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Project Name:
Project 1007 – Conceptual Site Model, Priority Area 1

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Date:
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Memo

Subject: Project 1007 Leapfrog Conceptual Site Model Technical Memo, Priority Area 1

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AECOM: 2015-04-13

1. Introduction

AECOM was retained by the Minnesota Pollution Control Agency (MPCA) to develop a three-dimensional Conceptual Site Model (CSM) to support Project 1007, a large flood control project consisting of a system of streams, lakes, stormwater pipes, open channels, catch basins, and two dams that direct water from the Tri-Lakes area of Minnesota to the St. Croix River at the Wisconsin border. AECOM has worked with the MPCA to investigate surface water and groundwater interaction and the migration of PFAS within the vicinity of Project 1007.

AECOM delineated Priority Areas in the East Metropolitan Area of the Twin Cities for focused development of a series of CSMs. These areas encapsulate the Project 1007 Corridor and were created to complete the CSM in phases with consideration of wells with existing PFAS data and previously identified groundwater PFAS plumes. Priority Areas (PA) are as follows:

- Priority Area 1: This area includes four (4) Beta Site locations with bedrock wells that were installed by AECOM between November 11, 2019 and January 21, 2020. PFAS data collected from these wells include soil and groundwater using a method called vertical aquifer profiling (VAP) to vertically delineate any detections of PFAS in a select borehole. One additional Beta Site location was added to PA1 in June 2020 and another Beta Site location is proposed near Sunfish Lake. PA1 also includes the downgradient plume of one of the primary Project 1007 PFAS source areas, the Washington County Landfill.
- Priority Area 2: This area includes two (2) new Beta Site locations with bedrock wells that were installed in May and June 2020 and at least four (4) proposed Beta Site locations. PFAS data collected from these wells include soil and groundwater using a method called VAP to vertically delineate any detections of PFAS in a select borehole. Several PFAS plumes have been depicted in PA2 and the greatest number of PFAS-impacted private wells are located in PA2.
- Priority Area 3: This area includes one (1) new Beta Site location with a bedrock well that was installed in June 2020 and two (2) proposed Beta Site locations. PFAS data collected from this well includes soil and groundwater using a method called VAP to vertically delineate any detections of PFAS in the borehole. Raleigh Creek, an intermittent stream with known PFAS exceedances that connects with the Project 1007 conveyance system, is located entirely within PA3. This area also includes the second primary Project 1007 PFAS source area, the Oakdale Disposal Site.
- Priority Area 4: This area includes the project extent north and south of the main Project 1007 Corridor and will incorporate any remaining wells with historic PFAS data into existing PFAS plumes.

This technical memorandum is intended to provide documentation for development of the CSM for Priority Area 1 while CSMs for Priority Area 2, 3, and 4 are subsequently recommended as an outcome of this work.

1.1 Background

According to PFAS surface water and sediment data collected from surface water bodies across the corridor, Project 1007 has exacerbated the spread of PFAS contaminants that emanate from two known source areas: the Washington County Landfill (WCL) in Lake Elmo, MN and the Oakdale Disposal Site (ODS) in Oakdale, MN. Piping from Project 1007 runs adjacent to the Washington County Landfill and was directly connected to PFAS-containing effluent water from the landfill for a period of approximately 7 years in the late 1980's to early 1990's. Additionally, the headwaters of Raleigh Creek, a small intermittent stream, begin just north of ODS. Raleigh Creek flows southeast and passes through ODS, eventually connecting with Project 1007 at Tablyn Park in western Lake Elmo where impacted surface water from ODS and WCL combine before continuing to flow east.

A CSM is a simplified representation of a real-world system that summarizes available information. For Priority Area 1, CSM development focused on integration of geographic information system (GIS), geological, hydrological, hydrogeological, and geochemical data to aid in the identification of surface water and groundwater flow pathways for the potential transport of PFAS.

Previously developed CSMs in the study area provide geological, hydrogeological, and PFAS contamination information that AECOM considered in the development of this CSM. Previous CSMs include those developed as part of the:

- Metro Model 3 groundwater model (Metropolitan Council, 2014);
- Northeast Metropolitan Lakes groundwater model (Jones et. al, 2017; S.S. Papadopulos & Associates, 2017), and the
- Twin Cities East Metro Area groundwater model (Wood, 2020a; Wood, 2020b).

