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TECHNICAL MEMORANDUM

CWMNW Arlington, OR

Overview of Geology and Hydrology at the Chemical Waste Management Site and Approach to Groundwater Pathway Modeling for the Bakken Oilfield Waste Disposals

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Submitted to Waste Management

RAC
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1. Introduction

This technical memorandum documents Risk Assessment Corporation's (RAC) conceptual model for evaluating impacts to the groundwater pathway from the disposal of technologically enhanced naturally occurring radioactive materials (TENORM) from the Bakken Oilfield in Landfill Unit #14 (L-14) in the Chemical Waste Management of the Northwest, Inc. (CWMNW) Treatment, Storage, and Disposal Facility in Arlington, OR. The disposals occurred between May 10, 2016, and July 15, 2019. Transportation of the waste was arranged by Oilfield Waste Logistics (OWL). It is referred to as Bakken Oilfield waste in this memorandum. In this technical memorandum the physiographic, geologic, and hydrologic setting at CWMNW is described and provides the basis for the conceptual model. The nearest aquifer underlying the L-14 disposal unit is non-potable and discharges to a bluff south of the facility where it evaporates. Thus, there is currently no actual user of the groundwater that would be impacted by the L-14 disposal unit. The information presented in this technical memorandum will be incorporated into RAC's Radiological Dose and Risk Assessment for Bakken Oilfield waste disposals in Arlington, OR.

2. Physiographic, Geologic, and Hydrologic Setting at CWMNW

The CWMNW facility occupies about 270 acres in Gilliam County, approximately seven miles south-southwest of the City of Arlington, Oregon within the south-central portion of the Columbia physiographic province (Deschutes-Umatilla Plateau). The physiographic features of the Arlington area are a function of several governing factors, which include: (1) a semi-arid climate (less than 11 inches of precipitation per year); (2) the presence of thick sequences of flood-basalt bedrock; (3) structural tectonic forces; and (4) multiple catastrophic floods occurring between 13,000 and 15,000 years ago.

The plateau CWMNW is located on has been cut by Alkali Canyon to the south. The site is primarily located above Alkali Canyon on a portion of the geologic province of the Deschutes-Umatilla Plateau (Figure 1). Only a small portion of the site including the main office is located in Alkali Canyon. The waste management activities, including operations in Landfill Unit L-14 where the subject Bakken Oilfield waste was disposed, are on the plateau above the canyon.

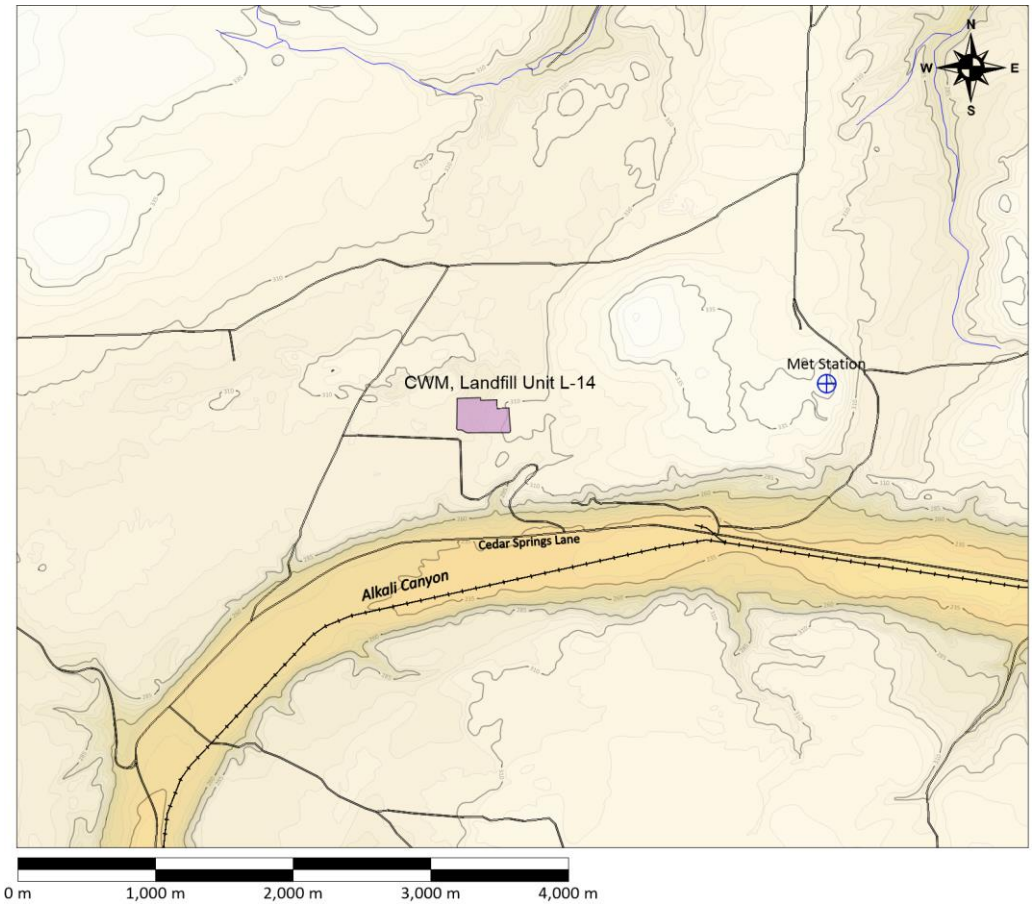

Figure 1. Location of the CWMNW facility, Landfill Unit L-14, and Alkali Canyon to the south.

