Assessment of Corrective Measures for Groundwater at Omaha Public Power District (OPPD) NC2 Ash Landfill

Nebraska OPPD Station –
NC2 Ash Disposal Area

Nebraska OPPD, Nebraska
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Acronyms

ACM	assessment of corrective measures
ASD	alternative source demonstration
bgs	below ground surface
BTVs	background threshold values
CCR	coal combustion residuals
CCR Rule	United States Environmental Protection Agency's Disposal of Coal Combustion Residuals from Electric Utilities
CFR	Code of Federal Regulations
COIs	constituents of interest
CY	cubic yards
Eh	oxidation potential
EPRI	Electric Power Research Institute
GWPS	groundwater protection standards
HDR	HDR Engineering, Inc.
ITRC	Interstate Technology & Regulatory Council
MCLs	maximum concentration limits
MNA	monitored natural attenuation
NC1	Nebraska City Station – Unit 1
NC2	Nebraska City Station – Unit 2
NDEE	Nebraska Department of Environment & Energy
NES	nature & extent study
O&M	operation and maintenance
OPPD	Omaha Public Power District
ppm	parts per million
PRB	permeable reactive barrier
SSL	statistically significant level above GWPS
USEPA	United States Environmental Protection Agency
WHO	World Health Organization
ZVI	zero-valent iron
µg/L	micrograms per liter

Professional Engineer Certification

I hereby certify that this engineering document was prepared by me or under my direct personal supervision and that I am duly licensed Professional Engineer under the laws of the State of Nebraska.

Print Name: Megan B. Seymour

Signature: Megan B. Seymour

Date: 12-22-2020

License #: E-15931

PROFESSIONAL (ENVIRONMENTAL) ENGINEER
MEGAN B. SEYMOUR
E-15931
STATE OF NEBRASKA
12-22-2020

My license renewal date is December 31, 2022.

Executive Summary

The Omaha Public Power District (OPPD) has a two-unit fossil fuel-fired generating station (NC1 and NC2), located 5.5 miles southeast of Nebraska OPPD, Nebraska, along the west shore of the Missouri River. This Station has two (2) existing coal combustion residuals (CCR) landfills that are permitted under the current Nebraska Department of Environment and Energy's (NDEE) Title 132 regulations for fossil fuel combustion ash disposal area: the NC1 Ash Disposal Area and NC2 Ash Disposal Area. The NC1 Ash Disposal Area was closed in 2020. This report covers the NC2 Ash Disposal Area (NDEE Permit No. NE0204421, Facility ID 58343).

The NC2 Ash Disposal Area is regulated under the United States Environmental Protection Agency's (USEPA) Disposal of Coal Combustion Residuals from Electric Utilities rule (CCR Rule), as specified in 40 CFR §257. The CCR Rule defines a set of requirements for the disposal and handling of CCR within CCR units (defined as either landfills or surface impoundments). OPPD reported on September 15, 2020 that concentrations of lithium and arsenic detected in one groundwater monitoring well (NC2MW-7) at the NC2 Ash Disposal Area represented a statistically significant level (SSL) above the groundwater protection standards (GWPS). Following the October 2020 sampling and analysis event, an additional SSL for arsenic at NC2MW-8 was detected. A notification for all three SSLs was published by OPPD on November 25, 2020.

Subsequent to these detections, HDR Engineering, Inc. (HDR) performed a desktop analysis of corrective measures that could potentially be implemented at the NC2 Ash Disposal Area to address constituents of interest (COIs) identified in groundwater in the vicinity of the NC2 Ash Disposal Area at levels that exceed the GWPS. Review of this information was completed to address requirements of 40 CFR §257.96 for assessment of corrective measures (ACM) and includes: (1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination; (2) The time required to begin and complete the remedy; (3) 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(s). This completed ACM is then placed in the facility's operating record as required by 40 CFR §257.105(h)(10).

In accordance with 40 CFR §267.97(b), the groundwater corrective measures considered must meet, at a minimum, the following threshold criteria:

1. Be protective of human health and the environment;
2. Attain the GWPS, as established under 40 CFR §257.95(d)(2);
3. Control the source(s) of releases to reduce or eliminate, to the maximum extent feasible, further releases of constituents of concern to the environment;
4. Remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, considering factors such as avoiding inappropriate disturbance of sensitive ecosystems; and,
5. Comply with standards (regulations) for waste management.

The analysis included review of readily available documents pertaining to site history; site-specific geologic and hydrogeologic conditions; groundwater quality; and statistical analysis of groundwater quality data. HDR evaluated the potential effectiveness to treat site-specific COIs, feasibility of implementation, and regulatory acceptance of each measure deemed feasible. HDR has also identified data gaps and provided recommendations on work that could be completed to gather additional data that would allow for further evaluation of alternative sources and refinement of each corrective measure deemed applicable and potentially feasible in effectively addressing COIs identified in groundwater near the regulated unit.

At a high level, HDR evaluated multiple corrective measures for applicability to the site-specific conditions at the NC2 Ash Disposal Area. These corrective measures included:

- Source Controls;
- Permeable Reactive Barrier;
- Groundwater Extraction and Treatment; and,
- Monitored Natural Attenuation.

After this evaluation, OPPD selected the following corrective measures for additional analysis:

- Source Controls;
- Groundwater Extraction and Treatment; and
- Monitored Natural Attenuation.

A summary of the applicability, technical feasibility, benefits, risks, and additional data needs for those measures deemed viable are summarized in **Table 1**.

1 Purpose

The Omaha Public Power District (OPPD) Nebraska City Station Fossil Fuel Combustion Ash Landfill (NC2 Ash Disposal Area) is regulated under Nebraska Department of Environment and Energy (NDEE) Title 132 – Integrated Solid Waste Management Regulations, Chapter 7, Ground Water Monitoring and Remedial Action program and the U.S. Environmental Protection Agency (EPA) final rule for the regulation and management of coal combustion residuals (CCR) under the Resource Conservation and Recovery Act (RCRA); referred to as the CCR Rule. The CCR Rule is formally promulgated in the U.S. Code of Federal Regulations (CFR), Title 40, Part 257.

OPPD is in the process of addressing the groundwater provisions of the CCR Rule and NDEE Title 132 regulations and recently published a notification that Appendix IV constituents (arsenic and lithium) have been identified as statistically significant levels (SSLs) above the established groundwater protection standard (GWPS) in at least one of the network monitoring wells (arsenic and lithium in NC2MW-7 and arsenic in NC2MW-8). In accordance with 40 CFR §257.96, if one or more Appendix IV constituents are detected above their established GWPS, the Owner/Operator must initiate the assessment of corrective measures (ACM) within 90 days of the detection. As part of the ACM, HDR Engineering, Inc. (HDR) has completed a desktop evaluation of potential corrective measures to assist OPPD in identifying an appropriate corrective measure or combination of measures to implement at the NC2 Ash Disposal Area.

Review of this information was completed to address requirements of 40 CFR §257.96 and includes: (1) The performance, reliability, ease of implementation, and potential impacts of appropriate potential remedies, including safety impacts, cross-media impacts, and control of exposure to any residual contamination; (2) The time required to begin and complete the remedy; (3) 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(s).

The purpose of this report is to summarize the evaluation of potentially viable corrective measures that could be implemented to effectively address the constituents of interest (COIs) that have been detected above their GWPS in groundwater underlying the OPPD NC2 Ash Disposal Area near Nebraska City, Nebraska. This evaluation is based on HDR's review and interpretation of available data as it relates to applicability, implementability and anticipated effectiveness, benefits and limitations associated with implementation, and ongoing operation and maintenance (O&M) for each corrective measure evaluated and deemed applicable and feasible.

2 Site Description/Background

OPPD owns and operates Nebraska City Station Unit 1 (NC1) and Unit 2 (NC2) Ash Disposal Areas, located approximately 5.5 miles southeast of Nebraska City, in Otoe County, Nebraska. The Nebraska City Station (herein referred to as "Station" or "Site") occupies approximately 1,600-acres of land on the Frazer Island Floodplain adjacent to the Missouri River (**Figure 1**). The Station currently has two fossil-fuel-fired generating units (Unit 1 and Unit 2), related facilities, and two on-site landfills for disposal of Unit 1 and Unit 2 ash. Unit 1 was commissioned in May 1979. A second generating unit (Unit 2 or NC2) began commercial operation in 2009. The Station has two landfills (NC1 Ash Disposal Area & NC2 Ash Disposal Area) that serve for disposal of CCR ash (**Figure 2**). The NC1 Ash Disposal Area has been closed and is currently awaiting final closure approval from NDEE. Currently, CCR generated at the Station is disposed in the NC2 Ash Disposal Area. Both the

NC1 and NC2 Ash Disposal Areas are permitted under the current NDEE Title 132 regulations for fossil fuel combustion. This report is specific to the NC2 Ash Disposal Area (NDEQ ID #58343, Program ID – IWM NE0204421).