A series of geological maps and cross-sections produced by the Minnesota Geological Survey (MGS, 2016) indicate that the geology of the Twin Cities area consists of Precambrian basement rock situated below Cambrian and Ordovician stratigraphy that is subsequently overlain by unconsolidated Quaternary glacial sediments. The Minnesota Geological Survey identifies multiple geologic units that include, from youngest to oldest in ascending order:

- Quaternary sediment;
- Decorah Shale and Platteville and Glenwood Formations;
- St. Peter Sandstone – Tonti and Pig's Eye Members;
- Shakopee Formation;
- Oneota Formation;
- Jordan Sandstone;
- St. Lawrence Formation;
- Tunnel City Group - Mazomanie Formation (aquifer) and Lone Rock Formation;
- Wonewoc Sandstone;
- Eau Claire Formation; and
- Mt. Simon Sandstone.

PFAS impacts of municipal wells, residential wells, and surface water bodies have been observed throughout the Project 1007 Corridor. Aquifers spanning from shallow, Quaternary water table aquifers down to the St. Lawrence Formation have known PFAS groundwater impacts, but the fate and transport of PFAS within these aquifers is poorly understood.

1.2 Objectives

The primary objectives of this work were to:

1. Develop a three-dimensional CSM for Priority Area 1 to visualize:
    a. Interpretations of surficial and bedrock geology;
    b. Groundwater chemistry data (With a focus on PFAS compounds PFOA and PFOS); and
    c. Develop visual interpretations of PFOA and PFOS plumes.
2. Use the CSM as a tool to investigate and identify:
    a. Spatiotemporal data gaps in hydrogeological and groundwater chemistry information; and
    b. Surface water and groundwater flow pathways that may contribute to PFAS transport.

3. Set the stage for integrated surface water and groundwater modelling by developing a geological and hydrogeological framework for future development of a regional-scale numerical model.
4. Develop a three-dimensional visualization that may be used to communicate technical concepts to a broad audience.

2. Data Sources

Data (summarized in Table 1 below) were incorporated from the following agencies:

- Minnesota Pollution Control Agency (MPCA);
- Minnesota Geological Survey (MGS);
- Minnesota Department of Natural Resources (DNR);
- Minnesota Department of Health (MDH);
- Metropolitan Council; and
- United States Department of Agriculture (USDA).

Table 1. Data Sources

Data	File Type	Source
Topography	LiDAR	DNR 2019
Lake Bathymetry	LiDAR	DNR 2019
Waterbodies and Watercourses	Shapefile	DNR 2019
Aerial Imagery	SID	USDA 2013
Project 1007 Infrastructure Designs	Shapefile	VBWD 2019
Boreholes and Monitoring Wells	Web Application	MDH 2020
Bedrock Geology	Map PDF, Raster	MGS 2016 (Atlas C-39 Part A Plate 2)
Bedrock Hydrostratigraphy	Map PDF	MGS 2016 (Atlas C-39 Part A Plate 2)
Surficial Geology (Sand Distribution Model)	Map PDF, Raster	MGS 2016 (Atlas C-39 Part A Plate 5)
Beta Site Monitoring Wells	gINT	AECOM 2020a
Groundwater Chemistry Data (PFOA, PFOS)	Web Application, EQuIS	MDH 2020, AECOM 2020a

3. Approach

3.1 Software

AECOM developed the CSM in Leapfrog Works 3.0 (Leapfrog Works). The Leapfrog Works implicit structure allows three-dimensional geological models to be constructed from borehole data, points, and surfaces and can easily be updated when new data is available. AECOM has previously used Leapfrog Works to develop CSMs in support of contaminated site investigations and civil infrastructure projects.

With Leapfrog Works ,a user can simultaneously visualize borehole data and groundwater chemistry data, interpret hydrostratigraphic surfaces and three-dimensional contaminant plumes, and visualize project infrastructure plans. Leapfrog Works can be used to export oblique views, cross sections, and three-dimensional visualizations that allow a user to pan, rotate, zoom, and slice cross sections with a freely available standalone Viewer program.