2.1. Geologic Units

Geologic units beneath Landfill Unit L-14 at CWMNW are, from shallowest to deepest:

- Sedimentary deposits of the Dalles Group (Alkali Canyon Formation)
- Selah Member and associated sedimentary deposits of the Ellensburg Formation
- Priest Rapids Member of the Wanapum Basalt (PRB) of the Columbia River Basalt Group (CRBG)

Older Members of the Wanapum Basalt and the Grande Ronde basalt of the CRBG are also present beneath the site but are not discussed here. Detailed descriptions of each of the geologic units are presented below.

The Alkali Canyon Formation of The Dalles Group outcrops at the surface and overlies the Selah. As seen in Figure 2. Conceptual model and geologic cross section of the CWMNW facility showing Landfill Unit L-14, aquifer in the Selah Member, and the deeper Priest Rapids basalt flow. The axis of the east-west trending anticline is shown north of Landfill Unit L-14 and the thrust fault is also shown, Landfill Unit L-14 penetrates the Alkali Canyon Formation and its base is in the Selah Member. The Alkali Canyon Formation is unsaturated at the site. It consists of three distinct sedimentary deposits (or facies): the basal portion consists of a conglomerate facies, a tuffaceous siltstone facies, and a channel gravel facies that incises down to the top of the Selah Member in the vicinity of L-14 (Dames and Moore 1987; RUST 1998a; RUST 1998b).

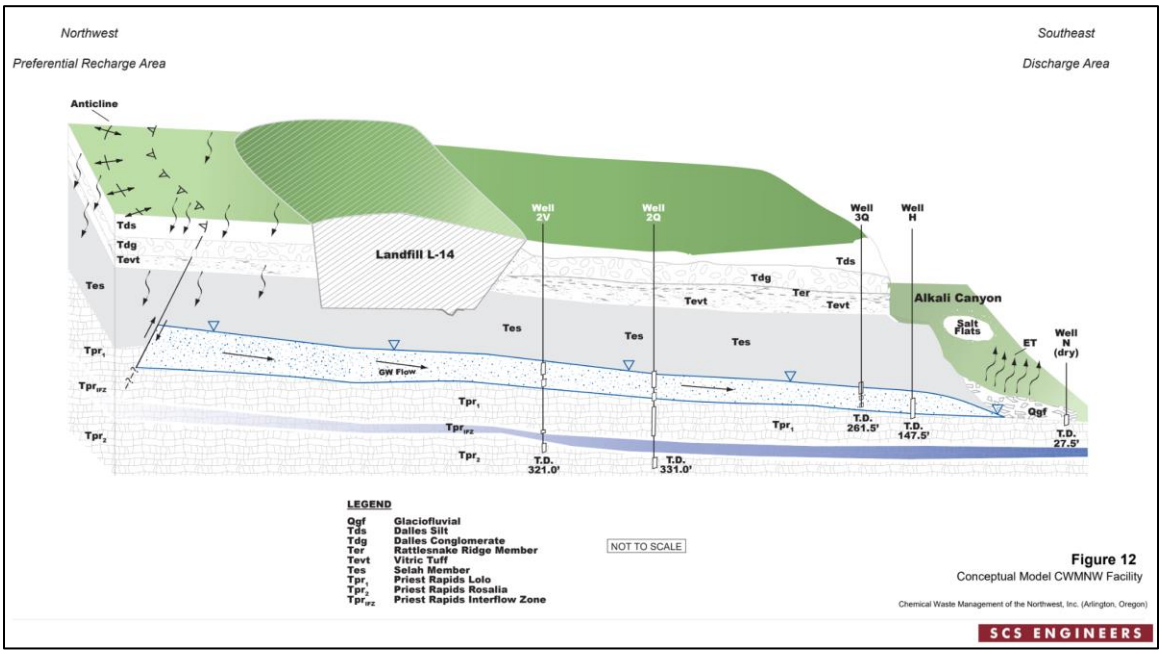

Figure 2. Conceptual model and geologic cross section of the CWMNW facility showing Landfill Unit L-14, aquifer in the Selah Member, and the deeper Priest Rapids basalt flow. The axis of the east-west trending anticline is shown north of Landfill Unit L-14 and the thrust fault is also shown.

