Assessment of Corrective Measures for Groundwater at Omaha Public Power District (OPPD) North Omaha Station

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Omaha Public Power District

PROFESSIONAL CIVIL ENGINEER
GARRETT MICHAEL WILLIAMS
E-15124
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STATE OF NEBRASKA

Contents

Acronyms

bgs	below ground surface
CCR	Coal Combustion Residuals
CCR Rule	United States Environmental Protection Agency's Disposal of Coal Combustion Residuals from Electric Utilities
COIs	Constituents of Interest
EPRI	Electric Power Research Institute
GPS	Groundwater Protection Standard
HDR	HDR Engineering, Inc.
ITRC	Interstate Technology & Regulatory Council
MCLs	Maximum Concentration Limits
MNA	Monitored Natural Attenuation
NDEQ	Nebraska Department of Environmental Quality
NOS	North Omaha Station
O&M	Operation and Maintenance
OPPD	Omaha Public Power District
PRB	Permeable reactive barrier
USEPA	United States Environmental Protection Agency
ZVI	Zero-Valent Iron

Executive Summary

The Omaha Public Power District (OPPD) operates the North Omaha Station (NOS), a fossil fuel-fired generating plant, in Omaha, Nebraska. The station is located east of Pershing Drive and Craig Street, approximately 3.5 miles northwest of the Eppley airfield, along the western shore of the Missouri River at mile 625.2. As part of the coal handling process, OPPD operates the North Omaha Ash Landfill (landfill), totaling approximately 23.8 acres with approximately 17.9 acres used for current ash disposal operations (active), approximately 4.5 acres of formerly closed under pre-Subtitle D regulations (inactive) and approximately 1.4 acres of permitted undeveloped area for ash disposal. The landfill is permitted under the current NDEQ Title 132 regulations for fossil fuel combustion ash disposal areas (NDEQ Permit No. NE0054739, Facility ID 59763) and is located in the north / northwest portion of the site.

The North Omaha Ash Landfill 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 coal combustion residuals (CCR) within CCR units (defined as either landfills or surface impoundments). Section 40 CFR 257.90(e) of the CCR Rule specifies that an owner or operator of a CCR landfill must prepare an annual groundwater monitoring and corrective action report to summarize key actions completed, problems encountered, and planned activities relating to the groundwater monitoring system.

In accordance with 40 CFR 257.95(g), OPPD published notification on February 14, 2019 that concentrations of arsenic, selenium, cobalt, lithium, and molybdenum detected in groundwater monitoring wells at the North Omaha Ash Landfill resulted in statistically significant increases (SSIs) above Groundwater Protection Standards. In correspondence dated May 30, 2019, OPPD notified NDEQ of their intent to initiate corrective measures at the North Omaha Ash Landfill.

Subsequent to this notification, HDR Engineering, Inc. (HDR) performed a desktop analysis of corrective measures that could potentially be implemented at the North Omaha Ash Landfill to address constituents of interest (COIs) identified in groundwater underlying the North Omaha Ash Landfill unit at levels that exceed the Groundwater Protection Standards (GPS). Review of this information was completed to address requirements of 40 CFR § 257.96 Assessment of Corrective measures 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 completed assessment of corrective measures is to be placed in the facility's operating record. The assessment has been completed when it is placed in the facility's operating record as required by § 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 GPS, as established under 40 CFR § 257.95(d)(2);

3. Control the source(s) of releases so as 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 initial statistical analysis of groundwater quality data. HDR evaluated the potential effectiveness to treat site-specific COIs, feasibility of implementation, regulatory acceptance, while providing an order-of-magnitude cost opinion of each measure deemed feasible (i.e. preferred). HDR has also identified data gaps and provided recommendations on work that could be completed to gather additional data that would allow for further refinement of each corrective measure deemed applicable and potentially feasible in effectively addressing COIs identified in groundwater underlying the regulated unit.

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

- CCR Source Removal;
- Installation of a Permeable Reactive Barrier (PRB);
- Groundwater Extraction and Treatment;
- In-situ Soil Flushing; and,
- Monitored Natural Attenuation.

Subsequent to our evaluation, HDR carried the following three corrective measures forward for additional analysis and cost estimating (Class 5):

- CCR Source Removal;
- Installation of a PRB; and,
- Groundwater Extraction and Treatment.

While in-situ soil flushing and monitored natural attenuation (MNA) were not carried forward as stand-along corrective measures for further evaluation, re-infiltration of treated groundwater was included within the Groundwater Extraction and Treatment measure to enhance the hydraulic gradient at the Site, and MNA is included with each of the corrective measures as part of ongoing long-term groundwater monitoring.

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

1.0 Purpose

The purpose of this report is to summarize the evaluation of potentially viable corrective measures that could be implemented to effectively address COIs that have been detected above their respective GPS in groundwater underlying the North Omaha Ash Landfill.

Review of this information was completed to address requirements of 40 CFR § 257.96 Assessment of Corrective measures 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 completed assessment of corrective measures in the facility's operating record.

This evaluation is based on our 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 deemed applicable and feasible (i.e. preferred measure).

2.0 Background

The NOS is a five-unit fossil fuel-fired generating plant located approximately 3.5 miles northwest of Eppley Airfield on approximately 120 acres of land. NOS is bounded by Pershing Drive to the west and the Missouri River to the east. The first power generating unit started operation in 1954 and the fifth, and final unit, started in 1968. Units 1-3 were retired from operation (converted to natural gas), while Units 4 and 5 are still operating as coal-burning units. The NOS North Omaha Ash Landfill is located in the north-northwestern portion of the NOS property and is permitted under Nebraska Department of Environmental Quality (NDEQ) Title 132 (Permit NE-0054739). The permitted landfill footprint is 23.84 acres, including active (17.9 acres), closed (4.5 acres), and undeveloped (1.4 acres) portions, as shown on **Figure 1**. The western portion of the landfill is accessed through agreement and/or easement with the Metropolitan Utilities District (MUD) and the City of Omaha. OPPD plans to operate the active portion of the landfill through 2023. The landfill receives ash that is not sold as beneficial material, including both dry fly ash, conditioned with water prior to disposal, and bottom ash from dewatering bins. Sluice water used to transport bottom ash from the boilers to the dewatering bins is temporarily stored in nearby lined process water ponds. An inactive construction and demolition landfill is located at the north end of the landfill, which has since been covered with ash. Ash disposal has occurred on the site since the 1950s. The North Omaha Ash Landfill is defined as the active portion of the ash disposal area (approximately 18 acres) (EA 2016).