3.2 GIS

The following GIS information was incorporated into the CSM to provide context:

- Aerial imagery (USDA, 2013);
- Waterbodies and watercourses (DNR, 2019);
- Project 1007 infrastructure Designs (VBWD, 2019); and
- PFAS source areas (MDH, 2019).

3.3 Geological Framework

Bounded spatially by Priority Area 1, the CSM extends from the ground surface to a depth of 165 ft below sea level (approximately 105 to 130 ft below the upper contact of the Undifferentiated Mesoproterozoic unit). A Digital Elevation Model (DEM) was developed from LiDAR-derived topography data at 2 m resolution (DNR, 2019). Bathymetry data for lakes were provided by the DNR and incorporated into the DEM.

Developed using publicly available data from the MGS, the geological framework of the CSM was vertically discretized into 32 layers of variable thickness to represent a combination of surficial sediments (20 layers) and bedrock stratigraphy (12 layers) in Priority Area 1.

3.3.1 Bedrock

Geological surfaces for bedrock contacts (provided as raster files from the Geologic Atlas of Washington County [MGS, 2016]) were clipped to the spatial extent of Priority Area 1 and imported into Leapfrog Works at 10 m resolution. Bedrock layers incorporated into the CSM, from top to bottom, include:

- Platteville-Glenwood Formation (Opg);
- St. Peter Sandstone (Os);
- Prairie du Chien Group (Shakopee Formation [Ops] and Oneota Dolomite [Opo]);
- Jordan Sandstone (Cj);
- St. Lawrence Formation (Cs);
- Tunnel City Group (Ct);
- Wonewoc Sandstone (Cw);

- Eau Claire Formation (Ce);
- Mt. Simon Sandstone (Cm); and
- Undifferentiated Mesoproterozoic.

QA/QC was performed on geological layers developed in Leapfrog Works by visual comparison between the geological model in Leapfrog Works to the originally provided geological surfaces (rasters) in ArcGIS. Furthermore, geological bedrock surfaces were compared to the Minnesota Bedrock Geology Map (MGS, 2016; Plate 2) to verify spatial extent.

3.3.1 Sand Distribution Model

Surficial sediments were represented using the Sand Distribution Model developed by the MGS (MGS, 2016). Surficial sediment layers were clipped to the spatial extent of Priority Area 1 and imported into Leapfrog Works at 10 m resolution. Sand Distribution Model layers incorporated into the CSM, from top to bottom, include:

- Undifferentiated sediment;
- Sc (organic clayey silt);
- Sl (sand to clay);
- Ss (sand and gravel);
- Qcr (sandy till);
- Qse (sand and gravel);
- Qce (sandy till);
- Qs1 (sand and gravel);
- Qr1 (sandy till);
- Qs2 (sand and gravel);
- Qr2 (sandy to loamy till);
- Qsx (sand and gravel);
- Qxt (loamy till);
- Qs3 (sand and gravel);
- Qr3 (sandy till);
- Qsp (sand and gravel);
- Qpt (loamy to clayey till);
- Qsv (sand and gravel);
- Qct (no description provided); and
- Qu (undifferentiated sediment).

Due to the complex hierarchy of geological surfaces, only layers for the base of each unit were incorporated into the CSM.

3.3.1 Borehole Data

AECOM incorporated borehole data from the Minnesota Department of Health's Minnesota Well Index (MWI) into the CSM as follows:

- Borehole collars (adjusted to coincide with the LiDAR-derived DEM);
- Borehole lithology data for Priority Area 1; and

- Monitoring well data for Priority Area 1, including coordinates, screened interval, screened geologic material and code, facility name, and well status.

AECOM incorporated high resolution borehole lithology data from Beta Site bedrock wells into the CSM (AECOM, 2020a). Borehole information included coordinates, hole ID, logged geologic intervals, USCS codes, and field description. Borehole lithology was re-coded (i.e. grouped) to simplify these logs in the CSM.

Borehole details from both the MWI and AECOM (AECOM 2020a) were imported as separate, standalone files to allow for flexibility in future updates to the CSM. Borehole detail discrepancies (i.e. no data, boreholes missing depth information, etc.) were identified and corrected.