Two minor units of the Ellensburg Formation are found below the Alkali Canyon Formation and above the Selah Formation. The two units have previously been classified as the Rattlesnake Ridge Member and the Vitric Tuff Member of the Ellensburg Formation based on their tuffaceous characteristics (RUST 1998b; CH2M HILL, 2008). The Rattlesnake Ridge Member is a 4- to 6-foot thick weathered tuffaceous siltstone that overlies the Vitric Tuff. The Vitric Tuff is composed of a soft-to-medium hard, blue-grey, well-sorted, fine-grained tuffaceous siltstone/sandstone. The vitric tuff is up to 30 feet thick. Both units have been eroded and are absent in localized areas where they were eroded during deposition of the Dalles Group (RUST 1998b; CH2M HILL 2008).

Underlying these two members of the Ellensburg Formation is the Selah Member. The Selah Member ranges in thickness from 35 to 49 meters (115 to 160 feet) beneath the upland plateau where the active area of the CWMNW facility is located. The upper portion of the Selah is unsaturated, with groundwater present in the lowest 6.1 to 21.3 meters (20 to 70 feet) of the Selah (CH2M HILL, 2008). Immediately south of the facility, the Selah Member is largely absent in Alkali Canyon, where it was eroded away by catastrophic floods of glacial origin that inundated the Columbia Plateau during the Pleistocene epoch. Even though the Selah is heterogeneous, the primary lithologic character of the Selah is a siltstone with varying degrees of clay and sand content.

The PRB consists of two flows at the site, a younger Lolo flow and the older Rosalia flow. The two flows have the typical characteristics of a basalt flow consisting of dense to columnar-jointed flow interior between a brecciated flow bottom and weathered flow top. The Lolo and Rosalia flows are separated by a partially lithified sedimentary interbed of the Ellensburg Formation composed of silt and clay. This interbed lies 15.2 to 22.9 meters (50 to 75 feet) below the Selah/PRB contact and ranges in thickness from 6.1 to 36.6 meters (2 to 12 feet) across the site (CH2M HILL 2008).

2.2. Geologic Structure

Tectonic activities folded and faulted the older geologic units of the Selah and PRB after they were deposited. An east-west trending anticline fold is present along the northern portion of the site based on geological borehole data and surface geophysical surveys. The fold dips to the north of the site and towards Alkali Canyon to the south. Additionally, a thrust fault that offsets beds within the Selah and PRB trends roughly parallel to the anticline in the portion of the site north of Landfill Unit L-14. The thrust fault is truncated by intact Holocene glacial flood deposit, indicating the fault pre-dated Holocene deposition (Dames and Moore 1987; RUST 1998a).

2.3. Groundwater Hydrology

The Selah contains the uppermost saturated zone beneath the Facility. The Selah underlies the more permeable sands and gravels of the Alkali Canyon Formation of the Dalles Group and overlies the PRB of the Columbia River Basalt Group. The regional groundwater source(s) are in the older CRBG units of the Frenchman Springs Member of the Wanapum Basalt and older flows of the Grande Ronde Basalt.

Recharge to the Selah occurs along the northern portion of the site near the structural features and through the unsaturated zone which varies between approximately 90 feet thick in the central area of the site, to 135 feet in the northern part of site, to 220 feet thick towards the western and eastern areas of the site. Recharge to groundwater is primarily from precipitation and has been previously estimated to be approximately 0.1 feet/year (RUST 1998b). Groundwater flow within the saturated portion of the Selah is generally toward the southeast and towards Alkali Canyon, consistent with the structural dip of the underlying PRB. Discharge of groundwater occurs predominately through evapotranspiration where the Selah is exposed along the bluff of Alkali Canyon within the southern boundary of the Facility.

In general, the Selah is a partially confined groundwater system at the site, although more confined conditions may exist toward the northwestern and southeastern portions of the site. In the northwestern area, a clay-rich horizon (designated the "grey clay" layer by Dames and Moore 1987), indicated by the natural gamma geo-physical logs, likely acts as a leaky confining layer, below which is a zone of lower clay content (and potentially higher hydraulic conductivity). Additionally, vertical gradients estimated from collocated well pairs that are screened in the upper and the lower portions of the saturated Selah suggest an upward vertical gradient to a neutral gradient from the lower Selah to the upper Selah is present across portions of the site (specifically near Landfill Unit L-14), further suggesting confined conditions are present in the lower Selah (CH2M HILL 2008).

The Selah has horizontal hydraulic conductivity values (K_h) ranging from 1×10^{-6} to 1×10^{-4} cm s^{-1} based on pumping test data, packer testing, and core sample testing (Dames and Moore 1987; RUST 1998a; CH2M HILL 2008). Horizontal hydraulic conductivity values estimated for test intervals crossing the Selah/PRB contact and the vertical hydraulic conductivity of the Selah Member have been estimated to range from 5×10^{-9} cm s^{-1} to about 5×10^{-6} cm s^{-1} with a geometric mean of about 5×10^{-8} cm s^{-1} (CH2M HILL 2008). For comparison, the horizontal hydraulic conductivity of materials used for engineered landfill liner materials to prevent releases of leachate from a landfill to the environment is typically less than 1×10^{-6} cm s^{-1}. Using the historic average hydraulic gradient of approximately 0.015 to 0.035 m m^{-1}, and the estimated hydraulic conductivity

of the Selah, groundwater flows laterally at an estimated rate of between 0.23 to 2.1 m yr^{-1} (0.77 to 6.9 ft yr^{-1}).