NDEQ-required groundwater monitoring has been conducted since 2001 for heavy metals, sulfate, and pH. Elevated concentrations have historically been observed for arsenic and sulfate in shallow monitoring wells, above USEPA MCLs, which are equivalent to NDEQ Title 118 Water Quality Standards (WQS).

OPPD is in the process of addressing the groundwater provisions of the CCR Rule and recently published a notification that the following Appendix IV constituents have been identified as SSIs above the established GPS: arsenic, selenium, cobalt, lithium, and molybdenum. In accordance with the Rule (Section 257.96), if one or more Appendix IV constituents are detected above their established GPS, the Owner/Operator must initiate the assessment of corrective measures (ACM) within 90 days of the detection. As part of the assessment of corrective measures, HDR has completed a desk top evaluation of potential corrective measures in an effort to assist OPPD identify appropriate corrective measure or combination of measures to implement at the NOS North Omaha Ash Landfill.

3.0 Assessment of Corrective Measures

HDR initially evaluated a number of corrective measures that were considered applicable to treat the COIs identified as SSIs in groundwater underlying the landfill. A brief description of each corrective measure that was identified as applicable to address CCR-related impacts to groundwater is presented below. After an initial review for technical feasibility, the list of corrective measures was narrowed down to those which were deemed feasible, based on the COIs and site constraints, and further evaluated for effectiveness, implementability, and regulatory acceptance.

For this evaluation, HDR has not coupled corrective measures, other than considering MNA with each corrective measure as a long-term, passive remedy for impacted groundwater. However, coupling of corrective measures such as partial source removal and PRB installation and/or groundwater extraction and treatment may be deemed viable alternatives, as additional site-specific testing and studies are conducted.

3.1 Description of Corrective Measures

3.1.1 Measure 1 – CCR Source Removal

Description. For the North Omaha Ash Landfill, CCR source removal consists of the excavation and disposal of CCR to an on-site (consolidated footprint) or an off-site lined facility. Initial CCR removal could be performed using conventional earth moving equipment. If dewatering of the lower portion of the landfill is required to facilitate dry removal or dredging of saturated ash, then additional specialized dewatering or dredging equipment would be required. CCR would then be loaded into trucks (or rail cars) for disposal in a newly permitted on-site CCR-compliant landfill, hauled off-site for disposal in a facility permitted to accept CCR material, or recycled via an on-site beneficiation facility.

Removal of CCR effectively eliminates the potential ongoing source of COIs leaching to groundwater; however, it does not immediately address COIs that have already reached groundwater. This measure can be expensive to implement depending on the amount of ash that requires disposal and the need to design, permit, and construct new or upgrade existing facilities to accept CCR. Additionally, depending on the extent of the impacts identified in groundwater down-gradient of the landfill and proximity to sensitive receptors (e.g., adjacent water bodies), active remediation may be necessary to control the migration of COIs in groundwater. Based on the estimated footprint of the ash disposal landfill and estimated thickness of ash (50 feet), HDR has estimated that approximately 1,000,000 cubic yards (CY) of ash will require excavation and relocation or disposal under this measure.

Through a combination of measures, it may be possible to reduce the amount of CCR that requires relocation and/or address site access and/or space limitations by relocating and/or consolidating all or a portion of the CCR in the regulated landfill unit. For example, HDR has employed engineering techniques at other facilities that allow ash to be vertically stacked or compacted within existing landfill space, reducing the footprint of the landfill and providing additional space for other uses (e.g., installation of a PRB and/or groundwater extraction and treatment facilities). The benefit can be a reduction in the relocation cost while increasing the implementability and effectiveness of the selected measure. This can also reduce the long-term O&M through the elimination or reduction in the source and treatment of the remaining COIs in groundwater, thereby reducing the time required to meet established groundwater protection standards. As stated earlier, with the exception of MNA, HDR has not evaluated the combination of measures but only the corrective measures individually.

Applicability to the North Omaha Ash Landfill. Some infrastructure at NOS (e.g. the adjacent rail line) is already in place and could be used to facilitate removal of CCR from the North Omaha Ash Landfill. However, a significant limitation that may impact the ability to implement this measure is the proximity of the landfill to the Missouri River. Due to the very close proximity of the landfill to the river any dewatering that is required to recover ash that exists below the water table will necessitate the removal and treatment of large volumes of water to overcome infiltration of water from the hyporheic zone of the river and maintain water levels that are below the bottom elevation of the ash. In turn, the structural stability of the levee could be compromised, if armoring (e.g., installation of sheet pile wall) of the levee is not performed prior to dewatering. This effort would also likely require US Army Corps coordination and approval.

Available land at NOS for siting a new CCR-compliant facility may also present challenges for on-site disposal. However, a beneficiation facility to recycle ash for use would occupy significantly less acreage than a new landfill and could take advantage of the rail line for off-site distribution of the finished product.

For off-site disposal, it is assumed that CCR would be excavated from the North Omaha Ash Landfill and loaded directly into rail cars on the adjacent rail line and transported to a permitted facility off site. As previously mentioned, a study is needed to identify off-site disposal facilities that are permitted to accept CCR. Factors such as loading, distance to permitted facilities, quantity of CCR to be transported, capacity of a facility to accept the CCR, and ability to accept rail shipments would need to be analyzed to evaluate logistic and economic feasibility of this alternative. Off-site disposal would also likely be limited by the need to dewater ash below the water table.

It is important to note that other utilities around the country (i.e., Virginia, North Carolina, and South Carolina) have either voluntarily or involuntarily (through litigation and new legislation) relocated CCR from unlined to lined facilities, potentially setting a precedent for subsequent CCR unit closures across the country.

