Hydrogeological Investigation Report

Eastern Expansion Construction Permit
Volume 2, Attachment 4

Ottawa County Farms Landfill

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Coopersville, Michigan

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ENGINEERING & ENVIRONMENTAL SOLUTIONS
400 136th Avenue, Suite B, Holland, Michigan 49424

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I EXECUTIVE SUMMARY

A hydrogeological investigation at the Ottawa County Farms Landfill, eastern expansion, was conducted by Engineering & Environmental Solutions (*E&E Solutions*) on behalf of Ottawa County Landfill, Inc. to meet the requirements of Part 115 of the Natural Resources and Environmental Protection Act, 1994 P.A. 451. The primary components of the hydrogeological investigation include (1) characterizing the areal and vertical extent of earth materials, (2) determining the hydraulic properties of soil and bedrock units, (3) defining the uppermost aquifer (upper aquifer) and aquifers hydraulically interconnected to it, (4) determining the groundwater flow direction, flow rates, and vertical and horizontal gradients of the aquifers, and (5) determining the groundwater quality and background quality in the aquifers.

An overview of the regional geology and hydrogeology was performed to establish a benchmark for comparison to site conditions. The site is located on the western side of the Michigan Basin. The basin is filled with approximately 2,400 feet of consolidated sedimentary rocks and is mantled by as much as 400 feet of unconsolidated glacial sediments. The basin-fill sedimentary rocks are primarily shale, sandstone, and limestone and the glacial sediments are clay, silt, sand, and gravel deposits. The principal aquifers in the basin are contained within sandstone, and glacial sand and gravel deposits. Groundwater in the western part of the basin generally flows from east to west towards Lake Michigan, consistent with regional topography. The Marshall sandstone contains the primary water-producing zone in the region and the glacial sediments produce substantial amounts of groundwater locally. These bedrock and soil units are the focus of this investigation because they underlie the site and contain the principal aquifers beneath the site.

An evaluation of the site geology is required by Part 115 to characterize the areal and vertical extent of earth materials at the site. The evaluation is required because earth materials control site hydrogeologic and aquifer conditions. The hydrogeological investigation confirmed the depth to bedrock and the stratigraphy of the upper portions of the bedrock and overlying glacial sediments.

Since the early 1990's, approximately 71 exploratory borings have been drilled at the site to determine the glacial sediment and bedrock stratigraphy. A total of 24 exploratory borings were completed as part of this investigation. Bedrock beneath the site consists of limestone and sandstone of the Marshall Formation and shale and gypsum of the Michigan Formation. The bedrock formations are overlain by approximately 165 to 205 feet of glacial sediments. The sediments are divided into four stratigraphic units based on their hydrogeologic characteristics; from top to bottom, they include an upper continuous clay unit which is 60 to 170 feet thick, an upper discontinuous sand unit which is 5 to 75 feet thick, a lower discontinuous clay unit which has a maximum

thickness of approximately 45 feet, and a lower discontinuous sand unit which has a maximum thickness of approximately 35.

An evaluation of the site hydrogeology is required by Rule 904 to define the upper aquifer beneath the site and determine the flow paths and hydraulic characteristics of the aquifer(s). During this investigation, *E&E Solutions* installed 5 monitoring wells to evaluate groundwater flow direction, flow rates, and horizontal and vertical gradients beneath the eastern expansion. Four of the new wells are proposed for the site's detection monitoring program. The monitoring network for the entire site includes one well screened in a perched water zone and 13 monitoring wells screened in the upper aquifer. A conceptual hydrogeologic model for the site was developed based on data collected during the 2015 investigation in addition to data collected during previous hydrogeological investigations. The conceptual model is the foundation on which the site's proposed Environmental Monitoring Plan was developed.

Fractured limestone and sandstone of the Marshall Formation has moderate permeability and contains a regional aquifer which is an estimated 200 to 300 feet thick. This bedrock aquifer underlies the entire site and is a source of drinking water in the area. The sand units in the overlying glacial sediments contain the upper aquifer at the site. The sand units have moderate permeability and are hydraulically interconnected with each other and with the lower bedrock aquifer. Groundwater in the lower aquifer flows west- northwest and groundwater in the upper aquifer flows south- southwest. Groundwater elevations in the lower aquifer are influenced by extensive groundwater pumping from farm and non-residential production water wells located west of the site. The site is in an aquifer recharge area characterized by downward hydraulic gradients. Groundwater in the upper and lower aquifers moves under a similar hydraulic gradient which ranges from 0.0015 to 0.0021 foot per foot. The average groundwater flow velocity in the lower aquifer is 42 feet per year and the average flow velocity in the upper aquifer is 8.3 feet per year.