The NC2 Ash Disposal Area is an active CCR landfill permitted under NDEE Title 132 regulations for 40.7 acres. Cell 1 (14.5 acres) and the East Leachate Pond were constructed in 2008/2009 and Cells 2 & 3 (26.2 acres) and the West Leachate Pond were completed in January 2018. All three cells were constructed with 24 inches of re-compacted clay overlain by a 60-millimeter (mil) high-density polyethylene (HDPE) geomembrane and geotextile fabric layer. The cells were constructed with a leachate collection system. Cell 1 collects leachate at a sump and is pumped into the East Leachate Pond. Cells 2 & 3 have two leachate sumps which are pumped into the West Leachate Pond. Phased closure of Cell 1 was completed in year 2015, resulting in filling of fly ash and bottom ash in Cells 2 & 3 of the NC2 Ash Disposal Area.

The Site is situated on the floodplain with the Missouri River to the east and uplands to the west. Natural topography within the vicinity of the Site generally slopes downward and eastward from the uplands to the Missouri River from approximately 1,210 feet to 900 feet elevation over an approximate distance of 6.6 miles. The area immediately surrounding the Site primarily consists of agricultural farmland. In the general vicinity of the Station, two primary sources of groundwater are present: Missouri River Alluvium and glacial deposits in the upland area west of the Station. Groundwater in the Missouri River Alluvium is found as shallow as 2 to 17 feet below ground surface (bgs) and is largely affected by the river stages. The uppermost aquifer, Missouri River Alluvium, thickness is anticipated to be from 2 feet to 100 feet bgs. Based on data in recent monitoring reports for the NC2 Ash Disposal Area, groundwater flow was in the south-southeasterly direction (**Figure 3**). For October 2020, based on a hydraulic conductivity range of 6.96 ft/day to 39.4 ft/day, a hydraulic gradient of 0.000372 ft/ft, and an effective porosity of 0.405, a representative best estimate for average seepage velocity across the entire site ranges from 0.00639 ft/day to 0.0362 ft /day (2.33 to 13.22 ft per year).

3 Summary of Groundwater Monitoring

The certified groundwater monitoring system currently consists of three (3) upgradient/background monitoring wells (NC2MW-4, NC2MW-5, and MW-13), four (4) downgradient monitoring wells (NC2MW-2, NC2MW-3, NC2MW-7, and NC2MW-8), and one (1) cross-gradient monitoring well (NC2MW-6). Monitoring wells for the NC2 Ash Disposal Area are shown in **Figure 2**. The NC1 Ash Disposal Area has its own monitoring network and program separate from the NC2 Ash Disposal Area.

Assessment monitoring was initiated for the NC2 Ash Disposal Area in April 2020. Results of the initial assessment monitoring sampling event for 40 CFR Appendix III to Part 257 (Detection Monitoring Constituents) & 40 CFR Appendix IV to Part 257 (Assessment Monitoring Constituents) at each well in the groundwater monitoring well network were used to calculate background threshold values (BTVs) and to establish GWPS for the Appendix IV (assessment monitoring) constituents. The subsequent assessment monitoring events were completed July 14-15, 2020 and October 5, 2020. As previously discussed, there were Appendix IV constituents detected as SSLs above the GWPS (arsenic & lithium in NC2MW-7 and arsenic in NC2MW-8) and; therefore, the owner must comply with 40 CFR §257.95(g) and NDEE Title 132 Chapter 7, Section 005.07.

Site investigations, including the Groundwater Assessment Report (GAR) dated November 2019 and the Site Assessment Report (SAR) dated June 2020, have been conducted to further evaluate detected Appendix III and IV constituents in the vicinity of the NC2 Ash Disposal Area. The GAR and

SAR evaluated soil samples from upwind and downwind of the NC2 Ash Disposal Area. Upwind/downwind direction of the CCR unit (from the north/northwest) was based on historic prevailing wind directions for the Site and the seasonal changes accompanying wind directions. Results of the soil samples in comparison with leachate, ash, and groundwater samples collected during the investigations determined arsenic was not found from sources of CCR at concentrations that could support the arsenic detected in downgradient monitoring wells. In summary, the results indicated arsenic detections at NC2 Ash Disposal Area is due to naturally occurring conditions. The GAR served as an alternate source demonstration (ASD) for arsenic in NC2MW-7 and was submitted to the NDEE for compliance with State groundwater requirements. NDEE provided a response in a May 5, 2020 correspondence letter that stated the ASD for arsenic in NC2MW-7 was accepted. Based on these results, arsenic is not considered a COI for remedial measures at the NC2 Ash Disposal Area.

Additionally, results of the GAR and SAR indicated that elevated detections of calcium (Appendix III constituent) and lithium (Appendix IV constituent) detected in groundwater downgradient of the NC2 Ash Disposal Area is due to windblown ash being deposited onto the ground surface downwind of the CCR Unit. As previously stated, the NC2 Ash Disposal Area has an engineered composite liner and leachate extraction system between the liner and the groundwater. Based on site investigations, it has been determined that the COIs are not a result of a release through the landfill and instead are from windblown ash being deposited outside of the landfill footprint. **Figure 4** shows the extent of elevated lithium concentrations (i.e. area of impact) downwind/downgradient of the NC2 Ash Disposal Area.

An ASD for lithium concentrations was not successful and therefore, the lithium concentrations measured at the NC2 Ash Disposal Area are considered an SSL above GWPS. In accordance with 40 CFR §257.95(g) and NDEE Title 132 Chapter 7, Section 005.07, when an SSL over the GWPS is detected for an Appendix IV constituent, the owner is required to characterize the extent of the release. Site investigation (SAR and GAR) data were used to develop a Nature and Extent Study (NES) Report to delineate lithium both horizontally and vertically downgradient of the NC2 Ash Disposal Area. Elevated lithium concentrations are limited to the area directly downgradient of the NC2 Ash Disposal Area within the OPPD property boundaries as shown in iso-concentration map for lithium at NC2 (**Figure 4**). Vertical characterization is discussed in the NES Report and was evaluated with sampling of a deeper groundwater monitoring well (NC1MW-7) near the NC2 Ash Disposal Area, sampling of three of the onsite production wells, and hydrogeological characteristics of the Site. Results indicated that onsite production wells (**Figure 5**) influence the flow of groundwater in the vicinity of the NC2 Ash Disposal Area and therefore provide a hydraulic containment for the transport of COIs from the NC2 Ash Disposal Area. A groundwater sample was collected from the three production wells (PW-1 through PW-3) as well as deeper screen NC2MW-7. Lithium was not detected above the GWPS or BTV in NC2MW-7 and the production well sample indicating vertical delineation of lithium at the Site.

4 Assessment of Corrective Measures Screening

Based on hydrogeological site conditions, COI (lithium) identified as an SSL, and the source of detected COI (windblown ash), HDR initially screened four corrective measures that were considered applicable to treat lithium in groundwater in the vicinity of the NC2 landfill. A brief description of each corrective measure that was identified as applicable to address CCR-related impacts to groundwater is presented in **Section 4.2** below. After an initial review for technical feasibility, the list of corrective measures was narrowed down three measures which were deemed feasible based on the COI and site constraints, and further evaluated (**Section 5**) for effectiveness as described in 40 CFR §257.96(c).

4.1 Corrective Measures Objectives

The effectiveness of potential corrective measures should also meet the requirements and objectives of 40 CFR §257.97. The objectives of the remedy pursuant to 40 CFR 257.97(b) are:

- Be protective of human health and the environment;
- Attain the GWPS;
- Control the source of release to reduce or eliminate, to the maximum extent feasible, further releases of constituents in Appendix IV to the environment;
- Remove from the environment as much of the contaminated material that was released from the CCR unit as is feasible, considering factors such as avoiding inappropriate disturbance of sensitive ecosystems;
- Comply with standards for management of wastes.

In achieving these objectives, the potential remedy should consider the long- and short-term effectiveness and protectiveness, along with a degree of certainty that the remedy will prove successful.