Benefits. Under this scenario, OPPD could benefit from CCR source removal as follows:

- Removal of CCR eliminates ongoing source of groundwater impacts;
- Provides additional land area for implementation of groundwater remedies; and,
- Demonstrated regulatory, third-party, and public acceptance.

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

- Costly and logistically challenging to implement; those challenges can include:
  - Creating and/or finding landfill capacity for the ash to be removed;
  - Transporting such a large volume of ash either by truck or rail to a remote location;
  - Addressing traffic concerns if ash is hauled offsite by trucks; and
  - Dewatering areas of ash sufficiently to mechanically remove it.
- May still require remediation of impacted groundwater through either active (i.e., pump and treat) or passive means (i.e., MNA).

Additional Data Needs. A desktop review should be performed to identify local and regional facilities, landfills, or operations that may be able to beneficially reuse the material, or that may be able to accept the material under their existing permit. The number of facilities, their distance from NOS, the volume of material they can accept, and the amount that can be beneficially reused are all critical factors to providing a more precise cost estimate and to further evaluate the feasibility of this measure either independently or in combination with other corrective measures.

Additionally, it is recommended that additional evaluation of groundwater flow conditions, either through aquifer testing or groundwater flow, fate, and transport modeling, be completed to evaluate the hydrogeologic properties affecting groundwater flow and COI persistence and migration over time. Dewatering rates for excavation and the potential need for active or passive groundwater treatment after source removal can be evaluated using data obtained from the aquifer testing and/or groundwater modeling.

Conclusions. Based on the foregoing, CCR source removal should be retained for further evaluation by itself or possibly in combination with other remedial strategies/technologies such as MNA. Further evaluation of CCR source removal should be conducted to provide a better understanding of geotechnical and hydrogeologic properties as they would apply to earthwork/dewatering near the river and potential coupling of other corrective measures (e.g. MNA, groundwater extraction, PRB installation) to treat impacted groundwater.

3.1.2 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 down-gradient 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; organic materials such as mulch or wood chips to promote the reduction of sulfate to sulfide and precipitation of COIs as sulfide minerals; and/or zero-valent iron (ZVI) that would reduce the levels of a number of COI metals through adsorption/precipitation.

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 North Omaha Ash Landfill. Applicability of a PRB as a corrective measure for the North Omaha Ash Landfill is primarily a function of the location of the PRB and the site-specific COIs to be treated.

Given the limited land between the permitted disposal boundary and the levee along the Missouri River, this effort would likely require US Army Corps coordination and approval. Installation of a PRB down-gradient of the landfill would likely require use of specialized equipment that can trench and backfill reactive media simultaneously or through use of a trenchless system. In a trenchless system, the reactive components are injected into a void space or fracture that is created at the desired depth(s) using a series of wells. To that end, estimated costs for this corrective measure include the use of a specialized single-pass trencher capable of excavating a trench to a depth of 40 feet, while simultaneously filling the trench with a mixture of ZVI and aggregate.

In accordance with the notification posted by OPPD, corrective measures are required to treat arsenic, selenium, cobalt, lithium, and molybdenum. PRBs filled with ZVI have been used to effectively treat arsenic-impacted groundwater by adsorption onto the ferric hydroxide that forms on the surface of ZVI. However, as arsenic is removed, some iron can be mobilized with this approach. The iron can be removed in a subsequent PRB cell. ZVI-filled PRBs have also been successful in removing selenium and molybdenum in limited field applications (Morrison, et al. 2003). Other reactive materials, such as aluminum hydroxide (Kappen and Webb, 2013), rice husks (Amin et al. 2006), and ferrihydrite-coated sand (Mähler and Persson, 2013) could also be considered as part of future batch and/or pilot studies to target other site-specific COIs.

Based on a review of the groundwater quality data from the NOS site, it appears that a PRB could be designed to effectively remove the COIs that are known to be present in groundwater underlying the landfill. Further evaluation of a PRB for the North Omaha Ash Landfill should consider the following:

- The optimal location of the PRB or gate system would be down-gradient of the landfill. The area between the landfill and the Missouri River is limited. The proximity of the Missouri River and the protecting levee system may provide challenges to the installation of a PRB system.
- PRBs are generally anchored in bedrock or a continuous clay with low hydraulic conductivity. Reportedly, bedrock beneath the landfill consists of limestone with shale at an approximate depth of 35 to 70 feet below ground surface. 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 reach the

Missouri River untreated.

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

- Potentially eliminates the need for more costly measures, (e.g., CCR source removal);
- Minimizes disruption to NOS site operations;
- Flexibility to treat a variety of constituents depending on media or mix of media selected, following batch and pilot studies;
- Lower O&M costs when compared to groundwater extraction and treatment; and,
- Demonstrated to effectively treat site-specific COIs of arsenic, selenium, and molybdenum.

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

- Limited space down-gradient of the landfill, possibly making installation difficult and expensive;
- Availability and expense of the quantity of ZVI needed for this application;
- Underlying bedrock may not be competent enough to anchor the base 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. Geochemical 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 properties and potential terminal depth of a PRB prior to design.

Conclusions. Based on the foregoing, installation of a PRB should be retained for further evaluation. Further evaluation of reactive media to treat site-specific COIs should be performed via bench-scale testing and/or pilot studies. Additional geotechnical and geologic assessment should also be conducted to evaluate the suitability of subsurface materials to support and anchor a PRB.

3.1.3 Measure 3 – Groundwater Extraction and Treatment

Description. As an alternative to in-situ groundwater treatment methods, impacted groundwater could be pumped to the surface and treated above grade (pump-and-treat) to provide hydraulic containment and prevent COIs from migrating beyond the waste boundary or to sensitive receptors (i.e., Missouri River). Following treatment, the water could be conveyed back to the plant process water ponds and used as make-up water, discharged directly to a surface water body through a NPDES permitted discharge, discharged to a local publically-owned treatment works (POTW), or re-infiltrated up-gradient of the landfill, depending on the site conditions and permitting requirements. Active groundwater treatment systems are generally costly to construct and require long-term operation and maintenance (O&M), but can be designed to provide effective hydraulic control of COIs.