A groundwater sampling and analysis program is being conducted for the eastern expansion to meet the requirements of Rule 904. A total of eight groundwater samples will be collected from six monitoring wells to evaluate background groundwater quality for the upper and lower aquifers beneath the eastern expansion. The background samples will be collected during individual sampling events beginning with the fourth quarter 2015 and ending with the fourth quarter 2016. All samples will be tested for the complete Part 115 landfill parameter list. Statistical evaluations of the background groundwater data will be used to determine the most desirable parameters for the site's detection monitoring program. Statistical limits will be developed for the proposed detection monitoring parameters.

1.0 INTRODUCTION

Engineering & Environmental Solutions presents in this report the results of a Hydrogeological Investigation for a proposed expansion of the Ottawa County Farms Landfill, Ottawa County, Michigan. The plan was prepared on behalf of the Ottawa County Landfill, Inc. to meet the requirements of the Natural Resources and Environmental Protection Act, 1994 PA 451 (Part 115).

1.1 SITE DESCRIPTION

Ottawa County Farms Landfill is a 242-acre Type II solid waste disposal facility located approximately 0.5 mile south of the City of Coopersville in Sections 26 and 27, T8N R14W, of Polkton Township, Ottawa County, Michigan (Figure 1). A legal description of the site is provided on Sheet 2 of the *Engineering Report* (Weaver Consultants Group, 2016). The proposed eastern expansion is contiguous with the exiting landfill and includes approximately 51.3 acres.

Natural ground elevations range from approximately 680 feet above mean sea level (MSL) along the southwestern part of the site to approximately 600 feet MSL 0.5 miles east of the site along Deer Creek (Figure 1). The topography of the area was formed by glacial features with the highest elevations associated with recessional glacial moraine deposits and lower elevations associated with the Deer Creek drainage system. Surface drainage is generally from west to east into Deer Creek. Figure 2 shows the site topography and drainage patterns. Land use in the area is primarily agricultural with some industrial uses north of the site in the City of Coopersville.

Sites defined under the Part 201, Environmental Remediation, Natural Resources and Environmental Protection Act, 1994 PA 451, as amended and sites containing leaking underground storage tanks were identified within 0.5 mile of the landfill (Michigan Department of Environmental Quality website accessed in 2016). These sites include Lemmon Oil Co. and Coopersville BP located approximately 0.3 to 0.4 miles northwest of the landfill.

1.2 SITE HISTORY

The initial subsurface investigation for Ottawa County Farms Landfill was conducted between August 1980 and February 1981 and included 25 exploratory borings (B-1 through B-25) located in Cells A through E (Appendix A). The borings were advanced to a depth of approximately 75 feet below ground surface (BGS) in the upper clay unit. Disposal operations began at the site in 1982 and have included the licensing and construction of the existing Type II Landfill. An additional 17 exploratory borings were drilled at the site in April and May 1988. These borings were located in Phase 1 through 4 and advanced to a depth of approximately 37 to 75 feet BGS (Appendix A).

The initial groundwater monitoring network was completed in August 1994 and included twenty exploratory borings, twelve of which were completed as monitoring wells. Three of these monitoring wells were screened in the lower aquifer, seven wells were screened in the upper aquifer, and two wells were screened in a perched water zone. The groundwater monitoring network approved for the 1995 Environmental Monitoring Plan included the following sixteen monitoring wells.

MW-11	DB-1	DB-11	DB-17
MW-12	DB-2	DB-14	DB-18
MW-1R	DB-3	DB-15	DB-19
MW-2R	DB-5	DB-16	DB-20

An updated construction permit and accompanying Hydrogeological Investigation Report for the facility was submitted in August 1995. At that time, monitoring wells DB-17 and DB-19 were replaced with wells DB-17R and DB-19R. In July 2000, monitoring wells DB-21 and DB-22 were installed along the southeastern edge of the site as part of the landfill expansion for Phases 3 and 4. These wells were screened in the upper aquifer. Monitoring well DB-23 was installed in 2003 to further characterize groundwater conditions in the upper aquifer upgradient from the landfill. This well was installed as part of the county consistency requirements for the eastern expansion.