Isotopic age dating of groundwater at the site is consistent with the long travel times for groundwater from the surface to the saturated zone of the low permeability Selah and horizontally within the Selah. Available radiocarbon dating using Carbon-14 suggests that the age of the shallow groundwater in the Selah is greater than 770 years with a probable age range of between 1,000 to 4,000 years (CH2M HILL 2008). For comparison, the maximum age range for the upper Priest Rapids is estimated to be between 9,600 and 12,900 years before present, and the deeper Frenchman Springs Basalt used for water supply at the site is estimated to be between 14,000 to 16,000 years old. These much older ages of groundwater from the basalt interflows suggest limited hydraulic connection, if any, between the shallow Selah water bearing zone and the deeper basalt aquifers.

2.4. Surface Water

Except for the onsite storm water management ponds, permanent surface water is absent at the facility. During the few storm runoff events, surface water generally drains from the upland plateau via overland flow to swales along the south-facing ridge of Alkali Canyon, then down into the broad canyon floor where it disperses or collects into ephemeral ponds. During winter and early spring, shallow seasonal ponds occasionally form in Alkali Canyon, south of the site. The only permanent surface water bodies are located several miles from the site including: the Columbia River, approximately 7 miles north of the site; the John Day River, approximately 7.5 miles west of the site; Rock Creek, approximately 3.5 miles southwest of the site; and Cedar Springs, approximately 1.5 miles west of the site.

3. Approach to Groundwater Pathway Modeling

As discussed in the earlier section, the Selah member of the Ellensburg formation underlies Landfill Unit L-14. To assess potential exposures via the groundwater pathway, unsaturated zone transport modeling will be performed assuming liquid can migrate through the landfill's engineered geosynthetic triple liner and leachate collection system and the unsaturated portion of the Selah to the saturated portion of the Selah (upper Selah aquifer). In this section, a conceptual and mathematical unsaturated and saturated zone transport model is presented to determine radionuclide travel times and potential maximum radiation doses from hypothetical ingestion from water in the upper Selah aquifer. It is emphasized that the upper Selah aquifer is not used for drinking water or irrigation and discharges south of the site into Alkali Canyon. In this context, this modeling effort is used to demonstrate compliance. That is, if performance objectives (i.e., radiation effective doses from ingestion and maximum contaminant limits) are achieved in the Selah aquifer, then they will be met in all underlying aquifers, namely the aquifer in the Priest Rapids member of the Wanapum Basalt. If performance objectives are not met in the Selah, then estimates of impacts to the underlying aquifers that are used for drinking water and irrigation will be considered.

3.1. Previous Modeling Efforts

Burns & McDonnell Inc. (1998) developed a flow and transport model for Landfill Unit L-14 using the semi-analytical model MULTIMED for unsaturated transport and MODFLOW for the saturated portion. The unsaturated flow and transport portion of the MULTIMED model assumes steady-state infiltration for initial concentrations in a source zone, and thereby provides fluxes and concentrations as a function of time that may be input to MODFLOW as an upper boundary condition. The MODFLOW simulation was discretized into 4 layers that included the Upper Selah water bearing unit, the Intermediate Grey Clay, the Lower Selah water bearing unit, and the underlying water-bearing units of the Priest Rapids member. The model included leakage from the upper Selah through the Grey Clay and into the Lower Selah, and leakage from the Lower Selah into the Priest Rapids aquifer. The purpose of the model was to evaluate the effectiveness of a proposed groundwater monitoring network for early warning of a potential release. Concentrations were expressed in terms of the normalized concentration. The normalized concentration is the concentration in the aquifer divided by the concentration in the source. Based on modeling from a sump source that drained into the Upper Selah, normalized concentrations in the Upper Selah, Grey Clay, Lower Selah, and underlying Priest Rapids were approximately 0.0019, 0.0003, <0.0001, and 0.0001, respectively. Thus, concentrations in the Priest Rapids aquifer were a factor of ~19 less than concentrations in the Upper Selah (0.0019/0.0001 = 19).

This model was considered a “worst case” model because the vertical leakage rates from the Upper Selah to the Priest Rapids was based on vertical hydraulic conductivities ranging from 5.0×10^{-9} to 4.6×10^{-7} cm s^{-1}. Recent analysis of leakage between the Upper Selah and Priest Rapids (CH2MHILL 2020) indicated vertical hydraulic conductivities were unlikely to be greater than 5×10^{-10} and may be less than 1×10^{-10} cm s^{-1}. Thus, concentrations in the Priest Rapids would be even less than predicted by Burns & McDonnell (1998). For these reasons, we have used the Upper Selah aquifer as a means of bounding any potential impacts to the Priest Rapids aquifer. Any impacts to the Priest Rapids aquifer will be at least a factor of 19 less than in the Selah aquifer.