Applicability to the North Omaha Ash Landfill. While appropriate design and operation of a groundwater extraction system would effectively provide hydraulic containment of impacted groundwater and prevent offsite migration of COIs, it is anticipated that a groundwater extraction and treatment system would have to operate until the groundwater has attained established GPS at the waste boundary. Without source removal this can take decades to achieve depending on the nature and extent of the impacts and the hydrogeology underlying the landfill. Additionally, the volume of groundwater extraction necessary could be influenced by the degree of hydraulic connectivity between the extraction wells and the Missouri River.

If a groundwater extraction system is installed subsequent to cessation of coal burning, treatment of the extracted groundwater could potentially be conducted in the two lined process water ponds, thereby reducing the amount of new infrastructure required under this corrective measure. Given that pump and treat technology has been used since the 1980s, methods to treat or remove arsenic, selenium, cobalt, lithium, and molybdenum have been well documented and are readily available.

This alternative is viable for use at the North Omaha Ash Landfill; however, it represents a significant capital commitment and long-term O&M investment. This effort would also likely require US Army Corps coordination and approval.

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

- Potentially eliminates the need for more costly CCR source removal;
- Could provide hydraulic control and plume stability over time;
- Potential repurposing of existing infrastructure to reuse the captured water (e.g. pump to existing process water ponds);
- Flexibility to treat a variety of constituents depending on methods selected, following batch and pilot studies; and,
- Well-known and generally accepted by regulatory agencies and third-party stakeholders.

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

- Generally requires a long-term O&M commitment;
- Proximity to Missouri River may result in higher extraction rates to provide containment and greater volume of water to treat; and,
- Generally works well for higher concentrations of contaminants, but is less efficient at treating lower concentrations of contaminants.

Additional Data Needs. This corrective measure will require the design of an extraction well network and water treatment system. 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. Pilot testing of various treatment technologies should also be completed to properly design a treatment system that will meet applicable discharge requirements. Additionally, it is also recommended that groundwater modeling be performed to evaluate pumping effects on the groundwater plume and Missouri River, and to estimate the time that will be required to meet the GPS at the waste boundary.

Conclusions. Based on the foregoing, installation of a groundwater extraction and treatment system should be retained for further evaluation. Assessment of hydraulic conditions and methods to treat site-specific COIs should be performed via aquifer testing, bench-scale testing, pilot studies, and groundwater modeling.

3.1.4 Measure 4 – In-Situ Soil Flushing

Description. In-situ soil flushing involves the infiltration of an aqueous solution into a zone of contaminated soil/groundwater, followed by down-gradient capture of groundwater and elutriate (flushing solution mixed with contaminants) and above-ground treatment to discharge or re-infiltrate. Flushing solutions are typically a mixture of water augmented by surfactants, co-solvents, or other reagents that facilitate the mobilization of COIs.

In-situ soil flushing may enhance conventional pump and treat technology through increasing the efficiency of a flushing pore volume, or accelerating natural flushing, thereby reducing the time required to meet cleanup criteria. The technology is potentially applicable to a very broad range of contaminants, and is not limiting in terms of contaminant depth or location within the hydrogeologic regime, although successful implementation is highly contaminant and site-specific. Some important site-specific parameters that must be considered include variations in hydraulic conductivity, degree of heterogeneity of the soil being treated, soil chemistry and soil organic content (Roote, 1997). Some of the contaminant-related factors include solubility, partitioning, pH, and Eh.

Applicability to the North Omaha Ash Landfill. As an independent corrective measure, in-situ flushing is not likely to be accepted by the regulatory community or third-party groups because there would be a concern it would result in “pushing” of impacted groundwater into the Missouri River. However, coupled with groundwater extraction and treatment, it could be designed such that the impacted groundwater is extracted, treated at the surface, and allowed to infiltrate up-gradient of the landfill.

The existing well network could be enhanced to support this technology. Down-gradient capture wells can be installed or existing wells modified in the area between the landfill and the Missouri River to capture groundwater that conveys the flush water off-site. Water pumped from the capture wells will be a combination of groundwater and flush water emanating from the landfill. The diluted water can be treated and re-infiltrated within or up-gradient of the landfill.

A possible limitation is the proximity of the extraction well system to the Missouri River, which may require significant volumes of water to be removed to maintain hydraulic control and demonstrate appropriate capture of the flushing water to get agency acceptance. Higher volumes of extracted water would result in higher treatment costs. This effort would also likely require US Army Corps coordination and approval.

Benefits. Under this scenario, OPPD could benefit from in-situ soil flushing as follows:

- Potentially eliminates the need for more costly CCR source removal;
- Could provide hydraulic control and plume stability over time, if appropriate pumping rates can be maintained without drawing water through the levee from the Missouri River;
- May reduce the time required to meet applicable GPS at the waste boundary when compares to conventional groundwater extraction and treatment;
- Potential repurposing of existing wells as extraction wells; and,

- Flexibility to treat a variety of constituents depending on methods selected, following batch and pilot studies.

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

- Not likely to be accepted by regulatory agencies or third-party groups as a stand-alone measure because of perceived “pushing” of impacted groundwater into the Missouri River;
- If coupled with groundwater extraction (for hydraulic control) and treatment, it generally requires significant capital expenditure and long-term O&M commitment for the treatment;
- Proximity to Missouri River may result in higher extraction rates, greater volume of water to treat, and/or introduction of non-CCR-related constituents from the Missouri River needing treatment;
- Underlying geology (potential karst conditions) may not be suitable for groundwater extraction, possibly allowing for preferential flow to the Missouri River; and,
- Generally works well for higher concentrations of contaminants, but not well suited for addressing lower concentrations of contaminants.