The monitoring network reached its current configuration in 2015 when 14 soil borings, 5 monitoring wells, and 5 gas probes were installed as part of a hydrogeological investigation for the eastern expansion. The soil borings, monitoring wells, and gas probes installed during the 2015 investigation are listed below.

MM-17	DB-25	SB-33	SB-39
MM-18	DB-26	SB-34	SB-40
MM-19	DB-27	SB-35	SB-41
MM-20	DB-28	SB-36	SB-42
MM-21	SB-31	SB-37	SB-43
DB-24	SB-32	SB-38	SB-44

One monitoring wells (DB-28) is screened in the lower aquifer and four monitoring wells (DB-24, DB-25, DB-26, and DB-27) are screened in the upper aquifer.

A total of 14 soil borings (SB-31 through SB-44) were drilled in the proposed landfill expansion area (Figure 3) to evaluate the subsurface characteristics of the upper clay unit and depth of the upper sand unit beneath the expansion area. The borings were advanced to a depth of approximately 54 to 118 feet BGS (Appendix B).

1.3 PROJECT DESCRIPTION

E&E Solutions conducted a hydrogeological field investigation at the proposed landfill expansion between October 2015 and December 2015. The key components of the

investigation are defined by Rule 904 of Part 115. The specific tasks conducted during the investigation and the items they address are presented below.

- A total of 24 borings were drilled around the perimeter of the landfill and within the footprint of the proposed eastern expansion. Information collected from the borings was used to determine the glacial sediment and bedrock stratigraphy and to define hydrogeologic characteristics of the sediment and bedrock units beneath the eastern expansion.

- Approximately 721 soil samples and 10 bedrock samples were collected from the borings. Representative soil samples were tested to determine soil classification, consolidation properties, and hydraulic characteristics.

- Based on the subsurface data collected at the soil borings, geologic cross sections were developed depicting the glacial sediment stratigraphy and depth to bedrock beneath the site.

- Five permanent groundwater monitoring wells were installed around the perimeter of the proposed landfill expansion to evaluate groundwater flow direction, gradients (horizontal and vertical), and groundwater flow velocity. One of the wells was screened in the lower bedrock aquifer and four of the wells were screened in the upper aquifer.

- Five gas monitoring probes (MM-17 through MM-21) were installed around the perimeter of the existing landfill and proposed expansion area. The gas probes were installed to the depth of the landfill and are designed to detect the migration of potential subsurface landfill gas.

- A total of eight background samples will be collected from six monitoring wells located around the perimeter of the proposed eastern expansion and tested for the full list of Part 115 parameters. The background samples will be collected during individual sampling events between December 2015 and December 2016. The background groundwater analytical data will be used to evaluate groundwater quality and develop statistical limits for monitoring purposes.

2.0 REGIONAL GEOLOGY

An overview of the regional geologic setting is presented in this section to compare with local site conditions. The regional characteristics of the sandstone bedrock and glacial sediments are the focus of the overview because they contain the primary groundwater aquifers beneath the site.

The Ottawa County Farms Landfill is situated along the western edge of the Michigan Basin. The geology of the area is shown on a Figures 4 and 5. The western part of the basin consists of approximately 2,400 feet of consolidated sedimentary rocks which are mantled by as much as 400 feet of unconsolidated glacial sediments. The basin-fill sedimentary rocks are primarily shale, sandstone, and limestone which were deposited during the Mississippian and Cambrian periods. The distribution of the sedimentary rocks and glacial sediments are shown on the Regional Bedrock and Glacial Geology maps (Figures 4 and 5). The surface distribution of the glacial sediments and sedimentary rocks are illustrated on the Regional Geologic Cross Section (Figure 6). The trace of the Regional Geologic Cross Section is shown on Figure 7. There are no known active bedrock faults or other seismic sources in the region. There is no known karst terrain in the area of the site.

Bedrock beneath the site consists of sandstone and limestone of the Marshall Formation overlain by shale and gypsum of the Michigan Formation (Figure 6). The regional extensive sandstone units of the Marshall Formation are approximately 200 to 300 feet thick and yield moderate quantities of freshwater. The Michigan Formation consists primarily of shale, gypsum, and limestone which yield limited quantities of groundwater. Regionally, the bedrock units dips to the east.