4.2 Description of Corrective Measures

4.2.1 Measure 1 – Source Control

Description. For the OPPD NC2 Ash Disposal Area, source control measures consist of windblown ash control measures to reduce open surface area of NC2 Ash Disposal Area and to minimize ash from being deposited outside of the landfill. Reduction of windblown ash on to the surrounding ground surface can be achieved with implementation of one or more dust control techniques. The following options were identified:

- *Binding surface particles*: Application of brines or oils, such as Posi-CLEAR to the surface of roadways and the open face of the landfill in order to lock surface materials and dust from the ash in place through surface tension.
- *Sealing surface with low to non-permeable materials:* Application of Posi-Shell (or equivalent) which consists of a spray-applied coating which is durable, non-flammable, and erosion resistant. The mixture coating consists of a combination of liquid, Portland cement, fly ash, fibers, and a setting agent. It provides an effective, long-term cover that can be quickly and easily placed over the open face of the landfill through use of specialized equipment or hydroseeding units.
- *Reduce exposed surface area:* Ensure the areas of the landfill are covered except for the reduced pertinent working area. A reduction in the open face could be completed using alternative covers including the tarping of idle areas with heavy duty roll-out tarps and ballasting with sandbags or cover with bottom ash, which is less likely to become airborne.
- *Slow velocity of wind over the area:* Position wind barriers, such as WeatherSolve Structures dust fencing (or equivalent), around the landfill in order to slow the velocity of wind around the operational areas. Barriers can be in operational areas where fly ash is present as well as

around areas where dumping/loading occurs. The barriers could be moved according to prevailing wind directions.

- *Dust Suppression Misters:* Tower misters could provide a constant mist of liquid in and around the active operations area in order to reduce the ability of dry ash to become airborne. The misters can be moved to applicable areas; however, may not be conducive for freezing temperatures in the area.

Applicability to the NC2 Ash Disposal Area. Based on site investigations conducted as part of the GAR and SAR, it was concluded that windblown ash from Cells 2 and 3 of NC2 Ash Disposal Area is a major contributor of elevated concentrations of lithium, both in the soil and the groundwater. The Site has an Operations Plan approved by NDEE that describes the site development and operations of the NC2 Ash Disposal Area and outlines procedures and controls for nuisance and health considerations to public and the environment. As part of the Operations Plan, the Site has protocols for conditioning of the fly ash with water to control dust and improve compaction. While these procedures are implemented at the Site, ash from the NC2 Ash Disposal Area has become airborne at times and deposits on the ground surface downgradient of the landfill (i.e. south of the CCR unit). During the SAR, HDR did a preliminary evaluation of options for dust control techniques, as listed above.

Benefits. Under this scenario, OPPD could benefit from one or more source control measures as follows:

- Dust mitigation technologies are proven technologies that have been implemented in both CCR and non-CCR industries;
- Ability to fully encapsulate idle areas of the NC2 Ash Disposal area, using sealing surface materials such as Posi-Shell, to significantly reduce the ability of fly ash to become airborne and fugitive;
- Application timing will vary based on technologies, weather, and mixture; however, in some cases, encapsulation of Posi-Shell has been viable for up to one year;
- Some techniques can be repositioned based on prevailing wind direction; and
- Can be managed and implemented by onsite personnel.

Limitations. Under this scenario, OPPD may experience the following limitations from source controls enacted:

- Some options may be costly to implement and require specialized equipment or outside vendors for installation;
- Application of water-based technologies, such as dust misters, are not conducive for freezing temperatures; and,
- Does not directly address groundwater restoration.

Additional Data Needs. It is recommended to obtain additional information from vendors on implementation of products for the NC2 Ash Disposal Area. Additional research to determine the impacts of added products on the ash landfill could have for future potential beneficial reuse of ash. Additional fate and transport modeling can determine the amount of time to reach GWPS once source control measures have been implemented.

Conclusions. Based on the foregoing, source control measures should be retained for further evaluation by itself or possibly in combination with other remedial strategies/technologies such as MNA and/or Groundwater Extraction & Treatment.

4.2.2 Measure 2 – Permeable Reactive Barrier

Description. Permeable reactive barriers (PRBs) are a passive form of in-situ groundwater treatment that can be constructed to remove both organic and inorganic contaminants. They are typically constructed by excavating a trench that penetrates the saturated zone perpendicular to the direction of groundwater flow. The PRB is keyed into an underlying barrier to groundwater movement such as a continuous clay layer or bedrock. The trench is then backfilled with reactive material while maintaining a transmissivity greater than the surrounding subsurface so that groundwater continues to flow through, rather than around the PRB. Reactive material may be media that adsorbs COIs or potentially forms precipitates with COIs to reduce their concentrations downgradient of the PRB.

The reactive material either removes the COIs or transforms them into less problematic valance states (e.g., hexavalent chromium to trivalent chromium), depending on the COI and the media (ITRC, 2005). The design of a PRB can incorporate multiple reactive materials depending on the site-specific COIs to treat and whether pretreatment is required to enhance the effectiveness of the intended removal mechanisms. The reactive material may be mixed together to create a single reactive zone or sequentially stacked so that the groundwater passes through several different reactive zones. The appropriate composition of a PRB at a CCR site would depend on the COIs, but might include a combination of limestone aggregate to provide PRB stability, transmissivity, and pH buffering, and/or zero-valent iron (ZVI) that would reduce the levels of a number of metals through adsorption/precipitation. Other reactive materials, such as aluminum hydroxide (Kappen and Webb, 2013), rice husks (Amin et al., 2006), and ferrihydrite-coated sand (Mahler and Persson, 2013) could be considered as part of a future batch and/or pilot study to target lithium.

To reduce the amount of reactive media required, the PRB can be designed as a funnel and gate system to channel impacted groundwater into a gate that contains the reactive material (Obiri-Nyarko et al., 2014). The funnels are non-permeable (e.g., slurry wall); the simplest design consists of a single gate with walls extending from both sides. The main advantage of the funnel-and-gate system is that a smaller reactive zone can be used to treat the plume, thereby, potentially reducing capital costs and long-term maintenance.

The PRB lifespan is a function of the COI concentration and the media removal characteristics, which may be influenced by site-specific geochemical conditions and other competing constituents. PRBs may be used as an interim or a long-term measure. Lifespan is generally proportional to cost, as the effectiveness generally increases with more media. Due to uncertainty and cost factors, it is common to look at conventional PRB design life in terms of decades; therefore, if it is anticipated that the COIs will continue to persist in groundwater for multiple decades, long-term remediation may require the periodic replacement of the PRB reactive media.

Applicability to the NC2 Ash Disposal Area. Applicability of a PRB as a corrective measure for the NC2 Ash Disposal Area is primarily a function of the location of the PRB and the site-specific COIs to be treated. Installation of a PRB would be required over a sufficient length of the downgradient side of the NC2 Ash Disposal Area in order to keep groundwater from passing around the reactive barrier. Given the area of groundwater impacts from the lithium plume along the southern boundary of the NC2 Ash Disposal area and groundwater flow towards the southeast, a PRB with a funnel and gate system would be required along the entire downgradient side of the landfill to capture flow of COIs. The PRB would be located between the NC2 and NC1 landfill units. Plume maps are provided in the OPPD Title 132/118 Nature and Extent Study (HDR, 2020) provided to the NDEE.

Based on review of the groundwater quality data from the NC2 Ash Disposal Area, it appears that a PRB could be designed to effectively remove lithium known to be present in groundwater in the vicinity of the landfill. Further evaluation of a PRB should consider the optimal location of the PRB or gate system downgradient of the landfill and depth to bedrock in the area. PRBs are generally anchored in bedrock or a continuous clay with low hydraulic conductivity to direct groundwater through the PRB rather than around it. Based on soil boring logs for the onsite production and service wells, bedrock at the Site consists of limestone at approximately 100 feet below ground surface (bgs) resulting in a significant depth for trenching/excavating in order to anchor the PRB into the bedrock In addition to the significant depth to bedrock (100 feet bgs), limestone can form solution cavities (karst) that may allow for preferential movement of groundwater around or beneath the PRB, reducing the effectiveness and potentially allowing groundwater COIs to migrate. Borings into the bedrock have not been conducted at the Site; therefore, the characterization of the limestone and ability to anchor the PRB into the bedrock is uncertain.

Benefits. Under this scenario, OPPD could benefit from PRB installation as follows:

- Flexibility to treat a variety of constituents in the future, if necessary, depending on media or mix of media selected, following batch and pilot studies;
- Minimizes disruption to Site operations; and,
- Demonstrated to effectively treat site-specific COI of lithium.

Limitations. Under this scenario, OPPD would experience the following limitations:

- Depth to underlying bedrock is anticipated to be approximately 100 feet bgs and is too deep for trenching/excavating for anchoring of the PRB; and,
- May require periodic replacement of PRB media and will require long-term groundwater monitoring to ensure effectiveness over time.

Additional Data Needs. If PRB is selected, geochemical bench scale and pilot testing is recommended to evaluate the optimal reactive media composition and PRB lifespan as a function of competing COI concentrations. Geotechnical and hydrogeologic testing should also be undertaken to evaluate soil and bedrock properties and potential terminal depth of a PRB prior to design.

Conclusions. Based on a review of the groundwater quality data from the OPPD groundwater monitoring and anticipated depth to bedrock, further evaluation of a PRB for the NC2 Ash Disposal Area should not be considered.