Additional Data Needs. A critical component of this alternative is the ability to capture impacted groundwater and flush water before it reaches the Missouri River. Groundwater modeling is recommended to predict the flow of groundwater and flush water and to demonstrate that impacted groundwater will be captured and treated before it reaches the Missouri River and that the infiltrated water would not pass back through in-place CCR at the base of the landfill. Additionally, it is recommended that aquifer testing and pilot testing be performed to properly design the groundwater capture, treatment, and infiltration systems.

Conclusions. Based on the foregoing, in-situ soil flushing, as a stand-alone measure should not be carried forward as a preferred measure. In combination with groundwater extraction and treatment, this measure may be viable, but additional testing and review of regulatory acceptance are needed.

3.1.5 Measure 5 – 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, b). 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 down-gradient of CCR disposal sites will, in turn, remove other COIs by adsorption.

Applicability to the North Omaha Ash Landfill. For MNA to be a viable option at the North Omaha Ash Landfill, 1) a sufficient buffer of non-impacted soil is required between the landfill and the Missouri River to allow for attenuation, 2) the source of groundwater impacts must be eliminated or controlled (i.e., CCR should not remain below the water table), and 3) subsurface conditions need to be appropriate to attenuate arsenic, selenium, cobalt, lithium, and molybdenum. In its current state, the NOS site does not have a sufficient buffer of non-impacted soil to attenuate the site-specific COIs. Our understanding of current site conditions is that some volume of CCR is located below the seasonal high water table, thus representing a continuing source of impacts to groundwater. MNA is not a viable option so long as the source material remains in contact with, or has the ability to leach to groundwater.

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

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

- Low cost to implement;
- Could eliminate the need for costly active corrective measures (e.g., groundwater extraction and treatment);
- 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:

- Limited space between down-gradient edge of landfill and Missouri River is likely not sufficient to attenuate site-specific COIs prior to discharge to the Missouri River;
- 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. If source control can be accomplished to eliminate the continuing source of groundwater impacts (CCR), then 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 must 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. Subsequent to laboratory testing, rate of attenuation could be demonstrated through groundwater modeling to predict concentration gradients over time and evaluate reaction mechanisms.

Conclusions. Based on the foregoing, MNA as a stand-alone measure should not be carried forward as a stand-alone measure, but further evaluated in combination with other viable measures. However, MNA may be deemed effective, pending evaluation of existing and new data, when coupled with a source control measure (i.e., Measure 1). However, MNA and long-term monitoring have been included with the three corrective measures carried forward for additional evaluation and costing.

4.0 Corrective Measures for further Evaluation

For the North Omaha Ash Landfill, HDR considered the following items when evaluating individual corrective measures:

- Proximity of the levee, rail line, and the Missouri River to the landfill;
- Access and space down-gradient of the landfill;
- Availability of space to relocate/consolidate ash on-site; and,
- Hydrogeology on-site and interaction with the Missouri River.

Based on the foregoing and the limited information currently available, HDR recommends that the following measures be further evaluated for implementation at the North Omaha Ash Landfill:

- CCR Source Removal
- Installation of a PRB
- Groundwater Extraction and Treatment

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**).

4.1 CCR Source Removal

4.1.1 Summary of Approach

This alternative involves removal of the source and the elimination of ongoing leaching of COIs from CCR. However, it does not eliminate the migration of COIs already in groundwater that will continue to migrate toward the Missouri River. Removal would be proposed as part of the landfill closure plan and be completed at the time the active portion of the landfill is closed. The timing of removal may be challenged by regulators and third-party groups.

Given the constrained nature of the NOS site, our opinion of probable cost is based on off-site disposal of CCR using industry-standard rates for shipping and disposal, as specific off-site facilities permitted to accept CCR have not yet been identified. Off-site disposal would entail dry ash excavation until saturated ash was encountered at the base of the landfill, at which time, dewatering would be required to facilitate removal of remaining saturated ash.

Removal of CCR material and subsequent backfilling/grading should create additional space necessary to treat arsenic, selenium, cobalt, lithium, and molybdenum, if deemed necessary by the regulatory agency. In the event treatment of residual groundwater impacts would be necessary, MNA could be considered as the long-term groundwater corrective measure in combination with the removal of the ash.

4.1.2 Assumptions

The following assumptions were made in considering this approach and preparing the opinion of probable cost:

- CCR above water can be removed via conventional dry handling techniques (e.g., trackhoe, bulldozer, etc.).
- Competent bedrock is uniformly located 40' beneath the landfill. Based on this assumption, a sheet pile wall with approximate dimensions of 3,600' long x 40' deep would be installed isolate the landfill from the Missouri River during dewatering.
- A well-point system consisting of 180 points to depths of 30 feet would be installed to dewater saturated ash at the base of the landfill to facilitate removal.
- The dewatering system can be designed such that dewatering rates can be achieved without drawing water from the Missouri River.
- Water generated during dewatering is treated at the surface using ZVI and granular filtration with pH adjustment, and is discharged through a NPDES-permitted outfall.
- The adjacent rail line could be used, with minimal improvements, to transfer CCR to an off-site disposal facility that facility is capable of accepting CCR via rail delivery.
- Results of USEPA Tiered Approach for MNA of arsenic, selenium, cobalt, lithium, and molybdenum indicates favorable subsurface conditions for attenuation with no enhancement necessary.
- Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following CCR removal.

4.2 Installation of a Permeable Reactive Barrier

4.2.1 Summary of Approach

This measure is intended to treat CCR-impacted groundwater, but does not directly address the source of COI impacts (i.e. CCR leaching to groundwater). Under this scenario, a PRB would be installed between the North Omaha Ash Landfill and the rail line that parallels the Missouri River in the vicinity of the landfill. Given the space constraints and potential for destabilization of the levee if conventional trenching is used, the PRB and reactive material would be designed as a funnel and gate system and installed trenchless methods. Periodic replacement of reactive material in the gate portion of the PRB would be required with the frequency of replacement based on results of bench-scale and pilot tests conducted during the design phase of work. A network of compliance monitoring wells would be installed down-gradient of the gate to facilitate monitoring the effectiveness of the PRB to treat arsenic, selenium, cobalt, lithium, and molybdenum.

