and diet (Schrauzer, 2002).

*Lithium Exposure*
In November 2018, the United States (U.S.) Department of Health and Human Services (HHS) Agency for Toxic Substances and Disease Registry (ATSDR) provided a health consultation for an environmental case involving, among other constituents, lithium in groundwater (ATSDR, 2018). The report offered the following relevant to lithium in groundwater:

- Residences with sensitive subpopulations (individuals undergoing lithium treatment, infants/children, pregnant women, those with significant renal or cardiovascular disease, etc.) should inform their physician of potential additional exposure to lithium through well water consumption.

- There is very limited toxicological literature on young children exposed to lithium. The potential for adverse health effects in sensitive subpopulations is uncertain because of the lack of relevant study data.

The concentrations of lithium detected to date in samples from the site monitoring wells range from below the detection limit to 59 µg/L. The GPS for lithium is 40 µg/L. The GPS for lithium is based on non-carcinogenic, child-based limits.

### 3.3.2 Potential Receptors and Pathways

As described in **Section 3.3**, ASTM E1689-20 provides a framework for identifying potential receptors (people or other organisms potentially affected by the groundwater impacts at SGS) and pathways (the ways groundwater impacts might reach receptors). In accordance with ASTM E1689-20, IPL considered both potential human and ecological exposures to groundwater impacted by the constituents identified in **Section 3.2.3**:

*Human Health*
In general, human health exposure routes to contaminants in the environment include ingestion, inhalation, and dermal contact with the following environmental media:

- Groundwater
- Surface Water and Sediments
- Air
- Soil
- Biota/Food

If people might be exposed to the impacts described in **Section 3.0** via one of the environmental medias listed above, a potential exposure route exists and is evaluated further. For the groundwater impacts at SGS, the following potential exposure pathways have been identified with respect to human health:

- Groundwater – Ingestion and Dermal Contact: The potential for ingestion of, or dermal contact with, impacted groundwater from SGS exists if water supply wells are present in the area of impacted groundwater and are used as a potable water supply. Based on a review of the Iowa Department of Natural Resources (IDNR) GeoSam well database and information provided by IPL, no water supply wells have been identified as downgradient or sidegradient in the vicinity of the CCR units.

- Surface Water and Sediments – Ingestion and Dermal Contact: The potential for ingestion or dermal contact with impacted surface water and sediments exists if impacted groundwater from SGS has interacted with adjacent surface water and sediments, to the extent that the constituents identified in **Section 3.2.3** are present in these media at concentrations that represent a risk to human health.

- Biota/Food – Ingestion: The potential for ingestion of impacted food exists if impacted groundwater from SGS has interacted with elements of the human food chain. Based on a review of existing land use and the location of known groundwater impacts within developed areas of Marshall County and the City of Marshalltown, no hunting or farming likely occurs within the current area of known groundwater impacts. Elements of the food chain may also be exposed indirectly through groundwater-to-surface interactions, which are subject to additional assessment.

Based on the lack of groundwater exposure and initial downgradient monitoring results indicating the lithium impacts do not extend to the Iowa River, no receptors with complete exposure pathways appear to be present; however, further evaluation will be completed with the next phase of monitoring well installation and sampling. The implementation of potential corrective measures may introduce secondary exposure pathways that are discussed in **Section 6.0** and will be evaluated further as a corrective measure is selected for SGS.

***Ecological Health***

In addition to human exposures to impacted groundwater, potential ecological exposures are also considered. If ecological receptors might be exposed to impacted groundwater, the potential exposure routes are evaluated further. Ecological receptors include living organisms, other than humans, the habitat supporting those organisms, or natural resources potentially adversely affected by CCR impacts. This includes:

- Transfer from an environmental media to animal and plant life. This can occur by bioaccumulation, bioconcentration, and biomagnification:
  - Bioaccumulation is the general term describing a process by which chemicals are taken up by a plant or animal either directly from exposure to impacted media (soil, sediment, water) or by eating food containing the chemical.
  - Bioconcentration is a process in which chemicals are absorbed by an animal or plant to levels higher than the surrounding environment; and
  - Biomagnification is a process in which chemical levels in plants or animals increase from transfer through the food web (e.g., predators have greater concentrations of a particular chemical than their prey).

- Benthic invertebrates within adjacent waters.

Based on the information presented in **Section 3.2.3** indicating that lithium impacts above the GPS do not extend to Iowa River, neither of these ecological exposure routes appears to be complete; however, further evaluation will be completed with the next phase of monitoring well installation and sampling.

# 4.0 POTENTIAL CORRECTIVE MEASURES

This section identifies potential corrective measures to meet the ACM goals identified in 40 CFR 257.96(a), which are to:

- Prevent further releases
- Remediate releases
- Restore affected areas to original conditions

The development of corrective measure alternatives is described further in the following sections. Corrective measure alternatives developed to address the groundwater impacts at SGS are described in **Section 5.0**. The alternatives selected are qualitatively evaluated in **Section 6.0**.

## 4.1 IDENTIFICATION OF CORRECTIVE MEASURES

As described in the U.S. EPA Solid Waste Disposal Facility Criteria Technical Manual (U.S. EPA, 1998), corrective measures generally include up to three components:

- Source Control
- Containment
- Restoration

Within each component, there are alternative measures that may be used to accomplish the component objectives. The measures from one or more components are then combined to form corrective measure alternatives (discussed in **Section 5.0**) intended to address the observed groundwater impacts. Potential corrective measures were identified based on site information available during development of the ACM for the purpose of meeting the goals described in **Section 4.0**.

Each component and associated corrective measures are further identified in subsequent paragraphs. The corrective measures are evaluated for feasibility and combined to create the corrective action alternatives identified in this section and further evaluated in **Section 5.0**. IPL continues to evaluate site conditions and may identify additional corrective measures based on new information regarding the nature and extent of the impacts.

### 4.1.1 Source Control

The source control component of a corrective measure is intended to identify and locate the source of impacts and provide a mechanism to prevent further releases from the source. For SGS, source control has already been provided through the closure of the existing CCR units at the facility, which included the consolidation of CCR materials into a single closure area and the installation of a vegetated low permeability soil cover that meets performance standards defined in the CCR Rule for final cover systems. Closure activities at SGS were completed in 2020, prior to the identification of groundwater impacts that required IPL to initiate the ACM. Although more time may be required to see a groundwater quality response to the closure activities completed in 2020, additional source control measures, or enhancements to existing source control measures, are identified below:

- **Cover Upgrade.** Final cover system enhancements beyond the requirements described in 40 CFR 257.102(d)(3) could further reduce infiltration and prevent transport of CCR constituents from unsaturated CCR materials into the groundwater if this is found to be the mechanism driving groundwater impacts.

- **In-Situ Stabilization.** An emplaced or injected amendment to the CCR mass to promote chemical reactions that reduce the leachability of lithium.

- **Excavation and Re-disposal.** Remove all CCR from the closure area and redispose to prevent further releases from the closure area.

Water movement through the CCR materials is the mechanism for CCR impacts to groundwater, including surface water that moves vertically through the CCR materials via infiltration of precipitation and surface water runoff. Based on the available information for this site, all of the additional source control measures above have the potential to prevent further releases caused by infiltration if GPSs are not achieved by the closure activities completed in 2020, and thus are retained for incorporation into alternatives for further evaluation. However, IPL continues to monitor and investigate the nature and extent of groundwater impacts and, with new information, source control measures may be added or removed from consideration.

### 4.1.2 Containment

The objective of containment is to limit the spread of the impacts beyond the source. Containment may also be implemented in combination with restoration as described in **Section 4.1.3**.

Containment may be a recommended element of a corrective measure if needed to:

- Prevent off-site migration of groundwater impacts.
- Cease completion of a confirmed exposure pathway (e.g., water supply well).

Aquifer characteristics that favor containment include:

- Water in the affected aquifer is naturally unsuited for human consumption.
- Contaminants are present in low concentration with low mobility.
- Low potential for exposure pathways to be completed, and low risk associated with exposure.
- Low transmissivity and low future user demand.

The following containment measures have potential to limit the spread of continued or remaining groundwater impacts at this site, if necessary:

- **Gradient Control with Pumping.** Gradient control includes a measure to alter the groundwater velocity and direction to slow or isolate impacts. This can be accomplished with pumping wells and/or a trench/sump collection system. If groundwater pumping is considered for capturing an impacted groundwater plume, the impacted groundwater must be managed in conformance with all applicable federal and state requirements.

- **Gradient Control with Phytotechnology.** Gradient control with phytotechnology relies on the ability of vegetation to evapotranspire sources of surface water and groundwater. Water interception capacity by the aboveground canopy and subsequent evapotranspiration through the root system can limit vertical migration of water from the surface downward. The horizontal migration of groundwater can be controlled or contained using deep-rooted species, such as prairie plants and trees, to intercept, take up, and transpire the water. Trees classified as phreatophytes are deep-rooted, high-transpiring, water-loving organisms that send their roots into regions of high moisture and can survive in conditions of temporary saturation.

- **Chemical Stabilization.** Stabilization refers to processes that involve chemical reactions that reduce the leachability of lithium. Stabilization chemically immobilizes impacts or reduces their solubility through a chemical reaction. The desired results of stabilization methods include converting metals into a less soluble, mobile, or toxic form. Chemically, this may include precipitation or alteration to render lithium less mobile in the environment. Evaluation of appropriate commodity amendments, in situ lithium treatment, focusing on in situ sorptive and reduction-oxidation (redox)-based precipitation remedies that may include zero-valent iron, colloidal activated carbon, and adjusting the redox potential of the zone of impact will occur during the remedy selection process.

Active containment may be required for this site due to the potential for CCR to be in contact with groundwater.

### 4.1.3 Restoration

Restoration is the process through which groundwater quality is restored to meet GPSs. If active treatment is implemented, water may be treated in-situ, on-site, or off-site. The need for active treatment depends on the nature and extent of impacts, exposure pathways, and risks to receptors. Active restoration may be needed if existing or future impacts require a more rapid restoration of groundwater quality.

Treated groundwater may be re-injected, sent to a local publicly owned treatment works (POTW), or discharged to a local body of surface water, depending on local, state, and federal requirements. Typical on-site treatment practices for metals include coagulation and precipitation, ion exchange, or reverse osmosis. Off-site wastewater treatment may include sending the impacted groundwater that is extracted to a local POTW or to a facility designed to treat the contaminants of concern.

In-situ methods may be appropriate, particularly where pump and treat technologies may present adverse effects. In-situ methods may include biological restoration requiring pH control, the addition of specific micro-organisms, the addition of nutrients and substrate to augment and encourage degradation by indigenous microbial populations, and /or phytoremediation, most likely by phyto-accumulation. These approaches require laboratory treatability studies and pilot field studies to determine the feasibility and reliability of full-scale treatment.

## 5.0 CORRECTIVE MEASURE ALTERNATIVES

IPL identified the following corrective measure alternatives for the groundwater impacts at SGS:

- Alternative 1 – No Further Action
- Alternative 2 – Cover Upgrade

- Alternative 3 – Gradient Control
- Alternative 4 – In-Situ Treatment with Physical/Chemical Amendment
- Alternative 5 – Groundwater Management with Barrier Wall
- Alternative 6 – Excavate and Re-dispose

These alternatives were developed by selecting components from the reasonable and appropriate corrective measures components discussed above. Each of the corrective measure alternatives meet the requirements in 40 CFR 257.97(b)(1) through (5) based on the information available at the current time. IPL may identify additional alternatives or eliminate alternatives based on the continued evaluation of site conditions.

## 5.1 ALTERNATIVE 1 – NO FURTHER ACTION

Closure of the CCR units at SGS was already complete when the groundwater impacts that required IPL to initiate the ACM process were identified. Closure activities at SGS included consolidation and capping of CCR in a single closure area (**Figure 2**) in accordance with the requirements for closure in place in 40 CFR 257.102(d).

Closure activities were completed in June 2020. The aquifer geochemical response to closure is not immediate; additional time is required to monitor the response in groundwater conditions to the closure activities and determine whether the final cover system results in decreases in constituent concentrations below the GPS. This alternative assumes that post-closure monitoring of groundwater will continue as described in Section 2.4 of the Post-Closure Plan for the CCR units at SGS issued in February 2018 and amended in July 2019.

IPL is committed to implementing corrective measures as required under the Rule, and the No Further Action alternative is included as a baseline condition and point of comparison for the other alternatives. Consideration of this alternative assumes continued monitoring of groundwater.

## 5.2 ALTERNATIVE 2 – COVER UPGRADE

Alternative 2 includes enhancements to the existing cover that was constructed over the closure area in 2020 in accordance with the criteria set forth in 40 CFR 257.102(d). Closure of the CCR units at SGS with CCR in place under a cap has already been completed. Under Alternative 2, the existing cap will be enhanced to further reduce the overall permeability of the final cover in the event the final cover system design prescribed in the CCR Rule and implemented in 2020 does not attain the GPS for lithium and the limited infiltration through the final cover is found to be the driver of lithium impacts in groundwater. Cover enhancements include one, or a combination, of the following:

- Increase the thickness of the infiltration layer (low-permeability clay layer).
- Increase the overall thickness of cover to promote evapotranspiration.
- Installation of a geomembrane over the existing infiltration layer (i.e., upgrade to composite cover).
- Installation of a drainage layer (e.g., geocomposite or granular soil layer) above the infiltration layer.

The closure areas will also be subject to more frequent groundwater sample collection and groundwater level measurements.

This alternative is expected to further reduce infiltration of surface water into the closure area. Leaching of metals and migration within groundwater may be reduced, which may eliminate GPS exceedances over time or reduce the time required to meet GPSs.

If further investigation indicates lithium GPS exceedances beyond the waste boundary (i.e., lithium is detected above the GPS in proposed down gradient wells), this alternative may need to be coupled with another alternative to reduce lithium to concentrations below the GPS.

## 5.3 ALTERNATIVE 3 – GRADIENT CONTROL

Alternative 3 includes gradient control measures to cease completion of confirmed exposure pathways and limit the spread of groundwater impacts. Under Alternative 3, gradient control measures will be installed to supplement the closure activities completed in 2020. Gradient control measures such as phytotechnology, modified conductivity zones, and/or groundwater pumping may be used. Alternative 3 may incorporate groundwater collection or an alternative technology such as phytoremediation to intercept groundwater contributing to potential exposure pathways, reduce the migration of groundwater impacts, and restore lithium in groundwater to concentrations below the GPS. With groundwater collection, impacted groundwater would be extracted by pumping for treatment. With phytoremediation, the likely mechanism for reducing lithium concentrations in groundwater would be by plant uptake.

## 5.4 ALTERNATIVE 4 – IN-SITU TREATMENT WITH PHYSICAL/CHEMICAL AMENDMENT

Alternative 4 includes adding a physical or chemical amendment within the source area or groundwater plume to reduce the mobilization of lithium to cease completion of confirmed exposure pathways, limit the spread of groundwater impacts and restore lithium in groundwater to concentrations below the GPS. Under Alternative 4, further leaching of metals and migration within groundwater would be prevented by fixation using a physical/chemical amendment. Depending on the approach selected and the results of further investigation beyond the CCR unit boundary, this alternative may need to be coupled with another alternative to restore lithium in groundwater to concentrations below the GPS.

## 5.5 ALTERNATIVE 5 – GROUNDWATER MANAGEMENT WITH BARRIER WALL

Alternative 5 incorporates the use of a barrier wall to restore lithium in groundwater to concentrations below the GPS. The barrier wall consists of two different approaches:

- Impermeable barrier: Directs upgradient groundwater away from known groundwater impacts.
- Permeable barrier: Intercepts impacted groundwater within a permeable zone to treat impacted groundwater.

Further leaching of metals and migration within groundwater will be reduced and may be eliminated over time as impacted groundwater is redirected and/or intercepted with a barrier wall to minimize the spread of lithium in groundwater. Depending on the approach selected and the results of further investigation beyond the CCR unit boundary, this alternative may need to be coupled with another alternative to restore lithium in groundwater to concentrations below the GPS.

## 5.6 ALTERNATIVE 6 – EXCAVATE AND RE-DISPOSE

Alternative 6 includes the removal of the existing final cover and excavation of CCR within the closure area and restoring lithium in groundwater to concentrations below the GPS. Under Alternative 6, CCR from the closure area will be excavated and appropriately re-disposed, either on or off-site, after the removal of the existing final cover. Further on-site releases from the CCR sources will be prevented by removing the source materials from the site or otherwise minimizing the potential for ongoing on-site leaching of constituents into groundwater. Depending on the approach selected and the results of further investigation beyond the CCR unit boundary, this alternative may need to be coupled with another alternative to restore lithium in groundwater to concentrations below the GPS.

# 6.0 EVALUATION OF CORRECTIVE MEASURE ALTERNATIVES

As required by 40 CFR 257.96(c), the following sections provide an evaluation of the effectiveness of corrective measure alternatives in meeting the requirements and objectives outlined in 40 CFR 257.97. The evaluation addresses the requirements and objectives identified in 40 CFR 257.96(c)(1) through (3), which include:

- The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to residual contamination;

- The time required to begin and complete the remedy; and

- The institutional requirements, such as state or local permit requirements, or other environmental or public health requirements that may substantially affect implementation of the remedy.

In addition to the discussion of the items listed above, **Table 4** provides a summary of the initial evaluation of the alternatives including each of the criteria listed in 40 CFR 257.97.

## 6.1 ALTERNATIVE 1 – NO FURTHER ACTION

As described in **Section 5.1**, the No Further Action alternative is the current condition and serves as a point of comparison for the other alternatives. Although this alternative has the potential to satisfy all five criteria in 40 CFR 257.97(b)(1) through (5), IPL currently considers this unlikely. Based on the limited likelihood of Alternative 1 to be selected, it has been retained for comparison purposes, and evaluated with regard to the criteria in 40 FR 257.96(c) below:

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – Ceasing wastewater discharges and closing the impoundments by capping as completed in 2020 is expected to address infiltration, which is a key contributor to groundwater impacts. However, this does not address CCR potentially in contact with groundwater.

  - Reliability – The expected reliability of capping is good. Capping is a common practice and standard remedial method for closure in place in remediation and solid waste management. There is significant industry experience with the design and construction of this method, which was incorporated into the requirements of 40 CFR

257.102(d). A deed notation is in place for closure with CCR left in place, which is a reliable means of communicating the on-site conditions.

- Implementation – Nothing is required to implement Alternative 1.

- Impacts – No additional safety or cross-media impacts are expected with Alternative 1. This alternative may not control current suspected routes of exposure to residual contamination.

- **Timing.** No time is required to begin. The time required to attain the GPS for lithium will be evaluated further during the remedy selection process, but is expected to take between 5 and 10 years after closure construction is complete. Alternative 1 has the potential to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** IPL must maintain the IDNR Closure Permit. The current IDNR Closure Permit expires in 2047. A deed notice to this effect was recorded with the Marshall County Recorder on December 22, 2017.

## 6.2 ALTERNATIVE 2 – COVER UPGRADE

As described in **Section 5.2**, Alternative 2 includes enhancements to the existing cover that was constructed over the closure area in 2020 in accordance with the criteria set forth in 40 CFR 257.102(d).

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – Enhancing the existing cap may further limit post-construction infiltration through the cap, which may contribute to groundwater impacts. IPL will monitor groundwater elevations to assess whether the seasonal high level is above the base of the CCR. In combination with the closure activities completed to date, Alternative 2 is capable of and expected to attain the GPS for lithium.

  - Reliability – The expected reliability of an enhanced cap is good if infiltration is driving groundwater impacts. IPL will monitor groundwater elevations to assess whether the seasonally high level is above the base of the CCR. The potential cap enhancements described in **Section 5.2** are in common use for closure in place for remediation and solid waste management. There is significant industry experience with the design and construction of this method, which was incorporated into the requirements of 40 CFR 257.102(d). A deed notation is in place for closure with CCR left in place, which is a reliable means of communicating the on-site conditions.

  - Implementation – The complexity of constructing the cap is low. The logistics of designing and installing cap enhancements increases the complexity of the alternative due to the limited space available at the facility. The local availability of cap upgrade materials will be evaluated further during remedy selection. The equipment and personnel required to implement Alternative 2 are not specialized and are generally readily available with the exception of the resources needed to install an upgrade that involves geosynthetic components, which may not be available locally.

  - Impacts – Safety impacts associated with the implementation of Alternative 2 are not significantly different than other heavy civil construction projects. The level of disturbance required to enhance the cap may represent some increase in safety risk due to site conditions and incoming/outgoing construction traffic. Cross-media impacts are not expected because it is unlikely that CCR must be exposed to upgrade the cap. The potential for exposure to residual contamination is low since CCR will remain capped.

- **Timing.** Enhancements to the existing cap can be completed within 1 year of remedy selection and issuance of required permits. The time required to attain the GPS for lithium will be evaluated further during the remedy selection process but is expected to take between 5 and 10 years after closure construction is complete. The cap enhancements may decrease the time to reach GPS due to reduced cover permeability. Alternative 2 is anticipated to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** The following permits and approvals are expected to be required to implement Alternative 2:
  - An amendment to the IDNR Closure Permit.
  - State and local construction permits.
  - State and local erosion control/construction storm water management permits.

- State and local erosion control/construction storm water management permits may also be required depending on the level of disturbance required to implement the alternative.

## 6.3 ALTERNATIVE 3 – GRADIENT CONTROL

As described in **Section 5.3**, Alternative 3 includes the installation of gradient control measures to cease completion of potential exposure pathways, limit the spread of groundwater impacts, and restore groundwater quality. This Alternative may include installing a groundwater pump and treat system or phytotechnology grove to prevent the migration of and/or recover groundwater with lithium concentrations greater than the GPS.

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – Gradient control measures can prevent the completion of an exposure pathway for groundwater containing lithium concentrations above the GPS and can reduce concentrations by removing lithium-impacted groundwater. Phytotechnology for gradient control or a groundwater pump and treat system may further reduce the potential for down-gradient migration of groundwater impacts after closure. The risk to surface water receptors is unknown; the potential for CCR to interact with groundwater remains although CCR was capped during closure. Alternative 3 further reduces the risk of potential ongoing groundwater impacts from an interaction between CCR and water. Phytotechnology or groundwater pump and treat systems offer additional flexibility to address changes in groundwater conditions or prevent cross-media impacts between groundwater and surface water. In combination with the closure activities completed to date, Alternative 3 is capable of and expected to attain the GPS for lithium.

  - Reliability – Depending on the method selected, the reliability of gradient control is good. There is significant industry experience with some gradient control methods used in groundwater remediation. The expected reliability of both phytotechnology and groundwater pump and treat are good. Groundwater pump and treat is a common method used to limit the migration of impacted groundwater or remove impacted groundwater to restore groundwater concentrations to levels below the GPS. Phytotechnology is a more recent method, and proven to limit the migration of impacted groundwater or remove impacted groundwater to restore groundwater concentrations to levels below the GPS

A deed notation is in place for closure with CCR left in place, which is a reliable means of communicating the on-site conditions.

- Implementation – The complexity of constructing a gradient control system is moderate. There is a high degree of logistic complexity due to the presence of a high-traffic rail corridor adjacent to the Closure Area and off-site property owner access. The materials, equipment, and personnel required to implement Alternative 3 may vary based on the method of gradient control selected. Some methods may be more specialized with limited local availability. The development, operation, maintenance, and monitoring of adequate treatment for large volumes of groundwater with relatively low concentrations of lithium likely increases the complexity of implementing this alternative. There is no on-site capacity to treat gradient control system discharge. If required, on-site capacity will need to be developed. Off-site ability/willingness to accept discharge is currently unknown.

- Impacts – No additional safety or cross-media impacts are expected with Alternative 3. The potential for exposure to residual contamination is low since residual CCR is capped. The active nature of a groundwater plume containment provided by pumping may offer further reduction of risks if groundwater conditions change. The potential exposure to contaminated groundwater is increased due to the ex-situ groundwater treatment required and the potential for worker exposure and spills.

- **Timing.** Gradient control may be completed within 1 to 3 years of remedy selection and issuance of required permits, depending on the method of gradient control used and treatment/discharge requirements. The time required to initiate this alternative and attain the GPS for lithium will be evaluated further during the remedy selection process but is expected to take between 5 and 10 years once implemented. Gradient control may decrease the time to reach GPS due to groundwater removal. Alternative 3 is anticipated to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** The following permits and approvals are expected to be required to implement Alternative 3:
  - Downgradient property owner access agreements.
  - Federal, state, and local floodplain/wetland permits.
  - Receiving treatment facility approval or agency approval to construct the necessary treatment facility.
  - State and local well installation permits.
  - National Pollutant Discharge Elimination System (NPDES) permitting for post-treatment groundwater discharges.
  - State and local construction permits.

– State and local erosion control/construction storm water management permits.

State and local erosion control/construction storm water management permits may also be required depending on the level of disturbance required to implement the alternative.

## 6.4 ALTERNATIVE 4 – IN-SITU TREATMENT WITH PHYSICAL/CHEMICAL AMENDMENT

As described in **Section 5.4**, Alternative 4 includes adding a chemical amendment, in-situ to the area surrounding the closed CCR unit to reduce the mobilization of lithium.

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – Alternative 4 further reduces the potential for ongoing groundwater impacts from that interaction between CCR and water. Application of the physical or chemical amendment is intended to address changes in groundwater conditions. The application of a physical amendment such as Portland cement may require disturbance of the existing cap. The application of a chemical amendment could be completed outside of the capped area to maintain the integrity of the cap. Bench scale and pilot scale testing are necessary to evaluate potential amendments and document performance prior to implementation. If testing indicates an amendment will be effective, Alternative 4 is capable of and expected to attain the GPS for lithium.

  - Reliability – Based on a review of information in the Federal Remediation Technologies Roundtable (FRTR) Technology Screening Matrix, both physical amendments and amending source material using site-specific chemistries can be an effective means of sequestering metals to limit the future release to groundwater from residual source material. The technology can be applied to source material and groundwater plumes. The approach has been used at full scale to remediate inorganics (FRTR, 2020).

  - Implementation – The complexity of in-situ amendment is moderate. The equipment and personnel required to implement in-situ amendment applications are specialized and may be in high demand.

  - Impacts – Safety impacts associated with the implementation of Alternative 4 are not significantly different than other construction projects. Although the risk to surface water receptors is unknown based on available data, the additional source control provided by Alternative 4 may offer further reduction of risks if groundwater conditions change. The potential for exposure to residual contamination is low because the CCR is capped, and groundwater impacts will be chemically stabilized.

- **Timing.** In-situ treatment with physical/chemical amendments may be completed within 1 to 3 years of remedy selection and issuance of required permits, depending on the method of in-situ treatment used. The time required to initiate this alternative and attain the GPS for lithium will be evaluated further during the remedy selection process but is expected to take between 3 and 5 years once implemented. In-situ treatment may decrease the time to reach GPS based on physical/chemical amendment efficacy. Alternative 4 is anticipated to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** The following permits and approvals are expected to be required to implement Alternative 4:
  - Federal, state, and local floodplain permits.
  - Injection permits.
  - State and local erosion control/construction storm water management permits.
  - Federal and state wetland permitting may also be required.

## 6.5 ALTERNATIVE 5 – GROUNDWATER MANAGEMENT WITH BARRIER WALL

As described in **Section 5.5**, Alternative 5 includes installing a barrier wall to prevent the migration of groundwater with lithium concentrations greater than the GPS.

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – The barrier wall may further reduce the potential for ongoing groundwater impacts after closure. The risk to surface water receptors is unknown, and the potential for CCR to interact with groundwater will remain although CCR was capped during closure. Alternative 5 further reduces the risk of potential ongoing groundwater impacts by reducing the interaction between CCR and water. Although it acts passively, the barrier wall reduces the risk of groundwater exposure to CCR by reducing contact. Alternative 5 is capable of and expected to attain the GPS for lithium.

  - Reliability – A barrier wall at SGS may consist of an impermeable wall, a permeable reactive barrier (PRB) due to the lack of an impermeable layer to key a low permeability barrier wall into, or a combination commonly referred to as a "funnel-and-gate." The purpose of the barrier is to reduce contact of groundwater with CCR. Additional information about the effectiveness of this alternative will be better understood after collection of additional data from new monitoring wells. In general, the reliability of PRBs for containment of inorganics is favorable based on information available in the FRTR Technology Screening Matrix (FRTR, 2020). The reliability of a PRB requires the identification of a suitable reactive media for the conditions at SGS and the ability to effectively locate the barrier, which requires additional evaluations. PRB performance can diminish over time as consumptive media is exhausted or hydraulic conditions change due to chemical precipitation or biofouling. Long-term monitoring and maintenance are required to ensure continued performance.

  - Implementation –The equipment and personnel required to install a barrier wall are specialized and may be in high demand. Highly specialized and experienced contractors are required to achieve proper installation. Dewatering is required for excavation and placement of the barrier wall. Success with this remedy relies on continued hydraulic conductivity of the selected barrier. Breaches or short-circuiting can develop and must be monitored.

  - Impacts – Safety impacts associated with the implementation of Alternative 5 are not significantly different than other heavy civil construction projects. Although the risk to surface water receptors is unknown based on available data, the enhanced nature of the passive groundwater plume containment provided by Alternative 5 may offer further reduction of risks if groundwater conditions change. The potential for exposure to residual contaminated source material is low because CCR is within the closed CCR unit.

- **Timing.** The time required to design and install the barrier wall is estimated to be approximately 2 to 3 years. Alternative 5 is anticipated to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** The following permits and approvals are expected to be required to implement Alternative 5:
  - Federal, state, and local floodplain permits.
  - State and local well installation permits.
  - State and local erosion control/construction storm water management permits.
  - Federal and state wetland permitting may also be required.

## 6.6 ALTERNATIVE 6 – EXCAVATE AND RE-DISPOSE

As described in **Section 5.6,** under Alternative 6, CCR from the closure area will be excavated and appropriately re-disposed, either on or off-site, after the removal of the existing final cover. Further on-site releases from the CCR sources will be prevented by removing the source materials from the site or otherwise minimizing the potential for ongoing on-site leaching of constituents into groundwater.

- **Performance, Reliability, Implementation, and Impacts.**
  - Performance – Removing and re-disposing CCR will eliminate the source material exposed to infiltration and groundwater, which are key contributors to groundwater impacts. The off-site disposal option for CCR prevents further releases at SGS but introduces the possibility of releases at the receiving facility. On-site re-disposal of CCR would be designed to control infiltration and eliminate contact with groundwater. Alternative 6 is capable of and expected to attain the GPS for lithium.

  - Reliability – The expected reliability of excavation and re-disposal is good. Off-site disposal facilities are required to meet the requirements in 40 CFR 257.70 or other similar requirements, which have been used for solid waste disposal including municipal and industrial waste for numerous years. There is significant industry experience with the design and construction of these disposal facilities.

  - Implementation – The complexity of excavating CCR for re-disposal is low. For off-site disposal, the scale of CCR excavation, off-site transportation, and the permitting/development of off-site disposal facility airspace makes this alternative logistically complex. Dewatering may be required to excavate CCR. Conditioning (e.g., drying) of excavated CCR is expected to facilitate off-site transportation and re-disposal. Alternative 6 can likely be achieved through standard dewatering and conditioning methods but may be impacted by the space available for these activities. Although the source area at SGS is eliminated, the development of off-site disposal airspace will put a high demand on the receiving disposal facility, which may not have the current physical or logistical capacity to receive large volumes of CCR in a short period of time. The equipment and personnel required to implement on-site and off-site aspects of Alternative 6 are not specialized and are generally readily available, with the exception of the resources needed to install the geosynthetic portions of the off-site composite liner and cover, which are not locally available.

– Impacts – Safety impacts associated with the implementation of Alternative 6 are not significantly different than other heavy civil construction projects. However, the level of disturbance required to excavate, transport, and re-dispose CCR and the traffic required to import composite liner and cap material at the receiving disposal facility are not typical and likely represent an increase in safety risk due to large volumes of incoming/outgoing off-site construction traffic at both sites. A risk of cross-media impacts is possible due to the large volume of CCR to be excavated and transported from the site. Although the risk to surface water receptors is unknown, Alternative 6 nearly eliminates the potential interaction between CCR and water after closure. If off-site disposal is selected, the potential for exposure to residual contamination on site is very low since CCR will be removed; however, the off-site potential for exposure to CCR is increased due to the relocation of the source material.

- **Timing.** Removal of the SGS closed CCR unit can be completed within 1 to 2 years of remedy selection. However, the time required to secure the off-site disposal airspace or design and construct on-site disposal airspace, including potential procurement, permitting, and construction, may extend this schedule significantly. The time required to attain the GPS for lithium will be evaluated further during the remedy selection process but is expected to take between 2 and 10 years after closure construction is complete. The level of source disturbance during construction may increase the time required to reach GPS. The removal of CCR from SGS may decrease the time to reach GPS. Alternative 6 is anticipated to provide full protection within the 30-year post-closure monitoring period.

- **Institutional Requirements.** The following permits and approvals are expected to be required to implement Alternative 6:
  – An amendment to the IDNR Closure Permit is likely required to implement this Alternative.

  – Depending on the disposal facility, approval of off-site disposal facility owner or landfill permit for new off-site facility, or permit/approval for.

  – State and local erosion control/construction storm water management and dewatering permits.

  – Transportation agreements and permits (local roads and railroads).

  Depending on the off-site disposal facility, state solid waste comprehensive planning approvals may also be required.

# 7.0 SUMMARY OF ASSESSMENT

An initial qualitative assessment of the advantages and disadvantages of each Corrective Measure Alternative presented in **Section 4.0** is provided in **Table 4**. Each of the identified Corrective Measure Alternatives exhibits both favorable and unfavorable outcomes with respect to the assessment criteria. In accordance with 40 CFR 257.97(c), the facility must consider all of the evaluation factors and select a remedy that meets the standards of 257.97(b) as soon as feasible.

IPL continues to advance additional data collection efforts to identify the appropriate corrective action measure for the Site. IPL will continue to update **Table 4** and develop a quantitative scoring matrix to identify a preferred corrective action.