3.4 Chemistry

All available well analytical results for PFOA and PFOS were imported into the CSM from data sources that include the MDH, MPCA, and AECOM Beta Sites (AECOM, 2020a). Imported data include well ID, depth to the midpoint of the screen, sample date, analyte, analyte concentration, screen from/to depth, geologic unit, method detection limit, reporting detection limit, and well status. Analyte data for the most recent measurements from 2013 to 2020 was displayed at the midpoint of the screen of completed monitoring wells.

QA/QC was performed on the PFAS analytical data acquired from MDH and MPCA to ensure consistency in the format of all input files, ensure consistency of units of all analytical data reported, and to eliminate any duplicate lines of data.

Leapfrog's proprietary FastRBF interpolation was used to develop three-dimensional plumes of PFOA and PFOS. Plumes were interpolated from the most recent date sampled to provide adequate coverage for the interpolation and to reduce the influence of antiquated data on the migration plumes. Plumes were interpolated from point data using ellipsoid ratios that were adjusted to accommodate anisotropy within the hydrostratigraphic units (i.e. preferential lateral dispersion of PFAS in hydrostratigraphic units with relatively higher permeability) and assumed hydraulic connection between surficial sediments and bedrock aquifers as the interpolation could applyPFOA and PFOS across the bedrock contact. Interpolated plumes were visually assessed for consistency with geochemical and geological data.

4. Leapfrog Works Viewer File

Three-dimensional visualizations for Priority Area 1 are provided in the accompanying Leapfrog Works Viewer file. The Leapfrog Works Viewer consists of the following four scenes:

- Scene 1:
    - Delineation of Priority Areas;
    - Waterbodies and watercourses (DNR, 2019);
    - Project 1007 infrastructure (VBWD, 2019);
    - Surficial sediment distributions as described by the Sand Distribution Model (MGS, 2016);
    - Bedrock surfaces as described by the Minnesota Geological Survey (MGS, 2016); and
    - Inferred hydrostratigraphic surfaces as described by the Minnesota Geological Survey (MGS, 2016). Hydrostratigraphy is classified as relatively high, low, and variable hydraulic conductivity for both surficial sediments and bedrock.
- Scene 2 (features presented in Scene 1 with):
    - Collars and screened intervals (if applicable) for boreholes from the MWI;
    - Borehole lithology data at AECOM Beta Sites;
    - PFOA and PFOS groundwater chemistry data with concentration posted for the most recent sample measurement between 2013 and 2020;
    - VAP sampling for PFOA and PFOS at AECOM Beta Sites;
    - A series of west-oriented and north-oriented fences (cross sections) through geologic and hydrostratigraphic layers; and
    - Fence along the currently interpreted alignment of the buried-bedrock valley.
- Scene 3 (features presented in Scene 2 with):
    - Interpolated three-dimensional PFOA plume;
    - Collars and screened intervals (if applicable) for boreholes from the MWI;
    - Borehole lithology data at AECOM Beta Sites;
    - PFOA and PFOS groundwater chemistry data with concentration posted for the most recent sample measurement between 2013 and 2020;
    - VAP sampling for PFOS and PFOA at AECOM Beta Sites;
    - A series of west-oriented and north-oriented fences through inferred hydrostratigraphy; and
    - Fence along the currently interpreted alignment of the buried-bedrock valley.
- Scene 4 (features presented in Scene 2 with):
    - Interpolated three-dimensional PFOS plume;
    - Collars and screened intervals (if applicable) for boreholes from the MWI;
    - Borehole lithology data at AECOM Beta Sites;
    - PFOA and PFOS groundwater chemistry data with concentration posted for the most recent sample measurement between 2013 and 2020;
    - VAP sampling for PFOA and PFOS at AECOM Beta Sites;

- A series of west-oriented and north-oriented fences through inferred hydrostratigraphy; and
- Fence along the currently interpreted alignment of the buried-bedrock valley.