4.2.2 Assumptions

The following assumptions were made in considering this approach and preparing the opinion of probable cost:

- Competent bedrock is uniformly located 40' beneath the landfill. Actual variation in bedrock depth will affect cost and methods of implementation of this measure.
- The PRB would be constructed as a 1000' long x 40' deep reactive barrier wall filled with a ZVI (50%) and sand (50%) mixture. Implementability and effectiveness of a funnel-and-gate

design could be evaluated as a lower-cost option, but may be limited by the space available for installation.

- COIs in saturated ash have either completely leached into groundwater, or have leached to the extent that passive treatment through a PRB could be accomplished within a period of time comparable to other corrective measures evaluated herein.
- The underlying limestone and shale bedrock is 1) shallow enough (not greater than 40 feet bgs) to allow for installation via on-pass trenching of a PRB and 2) competent and non-karst such that it provides an impermeable lower hydrogeologic boundary to anchor the PRB, thereby restricting groundwater flow beneath the PRB. If bedrock is greater than 40 feet bgs, alternate installation methods may be required.
- Subsequent to bench-scale and pilot testing, an adequate reactive media can be identified to treat site-specific COIs.
- Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following installation of the PRB.

4.3 Groundwater Extraction and Treatment

4.3.1 Summary of Approach

This measure is intended to treat CCR-impacted groundwater, but does not directly address the source of COI impacts (i.e. CCR leaching to groundwater). Under this scenario, existing groundwater monitoring wells MW-13, MW-2, and MW-15 would be repurposed as extraction wells and supplemented by the installation of six additional new extraction wells. Groundwater would be removed via pumping and discharged to a newly-constructed treatment facility designed to remove arsenic, selenium, cobalt, lithium, and molybdenum prior to discharge to the sanitary sewer or a NPDES-permitted discharge point.

4.3.2 Assumptions

The following assumptions were made in considering this approach and preparing the opinion of probable cost:

- Limited data was available to accurately estimate the pumping rate necessary to achieve hydraulic control. For this study, we have assumed a pumping rate of 100 gpm per extraction well and that pumping will not draw water (and potential additional COIs) from the Missouri River. The cost provided herein for this measure is highly variable, based on the design-level pumping rate determined during proposed pilot testing.
- COIs in saturated ash 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.
- Transmissivity of the aquifer is such that eight extraction wells can be installed on 125-foot centers to enable overlapping of radii of influence during pumping.
- The underlying limestone and shale 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.

- The local POTW is capable of accepting the volume and chemical composition of effluent from the treatment system without modification to their waste water treatment plant or the treated water can be discharged through an existing NPDES-permitted outfall at levels that meet permit requirements.
- Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following system start-up.

5.0 Additional Data Needs

During the course of completing this assessment of corrective measures, HDR identified the following data gaps that need to be addressed to further develop the conceptual site model, or to provide information on design and treatment options related to the site and the alternatives presented herein.

- Desktop evaluation of off-site facilities that have the capacity and are permitted to accept CCR.
- Additional information pertaining to the design/geometry of the inactive and active portions of the landfill, specifically as they apply to the estimated volume of CCR stored below the water table.
- Geochemical analyses of ash samples within the landfill. These data will be useful to evaluate treatment technologies, depending on which measure is pursued.
- Additional geotechnical and hydrogeologic investigation to evaluate subsurface soil conditions (e.g., permeability, transmissivity, sorption capacity), competency and depth of bedrock, and dissolved phase groundwater quality, depending on which alternative is pursued.
- Additional information regarding effects of flooding of the Missouri River on the groundwater flow regime in the vicinity of the North Omaha Ash Landfill. Based on documents available for review, shallow groundwater flow is toward the Missouri River. However, flooding events could temporarily shift or reverse groundwater gradients, which may impact design and/or effectiveness of a given corrective measure.
- Groundwater flow and transport modeling to evaluate interaction between shallow and deep groundwater, groundwater and the adjacent Missouri River, pumping rates necessary to dewater saturated ash or extract groundwater for treatment, estimate long- and short term effectiveness of alternatives to reduce COI concentrations to levels below established GPS, and to estimate the time required to meet GPS 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.

6.0 References

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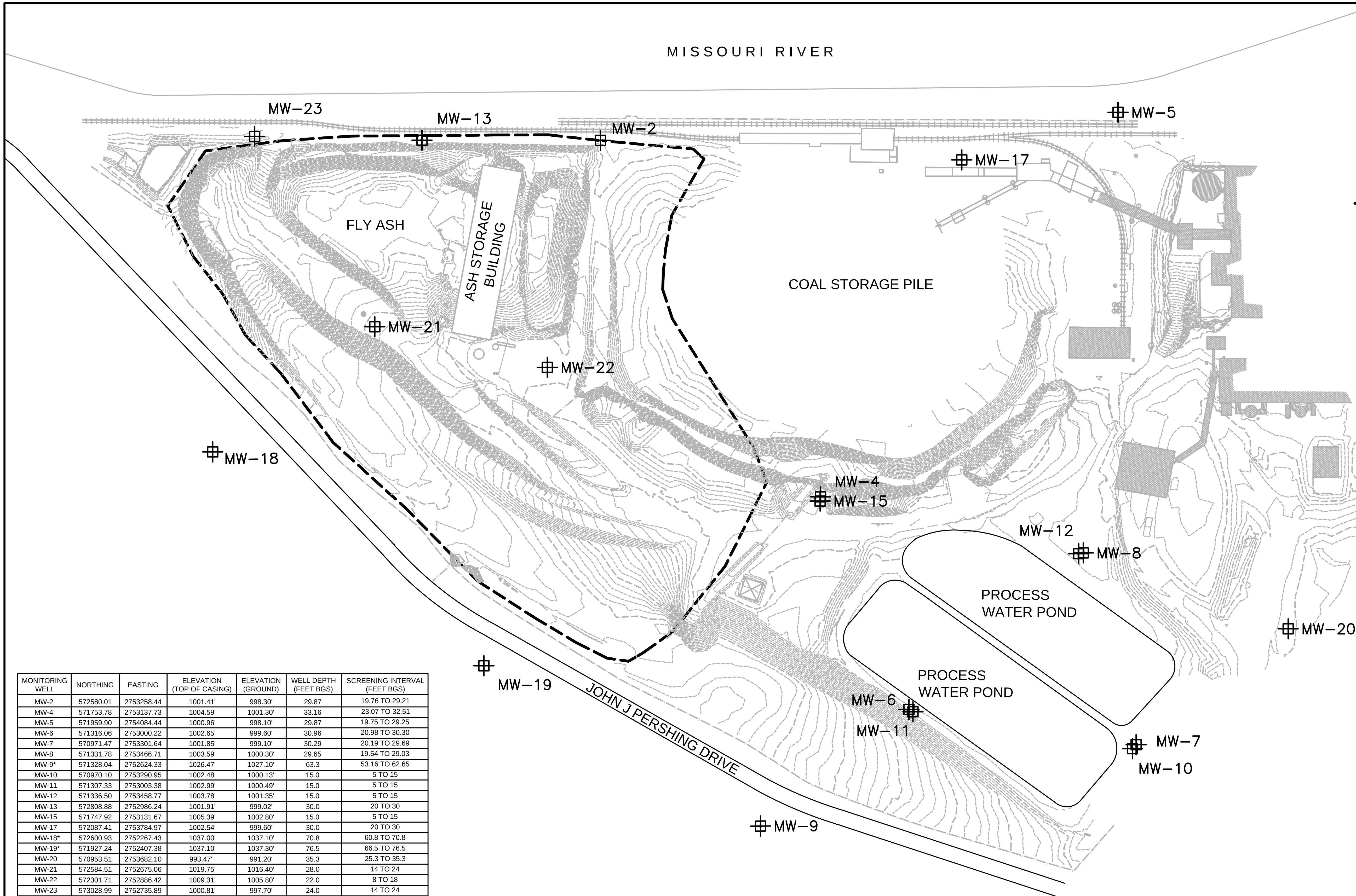
Figure 1 – CCR Unit Location Map