# 8.0 REFERENCES

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# Tables

## Table 1. Groundwater Monitoring Well Network
## Sutherland Generating Station / SCS Engineers Project #25222189.00

| Monitoring Well | Location in Monitoring Network | Role in Monitoring Network |
|---|---|---|
| MW-301 | Upgradient | Background |
| MW-302 | Upgradient | Background |
| MW-303 | Downgradient | Compliance |
| MW-304 | Downgradient | Compliance |
| MW-305 | Downgradient | Compliance |
| MW-306 | Downgradient | Compliance |
| MW-307 | Downgradient | Delineation |
| MW-308 | Downgradient | Delineation |
| MW-309 | Downgradient | Delineation |
| MW-310 | Downgradient | Delineation |
| MW-311 | Downgradient | Delineation |

Created by: RM Date: 12/14/2020
Last revision by: JAO Date: 5/26/2022
Checked by: NDK Date: 5/29/2022

**Table 2. Water Level Summary**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| Raw Data | Depth to Water in feet below top of well casing | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MW-301 | MW-302 | MW-303 | MW-304 | MW-305 | MW-306 | MW-307 | MW-308 | MW-309 | MW-310 | MW-311 |
| **Measurement Date** | | | | | | | | | | | |
| November 29, 2017 | 12.85 | 9.27 | 7.56 | 9.05 | 8.13 | 9.77 | NM | NM | NM | NM | NM |
| March 26-27, 2018 | 11.38 | 7.11 | 5.19 | 7.00 | 6.17 | 7.64 | NM | NM | NM | NM | NM |
| May 23, 2018 | 11.16 | 7.76 | 5.47 | 6.87 | 5.82 | 7.02 | NM | NM | NM | NM | NM |
| June 26, 2018 | 10.37 | 6.53 | 4.57 | 6.15 | 5.26 | 6.56 | NM | NM | NM | NM | NM |
| July 26, 2018 | 10.65 | 7.33 | 5.40 | 6.93 | 5.81 | 7.19 | NM | NM | NM | NM | NM |
| September 11, 2018 | 9.20 | 6.02 | 3.58 | 5.13 | 3.87 | 4.65 | NM | NM | NM | NM | NM |
| November 28, 2018 | 9.62 | 6.34 | 4.53 | 6.00 | 4.94 | 6.22 | NM | NM | NM | NM | NM |
| January 9, 2019 | 9.76 | 6.26 | 4.43 | 5.86 | 4.87 | 6.19 | NM | NM | NM | NM | NM |
| February 12, 2019 | 10.02 | 6.65 | 4.96 | 6.38 | 5.25 | 6.38 | NM | NM | NM | NM | NM |
| April 2, 2019 | 9.28 | 5.96 | 3.94 | 5.32 | 4.14 | 5.17 | NM | NM | NM | NM | NM |
| October 16, 2019 | 10.46 | 7.78 | 4.64 | 6.01 | 4.82 | 8.97 | NM | NM | NM | NM | NM |
| December 11-12, 2019 | 9.56 | 6.97 | 5.07 | 6.50 | 5.48 | 6.74 | NM | NM | NM | NM | NM |
| February 3, 2020 | 10.37 | 6.49 | 4.97 | 6.44 | 5.53 | 6.99 | NM | NM | NM | NM | NM |
| April 7, 2020 | 10.45 | 6.85 | 4.91 | 6.25 | 5.17 | 6.43 | NM | NM | NM | NM | NM |
| May 11, 2020 | NM | NM | NM | NM | 6.03 | 7.42 | NM | NM | NM | NM | NM |
| October 13, 2020 | 12.17 | 8.70 | 7.84 | 9.49 | 8.49 | 10.00 | NM | NM | NM | NM | NM |
| February 24, 2021 | NM | NM | NM | NM | NM | 10.57 | NM | NM | NM | NM | NM |
| April 6, 2021 | 12.23 | 8.23 | 6.33 | 7.64 | 6.79 | 8.34 | NM | NM | NM | NM | NM |
| July 14, 2021 | NM | NM | NM | NM | NM | 10.46 | NM | NM | NM | NM | NM |
| October 26, 2021 | 14.19 | 10.40 | 9.00 | 10.66 | 9.69 | 11.13 | NM | NM | NM | NM | NM |
| December 9, 2021 | NM | NM | NM | NM | NM | NM | 13.31 | 11.20 | 11.20 | NM | NM |
| April 21-22, 2022 | 12.74 | 8.04 | 7.19 | 8.82 | 7.90 | 9.31 | 12.11 | 9.99 | 9.99 | NM | NM |
| May 12, 2022 | NM | NM | NM | NM | NM | NM | NM | NM | 6.00 | 6.84 | 4.08 |
| May 24, 2022 | 12.39 | 8.70 | 6.45 | 7.81 | 6.81 | 8.10 | 11.04 | 9.05 | 8.03 | 8.61 | 5.73 |

| Ground Water Elevation in feet above mean sea level (amsl) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Well Number** | **MW-301** | **MW-302** | **MW-303** | **MW-304** | **MW-305** | **MW-306** | **MW-307** | **MW-308** | **MW-309** | **MW-310** | **MW-311** |
| **Top of Casing Elevation (feet amsl)** | 866.61 | 863.08 | 859.54 | 860.79 | 859.81 | 861.13 | 864.87 | 863.07 | 859.95 | 860.55 | 857.64 |
| **Screen Length (ft)** | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 | 15.00 | 15.00 | 10.00 |
| **Total Depth (ft from top of casing)** | 18.80 | 18.50 | 18.65 | 18.80 | 19.08 | 18.71 | 17.50 | 16.00 | 20.00 | 20.00 | 15.00 |
| **Top of Well Screen Elevation (ft)** | 857.81 | 854.58 | 850.89 | 851.99 | 850.73 | 852.42 | 857.37 | 857.07 | 854.95 | 855.55 | 852.64 |
| **Measurement Date** | | | | | | | | | | | |
| November 29, 2017 | 853.76 | 853.81 | 851.98 | 851.74 | 851.68 | 851.36 | NI | NI | NI | NI | NI |
| March 26-27, 2018 | 855.23 | 855.97 | 854.35 | 853.79 | 853.64 | 853.49 | NI | NI | NI | NI | NI |
| May 23, 2018 | 855.45 | 855.32 | 854.07 | 853.92 | 853.99 | 854.11 | NI | NI | NI | NI | NI |
| June 26, 2018 | 856.24 | 856.55 | 854.97 | 854.64 | 854.55 | 854.57 | NI | NI | NI | NI | NI |
| July 26, 2018 | 855.96 | 855.75 | 854.14 | 853.86 | 854.00 | 853.94 | NI | NI | NI | NI | NI |
| September 11, 2018 | 857.41 | 857.06 | 855.96 | 855.66 | 855.94 | 856.48 | NI | NI | NI | NI | NI |
| November 28, 2018 | 856.99 | 856.74 | 855.01 | 854.79 | 854.87 | 854.91 | NI | NI | NI | NI | NI |
| January 9, 2019 | 856.85 | 856.82 | 855.11 | 854.93 | 854.94 | 854.94 | NI | NI | NI | NI | NI |
| February 12, 2019 | 856.59 | 856.43 | 854.58 | 854.41 | 854.56 | 854.75 | NI | NI | NI | NI | NI |
| April 2, 2019 | 857.33 | 857.12 | 855.60 | 855.47 | 855.67 | 855.96 | NI | NI | NI | NI | NI |
| October 16, 2019 | 856.15 | 855.30 | 854.90 | 854.78 | 854.99 | 852.16 | NI | NI | NI | NI | NI |
| December 11-12, 2019 | 857.05 | 856.11 | 854.47 | 854.29 | 854.33 | 854.39 | NI | NI | NI | NI | NI |
| February 3, 2020 | 856.24 | 856.59 | 854.57 | 854.35 | 854.28 | 854.14 | NI | NI | NI | NI | NI |
| April 7, 2020 | 856.16 | 856.23 | 854.63 | 854.54 | 854.64 | 854.70 | NI | NI | NI | NI | NI |
| May 11, 2020 | NM | NM | NM | NM | 853.78 | 853.71 | NI | NI | NI | NI | NI |
| October 13, 2020 | 854.44 | 854.38 | 851.70 | 851.30 | 851.32 | 851.13 | NI | NI | NI | NI | NI |
| February 24, 2021 | NM | NM | NM | NM | NM | 850.56 | NI | NI | NI | NI | NI |
| April 6, 2021 | 854.38 | 854.85 | 853.21 | 853.15 | 853.02 | 852.79 | NI | NI | NI | NI | NI |
| July 14, 2021 | NM | NM | NM | NM | NM | 850.67 | NI | NI | NI | NI | NI |
| October 26, 2021 | 852.42 | 852.68 | 850.54 | 850.13 | 850.12 | 850.00 | NI | NI | NI | NI | NI |
| December 9, 2021 | NM | NM | NM | NM | NM | NM | 851.56 | 851.87 | NI | NI | NI |
| April 21-22, 2022 | 853.87 | 855.04 | 852.35 | 851.97 | 851.91 | 851.82 | 852.76 | 853.08 | NI | NI | NI |
| May 12, 2022 | NM | NM | NM | NM | NM | NM | NM | NM | 853.95 | 853.71 | 853.56 |
| May 24, 2022 | 854.22 | 854.38 | 853.09 | 852.98 | 853.00 | 853.03 | 853.83 | 854.02 | 851.92 | 851.94 | 851.91 |
| **Bottom of Well Elevation (ft)** | 847.81 | 844.58 | 840.89 | 841.99 | 840.73 | 842.42 | 847.37 | 847.07 | 839.95 | 840.55 | 842.64 |

Notes:
NM = not measured
NI = not installed

| | | |
|---|---|---|
| Created by: | NDK | Date: 1/15/2018 |
| Last revision by: | NDK | Date: 5/29/2022 |
| Checked by: | JAO | Date: 6/6/2022 |
| Proj Mgr QA/QC: | TK | Date: 6/6/2022 |

I:\25222076.00\Deliverables\2022 SGS ACM\Tables\[Table 2 - Groundwater Elevation Summary.xlsx]levels

## Table 3. Groundwater Analytical Results - Assessment Monitoring
## Sutherland Generating Station / SCS Engineers Project #25222076.00

| | | | | Background Wells | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Parameter Name | UPL Method | UPL | GPS | MW-301 | | | | | | MW-302 | | | | | |
| | | | | 2/3/2020 | 4/7/2020 | 10/13/2020 | 4/6/2021 | 10/26/2021 | 4/22/2022 | 2/3/2020 | 4/7/2020 | 10/13/2020 | 4/6/2021 | 10/26/2021 | 4/22/2022 |
| **Appendix III** | | | | | | | | | | | | | | | |
| Boron, ug/L | P | 307 | | 120 J | <100 | 370 | 76 J | 62 J | <58.0 | <100 | <100 | <80 | 67 J | <58 | 71 J |
| Calcium, mg/L | P | 96 | | 82 | 78 | 100 | 70 | 81 | 50 | 56 | 71 | 71 | 80 | 95 | 77 |
| Chloride, mg/L | P | 63.5 | | 28 | 21 | 71 | 85 | 9 | 2.4 J | 3.8 J | 5.2 | 5.6 | 85 | 7.2 | 17 |
| Fluoride, mg/L | P | 0.32 | | -- | 0.41 J | <0.23 | 2.5 | <0.28 | <0.22 | -- | 0.55 | 0.30 J | 2.5 | <0.28 | <0.22 |
| Field pH, Std. Units | P | 7.78 | | 6.79 | 6.87 | 6.66 | 6.69 | 6.21 | 6.23 | 7.31 | 7.36 | 7.43 | 6.96 | 7.30 | 7.11 |
| Sulfate, mg/L | P | 95.6 | | 32 | 17 | 98 | 160 | 83 | 33 | 17 | 14 | 12 | 180 | 43 | 91 |
| Total Dissolved Solids, mg/L | P | 516 | | 380 | 330 | 540 | 260 | 200 | 150 | 250 | 250 | 260 | 300 | 270 | 320 |
| **Appendix IV** | | | | | | | | | | | | | | | |
| Antimony, ug/L | P | 2.9 | 6 | -- | <0.58 | -- | <1.1 | <1.1 | <0.69 | -- | <0.58 | -- | <1.1 | <1.1 | 0.69 J |
| Arsenic, ug/L | P | 40 | 40 | <0.88 | <0.88 | <0.88 | <0.75 | <0.75 | <0.75 | 19 | 5.3 | 4.6 | 3 | 7.4 | 21 |
| Barium, ug/L | NP | 1,100 | 2,000 | 120 | 240 | 110 | 59 | 130 | 86 | 100 | 97 | 100 | 130 | 140 | 170 |
| Beryllium, ug/L | NP | 1.3 | 4 | -- | 0.33 J | <0.27 | <0.27 | <0.27 | <0.27 | -- | <0.27 | <0.27 | <0.27 | <0.27 | <0.27 |
| Cadmium, ug/L | P | 0.97 | 5 | 0.047 J | 0.17 | 0.077 J | <0.051 | 0.080 J | <0.055 | <0.039 | <0.039 | <0.049 | <0.051 | <0.051 | <0.055 |
| Chromium, ug/L | P | 3.7 | 100 | -- | 1.1 J | <1.1 | <1.1 | <1.1 | <1.10 | -- | <1.1 | <1.1 | <1.1 | <1.1 | <1.10 |
| Cobalt, ug/L | P | 8.8 | 8.8 | 0.75 | 1.6 | 0.28 J | 0.18 J | 0.24 J | 0.63 | 3.7 | 1.7 | 0.77 | 4.7 | 1.6 | 6.3 |
| Fluoride, mg/L | P | 0.32 | 4 | -- | 0.41 J | <0.23 | 2.5 | <0.28 | <0.22 | -- | 0.55 | 0.30 J | 2.5 | <0.28 | <0.22 |
| Lead, ug/L | P | 2.9 | 15 | 0.34 J | 0.50 | <0.11 | <0.21 | 0.52 B | 0.26 J | <0.27 | <0.27 | <0.11 | <0.21 | 0.31 J,B | <0.24 |
| Lithium, ug/L | NP | 13 | 40 | 2.7 J | 3.4 J | 3.2 J | 2.5 J | 2.8 J | 3.0 J | <2.3 | <2.3 | 2.8 J | 2.8 J | 2.9 J | 2.5 J |
| Mercury, ug/L | DQ | DQ | 2 | -- | <0.10 | -- | <0.15 | <0.15 | <0.11 | -- | <0.10 | -- | <0.15 | <0.15 | <0.11 |
| Molybdenum, ug/L | P | 18 | 100 | <1.1 | <1.1 | 2.5 | <1.3 | <1.3 | <1.20 | <1.1 | <1.1 | <1.1 | <1.3 | <1.3 | <1.20 |
| Selenium, ug/L | P | 16 | 50 | -- | <1.0 | -- | <0.96 | 2.8 J | 1.30 J | -- | <1.0 | -- | 2.5 J | 1.3 J | 22 |
| Thallium, ug/L | NP* | 0.43 | 2 | -- | <0.26 | -- | <0.26 | <0.26 | <0.26 | -- | <0.26 | -- | <0.26 | <0.26 | <0.26 |
| Radium 226/228 Combined, pCI/L | P | 3.2 | 5 | 0.388 | 0.291 | 0.463 | 0.256 | 1.07 | 0.244 | 0.808 | 0.547 | 0.580 | 0.6 | 0.614 | 0.663 |
| **Additonal Parameters - Selection of Remedy** | | | | | | | | | | | | | | | |
| Lithium, dissolved, ug/L | UPL or GPS not applicable | | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Iron, dissolved, ug/L | | | | -- | -- | -- | -- | -- | <36 | -- | -- | -- | -- | -- | <36 |
| Iron, ug/L | | | | -- | -- | -- | 120 | 170 | 410 | -- | -- | -- | 210 | 1000 | 780 |
| Magnesium, dissolved, ug/L | | | | -- | -- | -- | -- | -- | 9,300 | -- | -- | -- | -- | -- | 23,000 |
| Magnesium, ug/L | | | | -- | -- | -- | 21,000 | 16,000 | 9,500 | -- | -- | -- | 25,000 | 26,000 | 23,000 |
| Manganese, dissolved, ug/L | | | | -- | -- | -- | -- | -- | 150 | -- | -- | -- | -- | -- | 65 |
| Manganese, ug/L | | | | -- | -- | -- | 2,000 | 1,000 | 590 | -- | -- | -- | 590 | 1,000 | 600 |
| Potassium, ug/L | | | | -- | -- | -- | 1,700 | 1,600 | 1,400 | -- | -- | -- | 320 J | 440 J | 280 J |
| Sodium, ug/L | | | | -- | -- | -- | 7,900 | 13,000 | 9,300 | -- | -- | -- | 12,000 | 9,200 | 19,000 |
| Total Alkalinity, mg/L | | | | -- | -- | -- | 250 | 220 | 170 | -- | -- | -- | 280 | 400 | 200 |
| Carbonate Alkalinity, mg/L | | | | -- | -- | -- | <4.6 | <4.6 | <4.60 | -- | -- | -- | <4.6 | <4.6 | <4.60 |
| Bicarbonate Alkalinity, mg/L | | | | -- | -- | -- | 250 | 220 | 170 | -- | -- | -- | 280 | 400 | 200 |

Blue shaded cell indicates the compliance well result exceeds the UPL and the LOQ
Yellow shaded cell indicates the compliance well result exceeds the GPS.
Grayscale indicates Additional Parameters sampled for selection of remedy and evaluation of Monitored Natural Attentuation

See Page 5 for notes and abbreviations

**Table 3. Groundwater Analytical Results - Assessment Monitoring**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| Parameter Name | UPL Method | UPL | GPS | Compliance Wells | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MW-303 | | | | | | MW-304 | | | | | |
| | | | | 2/3/2020 | 4/7/2020 | 10/13/2020 | 4/6/2021 | 10/26/2021 | 4/22/2022 | 2/3/2020 | 4/7/2020 | 10/13/2020 | 4/6/2021 | 10/26/2021 | 4/21/2022 |
| **Appendix III** | | | | | | | | | | | | | | | |
| Boron, ug/L | P | 307 | | 440 | 530 | 710 | 360 | 400 | 130 | 560 | 580 | 830 | 570 | 480 | 630 |
| Calcium, mg/L | P | 96 | | 160 | 110 | 120 | 80 | 87 | 28 | 150 | 150 | 150 | 130 | 110 | 130 |
| Chloride, mg/L | P | 63.5 | | 12 | 11 | 14 | 81 | 3.8 J | <2.30 | 21 | 15 | 11 | 80 | <0.28 | 3.7 J |
| Fluoride, mg/L | P | 0.32 | | -- | 0.68 | 0.44 J | 2.7 | <0.28 | <0.22 | -- | 0.49 J | <0.23 | 2.5 | <0.28 | <0.22 |
| Field pH, Std. Units | P | 7.78 | | 6.84 | 7.17 | 7.12 | 7.04 | 6.84 | 7.30 | 6.71 | 6.68 | 6.64 | 6.61 | 7.04 | 6.77 |
| Sulfate, mg/L | P | 95.6 | | 350 | 210 | 190 | 250 | 160 | 33 | 360 | 350 | 330 | 430 | 170 | 310 |
| Total Dissolved Solids, mg/L | P | 516 | | 830 | 570 | 610 | 340 | 300 | 100 | 800 | 750 | 800 | 600 | 450 | 580 |
| **Appendix IV** | | | | | | | | | | | | | | | |
| Antimony, ug/L | P | 2.9 | 6 | -- | <0.58 | -- | <1.1 | <1.1 | <0.69 | -- | <0.58 | -- | <1.1 | <1.1 | <0.69 |
| Arsenic, ug/L | P | 40 | 40 | <0.88 | <0.88 | 1.6 J | 0.96 J | 4.8 | 1.9 J | <0.88 | <0.88 | <0.88 | <0.75 | <0.75 | <0.75 |
| Barium, ug/L | NP | 1,100 | 2,000 | 55 | 41 | 65 | 39 | 91 | 36 | 24 | 22 | 21 | 16 | 23 | 21 |
| Beryllium, ug/L | NP | 1.3 | 4 | -- | <0.27 | <0.27 | <0.27 | <0.27 | <0.27 | -- | <0.27 | <0.27 | <0.27 | <0.27 | <0.27 |
| Cadmium, ug/L | P | 0.97 | 5 | <0.039 | 0.20 | <0.049 | 0.086 J | 0.16 | 0.29 | 0.36 | 0.079 J | 0.075 J | 0.15 | 0.24 | 0.073 J |
| Chromium, ug/L | P | 3.7 | 100 | -- | <1.1 | <1.1 | <1.1 | <1.1 | <1.10 | -- | <1.1 | <1.1 | <1.1 | <1.1 | <1.10 |
| Cobalt, ug/L | P | 8.8 | 8.8 | 1.3 | 0.53 | 1.0 | 0.31 J | 0.66 | 1.4 | 0.19 J | 0.28 J | 0.11 J | <0.091 | 0.3 J | <0.19 |
| Fluoride, mg/L | P | 0.32 | 4 | -- | 0.68 | 0.44 J | 2.7 | <0.28 | <0.22 | -- | 0.49 J | <0.23 | 2.5 | <0.28 | <0.22 |
| Lead, ug/L | P | 2.9 | 15 | <0.27 | 0.31 J | <0.11 | <0.21 | 0.5 B | 0.73 | <0.27 | <0.27 | <0.11 | <0.21 | 0.75 B | <0.24 |
| Lithium, ug/L | NP | 13 | 40 | 22 | 23 | 26 | 17 | 20 | 7.8 J | <2.3 | <2.3 | 2.8 J | <2.5 | 6.8 J | <2.50 |
| Mercury, ug/L | DQ | DQ | 2 | -- | <0.10 | -- | <0.15 | <0.15 | <0.11 | -- | <0.10 | -- | <0.15 | <0.15 | <0.11 |
| Molybdenum, ug/L | P | 18 | 100 | 11 | 23 | 22 | 11 | 5.9 | 2.4 | 1.5 J | <1.1 | 1.4 J | <1.3 | <1.3 | <1.20 |
| Selenium, ug/L | P | 16 | 50 | -- | <1.0 | -- | <0.96 | 26 | 1.4 J | -- | <1.0 | -- | 1.1 J | <0.96 | <0.96 |
| Thallium, ug/L | NP* | 0.43 | 2 | -- | <0.26 | -- | <0.26 | <0.26 | <0.26 | -- | <0.26 | -- | <0.26 | <0.26 | <0.26 |
| Radium 226/228 Combined, pCi/L | P | 3.2 | 5 | 0.159 | 1.18 | 0.531 | 0.268 | 0.666 | 2.04 | 0.0516 | 0.494 | 0.606 | 0.0369 | 0.721 | 0.350 |
| **Additonal Parameters - Selection of Remedy** | | | | | | | | | | | | | | | |
| Lithium, dissolved, ug/L | UPL or GPS not applicable | | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- |
| Iron, dissolved, ug/L | | | | -- | -- | -- | -- | -- | <36 | -- | -- | -- | -- | -- | <36 |
| Iron, ug/L | | | | -- | -- | -- | 420 | 2,900 | 2,300 | -- | -- | -- | <36 | 71 J | <36 |
| Magnesium, dissolved, ug/L | | | | -- | -- | -- | -- | -- | 7,400 | -- | -- | -- | -- | -- | 34,000 |
| Magnesium, ug/L | | | | -- | -- | -- | 23,000 | 21,000 | 7,800 | -- | -- | -- | 34,000 | 29,000 | 34,000 |
| Manganese, dissolved, ug/L | | | | -- | -- | -- | -- | -- | 51 | -- | -- | -- | -- | -- | 5 J |
| Manganese, ug/L | | | | -- | -- | -- | 930 | 700 | 560 | -- | -- | -- | 180 | 270 | 61 |
| Potassium, ug/L | | | | -- | -- | -- | 3,300 | 3,900 | 2,000 | -- | -- | -- | <150 | 600 | <150 |
| Sodium, ug/L | | | | -- | -- | -- | 19,000 | 18,000 | 6,700 | -- | -- | -- | 38,000 | 33,000 | 41,000 |
| Total Alkalinity, mg/L | | | | -- | -- | -- | 240 | 230 | 88 | -- | -- | -- | 230 | 350 | 200 |
| Carbonate Alkalinity, mg/L | | | | -- | -- | -- | <4.6 | <4.6 | <4.60 | -- | -- | -- | <4.6 | <4.6 | <4.6 |
| Bicarbonate Alkalinity, mg/L | | | | -- | -- | -- | 240 | 230 | 88 | -- | -- | -- | 230 | 350 | 200 |

Blue shaded cell indicates the compliance well result exceeds the UPL and the LOQ
Yellow shaded cell indicates the compliance well result exceeds the GPS.
Grayscale indicates Additional Parameters sampled for selection of remedy and evaluation of Monitored Natural Attentuation

See Page 5 for notes and abbreviations

# Table 3. Groundwater Analytical Results - Assessment Monitoring
## Sutherland Generating Station / SCS Engineers Project #25222076.00

| Parameter Name | UPL Method | UPL | GPS | Compliance Wells | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MW-305 | | | | | | | MW-306 | | | | | | | | | |
| | | | | 2/3/2020 | 4/7/2020 | 5/11/2020 | 10/13/2020 | 4/6/2021 | 10/26/2021 | 4/21/2022 | 2/3/2020 | 4/7/2020 | 5/11/2020 | 10/13/2020 | 2/24/2021 | 4/6/2021 | 7/14/2021 | 10/26/2021 | 4/21/2022 |
| **Appendix III** | | | | | | | | | | | | | | | | | | | | |
| Boron, ug/L | P | 307 | | 930 | 850 | -- | 1,400 | 1400 | 1800 | 1100 | 2500 | 2500 | -- | 3,800 | -- | 3400 | -- | 4,400 | 4,400 |
| Calcium, mg/L | P | 96 | | 140 | 170 | -- | 140 | 150 | 110 | 140 | 220 | 220 | -- | 230 | -- | 210 | -- | 150 | 170 |
| Chloride, mg/L | P | 63.5 | | 17 | 12 | -- | 17 | 91 | 24 | 20 | 12 | 14 | -- | 21 | -- | 95 | -- | 20 | 19 |
| Fluoride, mg/L | P | 0.32 | | -- | 0.69 | -- | 0.46 J | 2.7 | <0.28 | <0.22 | -- | 0.75 J | -- | 0.65 | -- | 2.5 | -- | <0.28 | <0.22 |
| Field pH, Std. Units | P | 7.78 | | 6.61 | 6.70 | 5.97 | 7.33 | 6.68 | 7.58 | 6.99 | 7.61 | 7.72 | 7.08 | 7.62 | 7.61 | 7.64 | 8.11 | 7.44 | 7.71 |
| Sulfate, mg/L | P | 95.6 | | 440 | 450 | -- | 410 | 470 | 240 | 280 | 550 | 560 | -- | 400 | -- | 710 | -- | 440 | 470 |
| Total Dissolved Solids, mg/L | P | 516 | | 850 | 900 | -- | 790 | 800 | 500 | 590 | 1100 | 1100 | -- | 1,200 | -- | 1200 | -- | 690 | 780 |
| **Appendix IV** | | | | | | | | | | | | | | | | | | | | |
| Antimony, ug/L | P | 2.9 | 6 | -- | <0.58 | -- | -- | <1.1 | <1.1 | <0.69 | -- | <0.58 | -- | -- | -- | <1.1 | -- | <1.1 | <0.69 |
| Arsenic, ug/L | P | 40 | 40 | 6.3 | 8.8 | -- | 11 | 6.4 | 7.4 | 7.1 | 4.6 | 3.6 | -- | 4.4 | -- | 4 | -- | 4.1 | 4.0 |
| Barium, ug/L | NP | 1,100 | 2,000 | 32 | 41 | -- | 52 | 32 | 47 | 35 | 100 | 99 | -- | 110 | -- | 110 | -- | 74 | 80 |
| Beryllium, ug/L | NP | 1.3 | 4 | -- | <0.27 | -- | <0.27 | <0.27 | <0.27 | <0.27 | -- | <0.27 | -- | <0.27 | -- | <0.27 | -- | <0.27 | <0.27 |
| Cadmium, ug/L | P | 0.97 | 5 | <0.039 | <0.039 | -- | <0.049 | 0.052 J | <0.051 | 0.061 J | <0.039 | 0.045 J | -- | <0.049 | -- | <0.051 | -- | <0.051 | <0.055 |
| Chromium, ug/L | P | 3.7 | 100 | -- | <1.1 | -- | <1.1 | <1.1 | <1.1 | 2.8 J | -- | <1.1 | -- | <1.1 | -- | <1.1 | -- | <1.1 | <1.10 |
| Cobalt, ug/L | P | 8.8 | 8.8 | 1.6 | 2.1 | -- | 0.60 | 1.7 | 0.63 | 1.4 | 0.85 | 0.66 | -- | 0.68 | -- | 0.71 | -- | 0.59 | 0.54 |
| Fluoride, mg/L | P | 0.32 | 4 | -- | 0.69 | -- | 0.46 J | 2.7 | <0.28 | <0.22 | -- | 0.75 J | -- | 0.65 | -- | 2.5 | -- | <0.28 | <0.22 |
| Lead, ug/L | P | 2.9 | 15 | <0.27 | 0.48 J | -- | <0.11 | <0.21 | <0.21 | <0.24 | <0.27 | <0.27 | -- | <0.11 | -- | <0.21 | -- | 0.58 B | <0.24 |
| Lithium, ug/L | NP | 13 | 40 | 10 | 12 | -- | 22 | 29 | 35 | 32 | 39 | 40 | 42 | 52 | 55 | 48 | 59 | 55 | 52 |
| Mercury, ug/L | DQ | DQ | 2 | -- | <0.10 | -- | -- | <0.15 | <0.15 | <0.11 | -- | <0.10 | -- | -- | -- | <0.15 | -- | <0.15 | <0.11 |
| Molybdenum, ug/L | P | 18 | 100 | 18 | 20 | -- | 36 | 41 | 55 | 42 | 38 | 36 | -- | 42 | -- | 59 | -- | 66 | 83 |
| Selenium, ug/L | P | 16 | 50 | -- | <1.0 | -- | -- | <0.96 | <0.96 | <0.96 | -- | <1.0 | -- | -- | -- | <0.96 | -- | <0.96 | <0.96 |
| Thallium, ug/L | NP* | 0.43 | 2 | -- | <0.26 | -- | -- | <0.26 | <0.26 | <0.26 | -- | <0.26 | -- | -- | -- | <0.26 | -- | <0.26 | <0.26 |
| Radium 226/228 Combined, pCI/L | P | 3.2 | 5 | 0.510 | 3.1 | 0.557 | 0.986 | 0.340 | 1.02 | 0.349 | 0.214 | 0.36 | -- | 0.510 | -- | 0.261 | -- | 0.307 | 0.194 |
| **Additonal Parameters - Selection of Remedy** | | | | | | | | | | | | | | | | | | | | |
| Lithium, dissolved, ug/L | UPL or GPS not applicable | | | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | -- | 56 |
| Iron, dissolved, ug/L | | | | -- | -- | -- | -- | | | <36 | -- | -- | -- | -- | -- | | -- | | 46 |
| Iron, ug/L | | | | -- | -- | -- | -- | 250 | 230 | 200 | -- | -- | -- | -- | -- | 61 J | -- | 220 | 84 |
| Magnesium, dissolved, ug/L | | | | -- | -- | -- | -- | | | 31,000 | -- | -- | -- | -- | -- | | -- | | 35,000 |
| Magnesium, ug/L | | | | -- | -- | -- | -- | 40,000 | 25,000 | 31,000 | -- | -- | -- | -- | -- | 55,000 | -- | 26,000 | 37,000 |
| Manganese, dissolved, ug/L | | | | -- | -- | -- | -- | | | 1,200 | -- | -- | -- | -- | -- | | -- | | 2,300 |
| Manganese, ug/L | | | | -- | -- | -- | -- | 1,400 | 520 | 1,200 | -- | -- | -- | -- | -- | 3,400 | -- | 1,900 | 2,500 |
| Potassium, ug/L | | | | -- | -- | -- | -- | 3,900 | 5,900 | 4,800 | -- | -- | -- | -- | -- | 7,000 | -- | 7,400 | 7,900 |
| Sodium, ug/L | | | | -- | -- | -- | -- | 48,000 | 38,000 | 41,000 | -- | -- | -- | -- | -- | 46,000 | -- | 41,000 | 47,000 |
| Total Alkalinity, mg/L | | | | -- | -- | -- | -- | 200 | 230 | 250 | -- | -- | -- | -- | -- | 170 | -- | 100 | 120 |
| Carbonate Alkalinity, mg/L | | | | -- | -- | -- | -- | <4.6 | <4.6 | <4.6 | -- | -- | -- | -- | -- | <4.2 | -- | <4.6 | <4.60 |
| Bicarbonate Alkalinity, mg/L | | | | -- | -- | -- | -- | 200 | 230 | 250 | -- | -- | -- | -- | -- | 170 | -- | 100 | 120 |

Blue shaded cell indicates the compliance well result exceeds the UPL and the LOQ
Yellow shaded cell indicates the compliance well result exceeds the GPS.
Grayscale indicates Additional Parameters sampled for selection of remedy and evaluation of Monitored Natural Attentuation

See Page 5 for notes and abbreviations

**Table 3. Groundwater Analytical Results - Assessment Monitoring**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| Parameter Name | UPL Method | UPL | GPS | Delineation Wells | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | MW-307 | | MW-308 | | MW309 | MW-310 | MW-311 |
| | | | | 12/9/2021 | 4/21/2022 | 12/9/2021 | 4/21/2022 | 5/12/2022 | 5/12/2022 | 5/12/2022 |
| **Appendix III** | | | | | | | | | | |
| Boron, ug/L | P | 307 | | 460 | 500 | 330 | 370 | -- | -- | -- |
| Calcium, mg/L | P | 96 | | 150 | 180 | 96 | 120 | -- | -- | -- |
| Chloride, mg/L | P | 63.5 | | 19 | 21 | 17 | 14 | -- | -- | -- |
| Fluoride, mg/L | P | 0.32 | | <0.28 | <0.22 | <0.28 | <0.22 | -- | -- | -- |
| Field pH, Std. Units | P | 7.78 | | 6.53 | 6.62 | 6.96 | 7.12 | 7.42 | 7.44 | 7.17 |
| Sulfate, mg/L | P | 95.6 | | 320 | 350 | 89 | 120 | -- | -- | -- |
| Total Dissolved Solids, mg/L | P | 516 | | 700 | 750 | 390 | 390 | -- | -- | -- |
| **Appendix IV** | | | | | | | | | | |
| Antimony, ug/L | P | 2.9 | 6 | <1.1 | <0.69 | <1.1 | <0.69 | -- | -- | -- |
| Arsenic, ug/L | P | 40 | 40 | 2.6 | 4.4 | <0.75 | 0.9 J | -- | -- | -- |
| Barium, ug/L | NP | 1,100 | 2,000 | 47 | 46 | 69 | 81 | -- | -- | -- |
| Beryllium, ug/L | NP | 1.3 | 4 | <0.27 | <0.27 | <0.27 | <0.27 | -- | -- | -- |
| Cadmium, ug/L | P | 0.97 | 5 | 0.18 | 0.35 | <0.051 | <0.055 | -- | -- | -- |
| Chromium, ug/L | P | 3.7 | 100 | <1.1 | 1.3 J | <1.1 | <1.10 | -- | -- | -- |
| Cobalt, ug/L | P | 8.8 | 8.8 | 6.8 | 6.8 | 2.0 | 2.8 | -- | -- | -- |
| Fluoride, mg/L | P | 0.32 | 4 | <0.28 | <0.22 | <0.28 | <0.22 | -- | -- | -- |
| Lead, ug/L | P | 2.9 | 15 | <0.21 | 0.92 | 0.21 J | 0.34 J | -- | -- | -- |
| Lithium, ug/L | NP | 13 | 40 | 22 | 26 | 11 | 15 | 17 | 20 | 25 |
| Mercury, ug/L | DQ | DQ | 2 | <0.15 | <0.11 | <0.15 | <0.11 | -- | -- | -- |
| Molybdenum, ug/L | P | 18 | 100 | 6.5 | 4.1 | <1.3 | <1.20 | -- | -- | -- |
| Selenium, ug/L | P | 16 | 50 | <0.96 | <0.96 | <0.96 | <0.96 | -- | -- | -- |
| Thallium, ug/L | NP* | 0.43 | 2 | <0.26 | <0.26 | <0.26 | <0.26 | -- | -- | -- |
| Radium 226/228 Combined, pCI/L | P | 3.2 | 5 | 1.83 | 0.568 | 1.67 | 0.517 | -- | -- | -- |
| **Additonal Parameters - Selection of Remedy** | | | | | | | | | | |
| Lithium, dissolved, ug/L | UPL or GPS not applicable | | | -- | 23 | -- | -- | -- | -- | -- |
| Iron, dissolved, ug/L | | | | -- | 500 | -- | 590 | -- | -- | -- |
| Iron, ug/L | | | | -- | 1,200 | -- | 1,200 | -- | -- | -- |
| Magnesium, dissolved, ug/L | | | | -- | 44,000 | -- | 29,000 | -- | -- | -- |
| Magnesium, ug/L | | | | -- | 44,000 | -- | 30,000 | -- | -- | -- |
| Manganese, dissolved, ug/L | | | | -- | 5,600 | -- | 1,500 | -- | -- | -- |
| Manganese, ug/L | | | | -- | 5,500 | -- | 1,500 | -- | -- | -- |
| Potassium, ug/L | | | | -- | 4,500 | -- | 4,400 | -- | -- | -- |
| Sodium, ug/L | | | | -- | 27,000 | -- | 20,000 | -- | -- | -- |
| Total Alkalinity, mg/L | | | | -- | 290 | -- | 310 | -- | -- | -- |
| Carbonate Alkalinity, mg/L | | | | -- | <4.6 | -- | <4.6 | -- | -- | -- |
| Bicarbonate Alkalinity, mg/L | | | | -- | 290 | -- | 310 | -- | -- | -- |

Blue shaded cell indicates the compliance well result exceeds the UPL and the LOQ
Yellow shaded cell indicates the compliance well result exceeds the GPS.
Grayscale indicates Additional Parameters sampled for selection of remedy and evaluation of Monitored Natural Attentuation

See Page 5 for notes and abbreviations

**Table 3. Groundwater Analytical Results - Assessment Monitoring**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

Abbreviations:
UPL = Upper Prediction Limit
ug/L= micrograms per Liter
mg/L = milligrams per Liter
LOD = Limit of Detection

DQ= Double Quantification (not detected in background)
LOQ = Limit of Quantification
GPS = Groundwater Protection Standard
-- = Not Analyzed

P = Parametric UPL with 1-of-2 retesting
NP= Nonparametric UPL (highest background value)

Lab Notes/Qualifiers:
B = Analyte found in sample and associated blank.
J = Result is less than the reporting limit but greater than limits or equal to the method detection limit and the concentration is an approximate value.