3.2. Conceptual Model for Flow and Transport to the Upper Selah

A generalized conceptual model for assessment of the groundwater pathway is illustrated in Figure 3. The Bakken Oilfield waste is represented by a rectangular area source of fixed thickness. Radionuclide concentrations are assumed to be uniform throughout the source. Bakken Oilfield radionuclides partitioning into the infiltrating water move downward through Landfill Unit L-14. During active facility operations, this leachate will be captured by the triple geosynthetic liner/leachate collection system. A small fraction is assumed to pass through the system. After site closure, an infiltration reducing engineered cap is placed over the cell. For purposes of modelling the worst-case scenario, the leachate collection system is assumed to cease operation and the engineered triple liner is assumed to have failed hydrologically, allowing any infiltrating water to pass through the landfill and into the underlying vadose zone (or unsaturated zone). Over time, the hydrologic effectiveness of the engineered cap is assumed to degrade, resulting in infiltration through the engineered landfill cover system equivalent to natural background infiltration. Leachate travels downward vertically through vadose zone and enters the aquifer over a footprint area equivalent to the simulated Bakken Oilfield waste block in Landfill Unit L-14. Radionuclides that

enter the aquifer mix vertically within a defined region and migrate downgradient to a receptor well assumed at the downgradient edge of the source footprint.

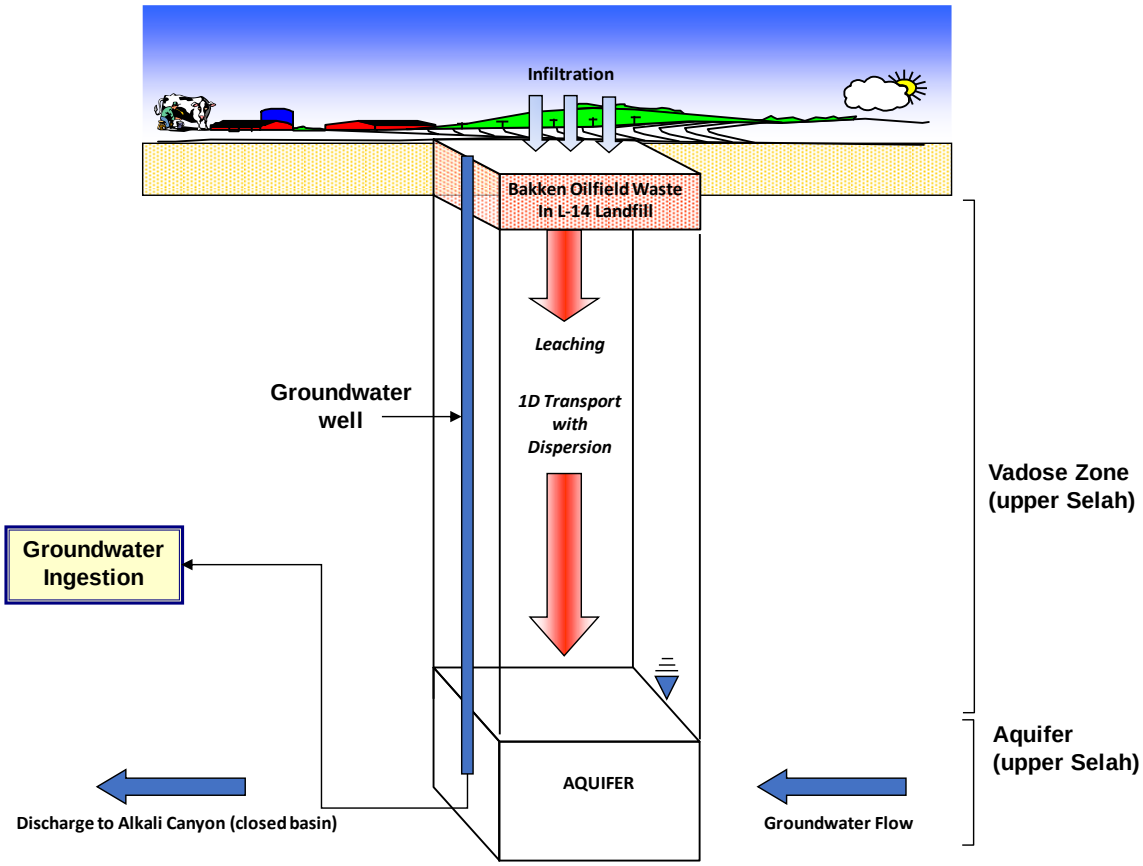

Figure 3. Generalized conceptual model for assessment of the groundwater pathway.

3.3. Mathematical Model and Code Selection

The conceptual model is typically represented mathematically by established equations for water flow in a porous medium and contaminant transport via advection, dispersion, and diffusion. Solutions to these equations for different boundary and initial conditions are derived from simple semi-analytical assessment models like RESRAD (Yu et al., 2001) to detailed numerical research-grade models like HYDRUS (Simunek et al., 1999) for unsaturated modeling and MODFLOW/MT3D for saturated zone modeling.

For this problem, the system was represented mathematically through a series of mixing cells that are connected via rate constants. This modeling approach is implemented in the GoldSim modeling software that has become an industry standard for Low-Level Radioactive Waste (LLRW) Performance Assessment (PA) models.