NOTES:

1. MONITORING WELL LOCATIONS BASED ON A JULY AND OCTOBER 2014 SURVEY PERFORMED BY E&A CONSULTING GROUP, INC.
2. MONITORING WELL ELEVATIONS OBTAINED FROM WELL LOGS.
3. COORDINATE SYSTEM IS A MODIFIED STATE PLANE.

LEGEND

MW-1 MONITORING WELL

ASH LANDFILL BOUNDARY

MONITORING WELL	NORTHING	EASTING	ELEVATION (TOP OF CASING)	ELEVATION (GROUND)	WELL DEPTH (FEET BGS)	SCREENING INTERVAL (FEET BGS)
MW-2	572580.01	2753258.44	1001.41'	998.30'	29.87	19.76 TO 29.21
MW-4	571753.78	2753137.73	1004.59'	1001.30'	33.16	23.07 TO 32.51
MW-5	571959.90	2754084.44	1000.96'	998.10'	29.87	19.75 TO 29.25
MW-6	571316.06	2753000.22	1002.65'	999.60'	30.96	20.98 TO 30.30
MW-7	570971.47	2753301.64	1001.85'	999.10'	30.29	20.19 TO 29.69
MW-8	571331.78	2753466.71	1003.59'	1000.30'	29.65	19.54 TO 29.03
MW-9*	571328.04	2752624.33	1026.47'	1027.10'	63.3	53.16 TO 62.65
MW-10	570970.10	2753290.95	1002.48'	1000.13'	15.0	5 TO 15
MW-11	571307.33	2753003.38	1002.99'	1000.49'	15.0	5 TO 15
MW-12	571336.50	2753458.77	1003.78'	1001.35'	15.0	5 TO 15
MW-13	572808.88	2752986.24	1001.91'	999.02'	30.0	20 TO 30
MW-15	571747.92	2753131.67	1005.39'	1002.80'	15.0	5 TO 15
MW-17	572087.41	2753784.97	1002.54'	999.60'	30.0	20 TO 30
MW-18*	572600.93	2752267.43	1037.00'	1037.10'	70.8	60.8 TO 70.8
MW-19*	571927.24	2752407.38	1037.10'	1037.30'	76.5	66.5 TO 76.5
MW-20	570953.51	2753682.10	993.47'	991.20'	35.3	25.3 TO 35.3
MW-21	572584.51	2752675.06	1019.75'	1016.40'	28.0	14 TO 24
MW-22	572301.71	2752886.42	1009.31'	1005.80'	22.0	8 TO 18
MW-23	573028.99	2752735.89	1000.81'	997.70'	24.0	14 TO 24