Notes:
1. An individual result above the UPL or GPS does not constitute a statistically significant increase (SSI) above background or statistically significant level above the GPS. See the accompanying letter text for identification of statistically significant results.
2. GPS is the United States Environmental Protection Agency (USEPA) Maximum Contamination Level (MCL), if established; otherwise, the values from 40 CFR 257.95(h)(2).
3. Interwell UPLs calculated based on results from background wells MW-301 and MW-302.

| | | | |
|---|---|---|---|
| Created by: | JAO | Date: | 5/23/2022 |
| Last revision by: | REO | Date: | 6/3/2022 |
| Checked by: | NDK | Date: | 6/3/2022 |
| Proj Mgr QA/QC: | TK | Date: | 6/7/2022 |

**Table 4. Preliminary Evaluation of Corrective Measure Alternatives**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| | Alternative #1<br>No Further Action | Alternative #2<br>Cover Upgrade | Alternative #3<br>Gradient Control | Alternative #4<br>In-Situ Treatment with Physical/Chemical Amendment | Alternative #5<br>Groundwater Management with Barrier Wall | Alternative #6<br>Excavate and Re-Dispose |
|---|---|---|---|---|---|---|
| **CORRECTIVE ACTION ASSESSMENT - 40 CFR 257.97(b)** | | | | | | |
| 257.97(b)(1)<br>Is remedy protective of human health and the environment? | Yes | Yes | Yes | Yes | Yes | Yes |
| 257.97(b)(2)<br>Can the remedy attain the groundwater protection standard? | Yes | Yes | Yes | Yes | Yes | Yes |
| 257.97(b)(3)<br>Can the remedy control the source(s) of releases so as to reduce or eliminate, to the maximum extent feasible, further releases of constituents in appendix IV to this part into the environment? | Yes | Yes | Yes | Yes | Yes | Yes |
| 257.97(b)(4)<br>Can the remedy remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible? | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. Alternative may be coupled with additional restoration activities if further investigation shows downgradient exceedances of GPS. | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. Alternative may be coupled with additional restoration activities if further investigation shows downgradient exceedances of GPS. | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. Alternative may be coupled with additional restoration activities if further investigation shows downgradient exceedances of GPS. | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. Alternative may be coupled with additional restoration activities if further investigation shows downgradient exceedances of GPS. | Yes, if groundwater impacts do not extend beyond the CCR unit boundary. Alternative may be coupled with additional restoration activities if further investigation shows downgradient exceedances of GPS. |
| 257.97(b)(5)<br>Can the remedy comply with standards for management of wastes as specified in §257.98(d)? | Not Applicable | Yes | Yes | Yes | Yes | Yes |
| **LONG- AND SHORT-TERM EFFECTIVENESS - 40 CFR 257.97(c)(1)** | | | | | | |
| 257.97(c)(1)(i)<br>Magnitude of reduction of existing risks | Existing risk reduced by achieving GPS | Existing risk reduced by achieving GPS in a shorter timeframe than Alternative #1. | Same as Alternative #2. Long-term risk may be reduced by treatment of collected groundwater. Groundwater extraction and treatment presents an additional risk and potential exposure pathways via surface release or disruption of treatment processes. | Similar to Alternative #2. Long-term risk may be reduced with additional source control and in-situ stabilization/fixation of CCR that may be in contact with groundwater. | Similar to Alternative #3. Long-term risk may be reduced with additional containment offered by barrier wall. | Material removed from the site eliminating existing risks from new releases at the Site. |
| 257.97(c)(1)(ii)<br>Magnitude of residual risks in terms of likelihood of further releases due to CCR remaining following implementation of a remedy | No reduction of existing risk for additional releases<br>Residual risk is limited for all alternatives because the facility is capped. | Potential reduction in release risk due to the reduced permeability of the final cover. Same as Alternative #1 with respect to CCR in potential contact with groundwater.<br>However, limited as no additional overall risk reduction is provided due to lack of current/anticipated future receptors for groundwater impacts | Potential reduction in release risk by way of the ability to respond to potential future/ongoing releases from CCR that might be in contact with groundwater following closure.<br>However, limited to no overall risk reduction is provided due to lack of current/anticipated future receptors for groundwater impacts. | Potential reduction in release risk by way of chemical / physical alteration of the source of impacts.<br>However, limited to no overall risk reduction is provided due to lack of current/anticipated future receptors for groundwater impacts. | Residual risk of source material in contact with groundwater is reduced by the containment of groundwater impacts provided by barrier walls;<br>However, limited to no overall risk reduction is provided due to lack of current/anticipated future receptors for groundwater impacts. | Same as Alternative #1 with further reduction in release risk due to removal of impounded CCR from site<br>However, limited as no additional overall risk reduction is provided due to lack of current/anticipated future receptors for groundwater impacts |
| 257.97(c)(1)(iii)<br>The type and degree of long-term management required, including monitoring, operation, and maintenance | 30-year post-closure groundwater monitoring<br>Groundwater monitoring network maintenance and as-needed repair/replacement<br>Final cover maintenance (e.g., mowing and as-needed repair)<br>Periodic final cover inspections<br>Additional corrective action as required based on post-closure groundwater monitoring | Same as Alternative #1 | Same as Alternative #1 with increased monitoring for maintenance of the gradient control system and any discharge-related water treatment. If pump-and-treat additional effort for groundwater pump operation and maintenance (O&M), groundwater treatment system O&M, and treatment system discharge monitoring/reporting. | Same as Alternative #2 | Same as Alternative #3 with additional monitoring of wall performance. | No on-site long-term management required<br>Limited on-site post-closure groundwater monitoring until GPSs are achieved<br>Receiving disposal facility will have same/similar long-term monitoring, operation, and maintenance requirements as Alternative #1 |

**Table 4. Preliminary Evaluation of Corrective Measure Alternatives**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| | Alternative #1<br><br>No Further Action | Alternative #2<br><br>Cover Upgrade | Alternative #3<br><br>Gradient Control | Alternative #4<br><br>In-Situ Treatment with Physical/Chemical Amendment | Alternative #5<br><br>Groundwater Management with Barrier Wall | Alternative #6<br><br>Excavate and Re-Dispose |
|---|---|---|---|---|---|---|
| **LONG- AND SHORT-TERM EFFECTIVENESS - 40 CFR 257.97(c)(1) (continued)** | | | | | | |
| 257.97(c)(1)(iv)<br>Short-term risks - Implementation | | | | | | |
| Excavation | None | Increased risk over Alternative #1 due to general construction activities that are not anticipated to expose CCR | Similar to Alternative #1 with some increased construction risk due to drilling, trenching, and excavation for groundwater pumping and treatment system construction. | Similar to Alternative #1 with some increased potential risk due to exposure during the application of a chemical amendment. | Similar to Alternative #1 with some increased construction risk due to excavation or installation of the barrier wall. | Increased risk to environment over Alternative #2 due to CCR excavation volumes required for removal and off-site re-disposal |
| Transportation | None | Increased risk over Alternative #1 from construction traffic due to final cover disturbance and import of cover upgrade materials | Similar to Alternative #1 with increased risk from importing groundwater pumping and treatment system materials. | Similar to Alternative #1 with increased risk from importing material for stabilization/treatment. | Similar to Alternative #1, with increased risk from importing barrier wall system materials. | Highest level of community and environmental risk due to CCR volume export |
| Re-Disposal | None | None | Long-term risk may be reduced by treatment of collected groundwater.<br>Groundwater extraction and treatment presents an additional risk and potential exposure pathways via surface release or disruption of treatment processes. | Similar to Alternative #1 with some increased potential risk due to exposure during the application of the physical/chemical amendment. | Similar to Alternative #3 | Increased risk to community and environment due to re-disposal of large CCR volume at another facility<br>Re-disposal risks are managed by the receiving disposal facility or by planning for onsite re-disposal |
| 257.97(c)(1)(v)<br>Time until full protection is achieved | To be evaluated further during remedy selection<br>Closure and capping was completed in 2020<br>Groundwater protection timeframe to reach GPS potentially 5 to 10 years following closure construction, achievable within 30-year post-closure monitoring period | Similar to Alternative #1 with some potential for decrease in time to reach GPS due to reduced cover permeability. | Similar to Alternative #2 with potential for decrease in time to reach GPS due to groundwater removal | Similar to Alternative #2.<br>Potential for reduction in time to reach GPS due to chemical/physical stability of CCR. | Similar to Alternative #2.<br>Potential decrease in time to reach GPS upon implementation of barrier wall. | Similar to Alternative #1<br>Potential for increase in time to reach GPS due to significant source disturbance during construction<br>Potential decrease in time to reach GPS due to CCR source removal |
| 257.97(c)(1)(vi)<br>Potential for exposure of humans and environmental receptors to remaining wastes, considering the potential threat to human health and the environment associated with excavation, transportation, re-disposal, or containment | No change in potential exposure | Same as Alternative #1 | Similar to Alternative #1 with potential for secondary impacts from releases of extracted groundwater or disruption in treatment. | Same as Alternative #1 | Same as Alternative #1 | No potential for on-site exposure to remaining waste since no waste remains on site if re-disposal is at an offsite facility<br>Risk of potential exposure is transferred to receiving disposal facility and is likely similar to Alternative #1<br>Little change from Alternative #1 if re-disposal is onsite |
| 257.97(c)(1)(vii)<br>Long-term reliability of the engineering and institutional controls | Long-term reliability of existing cap is good<br>Significant industry experience with methods/controls<br>Capping is common practice/industry standard for closure in place for remediation and solid waste management<br>Deed notation in place for closure with CCR left in place | Long-term reliability of enhanced cap is good<br>Significant industry experience with methods/controls<br>Capping is common practice/industry standard for closure in place for remediation and solid waste management<br>Deed notation in place for closure with CCR left in place | Similar to Alternatives 1 and 2.<br>Depending on the gradient control method selected, the long-term reliability can be good<br>There is significant industry experience with some potential gradient control methods used in remediation of groundwater impacts.<br>Remedy relies upon active equipment that will require additional operations and maintenance. | Same as Alternative #1. | Same as Alternative #1. Remedy relies on continued hydraulic conductivity of the selected barrier.<br>Breaches or short circuiting can develop and must be monitored. | Success of remedy at SGS does not rely on long-term reliability of engineering or institutional controls<br>Overall success relies on reliability of the engineering and institutional controls at the receiving facility |
| 257.97(c)(1)(viii)<br>Potential need for replacement of the remedy | Limited potential need for replacement of original cap placed in 2018 if maintained. | Same as Alternative #1 | Similar to Alternative #1, with reduced potential of remedy replacement, but added expectation for pump, conveyance system and treatment system replacement. | Similar to Alternative #1, with further reduction in potential need for remedy enhancement due to stabilized groundwater impacts. | Similar to Alternative #1, with reduced potential of remedy replacement, but added expectation for potential replenishment of consumptive barrier product. | No potential need for remedy replacement |

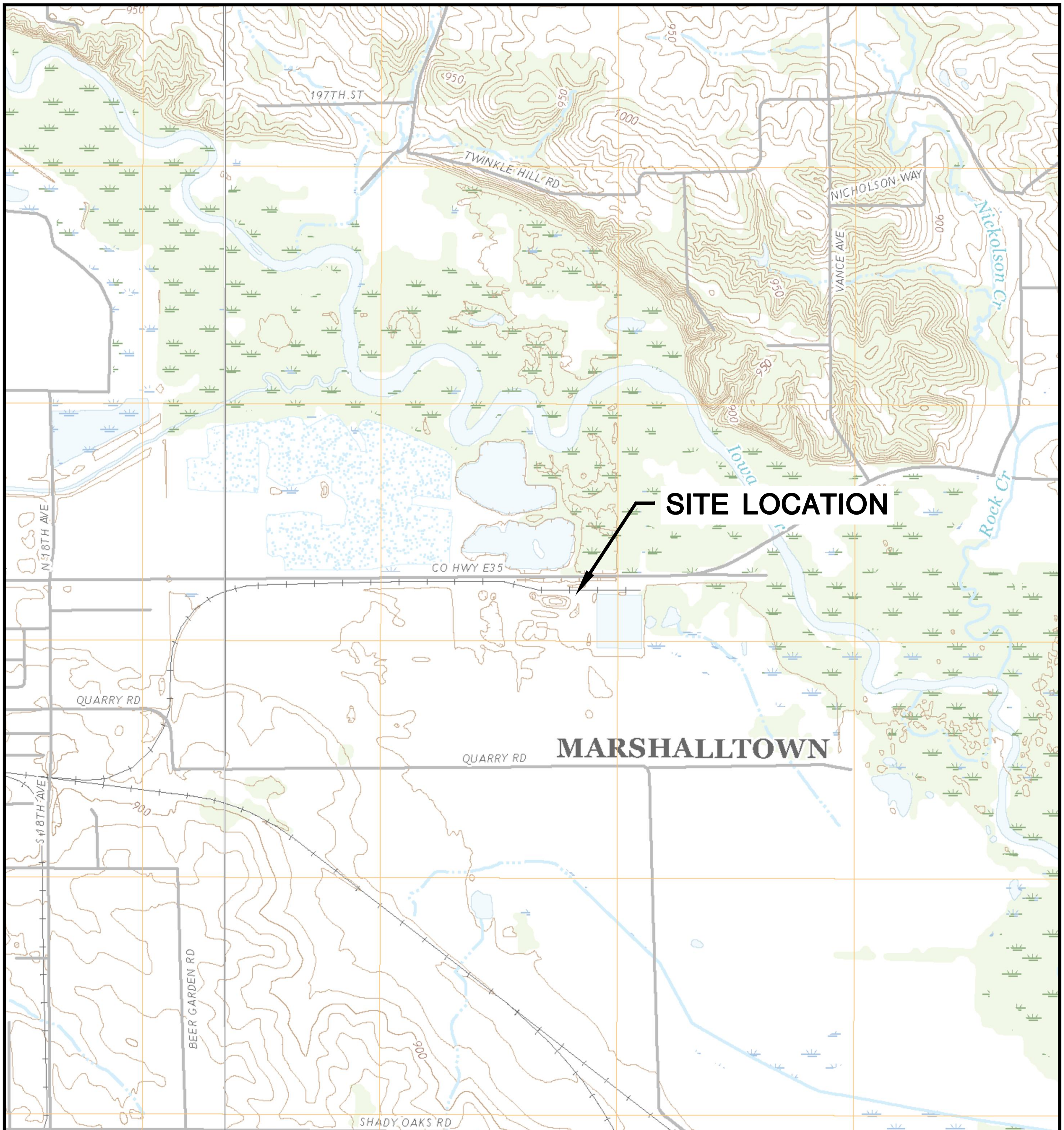
**Table 4. Preliminary Evaluation of Corrective Measure Alternatives**
**Sutherland Generating Station / SCS Engineers Project #25222076.00**

| | Alternative #1<br><br>No Further Action | Alternative #2<br><br>Cover Upgrade | Alternative #3<br><br>Gradient Control | Alternative #4<br><br>In-Situ Treatment with Physical/Chemical Amendment | Alternative #5<br><br>Groundwater Management with Barrier Wall | Alternative #6<br><br>Excavate and Re-Dispose |
|---|---|---|---|---|---|---|
| **SOURCE CONTROL TO MITIGATE FUTURE RELEASES - 40 CFR 257.97(c)(2)** | | | | | | |
| 257.97(c)(2)(i)<br>The extent to which containment practices will reduce further releases | Cap installed in 2020 will reduce further releases by minimizing infiltration through CCR. CCR remains in contact with Groundwater. | Same as Alternative #1 with possible reduction in further release risk due to lower cap permeability/ reduced infiltration through CCR | Similar to Alternative #1, with reduction in the mobility of a release, or maintain within the site boundary. | Similar to Alternative #1 with further reduction due to lower mobility of contaminants in residual source material as a result of physical/chemical amendment. | Similar to Alternative #1 with the added ability to contain groundwater impacts. | Removal of CCR prevents further releases at SGS Receiving disposal site risk similar to Alternative #2 |
| 257.97(c)(2)(ii)<br>The extent to which treatment technologies may be used | Alternative does not rely on treatment technologies | Alternative does not rely on treatment technologies for source control | Alternative does not rely on treatment technologies for source control. With pump-and-treat, this alternative relies on conventional pump and treat remediation. | Alternative relies on the identification and availability of a suitable amendment. Implementation of and contact with physical/chemical stabilizing agent will require specialized field implementation methods and health and safety measures. | Alternative relies on the identification and availability of a suitable barrier wall technology (e.g., permeable reactive barrier material or slurry wall). Implementation of and contact with barrier wall materials will require specialized field implementation methods and health and safety measures. | Alternative does not rely on treatment technologies for source control |
| **IMPLEMENTATION - 40 CFR 257.97(c)(3)** | | | | | | |
| 257.97(c)(3)(i)<br>Degree of difficulty associated with constructing the technology | No additional construction involved. | Low complexity construction<br>Moderate degree of design and logistical complexity to complete cap upgrade | Moderate complexity construction<br>Moderate degree of logistical complexity due to unimproved off-site property access.<br>Moderate degree of logistical complexity;<br>Moderate to low level of dewatering effort - dewatering required for material excavation/placement and capping.<br>Moderate complexity construction for the installation of extraction wells and conveyance to a site-specific groundwater treatment plant. | Moderate complexity construction due to the equipment required to apply the selected amendment; requirements to ensure consistent contact and dosing of amendment;<br>Medium degree of logistical complexity involving the import of specialty chemicals; | High complexity construction;<br>Barrier walls require specialty installation equipment and knowledge. Highly specialized and experience contractors required to achieve proper installation.<br>Moderate degree of logistical complexity;<br>Moderate to low level of dewatering effort - dewatering required for material excavation/placement. | Low complexity construction<br>High degree of logistical complexity including the excavation and off-site transport of large volume of CCR and permitting/development of re-disposal facility airspace<br>Moderate to high level of dewatering effort if dewatering is required for excavation of full CCR volume |
| 257.97(c)(3)(ii)<br>Expected operational reliability of the technologies | Not Applicable | High reliability based on historic use of capping as corrective measure | Operational reliability depends on method of gradient control required/selected, the level of extracted groundwater treatment required, and the location of groundwater treatment. However, success of this remedy relies on the successful operation of a site-specific groundwater treatment plant.<br>Overall expected reliability is good based on industry experience. | Similar to Alternative #2; however, success at SGS relies on the successful application of specialty amendment. | Similar to Alternative #3; however, success of this remedy relies on continued hydraulic conductivity of the selected barrier. Breaches or short circuiting can develop and must be monitored. | Success at SGS does not rely on operational reliability of technologies<br>Overall success relies on off-site disposal facility, which is likely same/similar to Alternative #2 |
| 257.97(c)(3)(iii)<br>Need to coordinate with and obtain necessary approvals and permits from other agencies | No further approvals or permits required | Need is low in comparison to other alternatives;<br>State Closure Permit amendment likely required;<br>State and local erosion control/construction stormwater management permits required | Need is high in comparison to other alternatives<br>State Closure Permit amendment likely required<br>Approval of facility receiving gradient control discharge for treatment required, or agency approval to construct the necessary treatment facility is required.<br>Well permitting for extraction well installation;<br>NPDES Permit for groundwater treatment and discharge;<br>State and local erosion control/construction stormwater management permits required;<br>Federal/State/Local Floodplain permitting likely required for downgradient work in floodplain. | Need is moderate in comparison to other alternatives;<br>Underground Injection Control Permit may be required if chemical materials placed within groundwater.<br>State and local erosion control/construction stormwater management permits required;<br>Federal/State/Local Floodplain permitting likely required. | Need is moderate in comparison to other alternatives<br>State Closure Permit required;<br>Well permitting for barrier wall monitoring;<br>Federal/State/Local Floodplain permitting required;<br>State and local erosion control/construction stormwater management permits required | Need is highest in comparison to other alternatives<br>State Closure Permit amendment likely required<br>Approval of off-site disposal site owner required<br>May require State solid waste comprehensive planning approval<br>Local road use permits likely required |
| 257.97(c)(3)(iv)<br>Availability of necessary equipment and specialists | Not Applicable | Low level of demand for cap construction material | Moderate level of demand expected<br>Level of demand may vary based on method of gradient control selected.<br>A site-specific, trained employee will be required to operate the groundwater treatment system. | Specialized mixing equipment likely required to apply physical/chemical amendment and achieve required dosing. | Similar to Alternative #2;<br><br>Availability of the necessary specialized equipment and extensive experience required for barrier installation is potentially low or in high demand. | Availability of necessary materials and equipment to develop necessary re-disposal facility airspace and transport large volume of CCR to new disposal facility will be a limiting factor in the schedule for executing this alternative |
| 257.97(c)(3)(v)<br>Available capacity and location of needed treatment, storage, and disposal services | Not Applicable | Not Applicable | There is no on-site capacity to treat gradient control system discharge<br>If required, on-site capacity will need to be developed.<br>Off-site capacity to treat gradient control system discharge may exist, but ability/willingness to accept discharge is currently unknown. | Capacity and location of treatment, storage, and disposal services is unlikely to be a factor for this alternative | Capacity and location of treatment, storage, and disposal services is unlikely to be a factor for this alternative | Re-disposal capacity, facility logistical capacity, or the time required to develop the necessary re-disposal and logistical capacity is a significant limiting factor |
| **COMMUNITY ACCEPTANCE - 40 CFR 257.97(c)(4)** | | | | | | |
| 257.97(c)(4)<br>The degree to which community concerns are addressed by a potential remedy (Anticipated) | To be determined based on input obtained through public meetings/outreach to be completed | To be determined based on input obtained through public meetings/outreach to be completed | To be determined based on input obtained through public meetings/outreach to be completed | To be determined based on input obtained through public meetings/outreach to be completed | To be determined based on input obtained through public meetings/outreach to be completed | To be determined based on input obtained through public meetings/outreach to be completed |

Created by: SK Date: 6/7/2022
Last revision by: EJN Date: 6/20/2022
Checked by: TK Date: 6/20/2022

I:\25222076.00\Deliverables\2022 SGS ACM\Tables\[Table 4 - Evaluation of Assessment of Corrective Measure_SGS.xlsx]SGS_Evaluation Matrix

Figures




LE GRAND QUADRANGLE
IOWA–MARSHALL COUNTY
7.5 MINUTE SERIES (TOPOGRAPHIC)
2018
SCALE: 1" = 2,000'

| CLIENT | SITE | |
|---|---|---|
| ALLIANT ENERGY<br>4902 N. BILTMORE LANE, #1000<br>MADISON, WI 53718 | ALLIANT ENERGY<br>SUTHERLAND GENERATING STATION<br>MARSHALLTOWN, IOWA | SITE LOCATION MAP |

| | | | | ENGINEER | |
|---|---|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS | SCS ENGINEERS<br>2830 DAIRY DRIVE MADISON, WI 53718-6751<br>PHONE: (608) 224-2830 | FIGURE |
| DRAWN: | 11/15/2019 | CHECKED BY: | MDB | | 1 |
| REVISED: | 01/14/2020 | APPROVED BY: | TK 3/20/2022 | | |

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LEGEND

- CCR MONITORING WELL
- CCR BACKGROUND MONITORING WELL
- CCR UNITS
- FINAL CLOSURE AREA LIMITS

NOTES:

1. 2020 AERIAL PHOTOGRAPH SOURCES: ESRI, DIGITALGLOBE, GEOEYE, I-CUBED, USDA FSA, USGS, AEX, GETMAPPING, AEROGRID, IGN, IGP, SWISSTOPO, AND THE GIS USER COMMUNITY.
2. MONITORING WELLS MW-301 THROUGH MW-306 WERE INSTALLED BY DIRECT PUSH ANALYTICAL, NOVEMBER 20-21, 2017.
3. MONITORING WELLS MW-307 AND MW-308 WERE INSTALLED BY TERRACON, INC. IN NOVEMBER 30, 2021.
4. MONITORING WELLS MW-309, MW-310, AND MW-311 WERE INSTALLED BY DIRECT PUSH ANALYTICAL ON MAY 4, 2022.
5. CCR UNIT LIMITS ARE APPROXIMATE.
6. THE BACKGROUND MONITORING WELLS FOR THE SUTHERLAND GENERATING STATION ARE MW-301 AND MW-302.

N

300 0 300

SCALE: 1" = 300'

| | | | |
|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS |
| DRAWN: | 11/14/2019 | CHECKED BY: | TK/NDK |
| REVISED: | 06/20/2022 | APPROVED BY: | TK 06/21/2022 |

ENGINEER: SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

CLIENT: ALLIANT ENERGY
4902 N. BILTMORE LANE, #1000
MADISON, WI 53718

SITE: ALLIANT ENERGY
SUTHERLAND GENERATING STATION
MASHALLTOWN, IOWA

SITE PLAN AND MONITORING WELL LOCATIONS

FIGURE 2

I:\25222076.00\Drawings\Site Plan and Monitoring Well Locations.dwg, 6/20/2022 10:31:42 AM


LEGEND

- CCR MONITORING WELL
- CCR BACKGROUND MONITORING WELL
- CCR UNITS
- **854.38** WATER TABLE ELEVATION (OCTOBER 25, 2021)
- **(NM)** NOT MEASURED
- WATER TABLE CONTOUR
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTES:

1. SEE FIGURE 2 FOR BASE MAP NOTES.
2. THE BACKGROUND MONITORING WELLS FOR THE SUTHERLAND GENERATING STATION ARE MW-301 AND MW-302.
3. MONITORING WELLS MW-309, MW-310, AND MW-311 WERE INSTALLED BY DIRECT PUSH ANALYTICAL ON MAY 4, 2022.
4. WATER TABLE CONTOURS ARE ESTIMATED BASED ON DATA OBTAINED ON 10/25/2021.

N

300 0 300

SCALE: 1" = 300'

| | | | |
|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS |
| DRAWN: | 02/17/2022 | CHECKED BY: | TK/NDK |
| REVISED: | 06/09/2022 | APPROVED BY: | TK 06/21/2022 |

ENGINEER: SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
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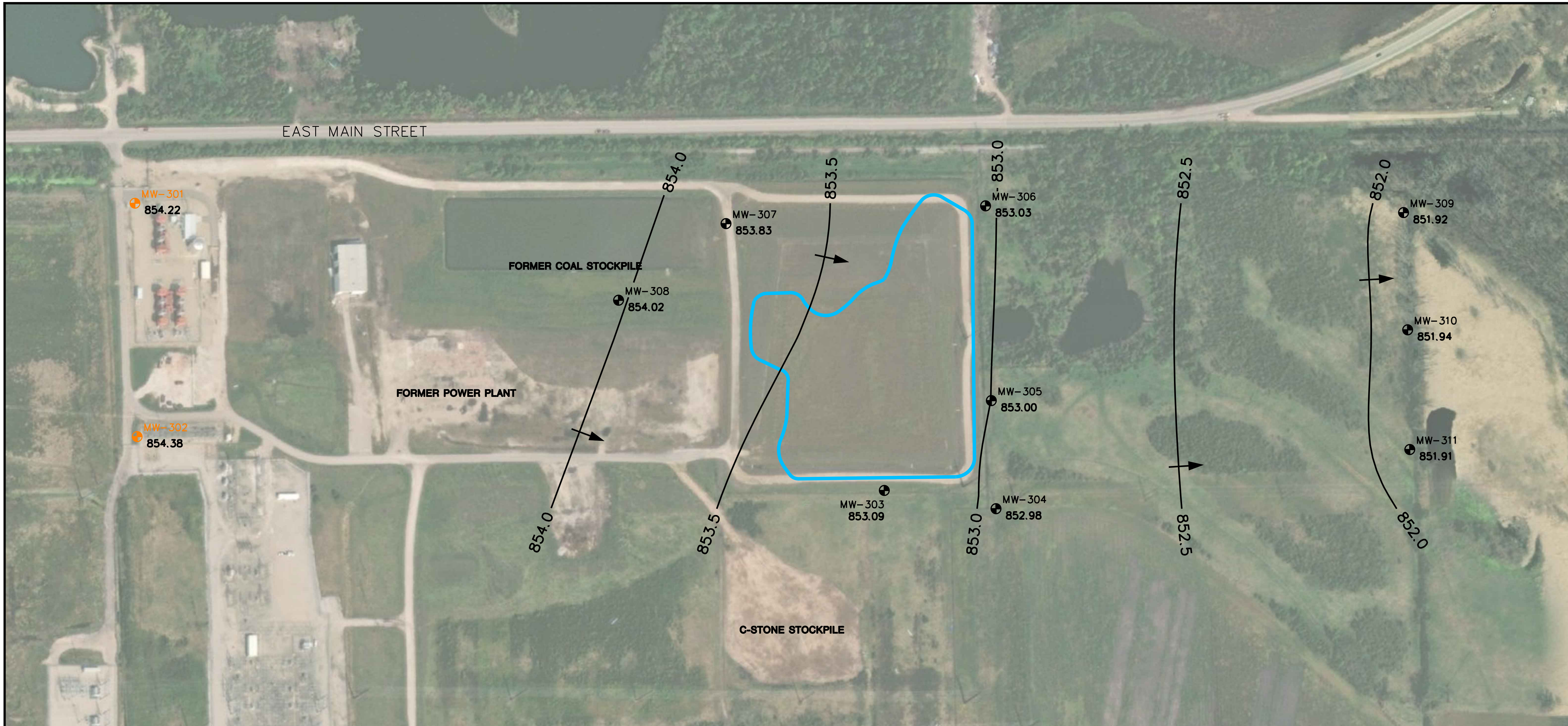
CLIENT: ALLIANT ENERGY
4902 N. BILTMORE LANE
MADISON, WI 53718

SITE: ALLIANT ENERGY
SUTHERLAND GENERATING STATION
MASHALLTOWN, IOWA

WATER TABLE MAP
OCTOBER 2021

FIGURE 3

I:\25222076.00\Drawings\2022 Wtbl Maps.dwg, 6/9/2022 6:19:44 AM




LEGEND

- CCR MONITORING WELL
- CCR BACKGROUND MONITORING WELL
- CCR UNITS
- **854.38** WATER TABLE ELEVATION (MAY 24, 2022)
- WATER TABLE CONTOUR
- APPROXIMATE GROUNDWATER FLOW DIRECTION

NOTES:

1. SEE FIGURE 2 FOR BASE MAP NOTES.
2. THE BACKGROUND MONITORING WELLS FOR THE SUTHERLAND GENERATING STATION ARE MW-301 AND MW-302.
3. WATER TABLE CONTOURS ARE ESTIMATED BASED ON DATA OBTAINED ON 05/24/2022.

| | | | |
|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS |
| DRAWN: | 06/01/2022 | CHECKED BY: | TK/NDK |
| REVISED: | 06/09/2022 | APPROVED BY: | TK 06/21/2022 |

ENGINEER: SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

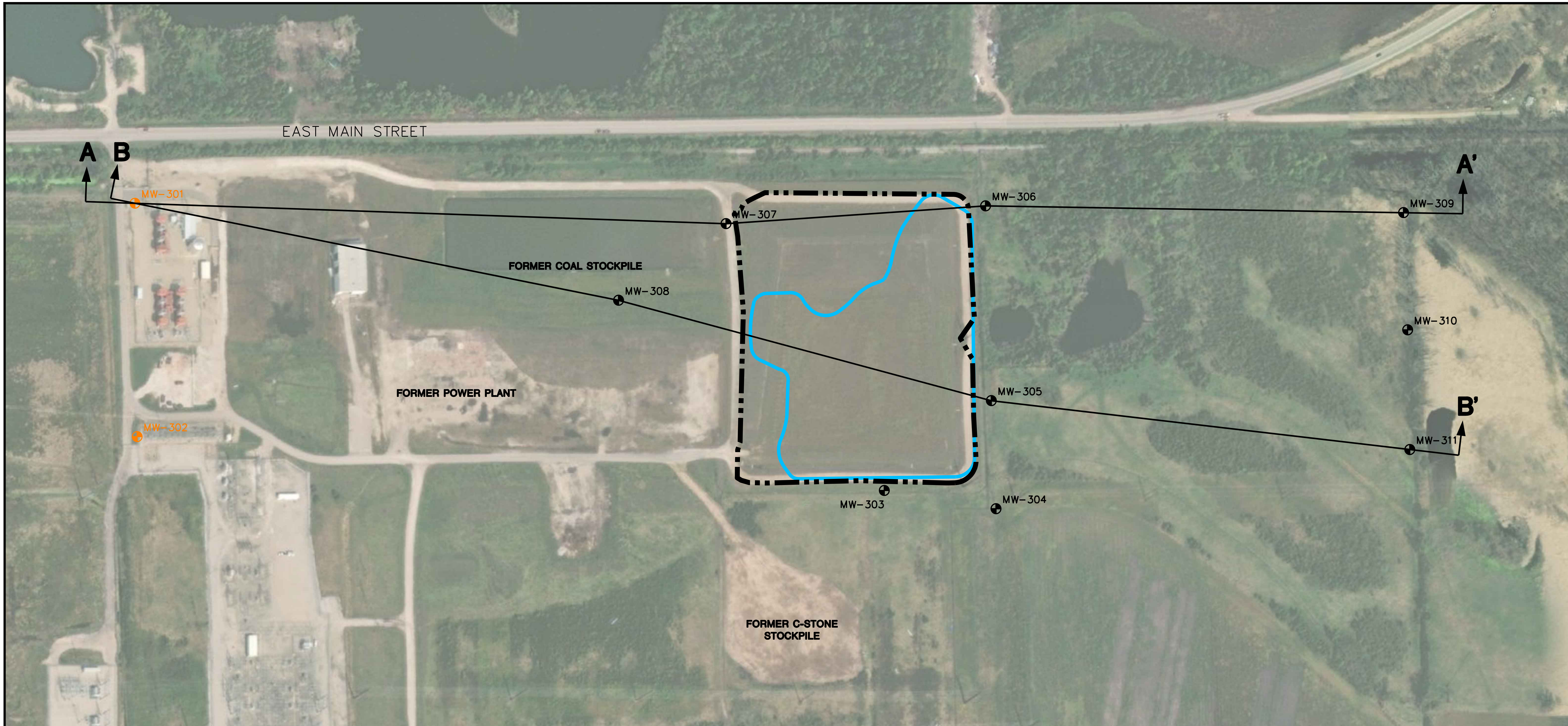
CLIENT: ALLIANT ENERGY
4902 N. BILTMORE LANE
MADISON, WI 53718

SITE: ALLIANT ENERGY
SUTHERLAND GENERATING STATION
MASHALLTOWN, IOWA

WATER TABLE MAP
MAY 2022

FIGURE
4

I:\25222076.00\Drawings\2022 Wtbl Maps.dwg, 6/9/2022 6:19:48 AM




LEGEND

- CCR MONITORING WELL
- CCR BACKGROUND MONITORING WELL
- CCR UNITS
- FINAL CLOSURE AREA LIMITS

NOTES:

1. SEE FIGURE 2 FOR BASE MAP NOTES.

N

300 0 300

SCALE: 1" = 300'

| | | | |
|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS |
| DRAWN: | 06/20/2022 | CHECKED BY: | TK/NDK |
| REVISED: | 06/13/2022 | APPROVED BY: | TK 06/21/2022 |

ENGINEER: SCS ENGINEERS
2830 DAIRY DRIVE MADISON, WI 53718-6751
PHONE: (608) 224-2830

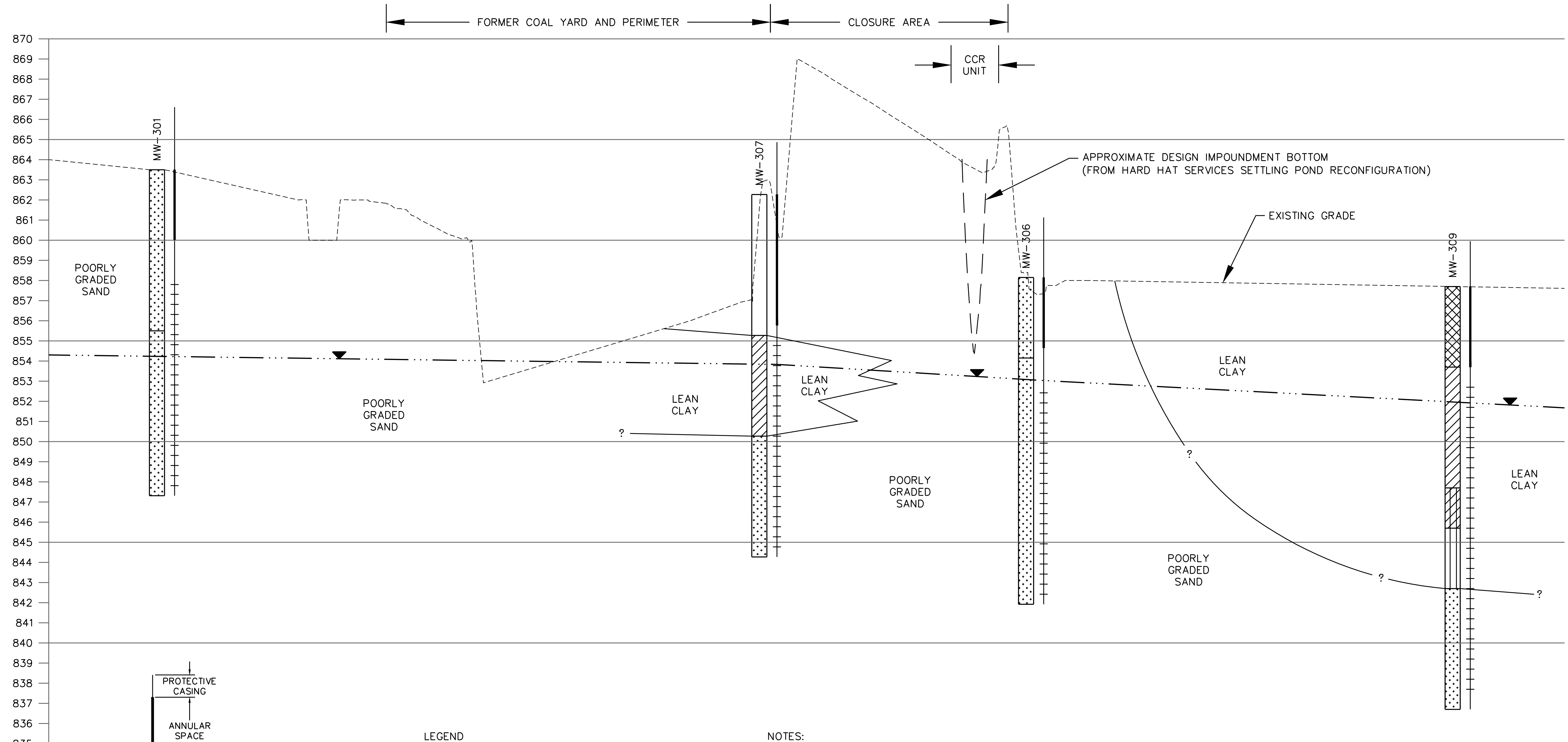
CLIENT: ALLIANT ENERGY
4902 N. BILTMORE LANE, #1000
MADISON, WI 53718

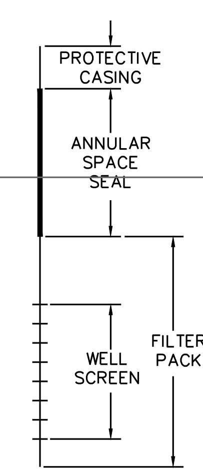
SITE: ALLIANT ENERGY
SUTHERLAND GENERATING STATION
MASHALLTOWN, IOWA

GEOLOGIC CROSS SECTION LOCATION MAP

FIGURE 5

I:\25222076.00\Drawings\Site Plan and Monitoring Well Locations.dwg, 6/20/2022 10:31:46 AM




WELL DETAIL

LEGEND

- NON-GEOLOGIC MATERIAL/TOPSOIL
- SAND, POORLY GRADED, LITTLE OR NO FINES (SP)
- SILT (ML)
- LEAN CLAY (CL)
- SILTY CLAY (CL-ML)
- ESTIMATED WATER TABLE BASED ON DATA OBTAINED ON 05/24/2022

NOTES:

1. MW-307 WAS HYDROVACED TO APPROXIMATELY 7.5'. HYDROVACING IS PERFORMED TO DETERMINE IF UNDERGROUND UTILITIES ARE PRESENT. HIGH PRESSURE WATER AND A VACUUM ARE USED TO CLEAR THE BOREHOLE AND GEOLOGIC SAMPLES ARE NOT COLLECTED. STARTING AT 7.5' THE NATIVE SOIL OBSERVED IS POORLY GRADED SAND. NATIVE SOIL IN THE VICINITY OF MW-309 IS CLAY.

0 300

HORIZONTAL SCALE: 1" = 300'
VERTICAL SCALE: 1" = 5'
VERTICAL EXAGGERATION = 60X

| | | | |
|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS |
| DRAWN: | 06/01/2022 | CHECKED BY: | TK/NDK |
| REVISED: | 06/09/2022 | APPROVED BY: | TK 06/21/2022 |

ENGINEER: SCS ENGINEERS, 2830 DAIRY DRIVE MADISON, WI 53718-6751, PHONE: (608) 224-2830

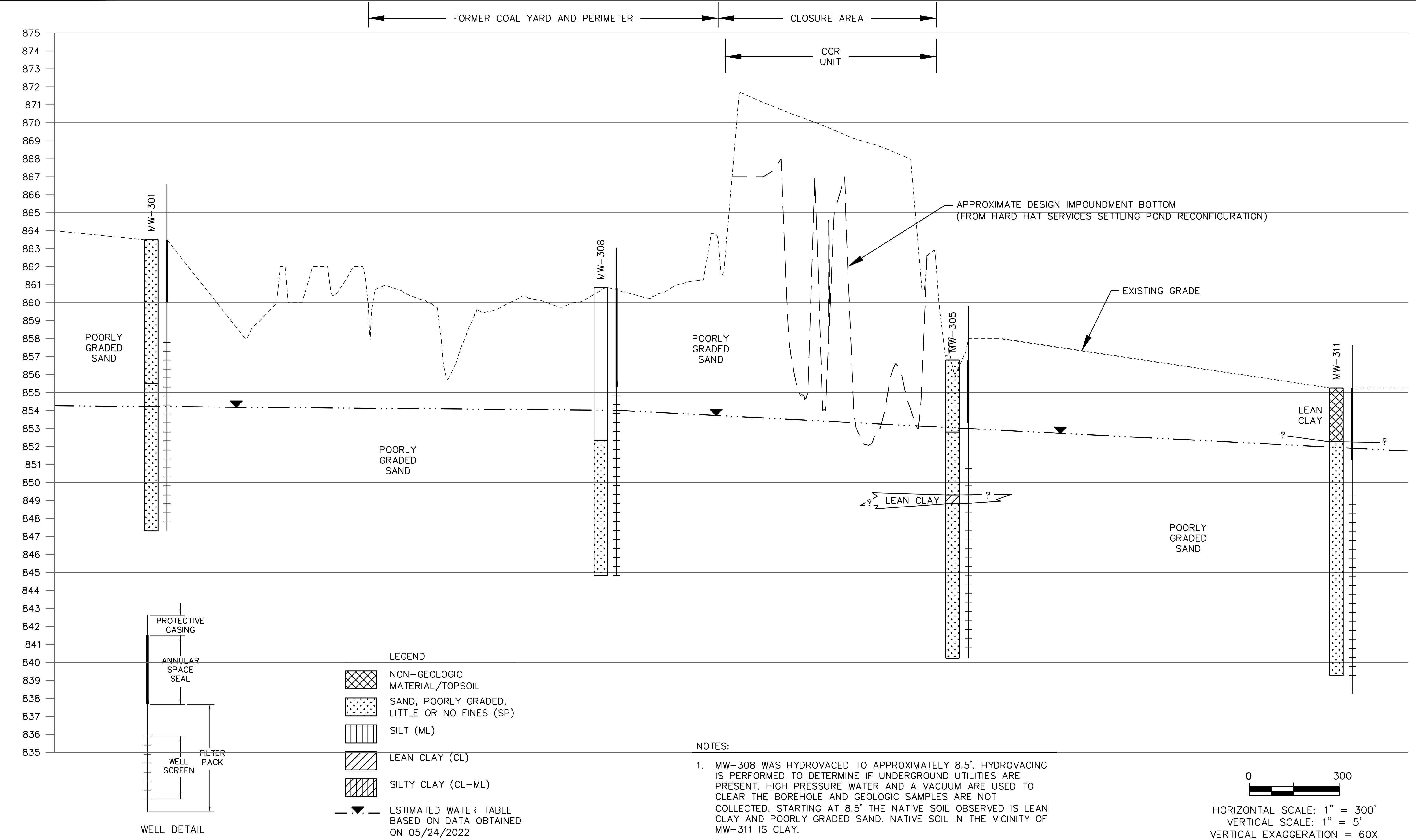
CLIENT: ALLIANT ENERGY, 4902 N. BILTMORE LANE, MADISON, WI 53718

SITE: ALLIANT ENERGY, SUTHERLAND GENERATING STATION, MASHALLTOWN, IOWA

GEOLOGIC CROSS SECTION A-A'

FIGURE 6

I:\25222076.00\Drawings\Section.dwg, 6/9/2022 6:41:21 AM




NOTES:

1. MW-308 WAS HYDROVACED TO APPROXIMATELY 8.5'. HYDROVACING IS PERFORMED TO DETERMINE IF UNDERGROUND UTILITIES ARE PRESENT. HIGH PRESSURE WATER AND A VACUUM ARE USED TO CLEAR THE BOREHOLE AND GEOLOGIC SAMPLES ARE NOT COLLECTED. STARTING AT 8.5' THE NATIVE SOIL OBSERVED IS LEAN CLAY AND POORLY GRADED SAND. NATIVE SOIL IN THE VICINITY OF MW-311 IS CLAY.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| PROJECT NO. | 25222076.00 | DRAWN BY: | BSS | ENGINEER: SCS ENGINEERS<br>2830 DAIRY DRIVE MADISON, WI 53718-6751<br>PHONE: (608) 224-2830 | CLIENT: ALLIANT ENERGY<br>4902 N. BILTMORE LANE<br>MADISON, WI 53718 | SITE: ALLIANT ENERGY<br>SUTHERLAND GENERATING STATION<br>MARSHALLTOWN, IOWA | GEOLOGIC CROSS SECTION B-B' |
| DRAWN: | 06/13/2022 | CHECKED BY: | TK/NDK | | | | FIGURE |
| REVISED: | 06/15/2022 | APPROVED BY: | TK 06/21/2022 | | | | 7 |

I:\25222076.00\Drawings\Section.dwg, 6/15/2022 1:05:59 PM

# Appendix A

# Regional Geological and Hydrogeological Information

The aquifers and rocks in central Iowa

| Aquifers | General thickness (feet) | Age of rocks | Name of rock units | General description of rock units |
|---|---|---|---|---|
| Surficial<br>Alluvial<br>Buried-channel<br>Drift | 0-380 | Quaternary (0-1 million years old) | Undifferentiated | Primarily alluvium and drift composed of gravel, sand, silt, and clay |
| | 0-900 | Cretaceous (63-135 million years old) | Undifferentiated | Shale, limestone, and sandstone; in Webster County only |
| | 0-550 | Permian(?) (230-280 million years old) | Fort Dodge beds | Gypsum and shales; in Webster County only |
| | | Pennsylvanian (280-310 million years old) | Undifferentiated | Shale, sandstone, thin limestones, and coal |
| Upper bedrock | 0-475 | Mississippian (310-345 million years old) | Ste. Genevieve<br>St. Louis<br>Warsaw<br>Keokuk<br>Burlington<br>Gilmore City<br>Hampton | Shale and limestone<br>Limestone, sandy<br>Shale and dolomite<br>Dolomite and limestone<br>Dolomite and limestone<br>Limestone<br>Limestone and dolomite |
| | 5-200 | | McCraney<br>English River<br>Maple Mill<br>Aplington<br>Sheffield | Limestone<br>Siltstone<br>Shale<br>Dolomite<br>Shale |
| Middle bedrock | 400-750 | Devonian (345-405 million years old) | Lime Creek<br>Cedar Valley<br>Wapsipinicon | Dolomite and shale<br>Limestone and dolomite<br>Limestone, dolomite, and shale |
| | 330-700 | Silurian (405-425 million years old) | Undifferentiated | Dolomite and sandy dolomite |
| | | Ordovician (425-500 million years old) | Maquoketa<br>Galena<br>Decorah<br>Platteville | Dolomite and shale<br>Dolomite and chert<br>Limestone and shale<br>Limestone, shale, and sandstone |
| Lower bedrock | 375-560 | | St. Peter<br>Prairie du Chien | Sandstone<br>Dolomite and sandstone |
| | | Cambrian (500-600 million years old) | Jordan<br>St. Lawrence | Sandstone<br>Dolomite |
| | 350-550 | | Franconia<br>Galesville<br>Eau Claire<br>Mt. Simon | Sandstone, siltstone, and shale<br>Sandstone<br>Sandstone, shale, and dolomite<br>Sandstone |
| | ----- | Precambrian (600 million to more than 2 billion years old) | | Igneous and metamorphic rocks, locally overlain by sedimentary rocks that are chiefly sandstone |

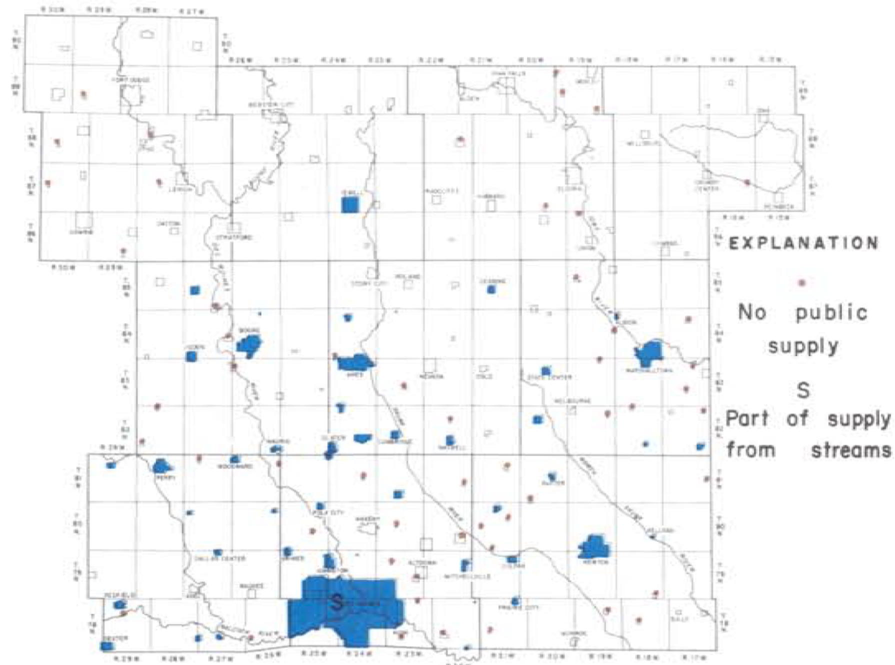


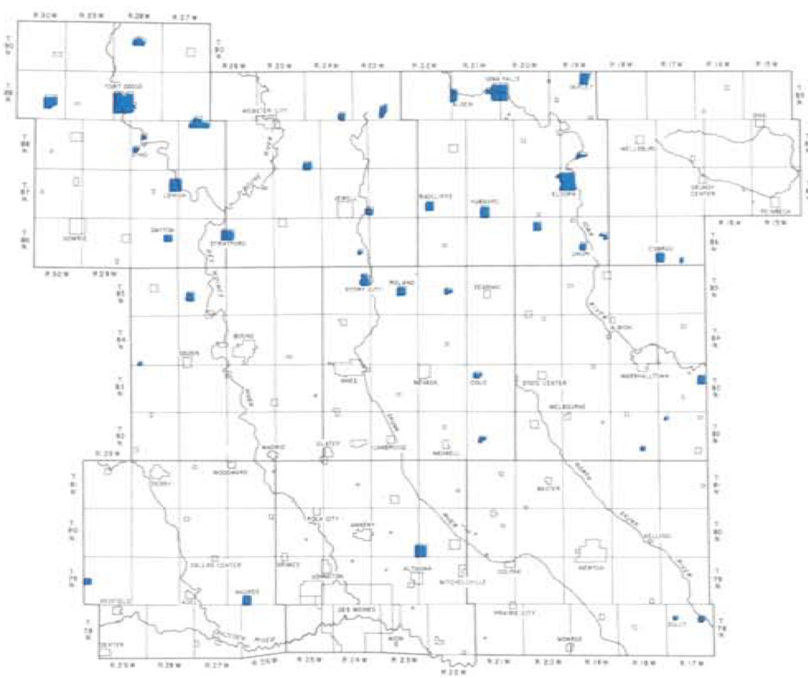
Source: F.R. Twenter and R.W. Coble, "The Water Story in Central Iowa," Iowa Geologic Survey Water Atlas Number 1, 1965.

## The aquifers that supply water for cities and communities

Various reasons determine why a city or community will choose one aquifer over the other as a source of water for their municipal supply. In general, however, the aquifer selected will be one that will provide the largest quantity of good water at the lowest cost.

The surficial aquifers are the source of water for municipal supplies in nearly 100 cities and communities in central Iowa. Also, they are the source of water for individual supplies in many of the small communities that have no municipal supply.

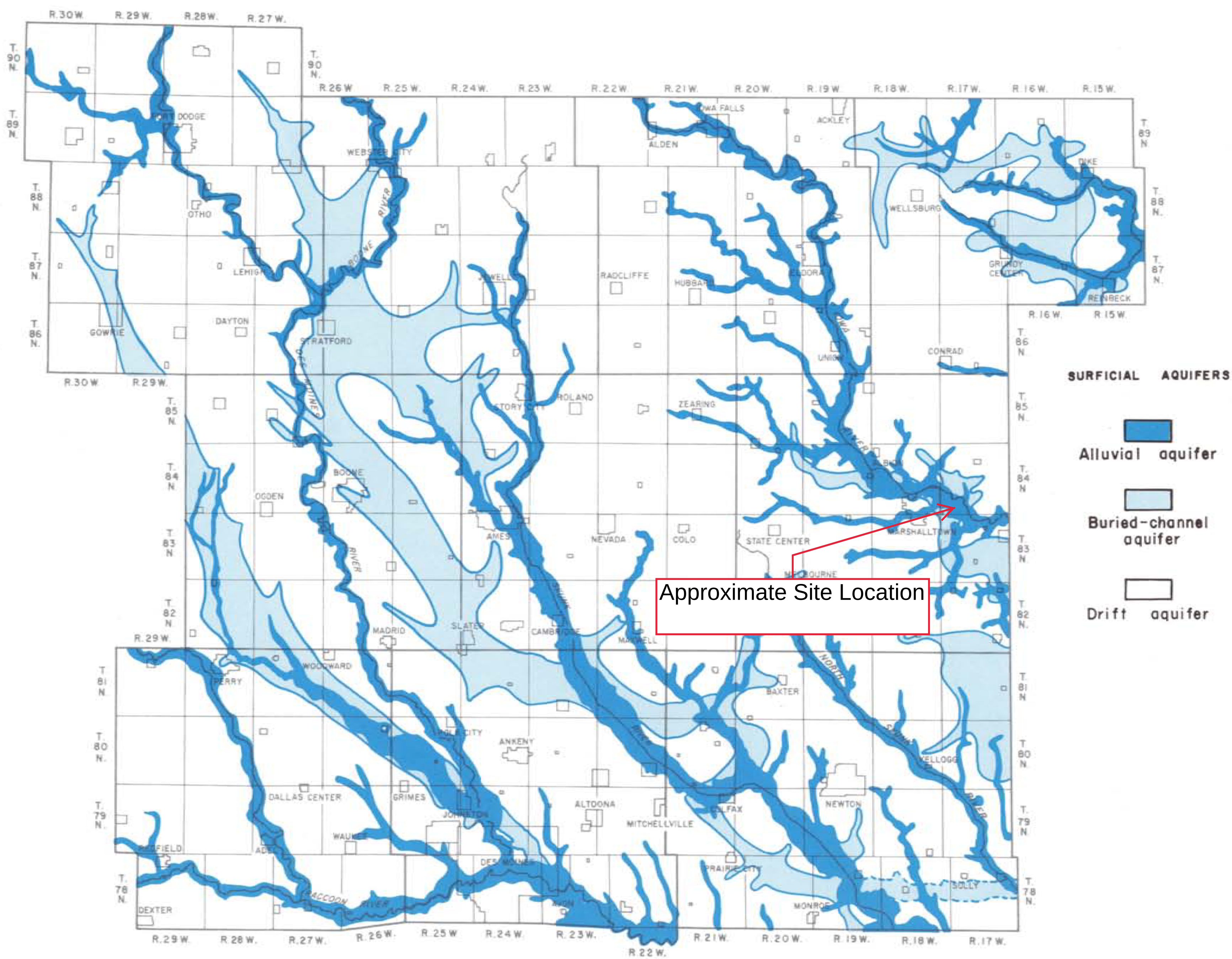


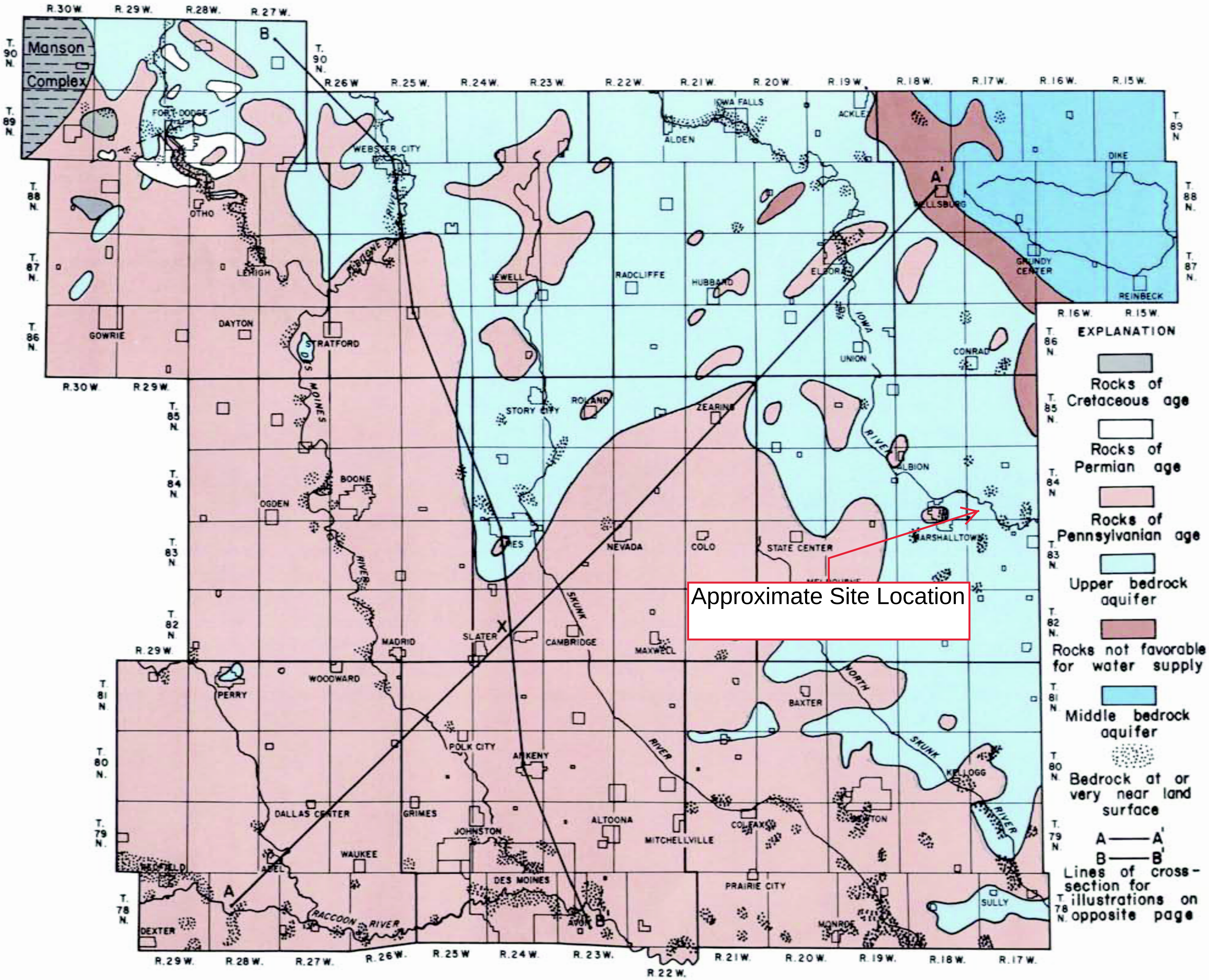
More than 40 cities and communities take all or most of their water from the upper bedrock aquifer.



Source: F.R. Twenter and R.W. Coble, "The Water Story in Central Iowa," Iowa Geologic Survey Water Atlas Number 1, 1965.




Source: F.R. Twenter and R.W. Coble, "The Water Story in Central Iowa," Iowa Geologic Survey Water Atlas Number 1, 1965.




The areal distribution and spatial relations of the upper and middle bedrock aquifers.

Source: F.R. Twenter and R.W. Coble, "The Water Story in Central Iowa," Iowa Geologic Survey Water Atlas Number 1, 1965.

# Appendix B

# Boring Logs

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| | | |
|---|---|---|
| Facility/Project Name: IPL-Sutherland Generating Statation SCS#: 25216149.00 | License/Permit/Monitoring Number: | Boring Number: MW-301 |
| Boring Drilled By: Name of crew chief (first, last) and Firm: Patrick Goetz, Direct Push Analytical | Date Drilling Started: 11/20/2017 | Date Drilling Completed: 11/20/2017 |
| Drilling Method: hollow stem auger | | |
| Unique Well No.: | DNR Well ID No.: | Common Well Name: MW-301 |
| Final Static Water Level: Feet | Surface Elevation: 863.5 Feet | Borehole Diameter: 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,481,478 N, 5,094,231 E S/C/N
NW 1/4 of NW 1/4 of Section 32, T 84 N, R 17 W

Lat ___° ___' ___"
Long ___° ___' ___"

Local Grid Location: Feet ☐ N ☐ S Feet ☐ E ☐ W

Facility ID: | County: Marshall | Civil Town/City/ or Village: Marshalltown

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–8 | POORLY GRADED SAND, fine to medium, tan, (10YR 4/6), (construction fill sand to fill in hydrovac hole cleared to 8 ft bgs). Blind drilled to 8 feet. | SP | | | | | | | | | |
| | | | 8–16.19 | POORLY GRADED SAND, fine to coarse, dark brown, (7.5YR 3/3). | SP | | | | | | | | | |
| S1 | 30 | | 10 | | | | | | | M+/W | | | | Depth to water at ~8 feet |
| S2 | 30 | | 14 | | | | | | | W | | | | |
| | | | 16.19 | End of boring at 16.19 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: [signature] for Nate Hermes

Firm: SCS Engineers
2830 Dairy Drive Madison, WI 53711
Tel: (608) 224-2830
Fax:

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| IPL-Sutherland Generating Statation SCS#: 25216149.00 | | MW-302 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Patrick Goetz<br>Direct Push Analytical | 11/20/2017 | 11/20/2017 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| . | | MW-302 | Feet | 860.1 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,480,768 N, 5,094,238 E S/C/N
NW 1/4 of NW 1/4 of Section 32, T 84 N, R 17 W
Lat ___° ___' ___"
Long ___° ___' ___"
Local Grid Location: ☐ N ☐ S Feet; ☐ E ☐ W Feet

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–8 | POORLY GRADED SAND, fine to coarse, (10YR 4/6), (construction fill sand to fill in hydrovac hole cleared to 8 ft bgs).<br>Blind drilled to 8 feet. | SP | | | | | | | | | |
| | | | 8–8.5 | LEAN CLAY, gray (10YR 6/1), soft, plastic. | CL | | | | | | | | | |
| | | | 8.5–9.7 | SILTY SAND, fine to medium sand, brown, (10YR 4/3). | SM | | | | | | | | | |
| S1 | 36 | | 9.7–14 | POORLY GRADED SAND, fine to coarse, grayish/brown, (10YR 5/2). | SP | | | | | M+/W | | | | Depth to water at ~9 feet. |
| S2 | 26 | | 14–15.98 | Same as above but very dark gray (10YR 3/1). | | | | | | W | | | | |
| | | | | End of boring at 15.98 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: [signature] for Nate Harris

Firm: SCS Engineers
2830 Dairy Drive Madison, WI 53711
Tel: (608) 224-2830
Fax:

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | | License/Permit/Monitoring Number | Boring Number |
|---|---|---|---|
| IPL-Sutherland Generating Station SCS#: 25216149.00 | | | MW-303 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Patrick Goetz<br>Direct Push Analytical | 11/20/2017 | 11/20/2017 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-303 | Feet | 856.7 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,480,604 N, 5,096,509 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location ☐ N ☐ E Feet ☐ S Feet ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–8 | POORLY GRADED SAND, fine to coarse, tan, (10YR 4/6), (construction fill sand to fill in hydrovac hole cleared to 8 ft bgs). Blind drilled to 8 feet. | SP | | | | | | | | | |
| S1 | 24 | | 8–16.31 | POORLY GRADED SAND with few fine sub-rounded gravel, dark brown, (5YR 3/3). | SP | | | | | W | | | | Depth to water at ~8 feet. |
| S2 | 30 | | | | | | | | | W | | | | |
| | | | 16.31 | End of boring at 16.31 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: [signature] for Nate Harris

Firm: SCS Engineers
2830 Dairy Drive Madison, WI 53711
Tel: (608) 224-2830
Fax:

**SCS ENGINEERS** — **SOIL BORING LOG INFORMATION**

Environmental Consultants and Contractors

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| IPL-Sutherland Generating Statation SCS#: 25216149.00 | | MW-304 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Patrick Goetz<br>Direct Push Analytical | 11/20/2017 | 11/20/2017 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-304 | Feet | 857.8 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,480,549 N, 5,096,849 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W

Lat ___° ___' ___"
Long ___° ___' ___"

Local Grid Location: ☐ N ☐ E; Feet ☐ S, Feet ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | USCS | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–4 | POORLY GRADED SAND, fine to coarse, tan, (construction fill sand to fill in hydrovac hole).<br>Blind drilled to 4 feet. | SP | | | | | | | | | |
| | | | 4–12 | LEAN CLAY, brown, (7.5YR 4/3), soft, plastic, trace organic fibers. | CL | | | | | | | | | |
| S1 | 30 | | 6 | | | | | | | M+/W | | | | Depth to water at ~7 feet. |
| S2 | 32 | | 10 | | | | | | | W | | | | |
| | | | 12–13 | POORLY GRADED SAND, fine to coarse, dark yellow brown, (10YR 3/6). | SP | | | | | | | | | |
| | | | 13–15 | SILTY SAND, very dark gray, (10YR 3/1), soft. | SM | | | | | | | | | |
| S3 | 42 | | 14 | | | | | | | W | | | | |
| | | | 15–16.3 | POORLY GRADED SAND with fine sub-rounded gravel, fine to coarse, dark yellow brown, (10YR 3/6). | SP | | | | | | | | | |
| | | | | End of boring at 16.30 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

| Signature | Firm | |
|---|---|---|
| Kyle [signature] for Nate Harris | SCS Engineers<br>2830 Dairy Drive Madison, WI 53711 | Tel: (608) 224-2830<br>Fax: |

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | | License/Permit/Monitoring Number | Boring Number |
|---|---|---|---|
| IPL-Sutherland Generating Statation SCS#: 25216149.00 | | | MW-305 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Patrick Goetz<br>Direct Push Analytical | 11/21/2017 | 11/21/2017 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-305 | Feet | 856.8 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,480,877 N, 5,096,835 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat ____°____'____"
Long ____°____'____"
Local Grid Location: Feet ☐ N ☐ S Feet ☐ E ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | USCS | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–4 | POORLY GRADED SAND, fine to coarse, tan, (construction fill sand to fill in hydrovac hole cleared to 7.5 ft bgs).<br>Blind drilled to 4 feet. | SP | | | | | | | | | |
| S1 | 18 | | 4–7.5 | POORLY GRADED SAND, fine to coarse, dark yellowish brown, (10YR 4/4), (construction fill sand to fill in hydrovac hole cleared to 7.5 ft bgs). | SP | | | | | M+/W | | | | Depth to water at ~7 feet. |
| | | | 7.5–8 | LEAN CLAY with trace medium to coarse sand, very dark gray, (2.5YR 3/1), medium stiffness. | CL | | | | | | | | | |
| S2 | 12 | | 8–16.58 | POORLY GRADED SAND with trace fine sub-rounded gravel, fine to coarse, light olive brown, (2.5YR 3/1 and 2.5YR 5/4). | SP | | | | | W | | | | |
| S3 | 30 | | | | | | | | | W | | | | |
| | | | | End of boring at 16.58 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

| Signature | Firm | |
|---|---|---|
| Kyle [illegible] for Nate Helms | SCS Engineers<br>2830 Dairy Drive Madison, WI 53711 | Tel: (608) 224-2830<br>Fax: |