This model is quantitatively represented in the Mixing Cell Model (MCM) code (Rood 2004; Rood 2005). MCM is an established model at the Idaho National Laboratory (DOE-ID 2007, 2008, 2011, 2012, 2018) and was also applied to the U.S. Ecology Site on the Hanford Reservation (Rood 2004) and used in the TENORM analysis at the Blue Ridge Landfill (RAC 2019). The MCM model has been benchmarked with HYDRUS and has shown comparable results. Furthermore, the model

has been used to abstract complex 3-dimensional vadose zone models into a simpler formulation that incorporates the salient features of the system (DOE-ID 2007).

MCM is a one-dimensional unsaturated flow and transport model but can also be used for saturated conditions. The model domain is discretized into a series of mixing cells where the model calculates water and solute balance. Water balance is based on the constituent relationships of hydraulic conductivity, pressure, and moisture content as described by van Genuchten (1980). Solute transport is based on a linearization of the advection-dispersion into fully mixed cells. One-dimensional dispersion and diffusion are addressed through either the dispersion implicit in model discretization or explicitly. The model addresses transient as well as steady-state water infiltration and is thus well-suited for assessments involving landfills with engineered landfill final cover. Transient infiltration occurs because infiltration-reducing covers do not last indefinitely resulting in infiltration through the waste and into the vadose zone that changes over time. The MCM model was used to compute water fluxes and solute transport in the vadose zone.

For the aquifer, the GWSCREEN code is typically used (Rood 1994; Rood 2002) because it interfaces with output from MCM. The GWSCREEN model is an application of the U.S. NRC semi-analytical groundwater models for time variable solute fluxes (Codell et al. 1981). The semi-analytical model assumes one-dimensional flow and three-dimensional dispersion in an aquifer of infinite lateral extent and finite thickness. However, for this application, a saturated MCM simulation was used instead because GWSCREEN does not perform differential transport among radioactive progeny. When flow velocities in the aquifer are rapid compared to unsaturated flow, this limitation in GWSCREEN makes little difference. However, horizontal flow velocities in the Upper Selah aquifer are very slow, allowing substantial ingrowth of radioactive progeny. The decay members included in the source term include the ^{238}U decay series and the ^{232}Th decay series. The abbreviated ^{238}U decay series that includes only long-lived progeny is

$$^{238}\mathrm{U} \rightarrow {}^{234}\mathrm{U} \rightarrow {}^{230}\mathrm{Th} \rightarrow {}^{226}\mathrm{Ra} \rightarrow {}^{210}\mathrm{Pb} \rightarrow {}^{206}\mathrm{Pb}\ \text{(stable)}.$$

The abbreviated ^{232}Th decay series that includes only long-lived progeny is

$$^{232}\mathrm{Th} \rightarrow {}^{228}\mathrm{Ra} \rightarrow {}^{228}\mathrm{Th} \rightarrow {}^{208}\mathrm{Pb}\ \text{(stable)}.$$

Short-lived radioactive progeny are assumed to be in secular equilibrium with their parent and are not modeled explicitly. For this reason, a saturated MCM model was used instead of GWSCREEN because MCM addresses differential transport of radioactive progeny. Differential transport occurs because each radionuclide has element-specific sorption coefficients that determine the speed at which the radionuclide travels in groundwater. Output from GWSCREEN and saturated MCM were compared to provide confidence in the MCM saturated simulation.

The conceptual model for unsaturated flow and transport in MCM is illustrated in Figure 4. The upper boundary condition for the flow model was the infiltration rate through the waste cell and into vadose zone, and the lower boundary is free drainage flow into the aquifer. The infiltration into the waste cell accounts for the presence of a geosynthetic engineered cover system. For transport, a zero-flux boundary condition was applied at the top and initial inventories assigned to the first layer.

For the saturated zone, the hydraulic conductivity and moisture content were fixed in each cell at the Darcy velocity and saturated aquifer porosity, respectively. Thus, a water flow simulation

was not necessary (i.e., Darcy velocity is assigned). The upper boundary condition for transport in the aquifer were the radionuclide fluxes from the MCM unsaturated simulation.