* FLUSH MOUNTED WELLS

Omaha Public Power District

OPPD
NORTH OMAHA STATION
OMAHA, NEBRASKA

MONITORING WELL LOCATION MAP

DATE
APRIL 2019

FIGURE
1

Table 1 – Risk Balanced Technical Options

Table 1. Risk Balanced Technical Options – North Omaha Ash Landfill

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, exposure to residual contamination)	Relative Time Required for Implementation / Completion of Remedy 1 = 1 - 5 years 2 = 5 - 10 years 3 = 10 - 50 years 4 = 50 -100 years 5 = 100+ years	Institutional Requirements (Permit or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Source Removal	**<u>Key Assumptions</u>** • CCR above water can be removed via conventional dry handling techniques (e.g., trackhoe, bulldozer, etc.). • Competent bedrock is uniformly located 40' beneath the landfill. A sheet pile wall with approximate dimensions of 3,600' x 40' would be installed isolate the landfill from the Missouri River during dewatering.A well-point system consisting of 180 points to depths of 30 feet would be installed to dewater saturated ash at the base of the landfill to facilitate removal. • The dewatering system can be designed such that dewatering rates can be achieved without drawing water from the Missouri River. • Water generated during dewatering is p treated at the surface using ZVI and granular filtration with pH adjustment, and is discharged through a NPDES-permitted outfall. • The adjacent rail line could be used, with minimal improvements, to transfer CCR to an off-site disposal facility that facility is capable of accepting CCR via rail delivery. • Results of USEPA Tiered Approach for MNA of arsenic, selenium, cobalt, lithium, and molybdenum indicates favorable subsurface conditions for attenuation with no enhancement necessary. • Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following CCR removal. **<u>Risks</u>** • 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). **<u>Benefits</u>** • Removal of CCR eliminates ongoing source of groundwater impacts. • Provides additional land area for implementation of groundwater remedies. • Demonstrated regulatory, third-party, and public acceptance.	2	No additional impacts anticipated	1 / 3-4* *Time required for implementation and remedy are estimates at this time. Additional information is needed for validation of time to implement and remedial timeline .	• Landfill will continue to be monitored per State regulations. Selected alternative will require State approval. • Coordination and/or USACE permitting is likely requires with earthwork activities in the proximity of the Missouri River	• Desktop review to identify local and regional facilities, landfills, or operations that may be able to beneficially reuse the material, or that may be able to accept the material under their existing permit. • Additional evaluation of groundwater flow conditions, either through aquifer testing or groundwater flow, fate, and transport modeling, be completed to evaluate the hydrogeologic properties affecting groundwater flow and COI persistence and migration over time. • Additional groundwater modeling scenarios will allow for determination of effectiveness of varying the volume and locations of ash removed.	• Further evaluation of this measure should be performed only if dictated by litigation or changes in legislation. • If pursued as an option, 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.

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, exposure to residual contamination)	Relative Time Required for Implementation / Completion of Remedy 1 = 1 - 5 years 2 = 5 - 10 years 3 = 10 - 50 years 4 = 50 -100 years 5 = 100+ years	Institutional Requirements (Permit or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Permeable Reactive Barrier	**Key Assumptions** • Competent bedrock is uniformly located 40' beneath the landfill. Actual variation in bedrock depth will affect cost and methods of implementation of this measure. • The PRB would be constructed as a 1000' long x 40' deep reactive barrier wall filled with a ZVI (50%) and sand (50%) mixture. Implementability and effectiveness of a funnel-and-gate design could be evaluated as a lower-cost option, but may be limited by the space available for installation. • COIs in saturated ash have either completely leached into groundwater, or have leached to the extent that passive treatment through a PRB could be accomplished within a period of time comparable to other corrective measures evaluated herein. • The underlying limestone and shale bedrock is 1) shallow enough (not greater than 40 feet bgs) to allow for installation via on-pass trenching of a PRB and 2) competent and non-karst such that it provides an impermeable lower hydrogeologic boundary to anchor the PRB, thereby restricting groundwater flow beneath the PRB. If bedrock is greater than 40 feet bgs, alternate installation methods may be required. • Subsequent to bench-scale and pilot testing, an adequate reactive media can be identified to treat site-specific COIs. • Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following installation of the PRB. **Risks** • Limited space down-gradient of the landfill, possibly making installation difficult and expensive. • Availability and expense of the quantity of ZVI needed for this application. • Underlying bedrock may not be competent enough to anchor the base of the PRB. • May require periodic replacement of PRB media, and will require long-term groundwater monitoring to ensure effectiveness over time. **Benefits** • Potentially eliminates the need for more costly measures, (e.g., CCR source removal). • Minimizes disruption to NOS site operations. • Flexibility to treat a variety of constituents depending on media or mix of media selected, following batch and pilot studies. • Lower O&M costs when compared to groundwater extraction and treatment. • Demonstrated to effectively treat site-specific COIs of arsenic, selenium, and molybdenum.	3-4	Addition of reagents or adjustment of pH/redox conditions may mobilize other contaminants in groundwater	1 / 2-3* *Time required for implementation and remedy are estimates at this time. Additional information is needed for validation of time to implement and remedial timeline	• EPA application may be required • Landfill will continue to be monitored per State regulations. Selected alternative will require State approval. • Coordination and/or USACE permitting is likely requires with earthwork activities in the proximity of the Missouri River	• Geochemical pilot testing 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 properties and potential terminal depth of a PRB prior to design.	• Further evaluation of this alternative should be conducted. • 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.

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, exposure to residual contamination)	Relative Time Required for Implementation / Completion of Remedy 1 = 1 - 5 years 2 = 5 - 10 years 3 = 10 - 50 years 4 = 50 -100 years 5 = 100+ years	Institutional Requirements (Permit or other environmental or public health requirements)	Additional Data Needs	Recommendations & Rationale
Groundwater Extraction and Treatment	**Key Assumptions** • Limited data was available to accurately estimate the pumping rate necessary to achieve hydraulic control. For this study, we have assumed a pumping rate of 100 gpm per extraction well and that pumping will not draw water (and potential additional COIs) from the Missouri River. The cost provided herein for this measure is highly variable, based on the design-level pumping rate determined during proposed pilot testing. • COIs in saturated ash 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. • Transmissivity of the aquifer is such that eight extraction wells can be installed on 125-foot centers to enable overlapping of radii of influence during pumping. • The underlying limestone and shale 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. • The local POTW is capable of accepting the volume and chemical composition of effluent from the treatment system without modification to their waste water treatment plant or the treated water can be discharged through an existing NPDES-permitted outfall at levels that meet permit requirements. • Performance monitoring of five monitoring wells is conducted quarterly for a period of 30 years following system start-up.	5	No additional impacts anticipated	1/3* with source control *Time required for implementation and remedy are estimates at this time. Additional information is needed for validation of time to implement and remedial timeline	• Landfill will continue to be monitored per State regulations. Selected alternative will require State approval. • Coordination and/or USACE permitting is likely requires with earthwork activities in the proximity of the Missouri River.	• 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. • Pilot testing of various treatment technologies should also be completed to properly design a treatment system that will meet applicable discharge requirements. • Additionally, groundwater modeling should be performed to evaluate pumping effects on the groundwater plume and Missouri River, and to estimate the time that will be required to meet the GPS at the waste boundary.	• Further evaluation of this alternative should be conducted. • 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.

Notes:

1. Actual determination of remedial alternative timeline and regulatory acceptance will require additional data collection and analysis for all referred to alternatives..