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☒
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| IPL-Sutherland Generating Statation SCS#: 25216149.00 | | MW-306 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Patrick Goetz<br>Direct Push Analytical | 11/21/2017 | 11/21/2017 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-306 | Feet | 858.2 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,481,470 N, 5,096,817 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat ___° ___' ___"
Long ___° ___' ___"
Local Grid Location: Feet ☐ N ☐ S Feet ☐ E ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–4 | POORLY GRADED SAND, fine to coarse, tan, (construction fill sand to fill in hydrovac hole cleared to 8 ft bgs). Blind drilled to 4 feet. | SP | | | | | | | | | |
| | | | 4–16.23 | POORLY GRADED SAND, fine to coarse, strong brown, (7.5YR 4/6), (construction fill sand to fill in hydrovac hole cleared to 8 ft bgs). | SP | | | | | | | | | |
| S1 | 12 | | 6 | | | | | | | M | | | | |
| S2 | 12 | | 10 | | | | | | | W | | | | Depth to water at ~8 feet. |
| S3 | 36 | | 14 | Same as above but dark yellowish brown color (10YR 3/4). | | | | | | W | | | | |
| | | | 16.23 | End of boring at 16.23 feet. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

| Signature | Firm | |
|---|---|---|
| [signature] for Nate Harris | SCS Engineers<br>2830 Dairy Drive Madison, WI 53711 | Tel: (608) 224-2830<br>Fax: |

**SCS ENGINEERS**
Environmental Consultants and Contractors

# SOIL BORING LOG INFORMATION

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| | | | |
|---|---|---|---|
| Facility/Project Name: IPL-Sutherland Generating Statation SCS#: 25221243.00 | License/Permit/Monitoring Number: | Boring Number: MW-307 | |
| Boring Drilled By: Name of crew chief (first, last) and Firm: Duncan List, Terracon | Date Drilling Started: 11/30/2021 | Date Drilling Completed: 11/30/2021 | Drilling Method: hollow stem auger |
| Unique Well No.: / DNR Well ID No.: / Common Well Name: MW-307 | Final Static Water Level: 13.3 Feet bgs | Surface Elevation: 862.3 Feet | Borehole Diameter: 8.25 in |
| Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒ State Plane 3,481,415 N, 5,096,028 E S/C/N; NE 1/4 of NW 1/4 of Section 32, T 84 N, R 17 W | Lat ° ' " / Long ° ' " | Local Grid Location: Feet ☐ N ☐ S; Feet ☐ E ☐ W | |
| Facility ID: | County: Marshall | Civil Town/City/ or Village: Marshalltown | |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–7.5 | Hydroexcavated to 7.5' bgs | | | | | | | | | | |
| | | | 7.5–12.0 | SANDY CLAY, dark brown, medium stiff | CL | | | | | | | | | |
| S1 | 20 | | 9.0 | | | | | | | M | | | | |
| S2 | 18 | | 11.0 | | | | | | | M | | | | |
| | | | 12.0–18.0 | POORLY-GRADED SAND, fine to coarse, dense, trace gravel | SP | | | | | | | | | |
| S3 | 17 | | 13.0 | | | | | | | W | | | | |
| S4 | 17 | | 15.0 | | | | | | | W | | | | |
| S5 | 16 | | 17.0 | color change to reddish brown at 17' bgs | | | | | | W | | | | |
| | | | 18.0 | End of boring at 18' bgs. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: [signature] Firm: SCS Engineers Tel: Fax:

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| IPL-Sutherland Generating Statation SCS#: 25221243.00 | | MW-308 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Duncan List<br>Terracon | 11/30/2021 | 11/30/2021 | hollow stem auger |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-308 | 11.2 Feet bgs | 860.8 Feet | 8.25 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☒
State Plane 3,481,182 N, 5,095,701 E S / C / N
NE 1/4 of NW 1/4 of Section 32, T 84 N, R 17 W
Lat ___ ° ___ ' ___ "
Long ___ ° ___ ' ___ "
Local Grid Location: Feet ☐ N ☐ S; Feet ☐ E ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–8.5 | Hydroexcavated to 8.5' | | | | | | | | | | |
| | | | 8.5 | POORLY GRADED SAND, medium to coarse, brown, dense | SP | | | | | | | | | |
| S1 | 9 | | 9.0 | | | | | | | W | | | | |
| S2 | 14 | | 10.5–12.0 | trace gravel | | | | | | W | | | | |
| S3 | 15 | | 13.5 | | | | | | | W | | | | |
| S4 | 9 | | 15.0 | | | | | | | W | | | | |
| | | | 16 | End of boring at 16' bgs. | | | | | | | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

| Signature | Firm | |
|---|---|---|
| [signature] | SCS Engineers | Tel:<br>Fax: |

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| Sutherland Generating Station SCS#: 25221243.00 | | MW-309 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Brian Kinzer<br>Direct Push Analytical | 5/4/2022 | 5/4/2022 | Geoprobe/HSA |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-309 | 854.2 Feet | 857.7 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☐
State Plane 3,481,449 N, 5,095,701 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat 42° 2' 55.1"
Long 92° 50' 56.1"
Local Grid Location ☐ N ☐ E Feet ☐ S Feet ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S1 | 22 | | 0–4 | CLAY, black, soft with roots and sticks and plant material (Topsoil). | CL | | | | | M | | | | Dual core and MC5 geoprobe were used. |
| S2 | 41 | | 4–10 | LEAN CLAY, brownish gray with orange mottling and trace organics, roots, and sand throughout, soft to medium stiff. | CL | | | | | M | | | | |
| S3 | 29 | | 10–12 | SILT, brownish gray with orange mottling, and black organic material (looks like decaying wood). | CL-ML | | | | | M | | | | |
| S4 | 22 | | 12–15 | SILT, gray to dark gray, very soft to soft with trace organics/wood. | ML | | | | | W | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature

Firm SCS Engineers
3900 Kilroy Airport Way Long Beach, CA 90806
Tel:
Fax:

Boring Number MW-309



| Sample: Number and Type | Sample: Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Soil Properties: Standard Penetration | Soil Properties: Moisture Content | Soil Properties: Liquid Limit | Soil Properties: Plasticity Index | Soil Properties: P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | POORLY GRADED SAND, fine to coarse grained, brown to reddish brown and dark brown. | | | | | | | | | | |
| | | | 16 | Same as above but fine to mostly coarse grained, brown to dark brown with fine and trace gravel. | | | | | | | | | | |
| | | | 17 | | SP | | | | | | | | | |
| S5 | 43 | | 18 | | | | | | | W | | | | |
| | | | 19 | | | | | | | | | | | |
| | | | 20 | | | | | | | | | | | |
| | | | 21 | End of boring at 21' below ground surface. | | | | | | | | | | |

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



| Facility/Project Name | License/Permit/Monitoring Number | Boring Number |
|---|---|---|
| Sutherland Generating Station SCS#: 25221243.00 | | MW-310 |

| Boring Drilled By: Name of crew chief (first, last) and Firm | Date Drilling Started | Date Drilling Completed | Drilling Method |
|---|---|---|---|
| Brian Kinzer<br>Direct Push Analytical | 5/4/2022 | 5/4/2022 | Geoprobe/HSA |

| Unique Well No. | DNR Well ID No. | Common Well Name | Final Static Water Level | Surface Elevation | Borehole Diameter |
|---|---|---|---|---|---|
| | | MW-310 | 851.9 Feet | 858.1 Feet | 8.3 in |

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☐
State Plane 3,481,093 N, 5,098,101 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat 42° 2' 51.6"
Long 92° 50' 56.0"
Local Grid Location ☐ N ☐ E; Feet ☐ S Feet ☐ W

| Facility ID | County | Civil Town/City/ or Village |
|---|---|---|
| | Marshall | Marshalltown |

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–4 | CLAY, black with roots and sticks and plant material (Topsoil). | | | | | | | | | | |
| S1 | 20 | | 2 | | | | | | | M | | | | Dual core and MC5 geoprobe were used. |
| | | | 4 | LEAN CLAY, light brown to brown, orange mottling with trace gray, roots and fine to medium grained sand, soft. | | | | | | | | | | |
| S2 | 22 | | 6 | | | | | | | M | | | | |
| | | | 8 | Same as above but with trace sand and silt, soft. | CL | | | | | | | | | |
| S3 | 26 | | 10 | | | | | | | M | | | | |
| | | | 11 | Same as above but dark gray. | | | | | | | | | | |
| | | | 12 | SANDY SILT, dark gray, sand is fine grained, soft. | ML | | | | | | | | | |
| S4 | 36 | | 14 | POORLY GRADED SAND, fine to coarse grained, brown with trace orange and gravel. | SP | | | | | W | | | | Driller noted water at 13' bgs. |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

| Signature | Firm | |
|---|---|---|
| [signature] | SCS Engineers<br>3900 Kilroy Airport Way Long Beach, CA 90806 | Tel:<br>Fax: |

Boring Number MW-310



| Sample: Number and Type | Sample: Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Soil Properties: Standard Penetration | Soil Properties: Moisture Content | Soil Properties: Liquid Limit | Soil Properties: Plasticity Index | Soil Properties: P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| S5 | 24 | | 16–20 | POORLY GRADED SAND, fine to coarse grained, brown with trace orange and gravel. *(continued)* | SP | | | | | W | | | | |
| | | | 21 | End of boring at 21' below ground surface. | | | | | | | | | | |

**SCS ENGINEERS**
Environmental Consultants and Contractors

**SOIL BORING LOG INFORMATION**

Route To: Watershed/Wastewater ☐ Waste Management ☐
Remediation/Redevelopment ☐ Other ☐



Facility/Project Name: Sutherland Generating Station SCS#: 25221243.00
License/Permit/Monitoring Number:
Boring Number: MW-311

Boring Drilled By: Name of crew chief (first, last) and Firm: Brian Kinzer, Direct Push Analytical
Date Drilling Started: 5/4/2022
Date Drilling Completed: 5/4/2022
Drilling Method: Geoprobe/HSA

Unique Well No.:
DNR Well ID No.:
Common Well Name: MW-311
Final Static Water Level: 849.6 Feet
Surface Elevation: 855.3 Feet
Borehole Diameter: 8.3 in

Local Grid Origin ☐ (estimated: ☐ ) or Boring Location ☐
State Plane 3,480,729 N, 5,098,107 E S/C/N
NW 1/4 of NE 1/4 of Section 32, T 84 N, R 17 W
Lat 42° 2' 48.0"
Long 92° 50' 56.0"
Local Grid Location: ☐ N ☐ E Feet ☐ S Feet ☐ W

Facility ID:
County: Marshall
Civil Town/City/ or Village: Marshalltown

| Sample Number and Type | Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Standard Penetration | Moisture Content | Liquid Limit | Plasticity Index | P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0–3 | CLAY, black, soft with roots and sticks (Topsoil). | | | | | | | | | | |
| S1 | 27 | | 0–4 | | | | | | | M | | | | Dual core and MC5 geoprobe were used. |
| | | | 3 | POORLY GRADED SAND, fine to coarse grained, brown with trace fine gravel and clay. | SP | | | | | | | | | |
| S2 | 8 | | 4–8 | | | | | | | W | | | | Driller noted water at 4' bgs. |
| | | | 8 | Same as above but with more gravel, fine to coarse grained, brown to dark brown. | | | | | | | | | | |
| S3 | 13 | | 8–12 | | | | | | | W | | | | |
| S4 | 18 | | 12–15 | | | | | | | W | | | | |

I hereby certify that the information on this form is true and correct to the best of my knowledge.

Signature: [signature]
Firm: SCS Engineers
3900 Kilroy Airport Way Long Beach, CA 90806
Tel:
Fax:

Boring Number MW-311



| Sample: Number and Type | Sample: Length Att. & Recovered (in) | Blow Counts | Depth In Feet | Soil/Rock Description And Geologic Origin For Each Major Unit | U S C S | Graphic Log | Well Diagram | PID/FID | Soil Properties: Standard Penetration | Soil Properties: Moisture Content | Soil Properties: Liquid Limit | Soil Properties: Plasticity Index | Soil Properties: P 200 | RQD/ Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 16 | POORLY GRADED SAND, fine to coarse grained, brown with trace fine gravel and clay. *(continued)* | SP | | | | | | | | | |
| | | | | End of boring at 16' below ground surface. | | | | | | | | | | |

Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station    Permit No.:

Well or Piezometer No: MW-301

Dates Started: 11/20/2017    Date Completed: 11/20/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft): 3481477.68 N, 5094230.68 E

Specify corner of site: NW of parcel 8417-32-126-002

Distance & direction along boundary: 82' E

Distance & direction from boundary to wall: 173' S

Elevations (± 0.01 ft MSL):

Ground Surface: 863.50

Top of protective casing: 866.9

Top of well casing: 866.61

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:

Direct Push Analytical
4N969 Old Lafox Rd Unit F
St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'-15.69' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'-3.5' bgs

Material: 3/8" Benseal Bentonite Chips

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No    Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 12.80    Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)

TOP OF PROTECTIVE CASING
ELEVATION 866.90

TOP OF WELL CASING
ELEVATION 866.61

GROUND SURFACE
ELEVATION 863.50

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 863.00
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 861.5
DEPTH 2.0'

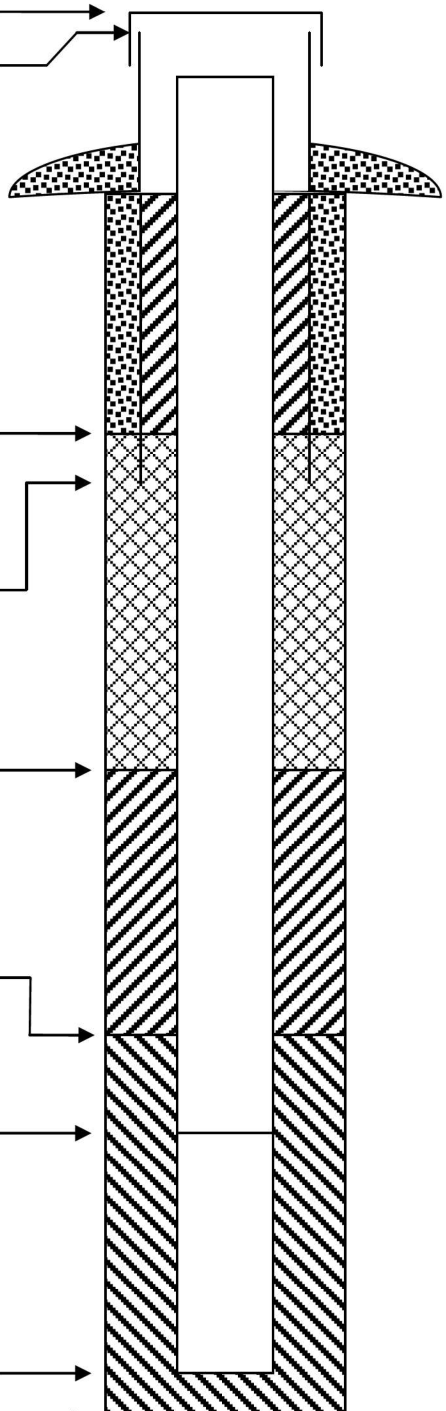
BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 860.0
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 857.81
DEPTH 5.69

BOTTOM OF SCREEN
ELEVATION 847.81
DEPTH 15.69'

BASE OF FILTER PACK
ELEVATION 847.31
DEPTH 16.19'



Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station    Permit No.:

Well or Piezometer No: MW-302

Dates Started: 11/20/2017    Date Completed: 11/20/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft): 3480767.91 N, 5094237.526 E

Specify corner of site: SW of parcel 8417-32-126-002

Distance & direction along boundary: 324' N

Distance & direction from boundary to wall: 42' E

Elevations (± 0.01 ft MSL):

Ground Surface: 860.06

Top of protective casing: 863.32

Top of well casing: 863.08

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:
Direct Push Analytical
4N969 Old Lafox Rd Unit F
St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'-15.48' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'-3.5' bgs

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No    Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

Material: 3/8" Benseal Bentonite Chips

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 9.10    Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

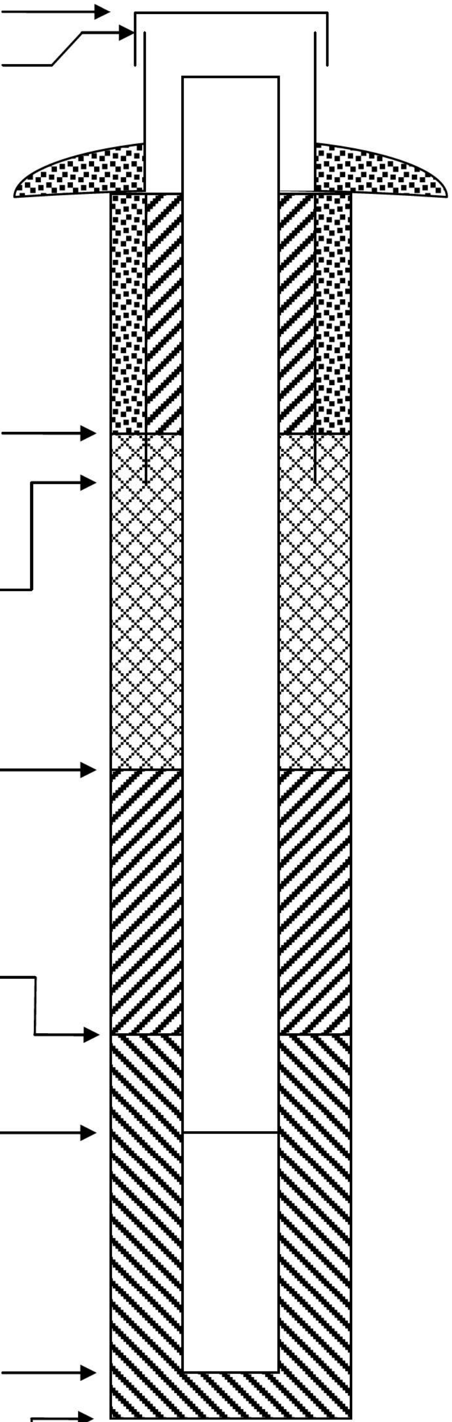
**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)



TOP OF PROTECTIVE CASING
ELEVATION 863.32

TOP OF WELL CASING
ELEVATION 863.08

GROUND SURFACE
ELEVATION 860.06

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 859.56
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 858.06
DEPTH 2.0'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 856.56
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 854.58
DEPTH 5.48'

BOTTOM OF SCREEN
ELEVATION 844.58
DEPTH 15.48'

BASE OF FILTER PACK
ELEVATION 844.08
DEPTH 15.98'

Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station　Permit No.:

Well or Piezometer No: MW-303

Dates Started: 11/20/2017　Date Completed: 11/20/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft): 3480604.15 N, 5096509.24 E

Specify corner of site: SE of parcel 8417-32-126-002

Distance & direction along boundary: 326' W

Distance & direction from boundary to wall: 200' N

Elevations (± 0.01 ft MSL):

Ground Surface: 856.70

Top of protective casing: 859.74

Top of well casing: 859.54

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:

Direct Push Analytical

4N969 Old Lafox Rd Unit F

St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'- 15.81' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'-3.5' bgs

Material: 3/8" Benseal Bentonite Chips

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No　Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 7.35　Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

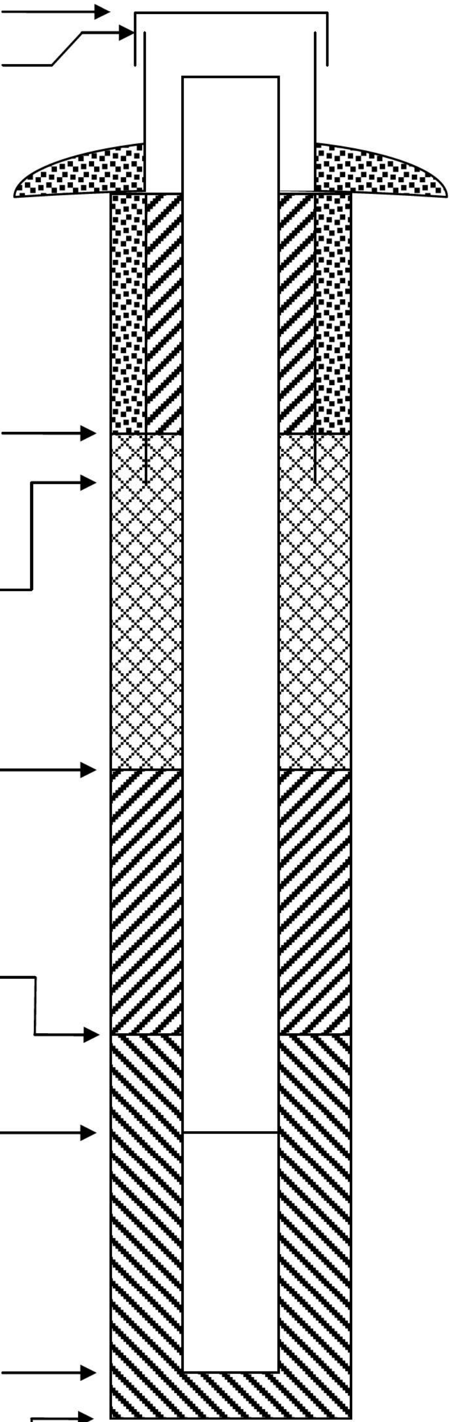
**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)



TOP OF PROTECTIVE CASING
ELEVATION 859.74

TOP OF WELL CASING
ELEVATION 859.54

GROUND SURFACE
ELEVATION 856.70

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 856.2
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 854.70
DEPTH 2.0'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 853.20
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 850.89
DEPTH 5.81'

BOTTOM OF SCREEN
ELEVATION 840.89
DEPTH 15.81'

BASE OF FILTER PACK
ELEVATION 840.39
DEPTH 16.31'

Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station Permit No.:

Well or Piezometer No: MW-304

Dates Started: 11/20/2017 Date Completed: 11/20/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft): 3480548.65 N, 5096849.06 E

Specify corner of site: SW of parcel 8417-32-200-002

Distance & direction along boundary: 156' N

Distance & direction from boundary to wall: 10' E

Elevations (± 0.01 ft MSL):

Ground Surface: 857.79

Top of protective casing: 861.06

Top of well casing: 860.79

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:
Direct Push Analytical
4N969 Old Lafox Rd Unit F
St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'-15.80' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'- 3.5' bgs

Material: 3/8" Benseal Bentonite Chips

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 8.91 Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)

TOP OF PROTECTIVE CASING
ELEVATION 861.06

TOP OF WELL CASING
ELEVATION 860.79

GROUND SURFACE
ELEVATION 857.79

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 857.29
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 855.79
DEPTH 2.0'

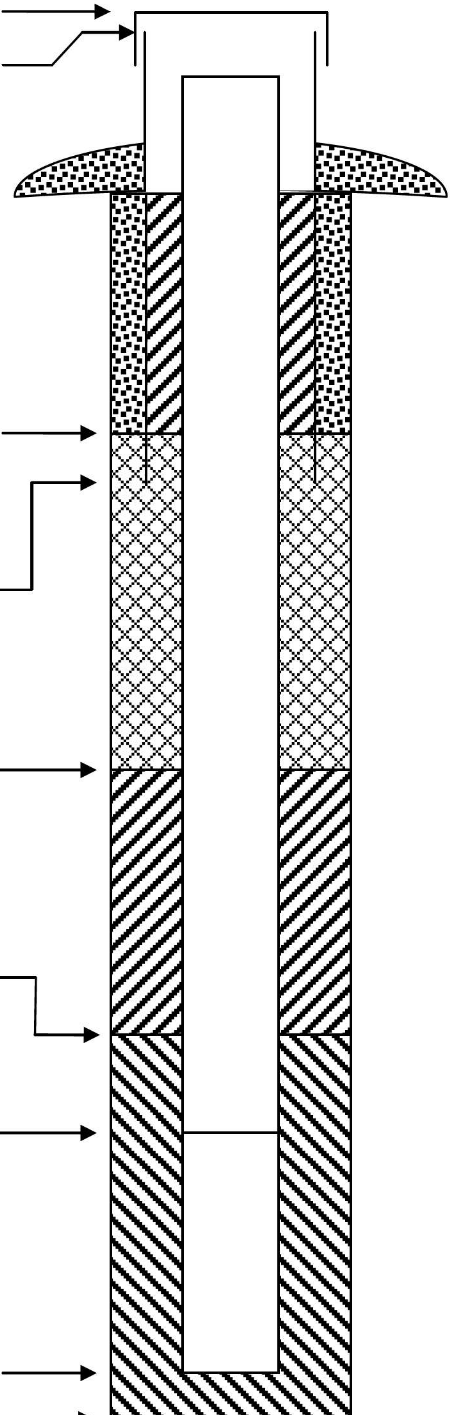
BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 854.29
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 851.99
DEPTH 5.80'

BOTTOM OF SCREEN
ELEVATION 841.99
DEPTH 15.80'

BASE OF FILTER PACK
ELEVATION 841.49
DEPTH 16.3



Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station Permit No.:

Well or Piezometer No: MW-305

Dates Started: 11/21/2017 Date Completed: 11/21/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft): 3480877.26 N, 5096834.70 E

Specify corner of site: SW of parcel 8417-32-200-002

Distance & direction along boundary: 545' N

Distance & direction from boundary to wall: 12' E

Elevations (± 0.01 ft MSL):

Ground Surface: 856.81

Top of protective casing: 860.12

Top of well casing: 859.81

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:
Direct Push Analytical
4N969 Old Lafox Rd Unit F
St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'-16.08' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'-3.5' bgs

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

Material: 3/8" Benseal Bentonite Chips

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 8.24 Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)

TOP OF PROTECTIVE CASING
ELEVATION 860.12

TOP OF WELL CASING
ELEVATION 859.81

GROUND SURFACE
ELEVATION 856.81

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 856.31
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 854.81
DEPTH 2.0'

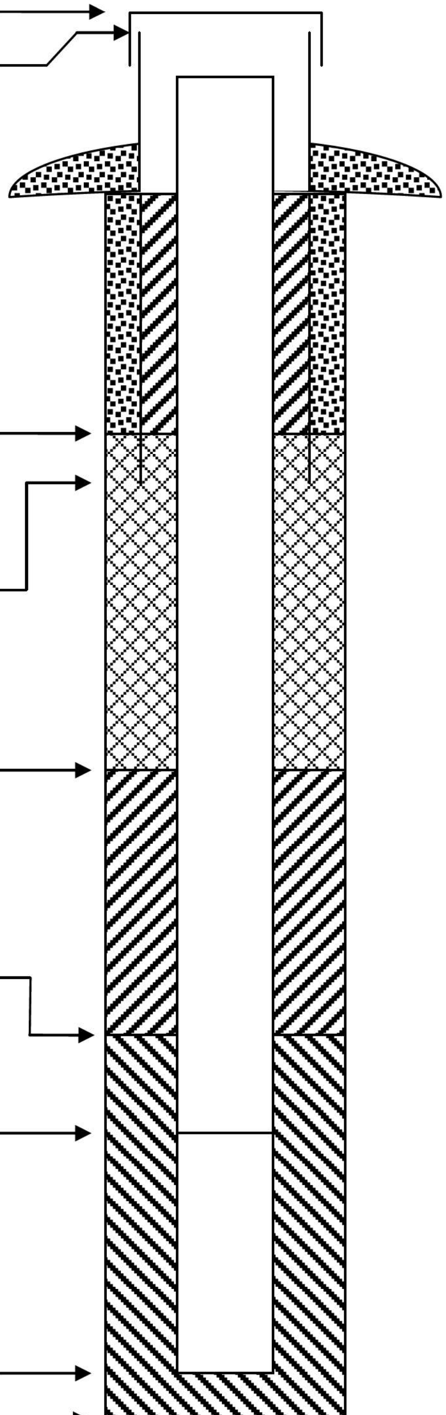
BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 853.31
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 850.73
DEPTH 6.08

BOTTOM OF SCREEN
ELEVATION 840.73
DEPTH 16.08'

BASE OF FILTER PACK
ELEVATION 840.23
DEPTH 16.58'



Print Form

IOWA DEPARTMENT OF NATURAL RESOURCES

# MONITORING WELL/PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL-Sutherland Generating Station    Permit No.:

Well or Piezometer No: MW-306

Dates Started: 11/21/2017    Date Completed: 11/21/2017

## A. SURVEYED LOCATIONS AND ELEVATIONS

Locations (± 0.5 ft):

Specify corner of site: NW of parcel 8417-32-200-001

Distance & direction along boundary: 222' S

Distance & direction from boundary to wall: 17' E

Elevations (± 0.01 ft MSL):

Ground Surface: 858.15

Top of protective casing: 861.36

Top of well casing: 861.13

Benchmark elevation: 590.75

Benchmark description: BM-001

## B. SOIL BORING INFORMATION

Name & Address of Construction Company:

Direct Push Analytical

4N969 Old Lafox Rd Unit F

St. Charles, IL 60175

Name of Driller: Patrick Goetz

Drilling Method: 4 1/4 Hollow Stem Auger

Drilling Fluid: N/A

Bore Hole Diameter: 8.5"

Soil Sampling Method: 2" Split Spoon

Depth of Boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC

Length of casing: 5'

Outside casing diameter: 2.38"

Inside casing diameter: 2"

Casing joint type: Flush Threaded

Casing/screen joint type: PVC

Screen material: PVC

Screen opening size: 0.010"

Screen length: 10'

Depth of well: 15'

Filter Pack: 3.5'-15.73' bgs

Material: RW Sidley

Grain size: #5

Volume: 2.1 cu ft

Seal (minimum 3 ft length above filter pack): 0.5'-3.5' bgs

Placement method: Gravity

Volume: 0.66 cu ft

Backfill (if different from seal): N/A

Material: N/A

Placement method: N/A

Volume: N/A

Surface seal design: 0'-0.5' bgs

Material of protective casing: Steel, 4" diameter

Material of grout between protective casing and well casing: Sand

Protective cap: 6" diameter

Material: Steel

Vented: ☒ Yes ☐ No    Locking: ☒ Yes ☐ No

Well Cap: 2" diameter

Material: Plastic with rubber gasket

Vented: ☒ Yes ☐ No

Material: 3/8" Benseal Bentonite Chips

## D. GROUNDWATER MEASURMENT (± 0.01 ft below top of inner well casing)

Water level: 9.77    Stabilization Time: <5 min

Well development method: surged with bailer and pumped

Average depth of frostline: 4 feet

**Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½x11 inch map showing locations of all monitoring wells and piezometers.**

**Please mail completed for to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E 9th St, Des Moines IA 50319-0034.

**Questions? Call or Email:** Nina Koger, Environmental Engineer Sr., 515-281-8986, Nina.Koger@dnr.iowa.gov

ELEVATIONS: ± 0.01 ft MSL
DEPTHS: ± 0.1 ft FROM GROUND SURFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
(SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL.)

TOP OF PROTECTIVE CASING
ELEVATION 861.36

TOP OF WELL CASING
ELEVATION 861.13

GROUND SURFACE
ELEVATION 858.15

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 857.65
DEPTH 0.5'

BASE OF PROTECTIVE CASING
ELEVATION 856.15
DEPTH 2.0'

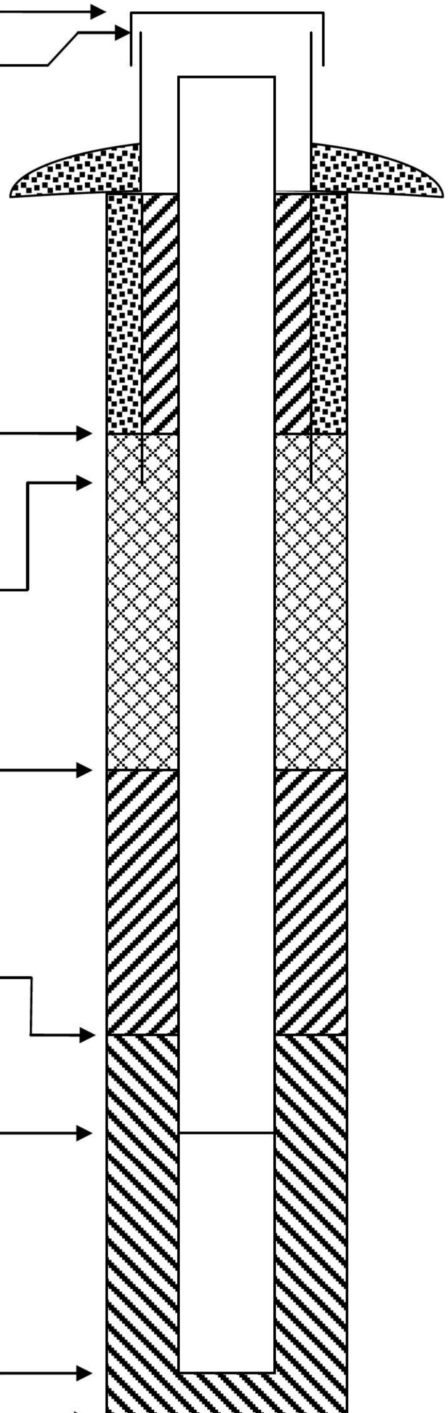
BASE OF BACKFILL
TOP OF SEAL
ELEVATION --
DEPTH --

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 854.65
DEPTH 3.5'

TOP OF SCREEN
ELEVATION 852.42
DEPTH 5.73'

BOTTOM OF SCREEN
ELEVATION 842.42
DEPTH 15.73'

BASE OF FILTER PACK
ELEVATION 841.92
DEPTH 16.23'



# MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL Sutherland Generating Station
Permit No.: County: WP2021-1(a)
Well or Piezometer No.: MW-307
Dates Started: 11/30/2021
Date Completed: 11/30/2021

## A. SURVEYED LOCATION AND ELEVATION OF POINT (+0.5 ft.)

Specify corner of site: NE
Distance and direction along boundary: 774 feet west
Distance and direction from boundary to surface monitoring well: 274 feet south
Elevation (+0.01 ft. MSL):
Ground Surface: 862.27
Top of protective casing: 865.1
Top of well casing: 864.87
Benchmark elevation:
Benchmark description:

## B. SOIL BORING INFORMATION

Construction Company Name: Terracon
Address: 2640 12th Street SW
City, State, Zip Code: Cedar Rapids, IA 52404
Name of driller: Duncan List
Drilling method: Hollow-stem auger
Drilling fluid: none
Bore Hole diameter: 8.25"
Soil sampling method: Split spoon
Depth of boring: 18'

## C. MONITORING WELL INSTALLATION

Casing material: PVC
Length of casing: 10'
Outside casing diameter: 2.38"
Inside casing diameter: 2.01"
Casing joint type: Flush threaded
Casing/screen joint type: Flush threaded
Screen material: PVC - factory slotted
Screen opening size: 0.010"
Screen length: 10'
Depth of Well: 17.5'

Filter Pack:
- Material: Sand - Gillibrand Industrial
- Grain Size:
- Volume: 2 cu. ft.

Seal (minimum 3 ft. length above filter pack):
- Material: 3/8" Bentonite chips - Holeplug

Placement method: Gravity - poured
Volume: 2.67 cu. ft.