4.2.3 Measure 3 – Groundwater Extraction and Treatment

Description. As an alternative to in-situ groundwater treatment methods, groundwater capture provides hydraulic control to reduce or prevent COIs from migrating offsite and/or to surface water receptors. The capture of groundwater can be done through conventional groundwater extraction wells or recovery trenches used to intercept groundwater flow. Extracted groundwater could be treated and conveyed back to the plant and used as make-up water, discharged directly to a surface water body through an NPDES permitted discharge, discharged to a local publicly-owned treatment works (POTW), or re-infiltrated upgradient of the landfill, depending on the site conditions and permitting requirements. Active groundwater treatment systems are generally costly to construct (depending upon the flow rate required) and require long-term O&M; but can be designed to provide effective hydraulic control of COIs.

Applicability to the NC2 Ash Disposal Area. An appropriately designed groundwater extraction system would effectively provide hydraulic containment of impacted groundwater and prevent migration of COIs. It is anticipated that a groundwater extraction and treatment system would operate until GWPSs have been attained at the waste boundary. Hydraulic control coupled with source control would decrease the amount of time required to attain compliance with established GWPSs downgradient of the NC2 Ash Disposal Area. Methods to treat or remove lithium have been well documented and are readily available.

OPPD currently has four production wells at the Station which are used to obtain water for onsite plant operations (**Figure 5**). The four production wells (PW-1 through PW-4) located southeast of the CCR unit provides hydraulic control of groundwater downgradient of the NC2 Ash Disposal Area and would reduce initial capital commitment and expediate implementation of a corrective measure. An initial steady-state groundwater flow model for the Site was completed in October 2018, and a transient flow model was completed in 2019. Although the flow models were originally completed for the NC1 Ash Disposal Area, they capture groundwater flow across the entire Station. The groundwater models include three of the four production wells (PW-1 through PW-3) and show groundwater flow downgradient of the NC2 Ash Disposal Area towards the production wells.

As previously mentioned, one sample of groundwater has been obtained from the three production wells (PW-1 through PW-3) and analyzed for lithium. Detections of lithium were below the BTV and GWPS; however, additional testing should be completed to further evaluate lithium concentrations in the groundwater extracted by the production wells.

Benefits. Under this scenario, OPPD may benefit from groundwater extraction and treatment as follows:

- Flexibility to capture and treat, if necessary, a variety of constituents in the future;
- Use of the existing production wells would reduce the amount of capital commitment and long-term O&M investment compared to other remedial alternatives; and,
- Well-known and generally accepted by regulatory agencies and third-party stakeholders.

Limitations. Under this scenario, OPPD may experience the following limitations:

- Distance of existing production wells from the area of lithium plume;
- May require additional monitoring wells located between the NC2 Ash Disposal Area and the production wells to monitor constituent concentrations and migration; and,
- Generally requires a long-term O&M commitment.

Additional Data Needs. With this measure, it is recommended that additional groundwater modeling for the fate and transport of COIs be performed to evaluate pumping effects on the groundwater plume and to estimate the time that will be required to meet the GWPS at the compliance wells. Additional groundwater samples from the production wells should be collected to further evaluate the current concentrations of lithium in the production wells. If concentrations of lithium increase at the production wells, then design and implementation of a water treatment system may be required. The existing production wells are currently used for plant operations. Groundwater extracted from the production wells would need to continue to be used for plant operations either with or without prior treatment.

Based on concentrations determined at the extraction/production wells, additional NPDES permitting efforts may be required to discharge groundwater with or without prior treatment. If necessary, pilot testing of various treatment technologies should also be completed to properly design a treatment system that will meet applicable discharge requirements.

Conclusions. Based on a review of the groundwater quality data from the OPPD groundwater monitoring (low concentrations) and the location of the lithium plume with respect to production wells, further evaluation of a groundwater capture and treatment system for the NC2 Ash Disposal Area should be considered at this time.

4.2.4 Measure 4 – Monitored Natural Attenuation

Description. Monitored natural attenuation (MNA) is a well-accepted strategy by state and federal regulators as an appropriate mitigative factor that should be considered when evaluating passive and active remedial options (USEPA, 1999, 2007a, 2007b). The USEPA has established a tiered series of steps to evaluate whether MNA would sufficiently lower concentrations of COIs on an appropriate timescale, and whether there is sufficient system capacity and stability for MNA mechanisms (USEPA, 1999, 2007a, 2007b). The MNA demonstration process results in increasing levels of confidence in the reliability of MNA as a corrective measure. Natural attenuation mechanisms include adsorption of COIs, ion exchange, precipitation of COI-containing minerals, and dilution/dispersion. In addition to adsorption to soil, clay particles, and organic matter, iron and manganese oxides that commonly precipitate downgradient of CCR disposal sites will, in turn, remove other COIs by adsorption.

The geochemical processes driving mobilization and sequestration of these metals are well documented. Detailed scientific studies conducted by and for the EPA on natural attenuation of metals have resulted in an understanding of the geochemical parameters which indicate that favorable conditions are present at a facility for natural attenuation of these redox sensitive metals to occur. The ability to achieve cleanup standards at the point of compliance can be demonstrated through long term monitoring.

Applicability to the NC2 Ash Disposal Area. For MNA to be a viable option at the NC2 Ash Disposal Area, 1) a sufficient buffer of non-impacted soil and groundwater is required between the landfill and off-site groundwater use wells and the Missouri River to allow for attenuation, 2) the source of potential groundwater impacts must be eliminated or controlled (i.e., additional management of windblown CCR), and 3) subsurface conditions need to be appropriate to attenuate COIs. The OPPD site has a sufficient buffer of non-impacted soil and groundwater to attenuate the site-specific COIs. Based on the data collected for the NES, lithium concentrations are localized at the downgradient monitoring points in the vicinity of the NC2 Ash Disposal Area. Modifications to the management of windblown ash from the NC2 Ash Disposal Area is expected to provide further control as a source or contributing factor (i.e., lithium concentrations downwind of the landfill). The NC2 Ash Disposal Area has an engineered composite liner and leachate extraction system between the liner and the groundwater. Based on site investigations, the COIs are not a result of a release through the landfill and instead are from windblown ash being deposited outside of the landfill footprint. The NC1 Ash Disposal Area is located downgradient of the NC2 Ash Disposal Area and has its own monitoring network wells which are monitored for the same COIs.

Per USEPA and EPRI studies, MNA has been demonstrated to be effective in reducing concentrations of arsenic through sorption to aquifer materials and dispersion/dilution. Less data are available for lithium, but additional sampling and bench-scale testing of site-specific materials could be conducted to evaluate the site-specific aquifer capability to attenuate lithium.

Implementation of MNA does not require intrusive construction which minimizes any potential safety impacts to site personnel. Residual generation of media of concern is restricted to those associated with sampling. Reliability as a remedial alternative has generally been higher at sites where the occurrence of natural attenuation has been documented. The specific case history for natural attenuation of lithium is limited; however, given the low concentrations on-site, the long-term reliability of MNA to achieve remedial goals is expected to be good. Implementation of MNA at the site can begin immediately upon selection. The installation of additional monitoring wells are not anticipated to be required.

Benefits. Under this scenario, OPPD could benefit from MNA as follows:

- Low cost to implement and can be implemented immediately;
- Could eliminate the need for costly active corrective measures (e.g., groundwater extraction and treatment);
- Monitoring provides tracking of COIs extent and upgradient levels;
- Has demonstrated record of regulatory acceptance for certain COIs; and,
- Does not require installation of new infrastructure.

Limitations. Under this scenario, OPPD may experience the following limitations:

- Must be demonstrated to be effective for site-specific COIs via completion of the USEPA Tiered Approach; and,
- Would require some form of source control.

Additional Data Needs. With source controls, the use of MNA for inorganic constituents should be evaluated using the USEPA Tiered Approach. To implement the EPA methodology, additional sampling of soil and groundwater should be conducted to evaluate potential attenuation mechanisms and capacity. This work would likely consist of solid-water pair comparison of COI concentrations and laboratory determination of solid-water partitioning coefficients to measure the susceptibility of COIs to sorb to solids and be attenuated. After laboratory testing, rate of attenuation could be demonstrated through groundwater modeling to predict concentration gradients over time and evaluate reaction mechanisms.

Conclusions. MNA should be further considered as a corrective measure for the NC2 Ash Disposal Area and carried forward for additional evaluation as either a standalone corrective measure, or in combination with other corrective measures (e.g. source control).

5 Corrective Measures for Further Evaluation

Based on the foregoing and the historical information, HDR recommends that the following measures be further evaluated for implementation at the NC2 Ash Disposal Area to address COI (lithium) identified as an SSL:

- Source Control Measures;
- Groundwater Extraction & Treatment; and
- Monitored Natural Attenuation.