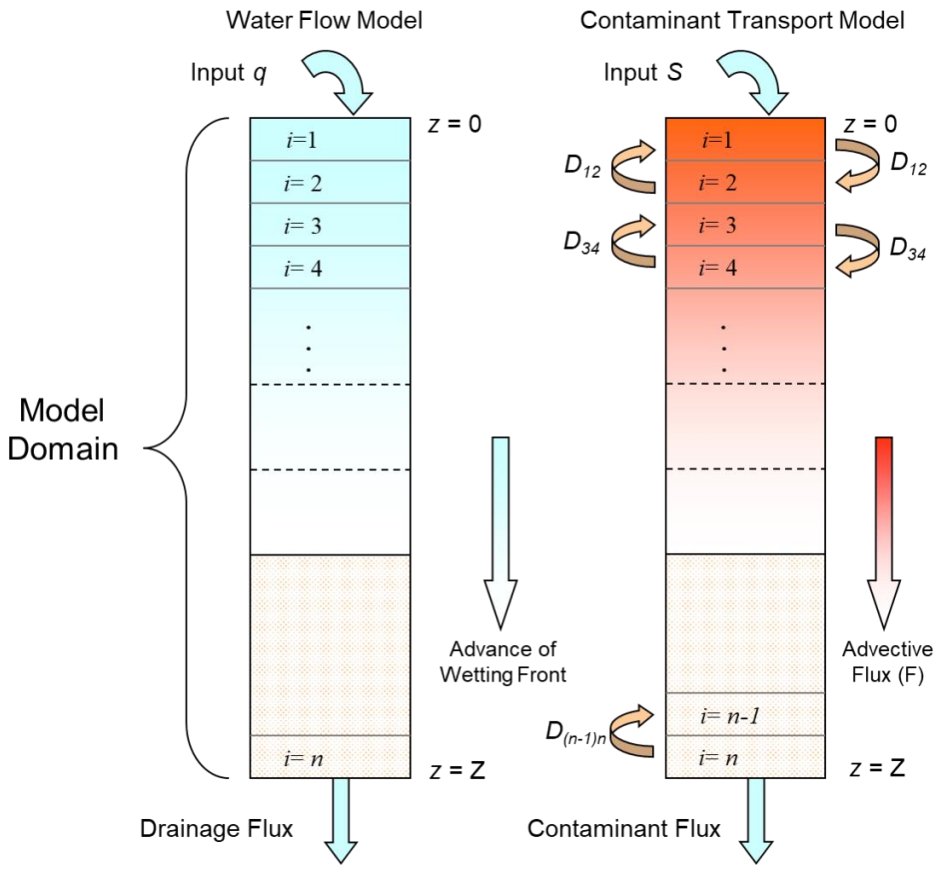

Figure 4. The MCM conceptual model for water flow (left) and contaminant transport (right). The model domain is discretized into *n* cells and extends to a depth of $z = Z$. Interchange between cells is indicated the variable $D_{i,j}$ where *i* is the index of the donor cell and *j* is the index of the receiving cell. The variable *q* is the water flux and *S* is the source or radionuclide flux (from Rood 2005).

3.4. Source Configuration and Receptor Locations

Based on landfill manifests, there were 64 shipments of Bakken Oilfield waste that were disposed in Landfill Unit L-14. The total waste mass was reported to be 1,285 tons (2,569,320 lbs or 1,167,873 kg). After disposal and burial, the bulk density of the disposal material was reported to be 1,300 kg m^{-3}. Assuming each disposal load was spread across the 25 ft ×25 ft (58 m^2) grid block, the total area of disposal was 64 × 58 m^2 =3,716 m^2. The individual disposal loads of Bakken Oilfield waste in Landfill Unit L-14 were spread over an area of 28,883 m^2.

The thickness of the waste in the model is calculated as

$$T = \frac{1{,}167{,}873 \text{ kg}}{1{,}300 \text{ kg/m}^3} \times \frac{1}{3{,}716 \text{ m}^2} = 0.24 \text{ m}$$

This calculation assumes all the waste is compressed into a single source region which provides a worst-case scenario. In reality the waste is spread out over a 28,883 m^2 area, resulting in increased dilution and ultimately lower groundwater concentrations. For the model, the source is assumed to represent a square area source with the length of a side equal to $(3{,}716)^{1/2} = 60.96$ m and a waste thickness of 0.24 m.

Figure 5 illustrates the actual and modeled ground source region and the location of the receptor well where groundwater impacts (concentrations and doses) are evaluated. Receptor wells are assumed to be in the upper Selah aquifer and placed on the downgradient edge of the source where maximum concentrations occur. A 100-m downgradient receptor is also added based on US DOE performance assessments allowing a 100-m receptor well for comparing predicted concentrations and doses with performance objectives.