Backfill (if different from seal): Same as seal
- Material:
- Placement method:
- Volume:

Surface seal design:
- Material of protective casing: Steel
- Material of grout between protective casing and well casing: bentonite chips

Protective cap:
- Material: Steel
- Vented?: ☒ Y ☐ N
- Locking?: ☒ Y ☐ N

Well cap:
- Material: Plastic
- Vented?: ☒ Y ☐ N

## D. GROUNDWATER MEASUREMENT (±0.01 foot below top of inner well casing)

**Water level** 13.24'
**Stabilization time** <20 minutes
**Well development method** Surged and purged with submersible pump. 10 well volumes removed during development.
**Average depth of frost line** 4'

## DRILLER'S CERTIFICATION

**I certify under penalty of law I believe the information reported above is true, accurate, and complete.**

**Signature** [signature] **Certification #** 1183 **Date** 12/23/21

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

**Please mail completed form to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
**Questions? Call or Email:** Nina Booker Environmental Engineer Sr., 515-725-8309, nina.booker@dnr.iowa.gov

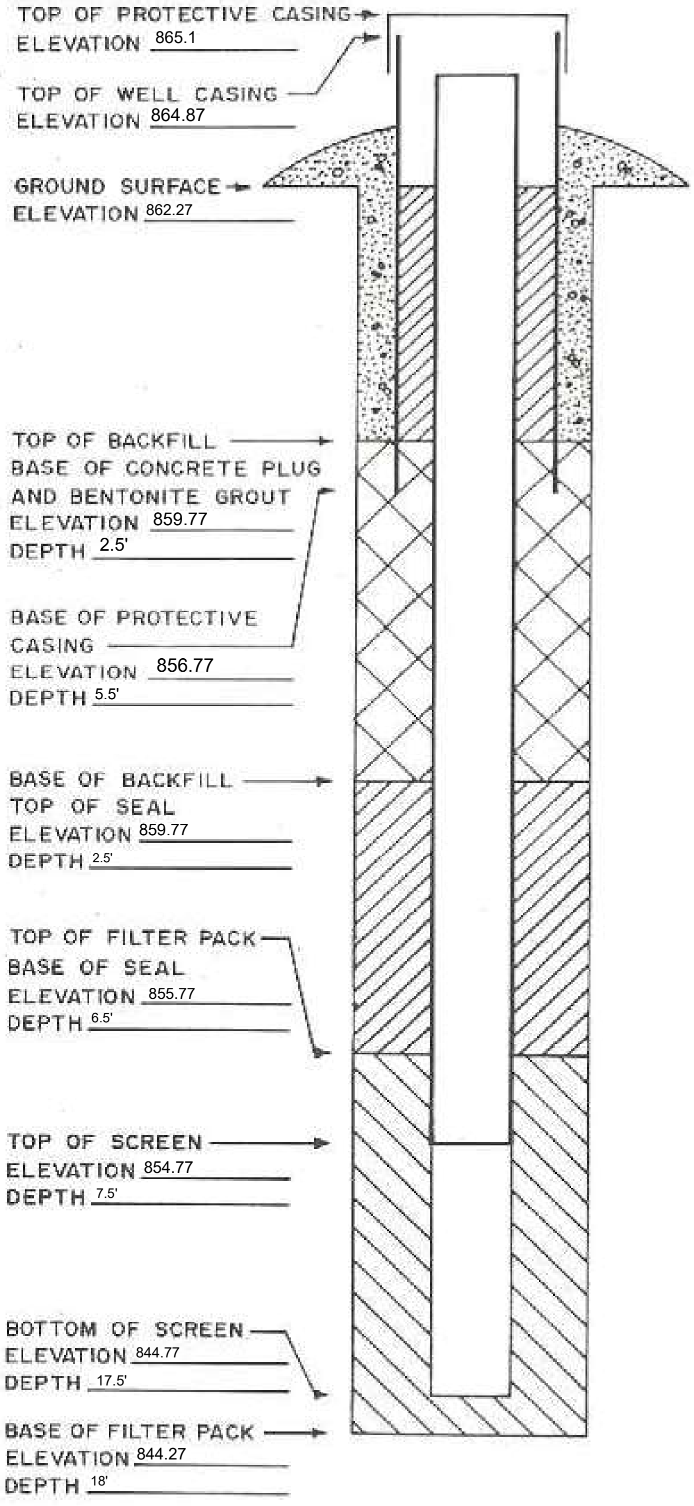
09/2017 cmc

DNR Form 542-1277

ELEVATIONS: ± 0.01 FT. MSL

DEPTHS: ± 0.1 FT. FROM
GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
( SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL ).



# MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: IPL Sutherland Generating Station
Permit No.: County: WP2021-1(b)

Well or Piezometer No.: MW-308
Dates Started: 11/30/2021
Date Completed: 11/30/2021

## A. SURVEYED LOCATION AND ELEVATION OF POINT (+0.5 ft.)

Specify corner of site: NE
Distance and direction along boundary: 1,101 feet west
Distance and direction from boundary to surface monitoring well: 508 feet south
Elevation (+0.01 ft. MSL):
Ground Surface: 860.83
Top of protective casing: 863.37
Top of well casing: 863.07
Benchmark elevation:
Benchmark description:

## B. SOIL BORING INFORMATION

Construction Company Name: Terracon
Address: 2640 12th Street SW
City, State, Zip Code: Cedar Rapids, IA 52404
Name of driller: Duncan List
Drilling method: Hollow-stem auger
Drilling fluid: none
Bore Hole diameter: 8.25"
Soil sampling method: Split spoon
Depth of boring: 16'

## C. MONITORING WELL INSTALLATION

Casing material: PVC
Length of casing: 10'
Outside casing diameter: 2.38"
Inside casing diameter: 2.01"
Casing joint type: Flush threaded
Casing/screen joint type: Flush threaded
Screen material: PVC - factory slotted
Screen opening size: 0.010"
Screen length: 10'
Depth of Well: 16'

**Filter Pack:**
- Material: Sand - Gillibrand Industrial
- Grain Size:
- Volume: 2 cu. ft.

**Seal** (minimum 3 ft. length above filter pack):
- Material: 3/8" Bentonite chips - Holeplug

Placement method: Gravity - poured
Volume: 2.67 cu. ft.

**Backfill** (if different from seal): Same as seal
- Material:
- Placement method:
- Volume:

**Surface seal design:**
- Material of protective casing: Steel
- Material of grout between protective casing and well casing: bentonite chips

**Protective cap:**
- Material: Steel
- Vented?: ☒ Y ☐ N
- Locking?: ☒ Y ☐ N

**Well cap:**
- Material: Plastic
- Vented?: ☒ Y ☐ N

## D. GROUNDWATER MEASUREMENT (+0.01 foot below top of inner well casing)

**Water level**: 11.12'
**Stabilization time**: <20 minutes
**Well development method**: Surged and purged with submersible pump. 10 well volumes removed during development.
**Average depth of frost line**: 4

## DRILLER'S CERTIFICATION

**I certify under penalty of law I believe the information reported above is true, accurate, and complete.**

**Signature** [signature] **Certification #** 11183 **Date** 12/23/21

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

**Please mail completed form to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
**Questions? Call or Email:** Nina Booker Environmental Engineer Sr., 515-725-8309, nina.booker@dnr.iowa.gov

ELEVATIONS: ± 0.01 FT. MSL

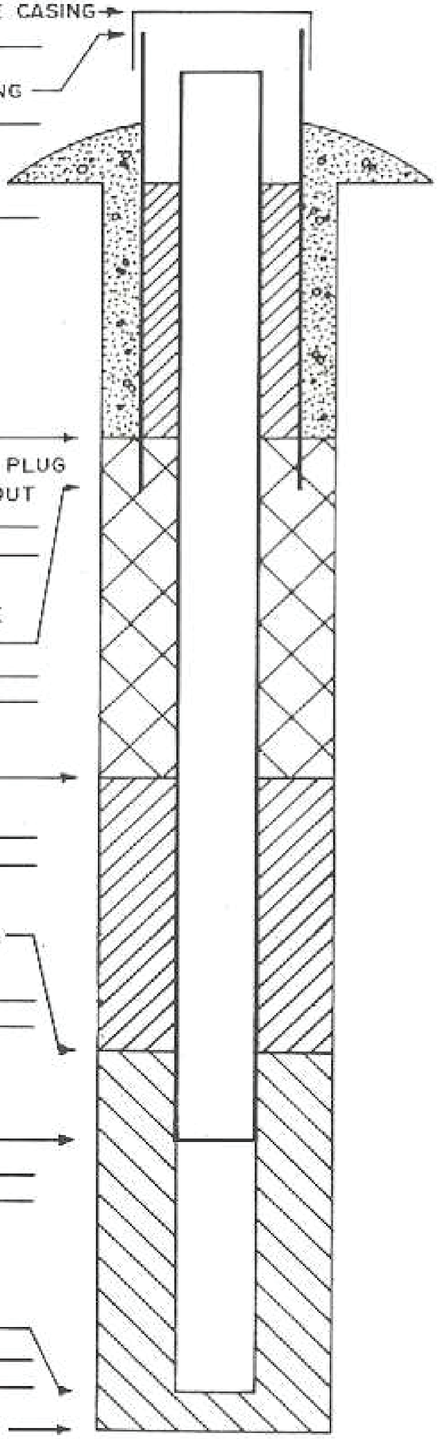
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
( SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL ).

TOP OF PROTECTIVE CASING
ELEVATION 863.37

TOP OF WELL CASING
ELEVATION 863.07

GROUND SURFACE
ELEVATION 860.83



TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 859.33
DEPTH 1.5'

BASE OF PROTECTIVE
CASING
ELEVATION 855.33
DEPTH 5.5'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION 859.33
DEPTH 1.5'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 855.33
DEPTH 5.5'

TOP OF SCREEN
ELEVATION 854.83
DEPTH 6'

BOTTOM OF SCREEN
ELEVATION 844.83
DEPTH 16'

BASE OF FILTER PACK
ELEVATION 844.83
DEPTH 16'

# MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: Sutherland Genterating Station    Permit No.:
Well or Piezometer No.: MW-309    Dates Started: 5/4/2022    Date Completed: 5/4/2022

## A. SURVEYED LOCATION AND ELEVATION OF POINT (+0.5 ft.)

Specify corner of site: NE    Distance and direction along boundary:
Distance and direction from boundary to surface monitoring well:
Elevation (+0.01 ft. MSL):
Ground Surface: 857.705'    Top of protective casing: 860.193'
Top of well casing: 859.954'    Benchmark elevation:
Benchmark description:

## B. SOIL BORING INFORMATION

Construction Company Name: Direct Push Analytical
Address: 4N969 Old Lafox Rd Unit E    City, State, Zip Code: Saint charles, IL 60175
Name of driller: Bryan Kinzer
Drilling method: Geoprobe/HSA    Drilling fluid: None    Bore Hole diameter: 8.25"
Soil sampling method: $' sample tubes    Depth of boring: 22'

## C. MONITORING WELL INSTALLATION

Casing material: Sch. 40 PVC
Length of casing: 23.19'
Outside casing diameter: 2.4"
Inside casing diameter: 2.05"
Casing joint type: Threaded
Casing/screen joint type: Threaded
Screen material: Sch. 40 PVC
Screen opening size: 0.01"
Screen length: 15'
Depth of Well: 21'
Filter Pack:
- Material: RW Sidley filter sand
- Grain Size: #5
- Volume: 2.75 ft^3 (5.5 bags)

Seal (minimum 3 ft. length above filter pack):
- Material: 3/8" Bentonite chips

Placement method: Poured/Hydrated
Volume:
Backfill (if different from seal):
- Material:
- Placement method:
- Volume:

Surface seal design:
- Material of protective casing: Steel
- Material of grout between protective casing and well casing:

Protective cap:
- Material: Steel
- Vented?: ☒ Y ☐ N    Locking?: ☒ Y ☐ N

Well cap:
- Material: Plastic
- Vented?: ☒ Y ☐ N

## D. GROUNDWATER MEASUREMENT (±0.01 foot below top of inner well casing)

**Water level**: 5.83    **Stabilization time**:
**Well development method**: Surge and purge with pump
**Average depth of frost line**: 4.5"

**DRILLER'S CERTIFICATION**
**I certify under penalty of law I believe the information reported above is true, accurate, and complete.**

**Signature**:    **Certification #**:    **Date**:

Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

**Please mail completed form to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
**Questions? Call or Email:** Nina Booker Environmental Engineer Sr., 515-725-8309, nina.booker@dnr.iowa.gov

ELEVATIONS: ± 0.01 FT. MSL

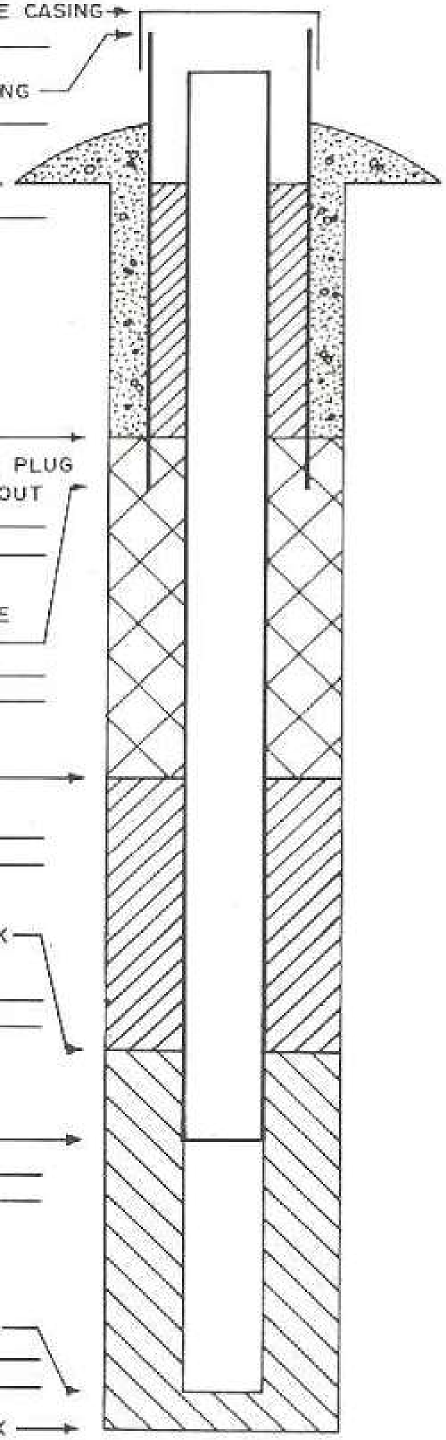
DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
( SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL ).

TOP OF PROTECTIVE CASING
ELEVATION 860.193'

TOP OF WELL CASING
ELEVATION 859.954'

GROUND SURFACE
ELEVATION 857.705'



TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 857.705'
DEPTH 0'

BASE OF PROTECTIVE
CASING
ELEVATION 855.705'
DEPTH 2'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION 857.705'
DEPTH 0'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 853.705'
DEPTH 4'

TOP OF SCREEN
ELEVATION 851.705'
DEPTH 6'

BOTTOM OF SCREEN
ELEVATION 836.764'
DEPTH 21'

BASE OF FILTER PACK
ELEVATION 835.764'
DEPTH 22'

# MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: Sutherland Genterating Station
Permit No.:

Well or Piezometer No.: MW-310
Dates Started: 5/4/2022
Date Completed: 5/4/2022

## A. SURVEYED LOCATION AND ELEVATION OF POINT (+0.5 ft.)

Specify corner of site: NE
Distance and direction along boundary:
Distance and direction from boundary to surface monitoring well:
Elevation (+0.01 ft. MSL):
Ground Surface: 858.096'
Top of protective casing: 860.925'
Top of well casing: 860.546'
Benchmark elevation:
Benchmark description:

## B. SOIL BORING INFORMATION

Construction Company Name: Direct Push Analytical
Address: 4N969 Old Lafox Rd Unit E
City, State, Zip Code: Saint charles, IL 60175
Name of driller: Bryan Kinzer
Drilling method: Geoprobe/HSA
Drilling fluid: None
Bore Hole diameter: 8.25"
Soil sampling method: $' sample tubes
Depth of boring: 22'

## C. MONITORING WELL INSTALLATION

Casing material: Sch. 40 PVC
Length of casing: 23.46'
Outside casing diameter: 2.4"
Inside casing diameter: 2.05"
Casing joint type: Threaded
Casing/screen joint type: Threaded
Screen material: Sch. 40 PVC
Screen opening size: 0.01"
Screen length: 15'
Depth of Well: 21'

Filter Pack:
- Material: RW Sidley filter sand
- Grain Size: #5
- Volume: 2.75 ft^3 (5.5 bags)

Seal (minimum 3 ft. length above filter pack):
- Material: 3/8" Bentonite chips
- Placement method: Poured/Hydrated
- Volume: 1, 50lbs bags

Backfill (if different from seal):
- Material:
- Placement method:
- Volume:

Surface seal design:
- Material of protective casing: Steel
- Material of grout between protective casing and well casing:

Protective cap:
- Material: Steel
- Vented?: ☒ Y ☐ N
- Locking?: ☒ Y ☐ N

Well cap:
- Material: Plastic
- Vented?: ☒ Y ☐ N

## D. GROUNDWATER MEASUREMENT (±0.01 foot below top of inner well casing)

**Water level** 6.74'
**Stabilization time**
**Well development method** Surge and purge with pump
**Average depth of frost line** 4.5"

**DRILLER'S CERTIFICATION**
**I certify under penalty of law I believe the information reported above is true, accurate, and complete.**

**Signature** ____ **Certification #** ____ **Date** ____

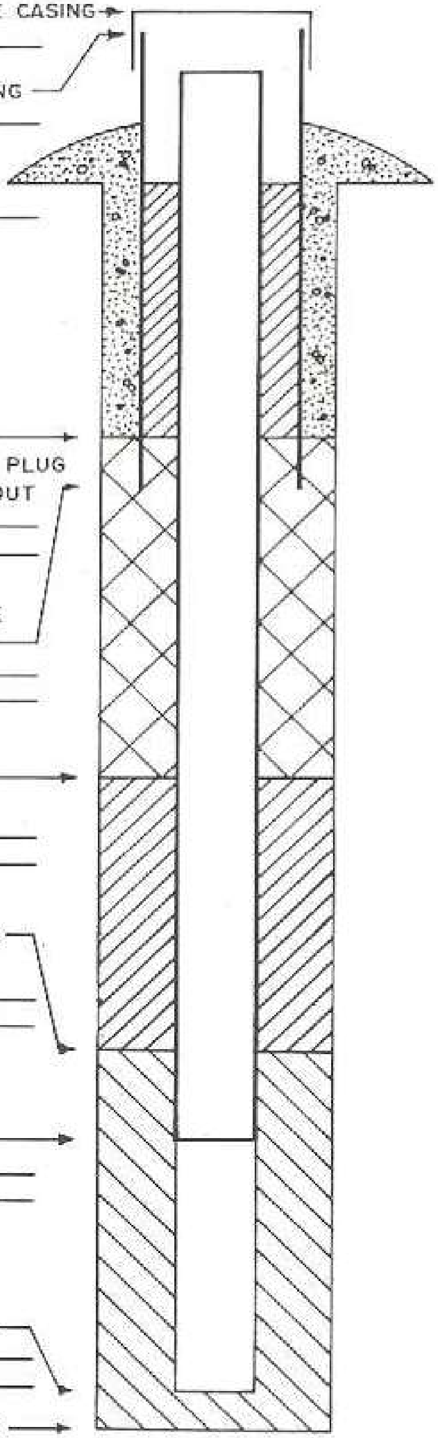
Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

**Please mail completed form to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
**Questions? Call or Email:** Nina Booker Environmental Engineer Sr., 515-725-8309, nina.booker@dnr.iowa.gov

ELEVATIONS: ± 0.01 FT. MSL

DEPTHS: ± 0.1 FT. FROM GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
( SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL ).



TOP OF PROTECTIVE CASING
ELEVATION 860.925'

TOP OF WELL CASING
ELEVATION 860.546'

GROUND SURFACE
ELEVATION 858.096'

TOP OF BACKFILL
BASE OF CONCRETE PLUG AND BENTONITE GROUT
ELEVATION 858.096'
DEPTH 0'

BASE OF PROTECTIVE CASING
ELEVATION 856.096'
DEPTH 2'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION 858.096'
DEPTH 0'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 854.096'
DEPTH 4'

TOP OF SCREEN
ELEVATION 852.096'
DEPTH 6'

BOTTOM OF SCREEN
ELEVATION 837.086'
DEPTH 21'

BASE OF FILTER PACK
ELEVATION 836.086'
DEPTH 22'

# MONITORING WELL / PIEZOMETER CONSTRUCTION DOCUMENTATION FORM

Disposal Site Name: Sutherland Genterating Station
Permit No.:
Well or Piezometer No.: MW-311
Dates Started: 5/4/2022
Date Completed: 5/4/2022

## A. SURVEYED LOCATION AND ELEVATION OF POINT (+0.5 ft.)

Specify corner of site: NE
Distance and direction along boundary:
Distance and direction from boundary to surface monitoring well:
Elevation (+0.01 ft. MSL):
Ground Surface: 855.26'
Top of protective casing: 858.01'
Top of well casing: 857.638'
Benchmark elevation:
Benchmark description:

## B. SOIL BORING INFORMATION

Construction Company Name: Direct Push Analytical
Address: 4N969 Old Lafox Rd Unit E
City, State, Zip Code: Saint charles, IL 60175
Name of driller: Bryan Kinzer
Drilling method: Geoprobe/HSA
Drilling fluid: None
Bore Hole diameter: 8.25"
Soil sampling method: $' sample tubes
Depth of boring: 17'

## C. MONITORING WELL INSTALLATION

Casing material: Sch. 40 PVC
Length of casing: 18.41'
Outside casing diameter: 2.4"
Inside casing diameter: 2.05"
Casing joint type: Threaded
Casing/screen joint type: Threaded
Screen material: Sch. 40 PVC
Screen opening size: 0.01"
Screen length: 10'
Depth of Well: 16'

Filter Pack:
- Material: RW Sidley filter sand
- Grain Size: #5
- Volume: 1 ft^3 (2 bags)

Seal (minimum 3 ft. length above filter pack):
- Material: 3/8" Bentonite chips

Placement method: Poured/Hydrated
Volume: 1, 50lbs bags

Backfill (if different from seal):
- Material:
- Placement method:
- Volume:

Surface seal design:
- Material of protective casing: Steel
- Material of grout between protective casing and well casing:

Protective cap:
- Material: Steel
- Vented?: ☒ Y ☐ N
- Locking?: ☒ Y ☐ N

Well cap:
- Material: Plastic
- Vented?: ☒ Y ☐ N

## D. GROUNDWATER MEASUREMENT (±0.01 foot below top of inner well casing)

**Water level**: 4.05'
**Stabilization time**:
**Well development method**: Surge and purge with pump
**Average depth of frost line**: 4.5"

**DRILLER'S CERTIFICATION**
**I certify under penalty of law I believe the information reported above is true, accurate, and complete.**

**Signature** ______ **Certification #** ______ **Date** ______

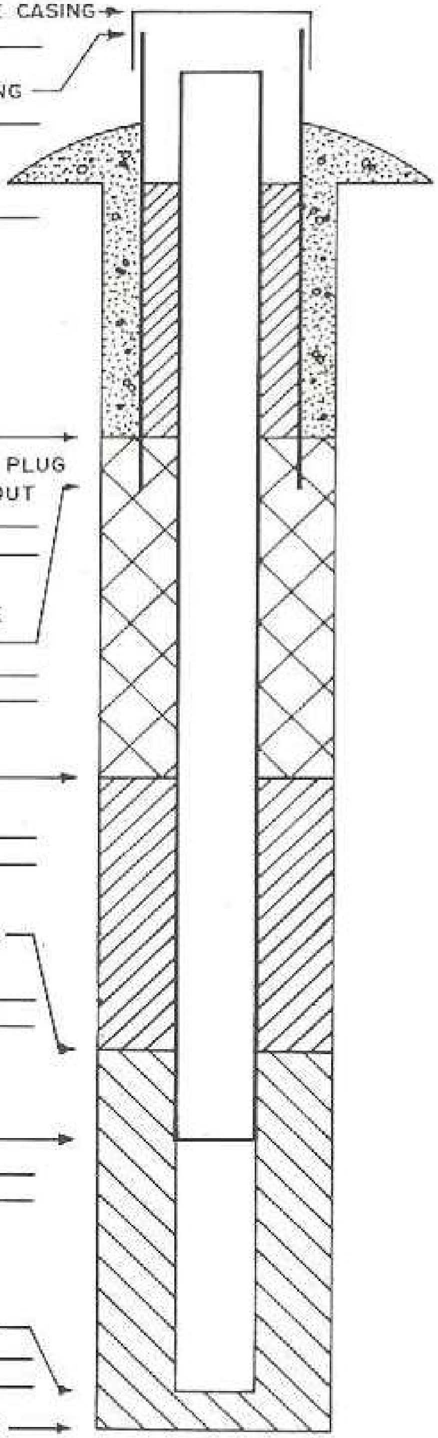
Attachments: Driller's log. Pipe schedules and grouting schedules. 8 ½ inch x 11 inch map showing locations of all monitoring wells and piezometers.

**Please mail completed form to:** Iowa Department of Natural Resources, Land Quality Bureau, 502 E. 9th St, Des Moines, IA 50319.
**Questions? Call or Email:** Nina Booker Environmental Engineer Sr., 515-725-8309, nina.booker@dnr.iowa.gov

ELEVATIONS: ± 0.01 FT. MSL

DEPTHS: ± 0.1 FT. FROM
GROUND SERFACE

SPACE TO ATTACH ENTIRE SOIL BORING LOG
( SHOW SCREENED INTERVAL AND FILTER PACK INTERVAL ).



TOP OF PROTECTIVE CASING
ELEVATION 858.01'

TOP OF WELL CASING
ELEVATION 857.638'

GROUND SURFACE
ELEVATION 855.26'

TOP OF BACKFILL
BASE OF CONCRETE PLUG
AND BENTONITE GROUT
ELEVATION 855.26'
DEPTH 0'

BASE OF PROTECTIVE
CASING
ELEVATION 853.26'
DEPTH 2'

BASE OF BACKFILL
TOP OF SEAL
ELEVATION 855.26'
DEPTH 0'

TOP OF FILTER PACK
BASE OF SEAL
ELEVATION 851.26'
DEPTH 4'

TOP OF SCREEN
ELEVATION 849.26'
DEPTH 6'

BOTTOM OF SCREEN
ELEVATION 839.23'
DEPTH 16'

BASE OF FILTER PACK
ELEVATION 838.23'
DEPTH 17'

Appendix C

Information on Lithium

Agency for Toxic Substances & Disease Registry

# JKLM Health Consultation Summary, Coudersport, Potter County, PA

November 2018

**Full public comment version of the ATSDR report available at:**

https://www.atsdr.cdc.gov/HAC/pha/JKLMNaturalGas/JKLM_HC-508.pdf.

The public comment process gives residents the opportunity to review the public comment version of this report and provide their input. If community members would like to share any water sampling information related to the JKLM release in 2015 that is not already included in ATSDR's report, they are invited to share this information with ATSDR using the public comment process. ATSDR's responses to comments received will be included in the final version of the report.

## Background

In September 2015, JKLM Energy, LLC (JKLM), an independent oil and natural gas exploration and production company, injected chemicals into an open wellbore (actual hole that forms the well) at the Reese Hollow 118 well pad in an attempt to retrieve a drill bit. The Pennsylvania Department of Environmental Protection (PADEP) and JKLM investigated the incident. Sampling revealed the injected chemicals and other naturally-occurring contaminants were present in drinking water supplies near the site. Residents were provided bottled water under an order from PADEP to JKLM within a few days after the contamination was detected. Bottled water was provided until the state determined impacts were resolved. During this time, groundwater was still used for other household purposes (e.g., showering) in the affected area.

Initially, 17 residents complained of private drinking water impacts. Over 100 individual water sources were then sampled in response to this incident. In 2016, PADEP determined that six drinking water sources out of the 100 sampled were impacted by the JKLM release. ATSDR accepted a petition to review the available water sampling data related to this incident.

### Timeline of JKLM Spill and Response

| | |
|---|---|
| ~09/18/2015 | JKLM injects unapproved chemicals into gas well |
| 09/21/2015 | PADEP receives 17 initial resident complaints of drinking water impacts |
| 09/21/2015 | PADEP and JKLM begin sampling of 100 water sources; bottled water provided |
| 09/30/2015 | PADEP issues notice of violation to JKLM |
| | PADEP issues determination letters to 6 residents stating impacts by JKLM across the date range of 10/27/2015-12/14/2015 |
| 02/29/2016 | ATSDR receives petition to assess environmental health concerns due to JKLM well incident |

## What did ATSDR Evaluate?

ATSDR focused on the community's possible exposures to contaminants detected in their drinking water supplies following the chemical release from the Reese Hollow 118 pad in September 2015. Data from over 100 water sources, including groundwater wells and springs, surface waters, and public and private drinking water source wells were evaluated by ATSDR. Industrial contaminants released by JKLM as well as naturally occurring contaminants in drinking water were detected and evaluated to determine if exposure could harm people's health.

U.S. Department of Health and Human Services
Agency for Toxic Substances and Disease Registry

C298845-A

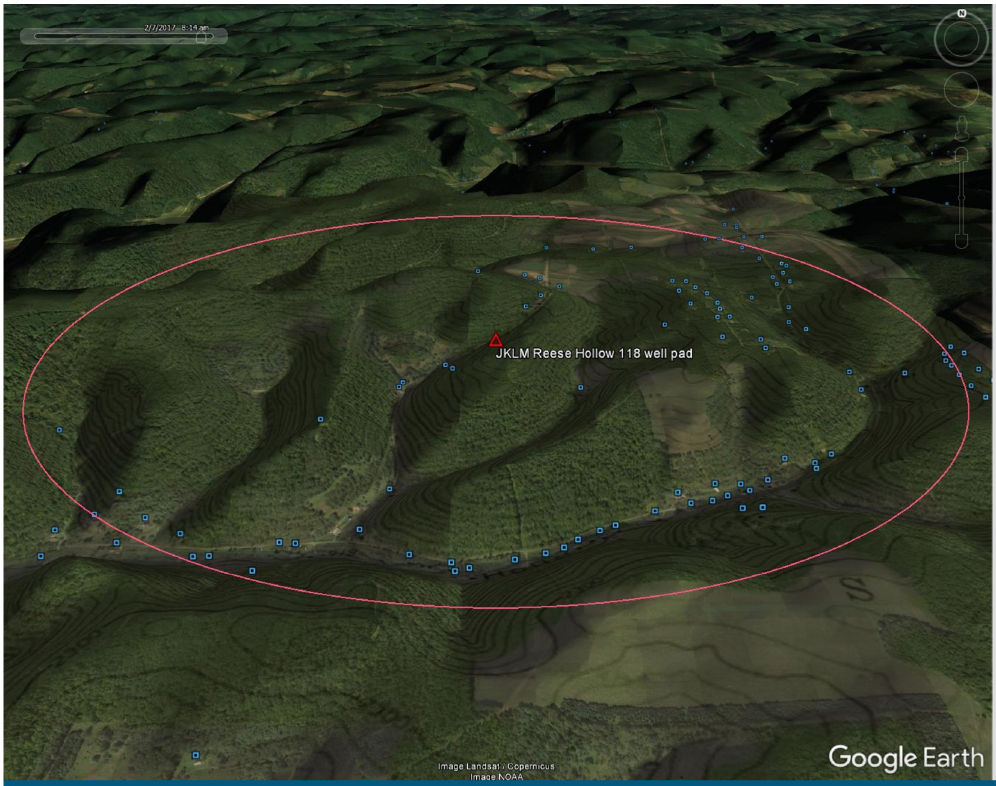
## Key Findings

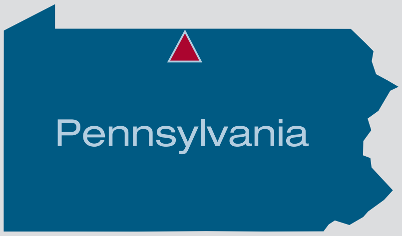
- **Isopropanol (a liquid alcohol released by JKLM) was detected in three private wells. Isopropanol in one private well was high enough to be of health concern from inhalation (but not ingestion) during household water use (e.g. showering).**
  - » Some people may have experienced temporary health effects, including eye, nose, and throat irritation from inhalation exposure. The responses to breathing isopropanol in air can vary from person to person.
  - » Isopropanol was not of health concern at the concentration detected in the other two wells.
- **People who consumed water with naturally occurring contaminants including bromide, iron, lead, lithium, manganese or sodium may be at risk for harmful non-cancer health effects associated with these chemicals.**
  - » **Bromide:** Health effects, including gastrointestinal upset (e.g.,nausea, vomiting) may have occurred for some individuals.
  - » **Iron:** Healthy individuals are not likely to experience adverse health effects; individuals on reduced-iron diets to treat hemochromatosis should consult their health professionals to discuss the additional iron exposures from consuming their well water.
  - » **Lead:** Chronic exposure to low lead levels in children has been shown to cause effects on the central nervous system, which can result in deficits in intelligence, behavior, and school performance.
  - » **Lithium:** Any person taking lithium for medical reasons should consult their physician if they are consuming water (i.e., drinking or cooking) from any of the wells with lithium levels above 40 micrograms per liter (µg/L).
  - » **Manganese:** Adverse neurological health effects may occur for infants and children consuming water with manganese greater than 300 µg/L. Adverse neurological health effects may occur for adults consuming water with manganese greater than 1,000 ug/L.
- **Health effects are not expected from exposures to all other chemicals assessed in Coudersport area drinking water sources, including other chemicals detected above health-based screening values but below health effect levels (acetone, aluminum, barium, and benzene) and chemicals detected below health-based screening values.**
- **Biological contamination (i.e., fecal coliform, E. coli) was found in thirty-one water sources that were tested. Drinking water containing fecal coliform can cause severe illness and serious infections with symptoms including, but not limited to, bloody diarrhea, stomach cramps, fever and vomiting.**

## Data Limitations

ATSDR could not fully assess the potential health effects from exposures to chemicals in the Coudersport area drinking water sources and surface waters due to incomplete information regarding:

- How long water supplies were impacted,
- How long people were exposed, and,
- The specific chemicals in mixtures.




**The JKLM Coudersport Site is located in Potter County, Pennsylvania. The site is situated near the ridgeline of a hill.**

**The hillshade image at the left depicts its position as seen looking from the south toward the north.**

**The blue dots indicate residential dwellings. The pink line indicates a 1-mile buffer around the site.**

## Recommendations and Next Steps

***Private Well Owners with Elevated Levels of:***

- Lead, lithium, manganese or sodium should take steps to reduce exposures from drinking water, work with water quality treatment professionals to install treatment systems specifically designed to remove these contaminants, continue to monitor the quality of their residential well water, and consult with their physician if their levels of these chemicals were elevated.

***Private Well Owners with Biological Contamination (i.e., fecal coliform, E. coli):***

- ATSDR recommends owners and operators of drinking water sources contaminated with fecal coliform or E. coli take immediate steps to eliminate exposures to the contaminated water, including installing treatment, evaluating/improving the wellhead area, and regularly testing the water supply.

***Local and State Environmental and Public Health Agencies Should***

- Continue to inform residents with drinking water wells of the importance of regular water testing, and of the responsibilities of all stakeholders (local government, industry, regulators, residents) involved in these types of incidents.
- Drillers and state regulators should develop site-specific procedures that protect the public from exposure to chemicals injected into open boreholes to recover drill bits and other ‘lost’ items.

Information on Penn State's private water well testing program can be obtained from the Potter County Penn State Extension Office (**814-274-8540**; PotterExt@psu.edu) or the Penn State Extension Lab Testing website (http://agsci.psu.edu/aasl/water-testing).

Penn State has also developed a fact sheet with specific recommendations for analytes appropriate to include in drinking water testing, visit: https://extension.psu.edu/common-water-test-parameters-related-to-natural-gas-drilling.

**Public comments on the report must be submitted in writing to the ATSDRRecordsCenter@cdc.gov, *or* mailed to:**

**Agency for Toxic Substances and Disease Registry**

**Attn: Records Center**

**Re: JKLM (Coudersport, PA)**

**4770 Buford Highway, NE (MS F-09)**

**Atlanta, Georgia 30341**

*Please talk to your health professional or call PADOH's Lead Information Line at 1-800-440-LEAD (5323) if you have concerns about exposure to lead and want more information on steps you can take to reduce exposures.*

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**For questions about ATSDR's report, please contact**

**Robert Helverson**,
Regional Representative, ATSDR Region 3
at 215-814-3139, gfu6@cdc.gov
*or*
**Lora Werner**,
Regional Director, ATSDR Region 3
at 215-814-3141, lkw9@cdc.gov.