A summary of each measure carried forward for further evaluation, including comments on feasibility of implementation, risks, benefits and limitations and what information is needed to further evaluate the effectiveness and implementability is provided in the attached Risk Balanced Technical Options table (**Table 1**).

5.1 Source Control Measures

5.1.1 Summary of Approach

Source controls are proposed to be implemented for the mitigation of windblown ash from the NC2 Ash Disposal Area. A further evaluation of the potential technologies and their effectiveness to reduce ash from leaving the landfill is required to determine which technology would best serve OPPD. Source controls removes the windblown ash as potential source of COIs through direct contribution from ash being deposited on the ground surface and mobilization of COIs Source controls can be initiated immediately and completed within year 2021.

5.1.2 Assumptions

The following assumptions were made in considering this approach:

- Costs can vary greatly between mitigation technologies chosen.
- OPPD will use onsite watering equipment to apply binding surface particles. Additional specialized equipment, such as hydroseeders, would be required for application of Sealing Surface with Low to Non-Permeable Materials.
- OPPD will apply products to the landfill with onsite personnel.

5.2 Groundwater Extraction & Treatment

5.2.1 Summary of Approach

This measure is intended to hydraulically control groundwater impacted from the COIs in the vicinity of the NC2 Ash Disposal area and, if necessary, treat CCR-impacted groundwater. It does not directly address the source of the COI impact (i.e. windblown ash leaching to groundwater). Under this scenario, existing production wells could be used for capture of CCR impacted groundwater. Groundwater from the production wells would be tested to determine if treatment prior to use in plant operations or subsequent discharge would be necessary. Additional monitoring wells located between the NC2 Ash Disposal Area and the production wells may be required to monitor lithium concentrations.

5.2.2 Assumptions

The following assumptions were made in considering this approach:

- The existing Site production wells and pumping rates adequately achieve hydraulic control.
- Up to four additional monitoring wells may need be installed between the NC2 Ash Disposal Area and the existing production wells to monitor COIs.
- Site-specific COIs in extracted groundwater can be treated using ZVI or other media and granular filtration with pH adjustment.
- The extracted groundwater can continue to be used in plant operations and/or discharged through an existing NPDES-permitted outfall at levels that meet permit requirements.

5.3 Monitored Natural Attenuation

5.3.1 Summary of Approach

This measure can be implemented immediately with the semi-annual sampling events. The USEPA has established a tiered series of steps to evaluate whether MNA would sufficiently lower concentrations of COIs on an appropriate timescale, and whether there is sufficient system capacity and stability for MNA mechanisms (USEPA, 1999, 2007a, b). The MNA demonstration process results in increasing levels of confidence in the reliability of MNA as a corrective measure. Natural attenuation mechanisms include adsorption of COIs, ion exchange, precipitation of COI-containing minerals, and dilution/dispersion. In addition to adsorption to soil, clay particles, and organic matter, iron and manganese oxides that commonly precipitate downgradient of CCR disposal sites will, in turn, remove other COIs by adsorption.

Additional sampling of soil and groundwater would be conducted to evaluate potential attenuation mechanisms and capacity. This work would likely consist of solid-water pair comparison of COI concentrations and laboratory determination of solid-water partitioning coefficients to measure the susceptibility of COIs to sorb to solids and be attenuated. After laboratory testing, rate of attenuation could be demonstrated through groundwater modeling to predict concentration gradients over time and evaluate reaction mechanisms.

5.3.2 Assumptions

The following assumptions were made in considering this approach:

- Development of MNA demonstration process for lithium via completion of the USEPA Tiered Approach.
- Results of USEPA Tiered Approach for MNA of lithium indicates favorable subsurface conditions for attenuation with no enhancement necessary.
- Quarterly groundwater monitoring of up to two additional monitoring wells for two years (delineation wells) followed by semi-annual monitoring is conducted for COIs for a period of 30 years.

6 Additional Data Needs

While completing this assessment of corrective measures, HDR identified the following data gaps that need to be addressed to further provide information on source control measures and monitoring options related to the NC2 Ash Disposal Area and the alternatives presented herein.

- Additional information from vendors on implementation of windblown ash mitigation products for the NC2 Ash Disposal Area, and additional research to determine the impacts, if any, of added products on the ash landfill could have for future potential beneficial reuse of ash.
- Groundwater modeling to confirm the effectiveness of existing production wells for hydraulic control of groundwater in the vicinity of the NC2 Ash Disposal Area. If the existing production wells can't be used, then additional modeling and design of a new extraction well network would be required.
- Groundwater sampling of existing production wells to determine if treatment of extracted groundwater is necessary. If necessary, pilot/bench scale studies of treatment options should be evaluated.
- Groundwater flow and transport modeling to estimate the time required to meet GWPS using a given alternative. Groundwater modeling can also provide technical justification that can be used with regulators and third-party groups who may question and/or challenge the decision-making process and/or effectiveness of the alternative selected.

7 References

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Figures

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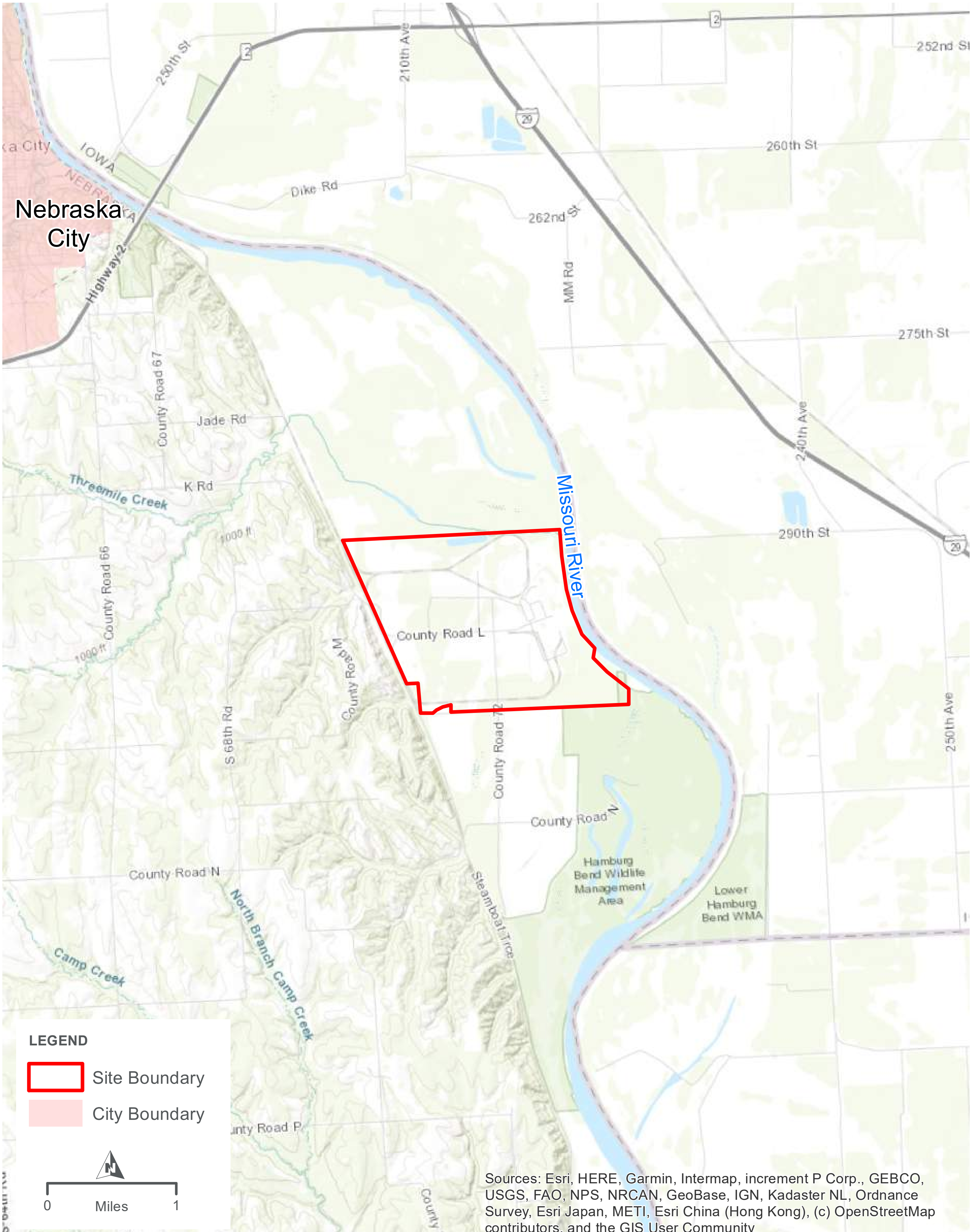
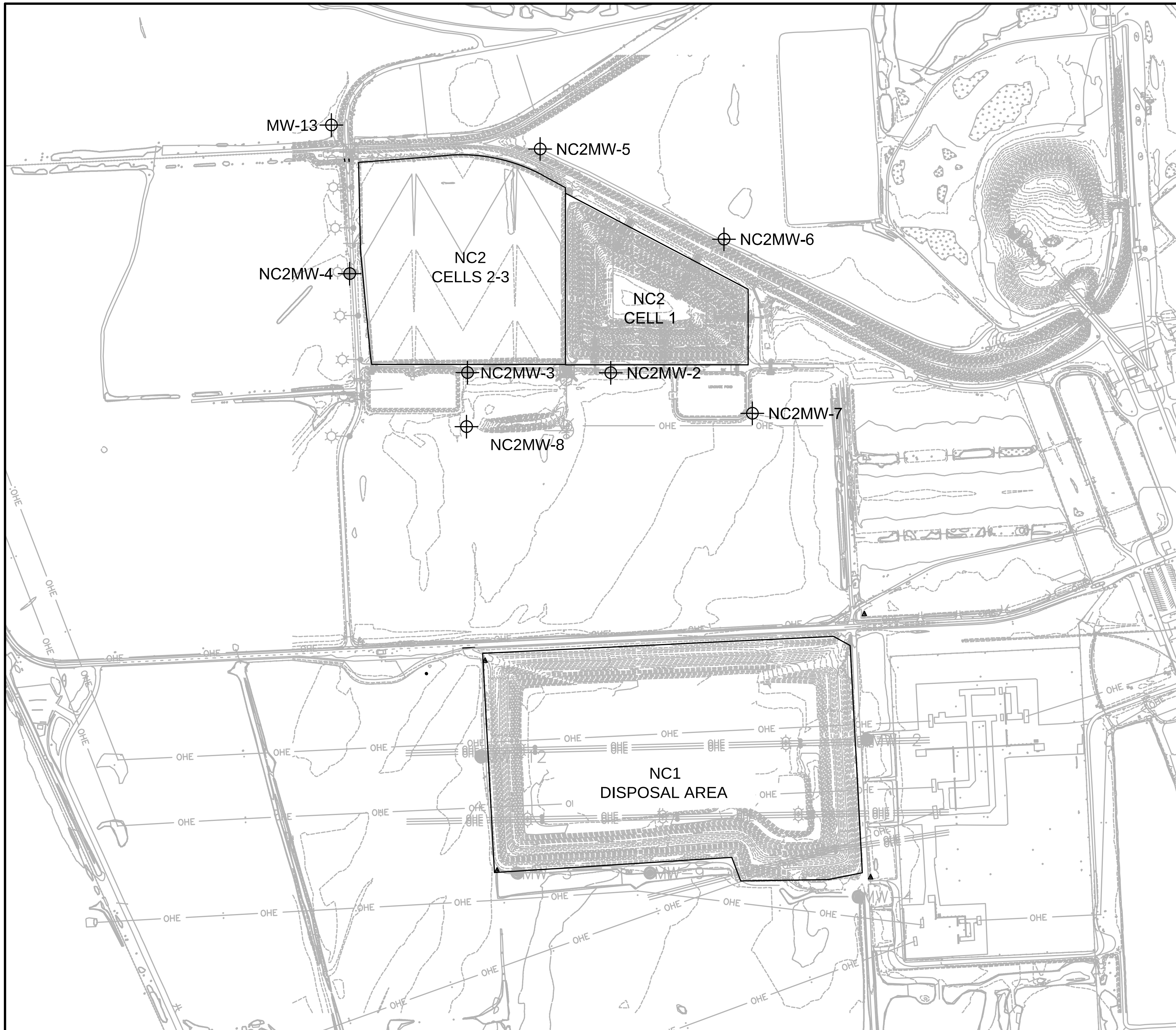