5. Limitations

The following limitations apply to the CSM developed herein:

- Geological surfaces were incorporated into the CSM from the Geologic Atlas of Washington County developed by the Minnesota Geological Survey. Quality of a geological model is directly dependent on the quantity and quality of input data. The geological data provided in the Geologic Atlas of Washington County is provided as “black box” without detailed information on how the geological model was generated. It is not clear to AECOM how the surfaces were developed, reviewed, or what boreholes from the MWI were incorporated into geological interpretations. It is therefore difficult to understand where the geological model may be more or less certain.
- PFAS is known to move through the groundwater system under the influence of several fate and transport processes. These processes include advection (the primary process affecting transport), dispersion (i.e. spreading of the groundwater plume laterally), and sorption and degradation. Inferred three-dimensional plume interpretations do not account for preferential transport due to groundwater flow, transport processes, or the complex behaviours of PFAS (for example, at the air-water interface). Geostatistical methods employed in developing this CSM provide a preliminary interpretation of where PFAS may have been transported to but by no means claims to be a definitive delineation of PFAS contamination.

6. Conclusions

The following conclusions may be made based on this work:

- A three-dimensional Conceptual Site Model has been developed for Priority Area 1 to visualize: interpretations of surficial and bedrock geology, groundwater chemistry data (PFAS compounds PFOA and PFOS), and interpretations of PFOA and PFOS plumes.
- The Conceptual Site Model has been used as a tool to investigate spatiotemporal data gaps in hydrogeological and groundwater chemistry information and identify surface water and groundwater flow pathways that may contribute to PFAS transport.
- The Conceptual Site Model provides a framework for integrated surface water and groundwater modelling by collating geological and hydrogeological information that may be imported into numerical modelling software.
- The Conceptual Site Model has been used to communicate technical concepts to a broad audience and can be a useful tool in the future if regularly maintained.

7. Recommendations

AECOM provides the following recommendations:

1. Expand the Conceptual Site Model for Priority Area 1 to include Priority Areas 2, 3, and 4.
2. Update, refine, and expand geological data in the Conceptual Site Model:
    a. Incorporate borehole lithology data from the MWI for Priority Areas 1, 2, 3, and 4.
    b. Incorporate borehole lithology data from Beta Sites for Priority Areas 2, 3, and 4.
    c. Incorporate existing Minnesota Geological Survey and AECOM fence diagrams to assist with QA/QC of the geological interpretations for Priority Areas 1, 2, 3, and 4.
    d. Incorporate geophysical information and modify the inferred buried-bedrock valley within the context of available regional geological information.
    e. Integrate regional faults into interpreted geological surfaces as needed.
3. Update, refine, and expand groundwater chemistry data in the CSM:
    a. Incorporate PFOA and PFOS data in Priority Area 2, 3, and 4 and any new PFOA and PFOS data in Priority Area 1.
    b. Refine three-dimensional interpretations of PFOA and PFOS plumes in Priority Area 1.
    c. Integrate three-dimensional plume interpretations across Priority Areas as needed.
4. Use the Conceptual Site Model to support surface water and groundwater modelling:
    a. Incorporate GIS data such as county boundaries, digital surficial geology and bedrock geology maps, land cover maps, meteorological stations, streamflow gauging stations, catchment boundaries, spring and karst locations, and snow cover distributions to leverage the Conceptual Site Model to support integrated surface water and groundwater model conceptualization and development.
    b. Delineate the spatial extent for an integrated surface water and groundwater model domain and expand the Conceptual Site Model to that boundary (beyond Priority Area 4). This would allow the Conceptual Site Model to be directly imported into numerical surface water and groundwater modelling software.
5. Interpretation of surficial sediments and its associated uncertainty will be critical to the transport of PFAS. Perform detailed QA/QC on the Sand Distribution Model and explore the possibility of revisiting the interpretation of the surficial sediments. Alternatively, a geological framework could be developed with borehole data and geostatistical methods (for example, indicator kriging) using both a lithology approach and a hydrostratigraphy (permeability) based approach to represent the complex distribution of buried-bedrock valley sediments. These methods could be used to generate multiple realizations of surficial sediments to help assess uncertainty in future simulated numerical model results.
6. Continue to use the Conceptual Site Model as a tool to support visualization, gap analysis, field characterization, and modelling efforts.

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9. Closure

This memorandum was prepared to document development of a Conceptual Site Model for Priority Area 1 using a combination of private and publicly available data. Please contact the undersigned for further information if you have any questions regarding this memorandum.

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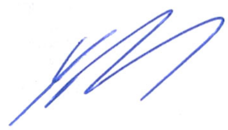

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