United States
Environmental Protection
Agency

EPA/690/R-08/016F
Final
6-12-2008

# Provisional Peer Reviewed Toxicity Values for

# Lithium
(CASRN 7439-93-2)

Superfund Health Risk Technical Support Center
National Center for Environmental Assessment
Office of Research and Development
U.S. Environmental Protection Agency
Cincinnati, OH 45268

## Acronyms and Abbreviations

| | |
|---|---|
| bw | body weight |
| cc | cubic centimeters |
| CD | Caesarean Delivered |
| CERCLA | Comprehensive Environmental Response, Compensation and Liability Act of 1980 |
| CNS | central nervous system |
| cu.m | cubic meter |
| DWEL | Drinking Water Equivalent Level |
| FEL | frank-effect level |
| FIFRA | Federal Insecticide, Fungicide, and Rodenticide Act |
| g | grams |
| GI | gastrointestinal |
| HEC | human equivalent concentration |
| Hgb | hemoglobin |
| i.m. | intramuscular |
| i.p. | intraperitoneal |
| IRIS | Integrated Risk Information System |
| IUR | inhalation unit risk |
| i.v. | intravenous |
| kg | kilogram |
| L | liter |
| LEL | lowest-effect level |
| LOAEL | lowest-observed-adverse-effect level |
| LOAEL(ADJ) | LOAEL adjusted to continuous exposure duration |
| LOAEL(HEC) | LOAEL adjusted for dosimetric differences across species to a human |
| m | meter |
| MCL | maximum contaminant level |
| MCLG | maximum contaminant level goal |
| MF | modifying factor |
| mg | milligram |
| mg/kg | milligrams per kilogram |
| mg/L | milligrams per liter |
| MRL | minimal risk level |
| MTD | maximum tolerated dose |
| MTL | median threshold limit |
| NAAQS | National Ambient Air Quality Standards |
| NOAEL | no-observed-adverse-effect level |
| NOAEL(ADJ) | NOAEL adjusted to continuous exposure duration |
| NOAEL(HEC) | NOAEL adjusted for dosimetric differences across species to a human |
| NOEL | no-observed-effect level |
| OSF | oral slope factor |
| p-IUR | provisional inhalation unit risk |
| p-OSF | provisional oral slope factor |
| p-RfC | provisional inhalation reference concentration |

| | |
|---|---|
| p-RfD | provisional oral reference dose |
| PBPK | physiologically based pharmacokinetic |
| ppb | parts per billion |
| ppm | parts per million |
| PPRTV | Provisional Peer Reviewed Toxicity Value |
| RBC | red blood cell(s) |
| RCRA | Resource Conservation and Recovery Act |
| RDDR | Regional deposited dose ratio (for the indicated lung region) |
| REL | relative exposure level |
| RfC | inhalation reference concentration |
| RfD | oral reference dose |
| RGDR | Regional gas dose ratio (for the indicated lung region) |
| s.c. | subcutaneous |
| SCE | sister chromatid exchange |
| SDWA | Safe Drinking Water Act |
| sq.cm. | square centimeters |
| TSCA | Toxic Substances Control Act |
| UF | uncertainty factor |
| µg | microgram |
| µmol | micromoles |
| VOC | volatile organic compound |

# PROVISIONAL PEER REVIEWED TOXICITY VALUES FOR LITHIUM (CASRN 7439-93-2)

## Background

On December 5, 2003, the U.S. Environmental Protection Agency's (EPA's) Office of Superfund Remediation and Technology Innovation (OSRTI) revised its hierarchy of human health toxicity values for Superfund risk assessments, establishing the following three tiers as the new hierarchy:

1. EPA's Integrated Risk Information System (IRIS).

2. Provisional Peer-Reviewed Toxicity Values (PPRTV) used in EPA's Superfund Program.

3. Other (peer-reviewed) toxicity values, including:

   - Minimal Risk Levels produced by the Agency for Toxic Substances and Disease Registry (ATSDR),
   - California Environmental Protection Agency (CalEPA) values, and
   - EPA Health Effects Assessment Summary Table (HEAST) values.

A PPRTV is defined as a toxicity value derived for use in the Superfund Program when such a value is not available in EPA's Integrated Risk Information System (IRIS). PPRTVs are developed according to a Standard Operating Procedure (SOP) and are derived after a review of the relevant scientific literature using the same methods, sources of data and Agency guidance for value derivation generally used by the EPA IRIS Program. All provisional toxicity values receive internal review by two EPA scientists and external peer review by three independently selected scientific experts. PPRTVs differ from IRIS values in that PPRTVs do not receive the multi-program consensus review provided for IRIS values. This is because IRIS values are generally intended to be used in all EPA programs, while PPRTVs are developed specifically for the Superfund Program.

Because new information becomes available and scientific methods improve over time, PPRTVs are reviewed on a five-year basis and updated into the active database. Once an IRIS value for a specific chemical becomes available for Agency review, the analogous PPRTV for that same chemical is retired. It should also be noted that some PPRTV manuscripts conclude that a PPRTV cannot be derived based on inadequate data.

## Disclaimers

Users of this document should first check to see if any IRIS values exist for the chemical of concern before proceeding to use a PPRTV. If no IRIS value is available, staff in the regional Superfund and RCRA program offices are advised to carefully review the information provided in this document to ensure that the PPRTVs used are appropriate for the types of exposures and circumstances at the Superfund site or RCRA facility in question. PPRTVs are periodically updated; therefore, users should ensure that the values contained in the PPRTV are current at the time of use.

It is important to remember that a provisional value alone tells very little about the adverse effects of a chemical or the quality of evidence on which the value is based. Therefore, users are strongly encouraged to read the entire PPRTV manuscript and understand the strengths and limitations of the derived provisional values. PPRTVs are developed by the EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center for OSRTI. Other EPA programs or external parties who may choose of their own initiative to use these PPRTVs are advised that Superfund resources will not generally be used to respond to challenges of PPRTVs used in a context outside of the Superfund Program.

### Questions Regarding PPRTVs

Questions regarding the contents of the PPRTVs and their appropriate use (e.g., on chemicals not covered, or whether chemicals have pending IRIS toxicity values) may be directed to the EPA Office of Research and Development's National Center for Environmental Assessment, Superfund Health Risk Technical Support Center (513-569-7300), or OSRTI.

## INTRODUCTION

Lithium (Li), an alkali metal, exists in two isotopic forms ($^{7}$Li and $^{6}$Li) and is naturally present in soil and water. Lithium has numerous industrial and commercial uses including as a cell additive in electrolytic aluminum production, a catalyst of chemical reactors, a component of fluxes and brazing alloys, a component of batteries, specialized glass and ceramics, and a sanitizing agent for swimming pools, hot tubs and spas (Leonard et al., 1995; Moore, 1995). Lithium carbonate and lithium citrate are also used for the therapeutic treatment of psychiatric disorders, primarily in the acute and long-term maintenance treatment of bipolar mood disorders.

A reference dose (RfD) or reference concentration (RfC) for lithium are not available on the Integrated Risk Information System (IRIS) (U.S. EPA, 2007), the Health Effects Assessment Summary Tables (HEAST) (U.S. EPA, 1997), or the Drinking Water Standards and Health Advisories list (U.S. EPA, 2004). The U.S. Environmental Protection Agency's (EPA) Chemical Assessments and Related Activities (CARA) (U.S. EPA, 1994) lists only Reportable Quantity (RQ) documents for lithium chromate and lithium hydride; the RQ documents (U.S. EPA, 1983, 1988) for these two compounds state that the data are not sufficient for derivation of an RQ as there are no subchronic or chronic studies. Neither the Agency for Toxic Substances Disease and Registry (ATSDR) (2006), the National Toxicology Program (NTP) (2006), the International Agency for Research on Cancer (IARC) (2006), nor the World Health Organization (WHO) (2006) has produced documents regarding lithium. The following sources were also consulted: Chemical Hazard Information Profiles (U.S. EPA, 1980), National Occupational Health Survey of Mining (NIOSH, 1990) and Information Profiles on Potential Occupational Hazards - Classes (NIOSH, 1978). Literature searches were conducted from 1965 to August 2006 in TOXLINE (including NTIS and BIOSIS updates), CANCERLIT, MEDLINE, CCRIS, GENETOX, HSDB, EMIC/EMICBACK, DART/ETICBACK, RTECS and TSCATS.

## REVIEW OF PERTINENT LITERATURE

### Human Studies

#### *Oral Exposure*

**Overview of the Therapeutic Use of Lithium –** Lithium carbonate, and more recently, lithium citrate have been used since 1949 in the treatment of bipolar affective (manic-depressive) disorder; thus, extensive clinical literature on the beneficial and adverse effects of lithium is available. Lithium is therapeutically used in the treatment of bipolar affective disorder as a sole therapy or in combination with other antidepressant drugs and in the treatment of schizophrenia in combination with anti-psychotic drugs. Although lithium is effective in the treatment of bipolar affective disorders, adverse effects are associated with therapeutic dose levels, resulting in a low therapeutic index (e.g., ratio of dose associated with therapeutic efficacy to dose associated with adverse effects). Thus, lithium is not simply prescribed by dose, but is monitored based on serum concentrations. For the treatment of bipolar disorder, the desired therapeutic serum concentrations range from 0.6 to 1.4 mmol Li/L, although concentrations of 0.8-1.0 mmol Li/L are generally accepted as providing optimal therapeutic effects (Physicians Desk Reference, 2006; Baldessarini and Tarazi, 2001).

Although the precise mechanism of action has not been established, it is unlikely that a single mechanism of action is responsible for the therapeutic and adverse effects of lithium. Several mechanisms for the therapeutic effects of lithium have been proposed. Since the chemical properties of lithium are similar to those of sodium, lithium can be substituted for sodium in generating action potentials and in some sodium transport processes across membranes. Lithium also appears to alter neurotransmitters, enhances some actions of serotonin, has variable effects on norepinephrine, augments the synthesis of acetylcholine and increases norepinephrine and dopamine turnover. Lithium also alters brain inositol phosphate levels, affecting second messenger responses for α-adrenergic and muscarinic transmission. A decrease in functioning brain protein kinases has also been identified as a consistent effect of lithium. Lithium also interacts with nuclear regulatory factors that affect gene expression (Baldessarini and Tarazi, 2001).

The potential for lithium to cause toxicity has been of significant concern due to its use on a maintenance basis for a lifelong disorder; thus, a large body of clinical literature on lithium-induced toxicity exists, including several reviews (Gitlin, 1999; Berk and Berk, 2003; Markowitz et al., 2000; Moore, 1995; McIntyre et al., 2001; Awad et al., 2002; Presne et al., 2003; Jefferson, 1998). Effects that are associated with therapeutic use of lithium include: neurological and psychiatric effects (tremor, choreoathetosis, motor hyperactivity, ataxia, aphasia, fatigue, cognitive impairment); decreased thyroid function; hyperparathyroidism; renal effects (nephrogenic diabetes insipidus, nephritis, chronic progressive renal disease); edema (related to sodium retention); cardiovascular effects (T wave flattening); acniform skin eruptions;

benign leukocytosis; and gastrointestinal effects (nausea, vomiting, abdominal pain, diarrhea). Since all therapeutic serum concentrations are associated with adverse effects, long-term treatment strategies for individual patients must balance the beneficial effects of lithium therapy with the risks and severity of toxicity. Although available data are not sufficient to define dose-response relationships, it is generally accepted that severity of adverse effects is related to serum lithium levels.

Adverse renal effects associated with lithium therapy have received extensive focus due to their serious nature and frequency of occurrence. Thus, lithium-induced renal toxicity has been the subject of numerous clinical and animal studies. The most common adverse renal effect is nephrogenic diabetes insipidus (NDI), which occurs over the range of therapeutic serum lithium concentrations (e.g., 0.6-1.4 mmol Li/L). The development of NDI involves lithium-induced down-regulation of the vasopressin-regulated water channel aquaporin-2, expressed on the apical plasma membrane of principal cells of the collecting duct (Markowitz et al., 2000). The consequence of this effect is to reduce the capacity of the kidneys to preserve free water, resulting in impaired renal concentrating ability and the production of excessively dilute urine. Clinically, this manifests as polyuria, with secondary thirst, and volume depletion. Although other mechanisms may also contribute to polyuria, interference with vasopressin-induced antidiuresis is considered the most important cause (Gitlin, 1999). It has been estimated that renal concentrating ability is impaired in at least 50% of patients undergoing lithium treatment, with polyuria and polydipsia in approximately 20% of patients (Presne et al., 2003; Gitlin, 1999; McIntyre et al., 2001). In a review of data from several studies published between 1979 and 1986, impairment of concentrating ability was seen in at least 54% of 1105 patients on chronic lithium therapy, with polyuria observed at serum lithium concentrations ranging from 0.6 to 1.2 mmol/L (Boton et al., 1987). Thus, periodic measurement of serum creatinine, creatinine clearance, 24-hour urine volume and urine protein has become integral to the management patients on long-term lithium therapy (Jefferson, 1998).

NDI appears to be reversible early in treatment, but may be progressive during the first decade, leading to irreversible damage over time (Gitlin, 1999). A small percentage of patients show progressive renal failure indicated by a pronounced decrease in glomerular filtration rate (GFR) and renal insufficiency, with little or no proteinuria (Markowitz et al., 2000). Severe decreases in GFR have resulted in the need for maintenance hemodiaylsis, typically after 10 or more years of lithium therapy. Results of renal biopsy on patients with chronic renal effects showed interstitial fibrosis, tubular atrophy, focal sclerosis, acquired renal cystic disease and cytoplasmic swelling with glycogen deposits in the distal convoluted tubules and collecting ducts (Markowitz et al., 2000; Gitlin, 1999). Confounding factors (other medical disorders such as hypertension, heart disease) may contribute to susceptibility and severity of irreversible damage (Gitlin, 1999).

**Studies on Adverse Effects in Patients Treated with Lithium: Renal Effects –** The results of retrospective and prospective studies and findings of case reports summarized below focus on adverse effects observed in patients maintained on chronic lithium therapy for the treatment of affective mood disorders. As expected based on the established pharmacological profile of therapeutic lithium, decreased renal concentrating ability is the most frequently reported adverse effect, although neurological, dermal, cardiovascular and endocrine effects are also observed. Interpretation of results from clinical studies is difficult due to many factors, including the lack of baseline data prior to lithium use, absence of control groups, presence of pre-existing renal and other diseases and use of concomitant medications. Furthermore, since clinicians rely upon serum lithium concentrations, rather than daily doses, to evaluate the dose-response relationships between lithium treatment, efficacy and adverse effects, daily lithium doses often are not reported nor were the results of male vs. female dosing reported separately. However, the clinical literature provides consistent evidence that the kidney is a primary target organ for lithium in men and women, and supports that adverse renal effects occur over the range of desired therapeutic serum concentrations (0.6-1.4 mmol Li/L).

In a prospective study, a cohort of 373 patients who started receiving lithium therapy at various times between 1979 and 1987 were given pre-treatment examinations to establish baseline levels for renal parameters (Schou and Vestergaard, 1988; Vestergaard and Schou, 1988). Patients were examined once before and on the average 3.3 times during lithium therapy. Patients who had been treated with lithium prior to entry into the cohort and patients taking neuroleptic agents during lithium therapy were excluded from analysis. On examination days, urine was collected every 24 hours and data were disregarded if less than 75% of the daily lithium dose was recovered. The desamino-8-D-arginine vasopressin (DDAVP) test was used to determine renal concentrating ability. The mean lithium dose was 23.2 mmol Li/day and the mean lithium serum concentration was 0.68 mmol/L. Because of a high drop-out rate (for various reasons), especially among men, and because the dosing durations of the full cohort ranged from 5 months to 7 years, data from a subcohort of 39 patients who received lithium therapy continuously for 4 years were compared with the data for the whole cohort to guard against errors due to selective sample attrition. The ratio of men to women in the whole cohort and in the subcohort remained constant.

Patients in the whole cohort developed a moderate rise in urine volume and a moderate fall in renal concentrating ability (Schou and Vestergaard, 1988; Vestergaard and Schou, 1988). Urine volume increased by 7% (not statistically significant) for the whole cohort and 23% for the subcohort ($p=0.05$). For the whole cohort, urine volume was positively correlated with lithium dosage ($r=0.29$, $p<0.001$). Renal concentrating ability fell by 7% ($p<0.01$) for the whole cohort and by 10% for the 4-year subcohort ($p<0.01$). Changes in renal concentrating ability took place within the first 1-2 years of lithium therapy for members of the whole cohort, with no additional changes in renal function when treatment duration was extended more than 2 years. There was no correlation between concentrating ability and lithium dosage in the whole cohort. Glomerular function, as determined by measurement of serum creatinine concentrations and urine creatinine concentrations, was not affected by lithium therapy in the whole cohort. In addition, there was no change in the incidence of proteinuria associated with lithium treatment. Complaints of increased thirst, frequent urination and nocturia were made more often during lithium therapy than before lithium therapy in both the cohort and the subcohort. Therefore, the results from the subcohort support the results from the entire cohort. Assuming that the average body weight was 70 kg, patients were exposed to 2.32 mg Li/kg-day. This study identifies a lowest-observed-adverse-effect level (LOAEL) of 2.32 mg Li/kg-day for increased urine volume and decreased urine concentrating ability.

A group of 53 patients (20 men and 33 women) was examined prior to starting long-term lithium therapy and again after 4 and 12 months on lithium (Smigan et al., 1984). Twenty-five patients of this cohort had previously received lithium, but treatment had been withdrawn for 27 months before the start of the present treatment. Over the course of the study, 13-28% of the 53 patients received neuroleptics. Lithium carbonate dosages were not provided, but serum lithium levels were maintained at approximately 0.6 mmol/L. A clinically significant change in renal concentrating ability (defined as having a urine osmolality below 600 mOsm/kg water) was observed in a small group (n=6) of patients after 12 months on lithium treatment. Of these six patients, five had been treated previously with lithium and had some signs of impaired renal concentrating ability at the start of the present treatment. Multiple regression analysis determined that concurrent treatment with neuroleptics did not contribute to the decline of renal function.

Polyuria and/or decreased urine concentrating ability were found among 112 women and 125 men (average weight, 76.2 kg) exposed to 12-57 mmol/day of lithium (mean dose of 32.6 mmol/day of lithium or 3.0 mg Li/kg-day) for 0.5-17 years (mean duration, 5.2 years) in a retrospective study by Vestergaard et al. (1979). Serum lithium concentration ranged from 0.2 to 2.0 mmol/L. Baseline renal function prior to lithium therapy was not assessed, since all patients were on maintenance lithium therapy prior to the start of the study. The majority of patients were also receiving concomitant therapy with other medications, such as neuroleptics and/or antidepressants, and 37% the patients received concomitant therapy with hypnotics or anxiolytics. In a follow-up study, 184 of the original 237 patients were re-examined 2 years later (Vestergaard and Amdisen, 1981). The 184 patients were divided into two groups; those patients who continued with lithium (147) and those who discontinued (37). Lithium-treated patients were compared with 68 manic-depressive patients that were about to receive lithium. Glomerular function did not change over the 2-year period. In patients who had discontinued lithium treatment, there was an improvement in renal concentrating ability when compared with the patients who continued with lithium therapy. However, maximal urine osmolality did not reach the level found in the control (pre-lithium treatment) group, although the urine volume approached levels in the control group. There was a further increase in urine volume and decreased in urine osmolarity for those patients that continued with lithium therapy.

In a study involving 116 men and 152 women who took an average of 1322 mg/day of lithium carbonate (3.57 mg Li/kg-day) for an average period of 37.6 months, maximum concentrating ability was lower in all patients receiving lithium than in 59 control patients not receiving lithium (Gelenberg et al., 1987). However, differences did not achieve statistical significance. A major limitation of this study is that baseline data were not available.

Results of a biopsy study in patients receiving lithium maintenance therapy provide evidence of lithium-induced histopathological changes to the kidney (Hestbech et al., 1977). Fourteen manic-depressive patients received an average of 42 mmol Li/day as lithium carbonate (4.2 mg Li/kg-day) for 1.5-15 years. Serum lithium concentrations ranged from 0.6 to 1.3 mmol/L. Thirteen age-matched patients without renal disease served as the source of kidney biopsy specimens for control observations. Impaired urine concentrating ability and polyuria was observed in lithium patients. Histopathological examination of the kidney biopsy samples revealed a pronounced degree of focal nephron atrophy and/or interstitial fibrosis in 13 of the

14 patients examined. Semiquantitative assessment of renal lesions revealed significantly greater degrees of focal cortical fibrosis, diffuse medullary fibrosis, mononuclear cell infiltrates and distal tubular dilatation in the patients than in the controls. Quantitative assessment revealed significantly greater percentages of totally sclerotic glomeruli, fibrous cortical tissue and unidentifiable and atrophic renal tubules in patients than in controls.

Hansen et al. (1979) also reported impaired renal concentrating ability in 14 patients (7 men and 7 women) treated with 36 mmol/day of lithium (3.6 mg Li/kg-day) for 1.3 to 12 years. Serum lithium concentrations ranged from 1.75 to 4.50 mmol/L. Results of renal biopsy showed interstitial fibrosis and tubular atrophy. Baseline levels were not available and controls were not used. There was a significant negative correlation between the degree of tubular atrophy and renal concentrating ability.

Walker et al. (1982) examined renal function and biopsy samples in 47 patients (18 men and 29 women) who were receiving an average of 1250 mg/day of lithium carbonate (3.38 mg Li/kg-day) for an average of 5 years. The median serum lithium concentration was 0.84 mmol/L. Thirty-two patients not receiving lithium therapy were used as the controls. Decreased urine concentrating ability and impaired urinary acidification, indicative of distal nephron dysfunction, were observed in patients receiving lithium relative to controls. Lithium-treated patients also exhibited decreased glomerular filtration rate, as measured by significantly increased serum creatinine, increased $\beta_2$-microglobulins, and decreased Cr-EDTA clearance, compared to controls. Histological examination of kidney biopsy samples did not reveal abnormalities.

Hansen and Amdisen (1978) reported effects on the kidneys in a case study of 23 patients who were exposed to therapeutic doses of 24-56 mmol Li/day (2.4-5.6 mg Li/kg-day) for 6.1-8.5 years. Patients were hospitalized due to severe lithium intoxication. Pre-exposure baseline levels were not available. Impaired renal concentrating ability was a consistent finding. Abnormal electroencephalography (EEG) was also reported. There was no relationship between the severity of symptoms of lithium intoxication and the serum lithium concentration on admission to the hospital. Many of the patients (22 out of 23) included in the Hansen and Amdisen (1978) study experienced frank adverse effects, including renal insufficiency in 17 patients, mental and neurological symptoms (decreased alertness or slight apathy) in18 patients, muscular rigidity and/or muscular fasciculations in 14 patients, slight ataxia in 6 patients, and stupor and latent convulsive movements in 14 patients. Severely abnormal electroencephalograms were observed in 19 patients. Two patients died and two patients developed persisting neurological sequelae.

**Studies on Adverse Effects in Patients Treated with Lithium: Other (Non-Renal) Adverse Effects –** Neurological effects, including tremors, are commonly reported in patients treated with lithium. Neurological effects of lithium were evaluated in 28 patients (15 men and 13 women) with bipolar affective disorder receiving 1012 mg/day of lithium carbonate (2.74 mg/kg-day) for 4.1 years. The mean serum lithium level was 0.68 mmol/L. Although patients did not develop overt neurological effects, nerve conduction velocities were prolonged (Chang et al., 1990). Electrodiagnostic tests revealed a slowing of motor and sensory nerve conduction velocities and prolonged central neural conduction times obtained from somatosensory and brainstem auditory evoked potentials that correlated with serum lithium levels. Another patient developed polyneuropathy after being exposed to 1.62 mg Li/kg-day for an unspecified period (years) (Tomasina et al., 1990). The patient had a sensorimotor peripheral neuropathy with mostly axonal degeneration. The patient improved after the lithium therapy was discontinued. Levine and Puchalski (1990) have also described two cases of pseudotumor cerebri syndrome in patients that were exposed to 900-1200 mg/day of lithium carbonate (2.43-3.24 mg Li/kg-day) for 4-8 years. The serum lithium concentration did not exceed 1.0 mmol/L. This syndrome is characterized by chronic headaches, bilateral papilledema and increased intracranial pressure in the absence of any localized neurological signs or symptoms.

Hagino et al. (1995) observed adverse effects on 20 children aged four through six exposed to oral lithium for the treatment of aggressive and/or mood-disordered children. All children were hospitalized during the course of the study as part of the medical intervention program. Daily lithium doses were adjusted to maintain serum lithium concentrations between 0.6 and 1.2 mmol/L and ranged from 12.2 to 48.9 mg/kg-day. Patients remained on lithium therapy for up to 37 days. Adverse effects to the central nervous system (tremor, drowsiness, ataxia, confusion) were the most commonly observed effects, reported in approximately 60% of patients. Other effects observed included gastrointestinal effects (nausea, vomiting, abdominal discomfort) in 25% of patients, renal effects (polyuria) in 10% of patients and blurred vision in 10% of patients. No adverse effects were observed in the cardiovascular, pulmonary, autonomic, hematological or integumental systems. The potential contribution of concomitant medications was not ruled out by the study authors. Sixteen of the 20 children also received one or more psychoactive medications and six children received antibiotics for infections.

Adverse effects on thyroid function, primarily asymptomatic hypothyroidism, have been reported in patients treated with lithium. Thyroid effects may be secondary to altered renal clearance of iodine, rather than to direct effects of lithium on the thyroid (Moore, 1995). A retrospective study was conducted involving 129 patients (46 men, 83 women) who were on lithium therapy for 2-180 months and 21 patients who served as controls (Bocchetta et al., 1991). Most of the patients receiving lithium had previously received or were receiving medication (antipsychotics and antidepressants) other than lithium. Serum lithium concentrations ranged between 0.5 and 1.0 mmol/L. Palpable and/or visible goiter was found in 51% of the patients receiving lithium ($p<0.01$), compared with 9.5% occurrence in the control group. Based on elevated thyroid stimulating hormone (TSH) levels, subclinical hypothyroidism was diagnosed in 19% of the patients on lithium compared with 9.5% in the control group. There were no differences in thyroid function tests between patients receiving lithium alone or receiving additional medication. The researchers noted that lithium-induced subclinical hypothyroidism may be transient and recommended that repeated determinations of TSH is required. Joffe et al. (1988) reported that 20% of the 42 patients receiving lithium carbonate therapy for 3 months required thyroid replacement or had evidence of subclinical hypothyroidism. Cowdry et al. (1983) also reported that 12 of 24 patients who were on lithium therapy for 12 months developed hypothyroidism. Only those patients with a median serum lithium concentration of 0.6 mmol/L were used in the study. When 22 women received lithium therapeutically for more than 2 years, there was evidence of subclinical hypothyroidism in 32% of these patients (Bartalena et al., 1990).

Hyperparathyroidism with progressive hypercalcemia was reported to occur in a patient who received lithium for 6 years (Graze, 1981). The daily dosage was not reported by the author. The patient had progressive hypercalcemia for the duration of the therapy and a parathyroid adenoma.

Raoof et al. (1989) demonstrated a concentration-dependent inhibition by lithium chloride on human sperm motility *in vitro* at semen concentrations that would be expected from therapeutic doses of lithium. However, Raboch et al. (1981) found no abnormality in sperm count, motility or morphology in semen samples obtained from 14 patients that were using lithium for an average of 4.1 years. The mean serum lithium level was 0.64 mmol/L and the mean lithium level in the semen was 1.48 mmol/L.

A group of 16 men and 4 women were treated with 1008 mg/day of lithium carbonate (2.72 mg Li/kg-day) as either a once-daily dose or as a divided twice-daily dose for an average of 4.4 years (Abraham et al., 1992). An elevated white cell count, increased serum phosphate, and elevated serum ionized calcium were observed in the study group receiving the once-daily lithium treatment. These effects were not seen in the study group that received lithium twice a day. No evidence of polyuria was observed in either group and no significant differences were observed between the two treatment regimens with respect to mental status, serum lithium or electrocardiograms.

Adverse effects on cardiac conductivity, including sinoatrial block, sinus bradycardia and junctional escape rhythm, have been reported in patients taking therapeutic lithium (Moore, 1995). A patient who received 600 mg/day of lithium carbonate (1.62 mg Li/kg-day) for 4 months (serum lithium concentration 1.3-2.0 mmol/L) developed symptomatic sinus node dysfunction, which disappeared after discontinuation of lithium therapy (Riccioni et al., 1983). Roose et al. (1979) also reported cardiac sinus node dysfunction during lithium treatment in several patients exposed to at least 8.6 mg/kg-day of lithium for 10 years.

**Studies on Developmental Effects of Lithium Treatment During Pregnancy –** The potential for lithium-induced developmental effects was the subject of an assessment conducted by Moore and an Institute for Evaluating Health Risks (IEHR) Expert Scientific Committee (Moore, 1995). Data from 139 references, including registries, prospective studies and case histories were reviewed. This assessment determined that sufficient evidence is available to conclude that therapeutic use of lithium causes developmental effects in offspring when maternal serum lithium concentrations are within the therapeutic range. Review of developmental effects reported in birth registries revealed reports of cardiovascular defects associated with lithium treatment. Reports of Ebstein's anomaly (a structural defect in which there is a downward displacement of the trisucpid valve into the right ventricle, and valvular redundancy with adherence of some cusps to the right ventricular wall; affected individuals may have right ventricular failure or conduction abnormalities), in particular, were in "substantial excess among all malformations." Although the magnitude of the increase could not be determined from birth registry reports, data indicate that first-trimester lithium exposure increases the risk of cardiac malformations. Other studies reviewed by Moore (1995) also report an association between maternal lithium treatment and cardiovascular defects in offspring. The literature reviewed also suggests a possible association between maternal lithium treatment and neonatal mortality.

There are also reports that newborn infants of mothers on lithium therapy may exhibit symptoms of acute lithium toxicity such as cyanosis, hypotonia and cardiac toxicity. However, the available data regarding developmental effects in humans are limited by insufficient dose-response information.

Jacobson et al. (1992) prospectively recruited and followed 148 women using lithium during the first trimester of pregnancy. Each study patient was matched with a woman (control) of similar age (within 2 years). The mean lithium dose was 927 mg/day of lithium carbonate (2.5 mg Li/kg-day); the authors did not report serum lithium concentrations. No significant differences between the exposed group and the controls were observed for congenital defects (3% in lithium patients and 2% in controls) and spontaneous abortions (9% in lithium patients and 8% in controls). Kallen and Tandberg (1983) identified a cohort of 350 mothers who were treated with lithium during their pregnancy. The authors reported that the total delivery outcome was poorer than expected, with high perinatal death and malformation rates compared to the national average expected rates in Sweden. Congenital heart defects occurred in 6 cases compared with the national expected number of 2.1 cases ($p<0.05$). However, the sample size was relatively small and the difference between delivery outcome in women on lithium and in women on other psychotropic drugs was not statistically significant. Weinstein and Goldfield (1975) reviewed 143 cases of lithium use during pregnancy collected by the Register of Lithium Babies. There were 13 malformed infants (9.1%) among the 143 in the register. Of these 13 malformed infants, 11 were born with significant malformations of the cardiovascular system. As was the case with the previous study, the daily lithium dosage was not reported and at least 6 of the 13 mothers who delivered malformed babies were exposed to other medications in addition to lithium. Krause et al. (1990) reported a case of severe polyhydramnios that developed from the 26th week of gestation. Except for weeks 6-13 of gestation, the mother was maintained on lithium (serum level, 0.7 mmol/L) prior to the diagnosis. Ang et al. (1990) described a similar case report in a woman who was exposed to lithium during pregnancy. The infant displayed symptoms of lithium toxicity, including polyuria.

**Studies on the Carcinogenic Potential of Therapeutic Lithium –** Controlled studies on the potential of therapeutic lithium to induce cancer have not been reported. Although a few case studies have reported associations between lithium therapy and recurrence of cancer, data are inadequate to establish any association between lithium and the development or recurrence of cancer in humans. Furthermore, given that the widespread clinical use of lithium as a long-term maintenance treatment in patients with affective mood disorders has not revealed an increased incidence or recurrence of cancer, it is unlikely that lithium is carcinogenic in humans. Nonetheless, the few studies examining potential carcinogenic effects of lithium are briefly reviewed below.

Several case reports that suggest an association of lithium-induced leukocytosis with induction or reinduction of acute and chronic leukemia. Orr and McKerna (1979) reported the recurrence of acute monocytic leukemia in a 64-year-old woman who was previously in remission. This patient received 600 mg/day of lithium carbonate for 7 weeks before the leukemic relapse occurred. Nielsen (1980) reported the development of acute myeloid leukemia in one male and one female patient administered lithium for a duration of 1 and 12 years, respectively. Jim (1980) reported the occurrence of chronic monocytic leukemia in a patient who received 900 mg/day of lithium carbonate for 11 months prior to the diagnosis of leukemia. A 37-year-old woman developed chronic granulocytic leukemia after receiving 600 mg of lithium carbonate 3 times/day for 5 years (Schottlander et al., 1980).

Contrary to anecdotal reports that attempt to associate an increased risk of leukemia with lithium intake, the limited epidemiological information suggests no increased risk. Resek and Olivieri (1983) examined the relationship between leukemia and chronic lithium therapy during 1971-1980 by examining hospital records of 187 leukemia patients to determine whether these patients were receiving lithium medication prior to the their illness. Only 7% of these patients had received psychiatric services and in all cases, these patients were not treated with lithium. The authors reported that there was no association between lithium therapy and leukemia. In a 14-year ecological study, one human population in El Paso exposed to lithium via drinking water (66 μg/L) was compared with another human population in Dallas-Fort Worth that was not exposed to lithium in drinking water (Frenkel and Herbert, 1974). There was no difference in the incidence of chronic or acute granulocytic leukemia in the two populations.

Only two separate cases have been reported in the literature of the possible association of lithium with cancers other than leukemia. Brownlie et al. (1980) reported the occurrence of papillary cell carcinoma of the thyroid in a 55-year-old woman after 3.5 years of lithium therapy. McHenry et al. (1990) also reported three cases of thyroid carcinoma occurring in association with chronic (9 years) lithium therapy.

**Studies of Adverse Effects of Lithium in Healthy Volunteers –** The effect of lithium therapy on short- and long-term memory was assessed in healthy volunteers exposed to daily oral lithium for 3 weeks (Stip et al., 2000). Groups of 15 healthy men and women were randomized into placebo or lithium treatment groups. Subjects in the lithium group were administered lithium twice daily at doses ranging from 1050 to 1950 mg/day (197 to 366 mg Li/day) in order to achieve a mean serum lithium concentration of 0.8 mmol/L. The form of the lithium was unstated but the dose is consistent with lithium carbonate. Actual serum lithium concentrations were not reported. Cognitive performance (attention and memory) was assessed in each subject at 3 times during the study: baseline, after 3 weeks of treatment and 2 weeks after discontinuation of treatment. After 3 weeks of treatment, performance scores for short-term memory tasks (assessed using an auditory digit span) for subjects taking lithium were significantly lower ($p<0.03$) compared to placebo. Results of long-term memory assessments (using recall tests) showed adverse effects in lithium-treated subjects compared to controls. Performance on short- and long-term memory tests improved 2 weeks after discontinuation of treatment. Results indicate that lithium produces effects in the central nervous system in healthy subjects at exposure levels corresponding to the target therapeutic serum concentrations. The mean dose, 1569 mg/day (295 mg Li/day) was a LOAEL in this study.