SITE LOCATION MAP

OPPD - NEBRASKA CITY STATION

FIGURE 1

PATH: D:\TEMP\AZIGLER\OPPD\NEBRASKA_CITY\FIG1_SITEMAP.MXD - USER: AZIGLER - DATE: 7/31/2019



MONITORING WELL NETWORK

WELL ID	NORTHING	EASTING	ELEVATION (TOC)	WELL DEPTH	LOCATION WITH RESPECT TO NC2 ASH DISPOSAL AREA
MW-13	318186.64	2808434.68	918.05	13.0	BACKGROUND / UPGRADIENT
NC2MW-2	316884.69	2809902.40	922.55	17.0	DOWNGRADIENT
NC2MW-3	316885.96	2809149.54	916.22	12.0	DOWNGRADIENT
NC2MW-4	317405.90	2808530.80	919.62	14.0	BACKGROUND / UPGRADIENT
NC2MW-5	318060.54	2809531.90	922.76	15.2	BACKGROUND / UPGRADIENT
NC2MW-6	317587.46	2810497.97	919.72	11.0	CROSSGRADIENT
NC2MW-7	316671.78	2810647.12	918.37	21.0	DOWNGRADIENT
NC2MW-8	316601.90	2809145.16	918.18	15.0	DOWNGRADIENT

NOTES:

1. TOC - TOP OF CASING
2. TOP OF CASING ELEVATION DETERMINED BY SURVEY DATA OBTAINED JUNE 2019.
3. WELL DEPTH MEASUREMENTS REPRESENT DEPTH BELOW GROUND SURFACE.
4. WINDBLOWN ASH IS SUSPECTED TO HAVE ORIGINATED FROM NC2 CELL 1 BEFORE CAPPING OCCURRED IN 2015. WINDBLOWN ASH IS SUSPECTED TO BE CURRENTLY ORIGINATING FROM NC2 CELLS 2 & 3.

Omaha Public Power District

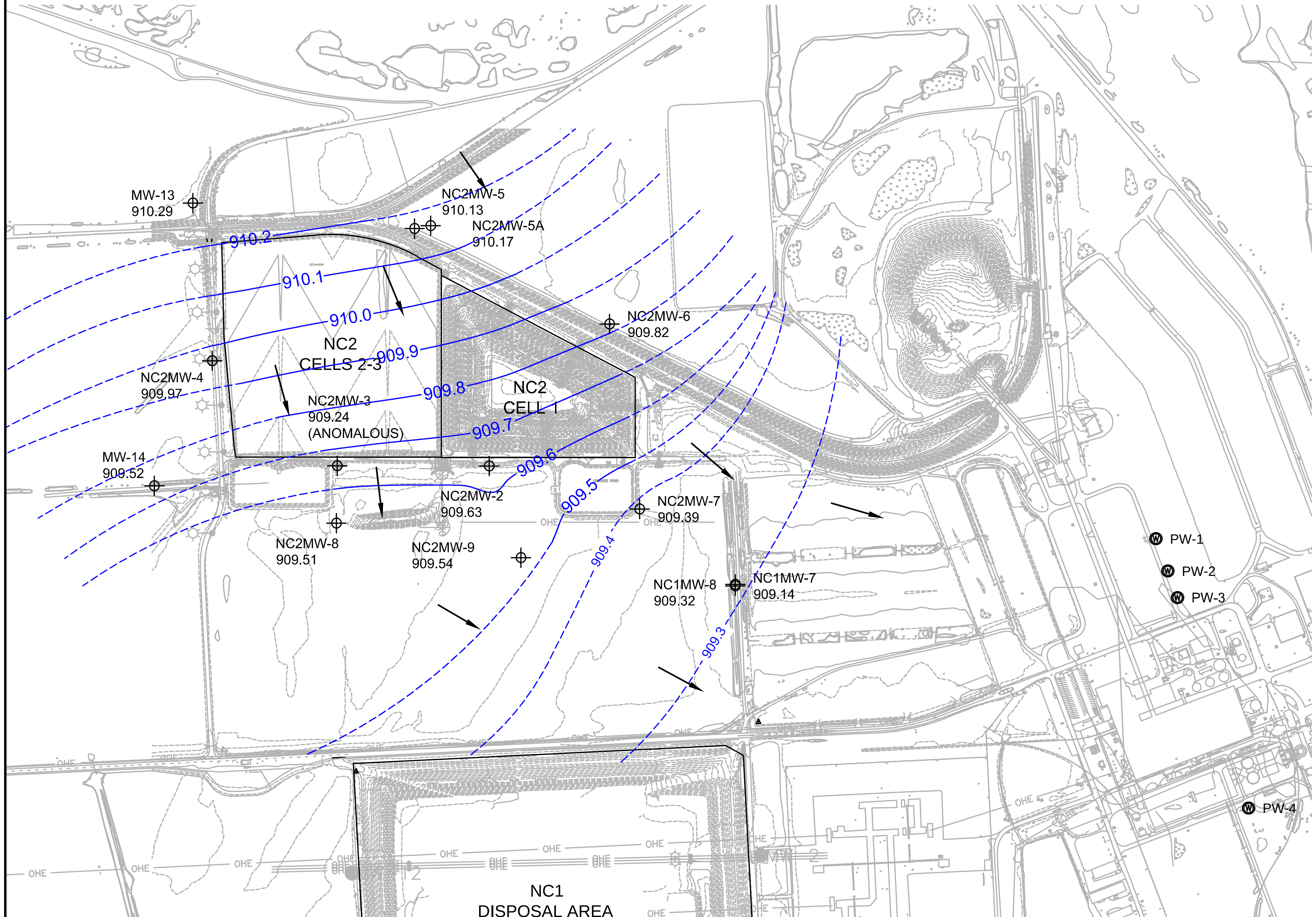
OPPD NEBRASKA CITY ASH LANDFILL
NEBRASKA CITY UNIT 2 - NC2
MONITORING WELL LOCATION MAP