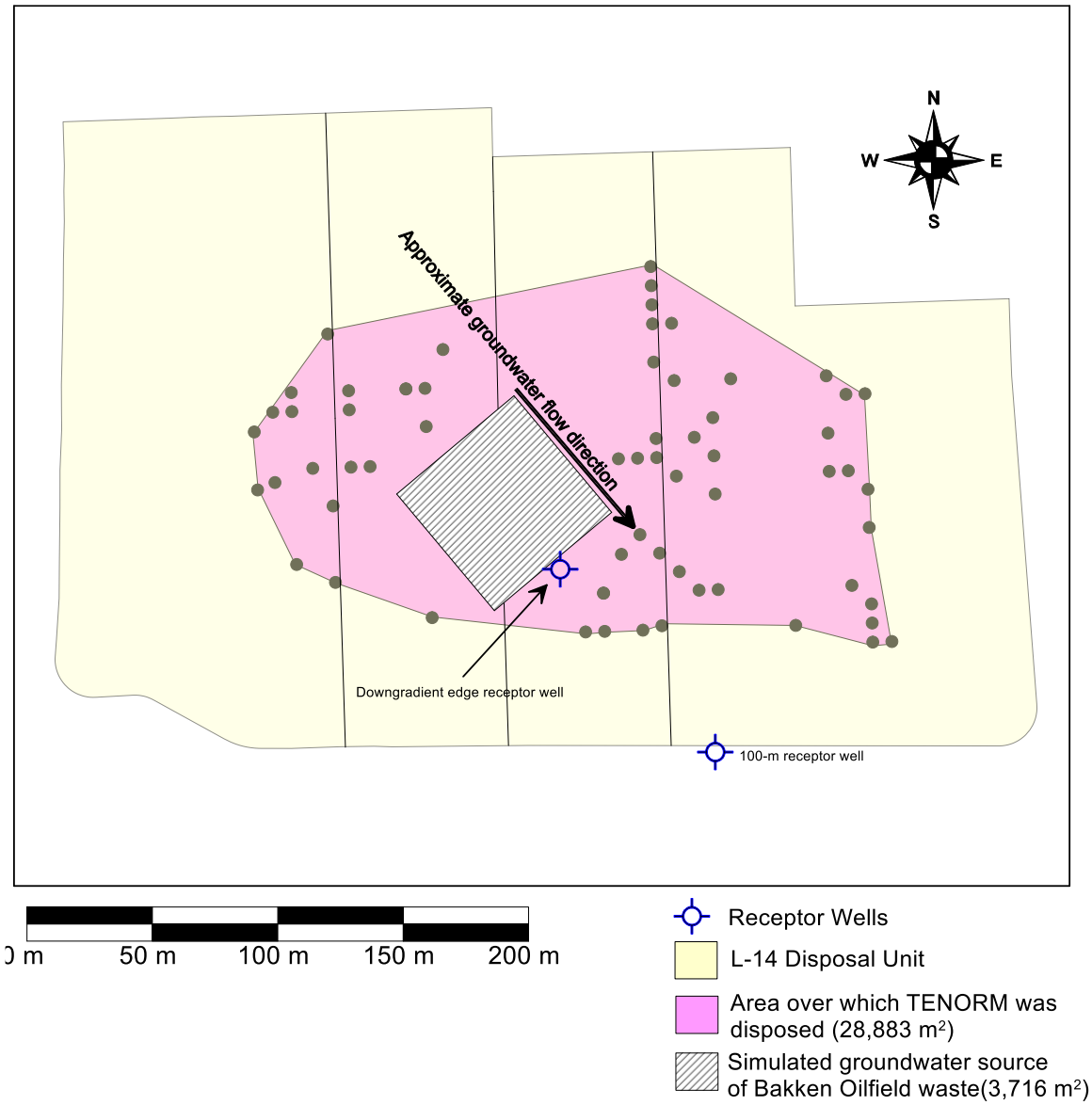

Figure 5. Landfill Unit L-14, the area over which the Bakken Oilfield waste disposals (dots) were reported, the simulated groundwater Bakken Oilfield source, and the receptor well locations.

The source configuration described here was intended to address the Bakken Oilfield waste disposals in question in a bounding manner only (i.e., will not underestimate the concentrations and resultant doses). If the model was applied to a greater volume of Bakken Oilfield waste, then the source geometry would need to be changed to better reflect that the waste was distributed over a much larger area.

3.5. Summary of Assumptions and Concluding Remarks

The assumptions for the unsaturated and saturated zone transport model are summarized below.

- Bakken Oilfield waste inventory assumes maximum radionuclide concentrations from the available data for all shipments and therefore likely overestimates the actual radionuclide inventory in Landfill Unit L-14.
- Bakken Oilfield waste is compressed into a single source cell measuring 60.96 m on each side. This assumption will result in higher predicted (modeled) concentrations in the upper Selah aquifer (i.e., minimizes radionuclide dilution if material assumed to be spread over larger area).
- Therefore, radionuclide fluxes to the upper Selah aquifer are distributed across an area equal to the modeled source area in Landfill Unit L-14.
- The model assumes releases of liquids through the engineered triple-liner system and leachate collection system after the site has been capped and no leachate is being generated. Thus, it represents a worst-case scenario.
- Concentrations (and doses) are evaluated at the downgradient edge of the source within the upper Selah aquifer, which is where the highest results are encountered. Results at this receptor location represent an upper bound estimate.
- Results at a well 100-m downgradient from the source will also be presented because this is the compliance point for DOE and NRC LLRW Performance Assessments.
- Results will be presented in the upper Selah aquifer, which is a non-potable aquifer. Concentrations and doses in the underlying potable aquifers will be significantly less than concentrations in the Selah based on hydrogeologic conditions. Concentrations in the underlying potable aquifers can be estimated by dividing concentrations in the upper Selah by a factor that represents the additional dilution and attenuation that occurs between water in the Selah and underlying aquifers.

It is noted that the results of the proposed modeling effort represent an upper-bound estimate of impacts for groundwater at the Arlington site and is a worst-case scenario. A more realistic assessment would incorporate the actual spatial distribution of the Bakken Oilfield waste disposals in the model, minimal infiltration of water through the final engineered landfill cap, and minimal movement of liquids through the engineered triple-liner and leachate collection system. This refinement can be performed using the same model and adjusting modeling inputs to reflect actual conditions.

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