Effects on the hemopoeitic system and clotting have also been reported in healthy volunteers exposed to lithium (Stein et al., 1981). Groups of at least five non-psychiatric volunteers received 900 mg/day lithium carbonate (2.43 mg Li/kg-day). Granulocyte count, expressed as a percent of baseline, was significantly increased by 25% ($p<0.05$), 32% ($p<0.001$), and 42% ($p<0.001$) after 1, 2 and 3 weeks of exposure. Volunteers administered 0, 300, 600, 900, 1200 or 1500 mg/day of lithium carbonate (0, 0.8, 1.62, 2.43, 3.24 or 4.05 mg Li/kg-day) orally for 1 week developed increased granulocytosis at doses $\geq$ 2.43 mg Li/kg-day. Granulocyte count was increased by 26, 55 and 43% of baseline values in the 2.43, 3.24 and 4.05 mg Li/kg-day groups, respectively. Decreased bleeding times were also observed in the 3.24 and 4.05 mg Li/kg-day dose groups, although there was no apparent treatment effect on platelet count. Serum lithium concentrations were not reported.

The use of lithium as a therapeutic agent to reverse chemotherapy-induced neutropenia and thrombocytopenia has been explored in humans, with studies providing conflicting results. Richmon et al. (1984) reported an increase in neutrophil and thrombocyte production in five cancer patients who received 900 mg/day of lithium carbonate (169 mg Li/day) for an unspecified duration. Twenty-two patients with oligoblastic leukemia receiving 900 mg/day of lithium carbonate for an unspecified time remained cytopenic without evidence of lithium-induced bone marrow proliferation (Barlogie et al., 1984). In another study, Friedenberg and Marx (1980) reported that lithium increased the granulocyte count in eight healthy volunteers who had received 900 mg/day of lithium carbonate for 1 week. Despite the observed increase in granulocyte number, there was a reduction in bactericidal capacity (function) of granulocytes in these individuals.

***Inhalation Exposure***

No studies on the effects of inhaled lithium in humans were identified.

**Animal Studies**

***Oral Exposure***

Subchronic and chronic oral exposure studies evaluating comprehensive toxicity endpoints in laboratory animals are not available. Few animal studies have investigated the adverse effects of chronic oral exposure to lithium. The primary purpose of animal studies has been to evaluate specific adverse effects associated with the therapeutic serum lithium concentration range, with most studies focusing on lithium-induced renal toxicity. The available data in animals provide supporting evidence that subchronic and chronic oral exposure to lithium induces similar adverse effects as those associated with the therapeutic use of lithium in patients. However, insufficient data are available to determine dose-response relationships for adverse effects.

**Cancer Bioassays –** No long-term animal bioassays examining the carcinogenicity of lithium were identified. An abstract by Prolov and Pliss (1991) reported that lithium carbonate promoted bladder carcinogenesis in rats previously exposed to N-buty-N-(4-hydroxybutyl)-nitrosamine; no additional publications of this finding were identified. Although Hori and Oka (1979) stimulated cell multiplication of mammary gland explants with lithium in C3H/HeN virgin female mice, Ziche et al. (1980) were unable to demonstrate any growth promoting effect of lithium on primary carcinomas induced by two chemical carcinogens (7,12-dimethylbenz[α]anthracene and N-nitrosomethylurea) in Sprague-Dawley and Buffalo/N female rats.

**Adverse Renal Effects –** Chronic renal failure was induced in male and female Wistar rats fed diets containing 0 or 40 mmol lithium chloride/kg diet (0 or 3.58 mg Li/kg-day) from birth for 55 to 56 weeks (Christensen and Ottosen, 1986). Plasma lithium concentration ranged from 0.6 to 0.7 mmol/L after 16 weeks and from 1.0 to 1.1 mmol/L after 48 weeks of treatment. Mortality was 51% in lithium-treated rats compared to only 6% in control rats. Mean plasma urea concentration was elevated by 74% after 16 weeks and 175% after 48 weeks, compared to controls. After 55 weeks of treatment, inulin clearance was reduced by 62% and lithium clearance was reduced by 39% compared to controls. Lithium-treated rats also had polyuria and diminished renal concentrating ability (assessed by failure to respond to exogenous vasopressin). No treatment-related effects on systolic or diastolic blood pressure were observed. Morphological examination of the kidneys of lithium-treated rats revealed large cortical cysts, dilated distal tubules and collecting ducts, and widespread interstitial fibrosis. Glomerular volume and proximal tubular mass were significantly reduced. Comprehensive toxicity endpoints were not examined in this study. A LOAEL of 3.58 mg Li/kg-day for adverse renal effects was identified; a NOAEL was not established.

Two groups of six male Wistar SPF rats were exposed to a diet containing 0 or 40 mmol LiCl/kg diet (0 or 4.5 mg Li/kg-day) for 3 weeks and then 0 or 60 mmol LiCl/kg (0 or 6.7 mg Li/kg-day) for an additional 18 weeks (Christensen et al., 1982). The time-weighted average daily dose was 6.4 mg Li/kg-day, with mean serum lithium concentrations of 0.7-0.8 mmol/L. Rats exposed to lithium developed polyuria and lowered renal concentrating ability after 2 weeks of exposure to diets containing lithium. Focal microscopic changes in distal convoluted tubules and collecting ducts were also observed. Focal basal vacuolization of the cytoplasm was observed after 2-4 weeks of lithium exposure. After 8 weeks of treatment, all rats had severe nuclear polymorphism, nuclear hyperchromasia and cellular polymorphism with tubular giant cells. In addition to these cellular changes, dilatations of the tubular lumen and focal atrophy of the tubular cells were observed in rats exposed to lithium for 21 weeks. Renal concentrating ability was significantly decreased after 2 weeks of dietary exposure. After lithium was withdrawn for 8 weeks, structural changes persisted, but concentrating ability was normalized. Based on their experimental findings, the authors concluded that the use of urinary concentrating ability as an index of lithium-induced structural damage may underestimate lithium-induced effects on the kidney. A LOAEL of 4.5 mg Li/kg-day for adverse renal effects observed after 2 weeks of treatment was identified; a NOAEL was not established.

Polyuria and vasopressin-resistant diabetes insipidus developed within 3 weeks of exposure to dietary lithium (Kling et al., 1984). Two groups of 12 male Wistar rats were exposed to 0 or 90 mmol/kg diet of lithium carbonate (11.6 mg Li/kg-day) for 126 days. Serum lithium concentration was maintained at 0.8 mmol/L. Early lesions were associated with the cortical collecting tubules and distal tubules, extending into the medullary collecting tubules by week 3 of treatment. There were alterations in nuclear size and shape and cytoplasmic basophilia of tubular cells, focal dilation and thinning of the tubular epithelium, and occasional sloughing of cells into the tubular lumen. In this study, early tubular lesions correlated with the polyuria. However, polyuria remained constant while morphological changes deteriorated for several more weeks of lithium exposure. A LOAEL of 11.6 mg Li/kg-day for adverse renal effects was identified; a NOAEL was not established.

Two groups of seven male Wistar rats were exposed to a control diets or a diet containing lithium for 112 days (Marcussen et al., 1969). Due to poor reporting of methods and results, the concentration of lithium in the diet or daily dose of lithium could not be determined. Rats exposed to lithium developed uremia and reduced body weight. All kidneys were polycystic in the cortical areas, and distal tubules and cortical collecting ducts were dilated. Severe fibrosis was observed in the interstitial space. Tubular glomeruli (67%) and some hypertrophic glomeruli were also observed. The hypertrophic glomeruli did not compensate adequately for other impaired glomerular function, as indicated by an overall decrease in GFR.

**Other (Non-Renal) Adverse Effects –** Reductions in body weights were observed in rats exposed to dietary lithium (Ehlers and Koob, 1985). Twenty-nine male Wistar rats were exposed to 0, 30 or 40 mmol Li/kg diet (0, 19 or 26 mg Li/kg-day) for 56 days. In the 40 mmol Li/kg diet group, body weight was reduced by 37% ($p<0.001$). A significant increase ($p<0.05$) in brain theta wave activity in the 6-8 Hz range in all lithium-treated animals was also observed. A LOAEL of 19 mg Li/kg-day for adverse effects to the central nervous system was identified; a NOAEL was not established.

The effect of dietary lithium on thyroid function was examined in two groups of 10 male Wistar rats exposed to 0 or 1100 mg lithium carbonate/kg diet (0 or 20 mg Li/kg-day) for 120 days (Dhawan et al., 1985). Serum lithium levels ranged from 0.44 to 0.65 mmol/L. There was a significant decrease ($p<0.01$) in circulating levels of $T_4$ and $T_3$ after 1 month of exposure to lithium. There was also a marked decrease ($p<0.001$) in thyroid hormone levels after 4 months of lithium treatment. A LOAEL of 20 mg Li/kg-day for adverse thyroid effects was identified; a NOAEL was not established. Etling et al. (1987) investigated the effect of lithium on thyroid hormone levels in rats exposed to 0, 300 or 600 mg lithium carbonate/L in drinking water (0, 12.8 or 25.6 mg Li/kg-day) for 5 weeks. Decreases in serum $T_3$ and $T_4$ were observed only in the 600 mg/L group. A NOAEL and LOAEL of 12.8 and 25.6 mg Li/kg-day, respectively, for adverse thyroid effects were identified.

The effect of 90-day dietary exposure to lithium on male reproductive organs was evaluated by Thakur et al. (2003). Groups of 20 sexually mature Wistar rats were exposed to lithium carbonate at dietary concentrations of 0, 500, 800 or 1100 mg/kg diet for 90 days (equivalent to 0, 6.6, 10.6 or 14.2 mg Li/kg body weight-day). Serum lithium concentrations were not reported. Assessments included weight of reproductive organs, histopathology of testis, epididymis, seminal vesicle, and prostate, testicular interstitial fluid volume, testosterone level, sperm morphology and fertility index. Weights of the testes and epididymis, sperm number from cauda epididymis, daily sperm production, serum testosterone and interstitial fluid volume were significantly reduced in the mid- and high-dose groups, compared to controls. Seminal vesicle and prostate secretions were completely blocked in the mid- and high-dose groups. The percentage of abnormal sperm was significantly increased in all lithium treatment groups. Histopathological assessments revealed degeneration of spermatogenic cells and vacuolization of Sertoli cell cytoplasm in the high-dose treatment groups. A LOAEL of 6.6 mg Li/kg body weight-day for increased percentage of abnormal sperm was identified; a NOAEL was not established.

Sharma and Iqbal (2005) evaluated the effects of oral exposure of male Wistar rats to lithium nitrate for 7 weeks. Groups of 12 rats were exposed to 0 or 20 mg Li/kg body weight by gavage on alternate days (10 mg Li/kg-day) for 7 weeks and examined for effects on blood chemistry and hematology at the end of the treatment period. Serum lithium concentration was not reported. Numerous blood chemistry and hematology parameters were significantly different from controls: decreased hemoglobin and erythrocyte count, elevated white cell count, elevated erythrocyte sedimentation rate, elevated glucose, decreased protein and elevated blood urea nitrogen (BUN), calcium and phosphorous. Histopathological effects observed in the kidney included ruptured epithelial lining of the proximal and distal tubules of the medulla, renal tubular necrosis, thickened capsular wall of the glomerulus and cytoplasmic vacuolization in the corticomedullary region. Comprehensive toxicity endpoints were not examined in this study. A LOAEL of 10 mg Li/kg body weight for hematological and renal effects was identified; a NOAEL was not established.

**Developmental Effects –** The review by Moore and an IEHR Expert Scientific Committee (Moore, 1995) on lithium-induced developmental effects included available data from studies in animals using a variety of experimental designs. The data in animals are of limited usefulness to providing a comprehensive picture of lithium-induced developmental effects because of limitations of available studies. Issues with some of the studies include small number of animals, inability to ascertain litter incidence, inadequate reporting, administration of only a single dose, and failure to report or describe chemical characteristics of test materials. Despite these limitations, sufficient data are available to suggest that prenatal developmental toxicity can occur in studies with rats and mice in which lithium is administered during pregnancy and fetuses are examined just before birth. Doses associated with adverse developmental effects ranged from 2.71 to 12.67 mmol/kg body weight-day. Evidence of maternal toxicity was often present. Specific cardiac developmental effects have not been reported in animal studies; however, it does not appear that rigorous assessments of cardiac morphology have been conducted. Results of selected animal developmental studies are briefly summarized below.

Hoberman et al. (1990) evaluated the developmental effects of lithium hypochlorite administered by gavage once daily to groups of 25 Sprague-Dawley rats on days 6 through 15 of gestation at dosages 0 (vehicle), 10, 50, 100 or 500 mg/kg-day (0, 0.4, 2.1, 4.2 or 21 mg Li/kg-day). Six of the 25 rats in the 500 mg/kg-day group died between days 12 and 20 of gestation. Decreased fetal body weight, wavy ribs and delayed ossification of the thoracic vertebrae (bifid centra), forepaw and hindpaw phalanges, and metatarsal and metacarpal bones were observed in the offspring of the highest exposure group. Maternal NOAEL and the developmental NOAEL for lithium hypochlorite were determined by the authors to be 100 mg/kg-day of lithium hypochlorite (4.2 mg Li/kg-day). The LOAEL for developmental toxicity is 500 mg/kg-day (21 mg Li/kg-day) and the maternal frank effect level (FEL) is 500 mg/kg-day (21 mg/kg-day).

Twenty albino Sprague-Dawley rats were exposed to 0 or 100 mg/kg-day (0 or 18.8 mg Li/kg-day) lithium carbonate on days 16 through 20 of gestation (Fritz, 1988). Signs of maternal toxicity, including reduced weight gain and feed consumption, polyuria and polydipsia, were observed. Enlarged renal pelvises were observed in 50% of the fetuses in the lithium-exposed group. Exposure of rats to a lower daily dose of lithium carbonate (11.3 mg Li/kg-day) on gestational days 16 through 20 induced similar maternal effects and some prenatal mortality; however, no signs of impaired renal development for the young offspring that survived were observed. A LOAEL of 11.3 mg Li/kg body weight for maternal effects was identified; a NOAEL was not established. For fetal effects, NOAEL and LOAEL values were identified as 11.3 and 18.8 mg Li/kg-day, respectively.

Developmental toxicity was evaluated in the offspring of 44 pregnant Wistar rats exposed to 0, 50 or 100 mg/kg-day of lithium carbonate (equivalent to 0, 9.5 or 19 mg Li/kg-day) by oral gavage on gestational days 6 through 15 (Marethe and Thomas, 1986). Reduction in the number of implantations, number of live fetuses and fetal body weights and a higher number of resorptions were reported in the 100 mg/kg-day group. A developmental NOAEL for lithium carbonate is 50 mg/kg-day (9.5 mg Li/kg-day) and a LOAEL of 100 mg/kg-day (19 mg Li/kg-day) was determined.

Statistically significant reductions in total body weights of the fetus and the fetal length were observed in the offspring of albino rats exposed to 7 mg/kg-day of lithium carbonate (1.3 mg Li/kg-day) for the first 10 days of gestation (Sharma and Rawat, 1986). The authors did not report the number of animals used in the study, but rather the number of abnormal developmental observations and expressed these as a percentage of control. The authors also reported a high incidence of cleft palate abnormalities (46%), fetal brain liquification (46%), hepatomegaly (46%) and non-ossification of upper and lower digits (30 and 37%, respectively). Lower incidences of cardiomegaly (3%) and hydronephrosis (3%) were observed. A LOAEL of 1.3 mg Li/kg body weight for adverse developmental effects was identified; a NOAEL was not established.

Groups of 12 female Sprague-Dawley rats were fed 0 or 1000 ppm lithium carbonate (0 or 18.5 mg Li/kg-day) in the diet throughout gestation (Ibrahim and Canolty, 1990). Following parturition, the dams were exposed to the same concentration of lithium and were also allowed to nurse the pups for an additional 21 days. Dietary lithium resulted in decreased growth in both the dams and the offspring, as well as increased mortality of the offspring. Litter size was decreased 25% and mean pup weight was decreased by 10%. The highest mortality was observed in the group of pups that were exposed to lithium during both gestation and lactation. Gross malformations were not observed in the newborn animals. A LOAEL of 18.5 mg Li/kg body weight for adverse developmental effects was identified; a NOAEL was not established.

Groups of three to six mice (HmM/ICR strain) were exposed to 0, 200 or 465 mg/kg-day of lithium carbonate (0, 37.8 or 87.9 mg Li/kg-day) on gestational days 6 through 15 (Szabo, 1970). The human equivalent dose for mice, based on lithium plasma levels of 0.6-1.6 mmol/L, was calculated by the authors as 465 mg/kg-day. The highest dose, 465 mg/kg-day, caused an increased incidence of maternal (37%) and fetal (32%) deaths. Nineteen percent of the surviving fetuses had cleft palate. The 200 mg/kg-day dose (37 mg Li/kg-day) did not cause maternal or fetal deaths; the incidence of cleft palate in fetuses was 0.4%, which was not statistically significantly elevated relative to controls. Cleft palate was not observed in any of the 181 fetuses in the control group. NOAEL and LOAEL values for maternal effects and developmental effects were identified as 37.8 and 87.9 mg Li/kg-day, respectively.

### *Inhalation Exposure*

Only three studies that evaluated the effect of inhaled lithium in animals were identified (Johansson et al., 1988; Greenspan et al., 1986; Rebar et al., 1986). Greenspan et al. (1986) exposed groups of eight male and eight female F344/Lov rats to an aerosol mixture containing lithium carbonate (80%) and lithium hydroxide (20%) at concentrations of 0, 620, 1400, 2300 or 2600 mg Li/$m^3$ once for 4 hours (Greenspan et al., 1986). The 14-day $LC_{50}$ values were estimated to be 1700 mg Li/$m^3$ for the males and 2000 mg Li/$m^3$ for the females from the single exposure. No clinical signs of toxicity were observed in animals exposed to 620 mg Li/$m^3$. At concentrations $\geq$ 1400 mg/$m^3$, signs of acute effects on the respiratory system included respiratory distress and bronchospasms. At necropsy, severe congestion of the lungs was observed in 14 out of the 16 animals in the two highest exposure groups. Three of 16 animals at 1400 mg Li/$m^3$ showed congestion in the lungs. Histopathologic lesions in the respiratory tract were seen in the $\geq$ 1400 mg/$m^3$ groups, and were found only in animals dying within 12 days of exposure. Lesions were characterized as necrotizing rhinitis, necrotizing laryngitis and secondary suppurative bronchiolitis and bronchopneumonia. There was congestion of the thymus and tracheobronchial lymph nodes in almost half of the animals exposed to lithium aerosols. Similar observations were reported by Rebar et al. (1986) in groups of eight male and eight female rats that were exposed to an aerosol mixture of lithium monoxide and lithium hydroxide at concentrations of 0, 570, 840, 1200 or 1500 mg Li/$m^3$ for 4 hours. The 14-day $LC_{50}$ value was 940 mg/$m^3$. In this same study, the 14-day $LC_{50}$ value for a 4-hour exposure to an aerosol containing only lithium hydroxide was 960 mg Li/$m^3$. Clinical signs and pathological changes were similar to those described in the Greenspan et al. (1986) study. Exposure to the lithium hydroxide/lithium monoxide aerosol mixture at concentrations of 570 Li mg/$m^3$ and greater resulted in upper respiratory tract and pulmonary lesions.

No adverse respiratory effect were observed in groups of eight male rabbits exposed to aerosols of 0, 0.1 or 0.32 mg Li/$m^3$ as lithium chloride for 6 hours/day, 5 days/week for 4-8 weeks (Johansson et al., 1988). Inhalation of lithium chloride produced no adverse effects on lung morphology or phospholipid content. The number of alveolar macrophages in lithium-treated animals was not different compared to controls.

## Supporting Studies

### *Toxicokinetic*

The clinical pharmacokinetics of lithium has been extensively studied. Reviews and clinical pharmacology text books provide summaries of the pharmacokinetic profile of therapeutic lithium (Ward et al., 1994; Baldessarini and Tarazi, 2001; Potter and Hollister, 2001). The bioavailability of oral lithium preparations ranges from 80 to 100%, although it is generally accepted that the oral bioavailability of lithium is 100%. Peak plasma concentrations are typically reached within 2 hours of administration of lithium. Lithium does not bind to plasma proteins. The volume of distribution of lithium is calculated as 0.66 L/kg. Although lithium is distributed into total body water, lithium distribution is not uniform in all tissue compartments. As an element, lithium is not metabolized and is excreted intact, primarily by the kidney; elimination through sweat, saliva and feces is negligible. Approximately 80% of the filtered load of lithium is reabsorbed by the kidney and elimination correlates with renal function. Excretion follows first-order kinetics, with an average half-life of 22 hours and an average clearance of 0.35 mL/min-kg (0.5 L/day-kg).

***Genotoxicity***

Moore (1995) reviewed genotoxicity data as part of their assessment of the developmental effects of lithium and concluded that there is no evidence demonstrating genetic toxicity of lithium in bacterial or *in vitro* mammalian test systems. Garson et al. (1981) reported no increase in the occurrence of chromosome breaks in 23 human subjects under continuous lithium treatment for a period of 1-8 years when compared with 19 healthy age-matched controls. Lithium hypochlorite was not mutagenic in the Ames test nor did it induce DNA damage in the unscheduled DNA synthesis assay using rat primary hepatocytes or increase chromosome aberrations when tested orally in rats at maximally tolerated doses (Weiner et al., 1990).

## DERIVATION OF PROVISIONAL SUBCHRONIC AND CHRONIC RfD VALUES FOR LITHIUM

The use of lithium as a long-term maintenance therapy in the treatment of bipolar affective disorders has led to an extensive body of literature on the adverse effects associated with oral lithium therapy. Adverse effects, which are observed in several organs and systems, are associated with the entire target therapeutic serum lithium concentration range, leading to treatment strategies based on a risk-benefit assessment for individual patients. The available clinical data identify the lower bound of the therapeutic serum lithium concentration range (0.6 mmol/L) as a LOAEL; the clinical literature does not identify a NOAEL for adverse effects associated with therapeutic lithium. Data reported in humans studies are not sufficient to define the relationship between serum lithium concentrations and the development or severity of adverse effects, although it is generally accepted that the severity of adverse effects is related to serum lithium levels. Given the lack of adequate dose-response data, a single critical effect cannot be identified for lithium. Occupational and environmental oral exposure studies in humans are not available.

Adverse renal effects associated with lithium therapy have received extensive focus due to their serious nature and frequency of occurrence. The most common adverse renal effect is impaired renal concentrating ability and the production of excessively dilute urine. Clinically, this manifests as polyuria, with secondary thirst, and volume depletion. The onset of impaired renal concentrating capacity typically is within the first 2 years of treatment. Although altered renal function appears to be reversible early in treatment, it may be progressive during the first decade of lithium treatment, leading to irreversible damage over time.

Lithium therapy produces side effects in a number of organs and systems other than the kidney. The most frequent neurologic side effects are lethargy, fatigue, weakness, tremor and cognitive impairment. Endocrine glands such as the thyroid and parathyroid can also be affected. Although serious cardiovascular effects are rare, they do occur, the most common being changes in the EKG. Gastrointestinal side effects include nausea, vomiting, diarrhea and abdominal cramping. The most frequently observed hematological reaction is a benign leukocytosis. Developmental effects, primarily involving the heart, undoubtedly represent the most serious type of unwanted effects.

The available animal data provide supportive evidence that lithium produces adverse effects in several organs and systems at exposure levels that result in serum lithium concentrations in same range as that targeted for therapeutic use in humans. However, available studies do not evaluate comprehensive toxicity endpoints or identify a NOAEL for adverse effects. Thus, although results of toxicity studies in animals are consistent with the adverse effects profile in humans exposed to therapeutic lithium, data are not suitable as the basis for the provisional subchronic and chronic RfD.

The lower bound of the therapeutic serum lithium concentration range of 0.6 mmol/L is selected as the basis for derivation for the provisional RfD and subchronic RfD (p-RfD; p-sRfD). Given that the adverse effects profile of therapeutic lithium is similar for patients on short- and long-term lithium therapy, an RfD based on the LOAEL of 0.6 mmol Li/L is applicable for subchronic and chronic exposures. Based on the pharmacokinetic considerations detailed below, to achieve a serum lithium concentration of 0.6 mmol Li/L, the daily ingestion of lithium by a 70-kg individual is calculated as approximately 1.8 mg Li/kg-day.

At steady state,

$$D = \frac{C_P \cdot Cl}{f}$$

where D is the dose (mg/kg-day), $C_p$ is the plasma concentration (mg/L), Cl is the plasma clearance (L/kg-day) and f is the fraction of the dose absorbed. Assuming values of 0.5 L/kg-day for Cl and 1 for f (Baldessarini and Tarazi, 2001), a steady-state plasma concentration of 0.6 mmol/L (4.2 mg Li/L) corresponds to a daily dose of 2.1 mg Li/kg-day.

The provisional subchronic and chronic RfD for lithium was derived from the LOAEL of 2.1 mg/kg-day for adverse effects in several organs and systems. Dividing the LOAEL of 2.1 mg/kg-day by an uncertainty factor of 1000 yields a subchronic and chronic p-**RfD of 0.002 mg/kg-day or 2 µg/kg-day**.

p-RfD = LOAEL ÷ UF
= 2.1 mg/kg-day ÷ 1000
= 0.002 mg/kg-day or 2 µg/kg-day

The composite uncertainty (UF) of 1000 includes a factor of 10 to extrapolate from a LOAEL to a NOAEL, a factor of 10 to protect susceptible individuals and a factor of 10 to account for database insufficiencies as follows:

● A default 10-fold UF for extrapolation from a LOAEL to a NOAEL was used because the lower bound of the therapeutic serum lithium range is associated with the development of adverse effects in several organs and systems; a NOAEL for adverse effects of therapeutic lithium has not been established in the clinical or animal literature.
● A default 10-fold UF was used to account for potentially susceptible individuals in the absence of quantitative information on the variability of response to lithium in the human population. Since lithium adversely affects several organs and systems, numerous pre-existing disease states (e.g., renal disease, cardiovascular disease, endocrine disease) may increase susceptibility to lithium.
● A UF of 10 was applied for database uncertainties. The renal effects of lithium have been extensively studied in humans and animals. However, much less information is available on the effects of lithium in other systems, including the cardiovascular, neurological and endocrine systems, and subchronic and chronic exposure studies in animals assessing comprehensive endpoints are not available. Furthermore, although lithium appears to produce developmental effects in humans, the database lacks well-controlled epidemiology studies and multi-generation reproduction studies in animals.

A wide range of estimates for daily dietary intake of lithium has been reported. Several authors report estimates for the average daily dietary intake of lithium, ranging from 0.24 to 1.5 μg/kg-day (Noel et al., 2003; Clarke et al., 1987; Hamilton and Minski, 1973; Evans et al., 1985; Clark and Gibson, 1988). A much higher estimate for daily intake from food and municipal drinking water ranging from 33 to 80 μg Li/kg-day was reported by Moore (1995). The source of the discrepancy between these estimates is unknown. The p-RfD of 2 μg/kg-day is above most estimates of daily dietary intake, but below the range estimated by Moore (1995).

Confidence in the LOAEL value is low-to-medium. Since the clinical literature has focused on the therapeutic treatment of patients, information on effects observed below the minimally effective dose is lacking. Confidence in the database is also low-to-medium. Although there is an extensive database demonstrating the adverse effects of chronic exposure to therapeutic lithium, information regarding the dose-response relationship of lithium to the development of adverse effects is lacking. Thus, the relative sensitivity of the different target organs cannot be identified based on human data. Furthermore, since most animals studies have been designed to evaluate specific adverse effects associated with the therapeutic serum lithium concentration range, NOAEL and LOAEL values have not been established in animals studied for comprehensive toxicity endpoints. The database also lacks well-controlled epidemiology studies and multi-generation reproduction studies in animals, even though there is evidence of developmental effects in lithium patients. Low-to-medium confidence in the p-RfD is the result.

## FEASIBILITY FOR DERIVING A PROVISIONAL SUBCHRONIC RfC FOR LITHIUM

No studies investigating the effects of acute, subchronic or chronic inhalation exposure to lithium in humans were identified. The available studies in animals did not evaluate comprehensive histopathological, biochemical and clinical endpoints of inhalation exposure.

Thus, due to the lack of data, derivation of a provisional subchronic or chronic RfC for lithium is precluded.

## PROVISIONAL CARCINOGENICITY ASSESSMENT FOR LITHIUM

### Weight of Evidence Descriptor

Cancer studies in humans and cancer bioassays in animals exposed to lithium by the oral or inhaled routes were not found. Results of *in vitro* and *in vivo* studies in bacterial and mammalian systems indicate that lithium is not genotoxic. Under EPA's *Guidelines for Carcinogen Risk Assessment* (U.S. EPA, 2005), the hazard descriptor, "data are inadequate for an assessment of human carcinogenic potential," is appropriate for lithium.

### Quantitative Estimates of Carcinogenic Risk

Due to the lack of data, derivation of an oral cancer slope factor and an inhalation cancer unit risk are precluded.

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# Appendix D

# Statistical Evaluation

# Confidence Interval

Sutherland Generating Station     Client: SCS Engineers     Data: SUT- Chempoint- export-Dec2020     Printed 12/13/2021, 10:42 PM

| Constituent | Well | Upper Lim. | Lower Lim. | Compliance | Sig. | N | %NDs | ND Adj. | Transform | Alpha | Method |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Lithium (ug/L) | MW-301 (bg) | 3.576 | 2.458 | 40 | No | 6 | 0 | None | No | 0.01 | Param. |
| Lithium (ug/L) | MW-302 (bg) | 2.9 | 1.15 | 40 | No | 6 | 33.33 | None | No | 0.0155 | NP (normality) |
| Lithium (ug/L) | MW-303 | 27.62 | 17.38 | 40 | No | 6 | 0 | None | No | 0.01 | Param. |
| Lithium (ug/L) | MW-304 | 5.018 | 1.746 | 40 | No | 6 | 50 | Kapla... | ln(x) | 0.01 | Param. |
| Lithium (ug/L) | MW-305 | 34.23 | 7.105 | 40 | No | 6 | 0 | None | No | 0.01 | Param. |
| **Lithium (ug/L)** | **MW-306** | **55.25** | **40.3** | **40** | **Yes** | **9** | **0** | **None** | **No** | **0.01** | **Param.** |

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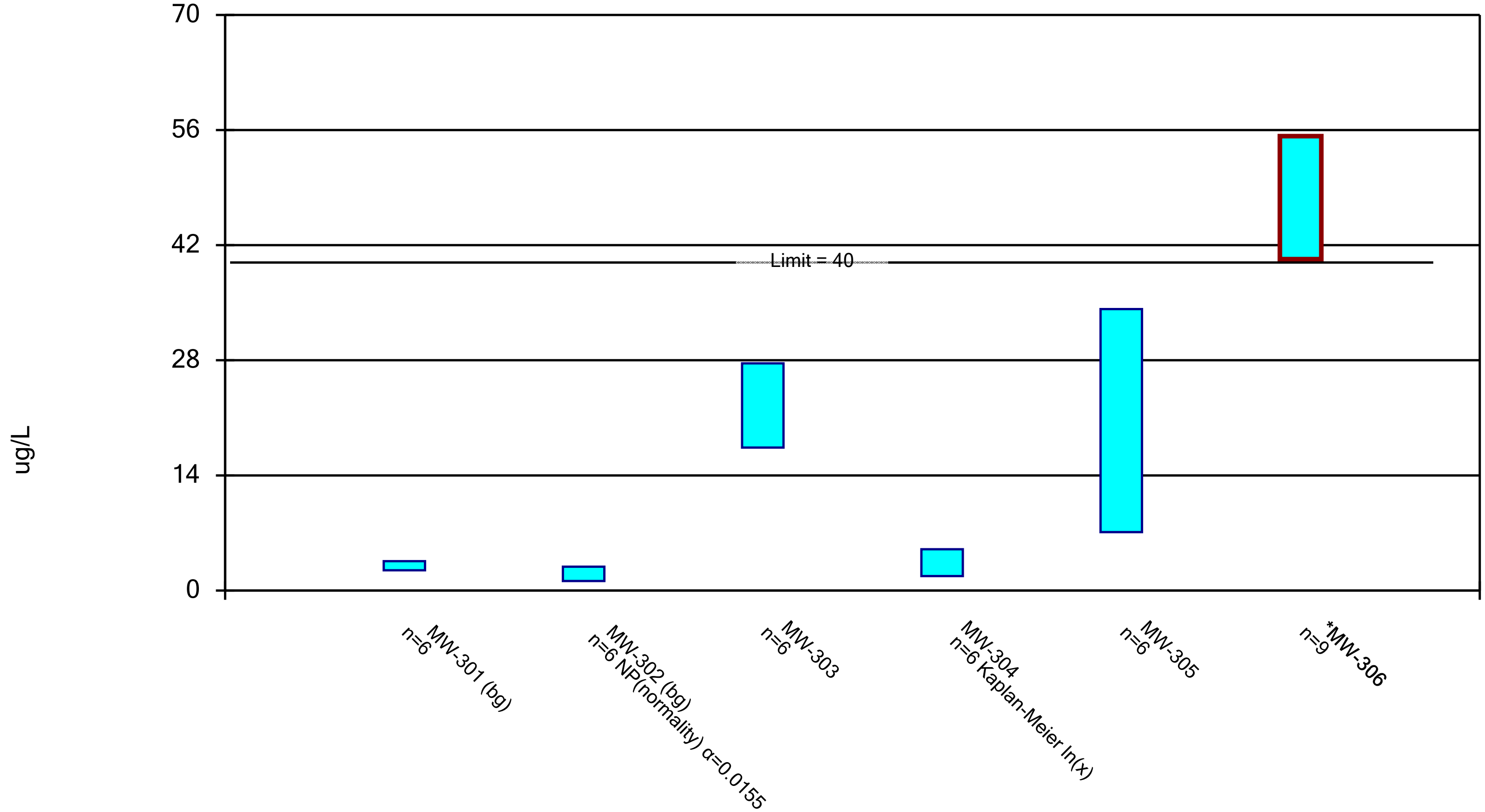
# Parametric and Non-Parametric (NP) Confidence Interval

Compliance limit is exceeded.* Per-well alpha = 0.01 except as noted. Normality Test: Shapiro Wilk, alpha based on n.




Constituent: Lithium Analysis Run 12/13/2021 10:41 PM

Sutherland Generating Station Client: SCS Engineers Data: SUT- Chempoint- export-Dec2020

# Confidence Interval

Constituent: Lithium (ug/L)    Analysis Run 12/13/2021 10:42 PM

Sutherland Generating Station    Client: SCS Engineers    Data: SUT- Chempoint- export-Dec2020

| | MW-301 (bg) | MW-302 (bg) | MW-303 | MW-304 | MW-305 | MW-306 |
|---|---|---|---|---|---|---|
| 12/11/2019 | 3.5 (J) | | | | | |
| 12/12/2019 | | 2.8 (J) | 27 | 2.9 (J) | 16 | 40 |
| 2/3/2020 | 2.7 (J) | <2.3 (U) | 22 | <2.3 (U) | 10 | 39 |
| 4/7/2020 | 3.4 (J) | <2.3 (U) | 23 | <2.3 (U) | 12 | 40 |
| 5/11/2020 | | | | | | 42 |
| 10/13/2020 | 3.2 (J) | 2.8 (J) | 26 | 2.8 (J) | 22 | 52 |
| 2/24/2021 | | | | | | 55 |
| 4/6/2021 | 2.5 (J) | 2.8 (J) | 17 | <2.5 (U) | 29 | 48 |
| 7/14/2021 | | | | | | 59 |
| 10/26/2021 | 2.8 (J) | 2.9 (J) | 20 | 6.8 (J) | 35 | 55 |
| Mean | 3.017 | 2.267 | 22.5 | 2.675 | 20.67 | 47.78 |
| Std. Dev. | 0.407 | 0.8658 | 3.728 | 2.18 | 9.873 | 7.742 |
| Upper Lim. | 3.576 | 2.9 | 27.62 | 5.018 | 34.23 | 55.25 |
| Lower Lim. | 2.458 | 1.15 | 17.38 | 1.746 | 7.105 | 40.3 |