ASSESSMENT OF CORRECTIVE MEASURES

DATE
DECEMBER 2020

FIGURE
02

C:\pwworking\central01\d1756684\NC 2 - Figure 1.dwg, ACM, 12/4/2020 12:50:46 PM, WNICHOLSON



N

600 0 600 1200

SCALE IN FEET

LEGEND:

- PRODUCTION WELL
- MONITORING WELL
- 909.39 GROUNDWATER ELEVATION
- 910 GROUNDWATER CONTOUR
- INFERRED GROUNDWATER CONTOUR
- INFERRED GROUNDWATER FLOW DIRECTION

NOTES:

1. ANOMALOUS - WATER LEVELS LABELED AS SUCH HAVE BEEN OMITTED FROM THE GROUNDWATER CONTOUR.
2. MONITORING WELL MW-14 WAS NOT USED IN GENERATION OF CONTOUR MAP DUE TO BEING SCREENED IN CLAY MATERIAL AND ALL OTHER WELLS BEING SCREENED IN SAND.
3. MONITORING WELL NC1MW-7 WAS NOT USED IN GENERATION OF CONTOUR MAP DUE TO BEING SCREENED AT A DEEPER INTERVAL.

VELOCITY COMPUTATIONS

TRACER VELOCITY = $V_T = \frac{Ki}{n}$

K = HYDRAULIC CONDUCTIVITY (SEE TABLE)

i = GRADIENT = $\frac{1.0 \text{ FT}}{3{,}109 \text{ FT}}$ = 0.000322 FT/FT

n = POROSITY = 0.405

	K	V_T
LOW	6.96 FT/DAY	0.00553 FT/DAY
HIGH	39.4 FT/DAY	0.0312 FT/DAY

OPPD
Omaha Public Power District

HDR

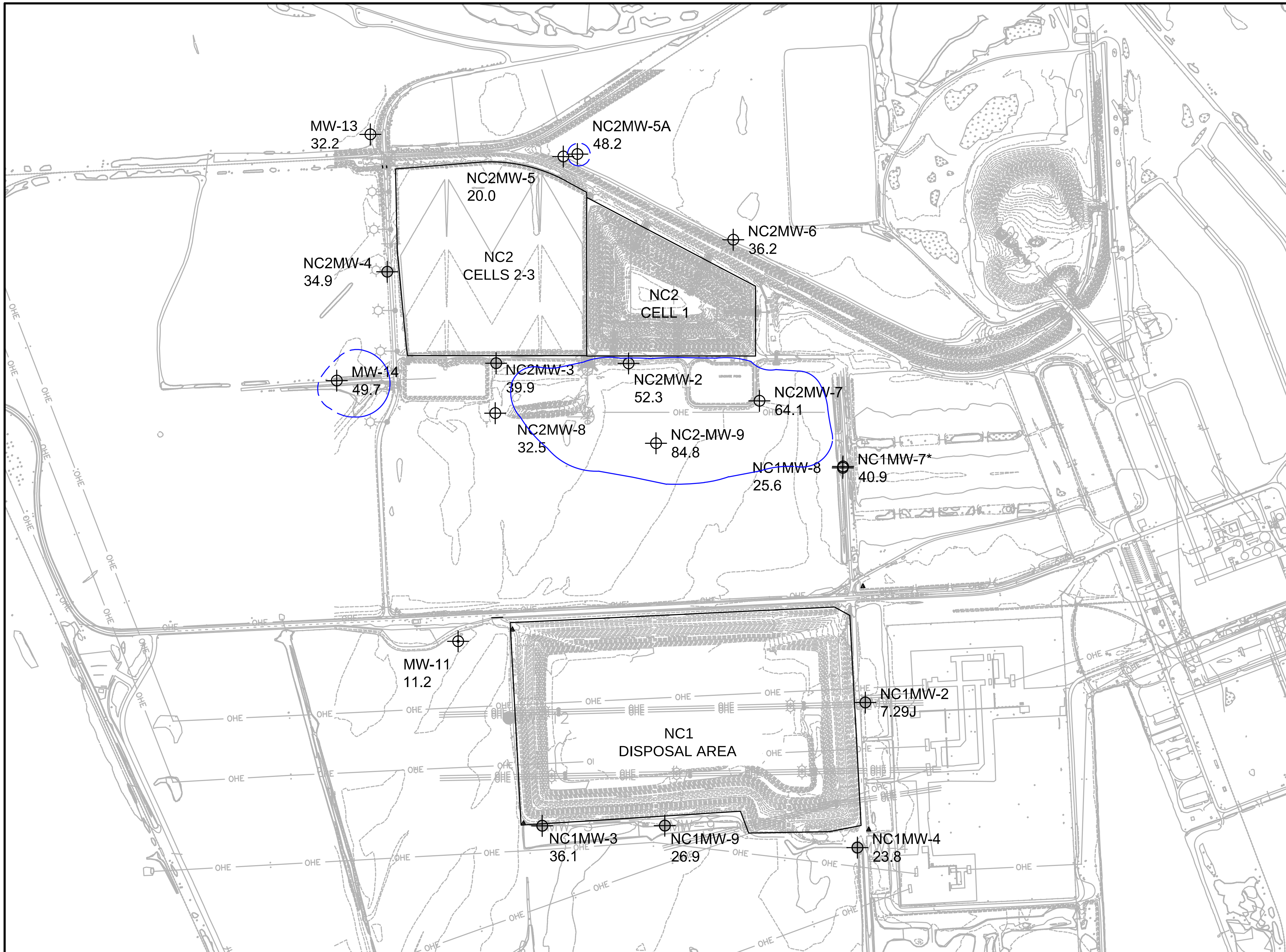
OPPD NEBRASKA CITY ASH LANDFILL
GROUNDWATER CONTOUR MAP
OCTOBER 2020

ASSESSMENT OF CORRECTIVE MEASURES

DATE
DECEMBER 2020

FIGURE
03

C:\pwworking\central01\d1756684\NC 1_2 - Figure 1 - Fall 2020 - NO NC1 or MW-14.dwg, ACM, 12/15/2020 12:22:37 PM, WNICHOLSON



N

600 0 600 1200

SCALE IN FEET

LEGEND

NC2MW-6 36.2 — MONITORING WELL CONCENTRATION - ug/L

BTV & GWPS - 42.3 ug/L

NOTES:

1. BTV - BACKGROUND THRESHOLD VALUE.
2. GWPS - GROUNDWATER PROTECTION STANDARD.
3. GWPS IS ESTABLISHED AS THE U.S. EPA MAXIMUM CONTAMINANT LEVEL (MCL) OR THE GWPS SPECIFIED IN §257.95(h)(2).
4. GWPS IS ESTABLISHED AS THE BTV WHEN THE BACKGROUND LEVEL IS HIGHER THAN THE U.S. EPA MCL OR THE GWPS SPECIFIED IN §257.95(h)(2).
4. < - DENOTES CONCENTRATION IS BELOW THE ANALYTICAL METHOD DETECTION LIMIT.
5. *MONITORING POINT NC1MW-7 IS A DEEP SCREENED WELL AND THEREFORE WAS NOT UTILIZED IN THE GENERATION OF THIS ISO-CONCENTRATION MAP.
6. ONLY UPGRADIENT WELLS FOR THE NC1 ASH DISPOSAL AREA WERE UTILIZED IN THE GENERATION OF ISO-CONCENTRATION MAPS.
7. THE AREA OUTLINED AS THE BTV & GWPS COMPLIANCE LINE IS THE AREA OF CONCERN SUSPECTED TO BE IMPACTED FROM WINDBLOWN ASH ORIGINATING FROM NC2 CELLS 2 & 3.

C:\pwworking\central01\d1756684\NC 2 - Figure 8 - Lithium Concentration Map - October 2020.dwg, ACM, 12/4/2020 1:26:37 PM, WNICHOLSON

OPPD Omaha Public Power District

HDR

OPPD NEBRASKA CITY ASH LANDFILL
NEBRASKA CITY UNIT 2 - NC2
ISO-CONCENTRATION - LITHIUM OCTOBER 2020

ASSESSMENT OF CORRECTIVE MEASURES

DATE
DECEMBER 2020

FIGURE
04

C:\pwworking\central01\d1756684\NC 2 - Figure 6 - Lithium Concentration Map - October 2020.dwg, Plot, 11/9/2020 11:16:09 AM, WNICHOLSON

OPPD
Omaha Public Power District

HDR

OPPD NEBRASKA CITY ASH LANDFILL
NEBRASKA CITY UNIT 2 - NC2
ON-SITE PRODUCTION WELL LOCATIONS

ASSESSMENT OF CORRECTIVE MEASURES

DATE
DECEMBER 2020

FIGURE
05

Table 1 – Risk Balanced Technical Options

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Table 1. Risk Balanced Technical Options – NC2 Ash Disposal Area

Corrective Measures	Risks, Key Assumptions, & Benefits	Relative Ease of Implementation 1 = easy 2 = moderately easy 3 = moderate 4 = moderately difficult 5 = difficult	Potential Impacts of Remedy (Safety, cross-media impacts, expose to residual contamination)	Relative Time Required for Implementation / Completion of Corrective Measure 1 = 1 – 5 years 2 = 5 – 10 years 3 = 10 – 50 years 4 = 50 – 100 years 5 = 100+ years	Institutional Requirements (Permits or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Source Control Measures	**Key Assumptions** • Dust mitigation technologies can be applied to CCR operations. • Application of products would not affect the potential for recovery of CCR in the future for beneficial reuse. • Most of the mitigation technologies can be implemented and maintained by OPPD personnel • Source control measures would be coupled with long-term monitoring (LTM) to gage the effectiveness over time. **Risks** • Some technologies can be costly and logistically challenging to implement. • May still require remediation of impacted groundwater through either active (i.e., pump and treat) or passive means (i.e., MNA). • Water-based applications may create safety concerns in freezing temperatures. **Benefits** • Removal of windblown CCR eliminates ongoing source of groundwater impacts. • Application timing can vary and may only require limited applications throughout the year. • Depending on the technology, can be repositioned or applied based on prevailing wind direction.	2 to 3 Depending on the selected source control measure(s)	• Water-based applications may create safety concerns in freezing temperatures. • No additional exposure to CCR materials with implementation of source control measures. • Source control measures will be implemented within the landfill, so no cross-media impacts are anticipated.	1 / 2-3* • Source control measures can be implemented and completed sooner than other measures. • *Source control will continue for the estimated lifespan of the NC2 Ash Disposal Area (approximately 4 years). • LTM would be required to monitor for decreases in COIs in groundwater.	• Landfill will continue to be monitored per State and Federal regulations. Selected alternative will require State approval. • No permits or other requirements anticipated.	• Additional research to determine potential impacts of added products on ash within the landfill and how it could impact potential future beneficial reuse of the ash.	• Obtain further information from vendors on application at NC2 Ash Disposal Area; including additional implementation data, cost analysis, and effectiveness of each source control measure for the NC2 Ash Disposal Area

Corrective Measures	Risks, Key Assumptions, & Benefits	Relative Ease of Implementation 1 = easy 2 = moderately easy 3 = moderate 4 = moderately difficult 5 = difficult	Potential Impacts of Remedy (Safety, cross-media impacts, expose to residual contamination)	Relative Time Required for Implementation / Completion of Corrective Measure 1 = 1 – 5 years 2 = 5 – 10 years 3 = 10 – 50 years 4 = 50 – 100 years 5 = 100+ years	Institutional Requirements (Permits or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Groundwater Extraction and Treatment	**Key Assumptions** • The existing Site production wells and pumping rates would adequately maintain hydraulic control. Additional groundwater modeling will be used to verify use of existing wells. • Additional monitoring wells (up to four) installed between the NC2 Ash Disposal Area and existing production wells would be installed to monitor constituent concentrations at depths greater than compliance monitoring wells. • COIs in soil have either completely leached into groundwater or have leached to the extent that extraction and treatment could be accomplished within a period of time comparable to other corrective measures evaluated herein. • The underlying limestone bedrock is competent and non-karst such that it provides an impermeable lower hydrogeologic boundary that restricts upward flow of groundwater from bedrock to overburden during pumping. • Site-specific COIs in extracted groundwater can be treated using ZVI and granular filtration with pH adjustment, if necessary. • The extracted groundwater can be used in plant operations and/or discharged through an existing NPDES-permitted outfall at levels that meet permit requirements. • Performance monitoring of existing monitoring network plus up to 6 additional monitoring wells is conducted semi-annually for a period of 30 years following system start-up. **Risks** • Existing production wells may not be sufficient for hydraulic control and a new extraction system may be required. • This corrective action alone does not address ongoing management of windblown ash from the NC2 Ash Disposal Area to provide further control as a source.	1 Assuming existing Site Production Wells are used	• No safety or exposure to contamination anticipated. Existing production wells are used for plant operations and are not sources of potable water for the Site. • Groundwater extracted from Site production wells are expected to have low concentrations of COIs based on historical sampling data. • No additional exposure to COIs with implementation of this corrective measure.	1 / 2-3* • *Time required for completion of remedy is estimated at this time. Additional information is needed for validation of remedial timeline. • LTM would be required to monitor for decreases in COIs in groundwater.	• Landfill will continue to be monitored per State and Federal regulations. Selected alternative will require State approval. • May need revision to existing NPDES permit for discharge of extracted groundwater.	• Additional evaluation of the existing groundwater model should be performed to use of existing Site production wells for extraction wells. • If existing production wells are not sufficient then additional aquifer testing and hydrogeologic assessment should be conducted to provide data necessary for detailed system design. This should include completion of 72-hour step, drawdown, and continuous rate aquifer pumping tests to evaluate hydraulic conductivity and refine estimated quantity/location of extraction wells. • Additional samples from existing production wells to determine concentration of COIs in production wells. • Pilot testing of various treatment technologies may be required to properly design a treatment system if additional discharge limits are required by NDEE. • Groundwater modeling to estimate the time that will be required to meet the GWPS at the compliance monitoring wells.	• This corrective action could be a viable option if existing production wells provide appropriate hydraulic control and capture of the COIs downgradient of the NC2 Ash Disposal Area. • Additional groundwater monitoring wells should be installed between the NC2 Ash Disposal Area and production wells to monitor COIs. • Groundwater Fate and Transport modeling should be done to determine constituent transport and time required to meet the GWPS. • Source control measures should be implemented to eliminate ongoing source of COIs.

Corrective Measures	Risks, Key Assumptions, & Benefits	Relative Ease of Implementation 1 = easy 2 = moderately easy 3 = moderate 4 = moderately difficult 5 = difficult	Potential Impacts of Remedy (Safety, cross-media impacts, expose to residual contamination)	Relative Time Required for Implementation / Completion of Corrective Measure 1 = 1 – 5 years 2 = 5 – 10 years 3 = 10 – 50 years 4 = 50 – 100 years 5 = 100+ years	Institutional Requirements (Permits or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Groundwater Extraction and Treatment (continued)	**Benefits** • Flexibility to capture and treat (if necessary) a variety of constituents in the future. • Well-known and generally accepted by regulatory agencies and third-party stakeholders.						
Monitored Natural Attenuation	**Key Assumptions** • Natural attenuation mechanisms include adsorption of COIs, ion exchange, precipitation of COI-containing minerals, and dilution/dispersion. In addition to adsorption to soil, clay particles, and organic matter, iron and manganese oxides that commonly precipitate downgradient of CCR disposal sites will, in turn, remove other COIs by adsorption. • COIs in soil have either completely leached into groundwater or have leached to the extent that extraction and treatment could be accomplished within a period of time comparable to other corrective measures evaluated herein. • Performance monitoring of existing monitoring network plus up to 4 additional existing delineation monitoring wells is conducted semi-annually for a period of 30 years following system start-up. **Risks** • The ability to achieve cleanup standards at the point of compliance wells will not be met in a reasonable timeframe. • This corrective action alone does not address ongoing management of windblown ash from the NC2 Ash Disposal Area to provide further control as a source **Benefits** • Low cost to implement and can be implemented immediately • Does not require installation of new infrastructure	1	• No additional exposure to COIs with implementation of this corrective measure.	1 / 3* • *Time required for completion of remedy is estimated at this time. Additional information is needed for validation of remedial timeline.	• Landfill will continue to be monitored per State and Federal regulations. Selected alternative will require State approval. • No permits or other requirements anticipated.	• Completion of the USEPA Tiered Approach for MNA should be conducted to evaluate if attenuation is occurring and estimate the rate of attenuation as a means of passive groundwater remediation.	• MNA should be used in conjunction with LTM and source control measures.