Unconsolidated glacial sediments overlie the bedrock formations and form part of the extensive north-south trending Lake Border moranic system. The glacial sediments include moraine, ground moraine, and outwash deposits. The glacial geology of the area is shown on Figure 5. The regional glacial stratigraphy is in part, based on logs of water wells drilled within 0.5 mile of the site (Figure 7). Drillers' logs for these water wells are presented in Appendix C. The characteristics of the glacial sediments are the focus of the hydrogeological investigation because they contain the upper aquifer beneath the site. The moraine deposits are exposed at the site and consist primarily of massive beds of clay. The thick clay beds have low-permeability and restrict vertical groundwater flow. Outwash deposits beneath the site consist of well-sorted layers of sand and gravel and contain the site's upper aquifer. These coarse grained sediments typically contain limited aquifers in relatively small areas (Western Michigan University, 1981). None of these outwash deposits are regionally continuous.

Because of the limited topographic relief in the area, the glacial sediments are not susceptible to mass movement.

3.0 SITE GEOLOGY

An evaluation of the site geology is required by Part 115 to characterize the areal and vertical extent of earth materials. The evaluation is required because earth materials control site hydrogeologic and aquifer conditions. The geologic investigation focused on determining the depth to bedrock and the stratigraphy of the glacial sediments. Methods used for this investigation are discussed first, followed by a discussion of the bedrock and glacial stratigraphy.

3.1 METHODS OF INVESTIGATION

Subsurface information collected during this and previous investigations was used to evaluate the site geology. During this investigation, 24 exploratory borings were drilled around the perimeter of the landfill and within the footprint of the proposed landfill expansion. Figure 3 shows the proposed eastern expansion, the location of the exploratory borings, and the trace of six geologic cross sections. During previous site investigations, approximately 71 exploratory borings were drilled around the perimeter of the site and beneath the existing landfill (Appendix A). The history of past exploratory drilling at the site is provided in Section 1 and Appendix A of this report. An overview of the drilling and soil sampling procedures are presented in Appendix D and logs of exploratory borings are provided in Appendix B.

3.2 STRATIGRAPHY

Information collected during the hydrogeological investigation indicates that the underlying unconsolidated glacial sediments include a laterally continuous clay unit with uniform characteristics. The clay unit is underlain by discontinuous sand and clay units. The glacial sediments are underlain by sandstone and limestone bedrock of the Marshall Formation and shale and gypsum of the Michigan Formation. The subsurface distribution of these soil and bedrock units are illustrated in Cross Sections A-A' through F-F' (Figures 8 through 13). The results of soil classification and hydraulic conductivity testing are included on the cross sections.

Of the 721 soil samples collected during the hydrogeological investigation, approximately 584 samples were taken from the upper clay unit, 84 samples were collected from the upper sand unit, 46 samples were collected from the lower clay unit, and 7 samples were collected from the lower sand unit. A total of 10 core samples were collected from the bedrock formations. Soil testing results are included on the boring logs and are summarized in Table 1. The following geologic descriptions are based on findings from the exploratory borings (Appendix B).

3.2.1 Bedrock

Bedrock underlies the site at depths ranging from approximately 165 to 205 feet BGS and consists of sandstone and limestone of the Marshall Formation and shale and gypsum of the Michigan Formation (see Cross Sections A-A' through F-F'; Figures 8 through 13). The subsurface configuration of the bedrock surface was determined by the deep exploratory borings and is relatively flat. The contact between the bedrock and overlying glacial sediments dips to the south and west away from a pre-glacial bedrock high (165 ft BGS) encountered at deep boring DB-28 (see Cross Sections B-B', C-C', and D-D'; Figures 9, 10, and 11).

Marshall Formation

The upper part of the Marshall Formation consists of a maximum of 20 feet of limestone that caps a thick sandstone. The extent and thickness of the limestone unit was determined from the deep exploratory borings and water well logs (Appendices B and C). Bedrock core samples collected from the Marshall Formation at well DB-28 consisted of well-sorted, fine- to medium-grained greenish gray quartz sandstone and approximately 9 feet of laminated gray limestone (see Cross Section C-C'; Figure 10). The limestone contains vertical and horizontal fractures which are filled with pyrite (Dell 1995). The underlying sandstone unit is estimated to be approximately 200 to 300 feet thick (Mandle and Westjohn, 1988). The sandstone unit has moderate permeability and does not restrict groundwater flow. Groundwater conditions in the bedrock are discussed in Section 5.

Michigan Formation

The Michigan Formation consists of shale and gypsum units and overlies the Marshall Formation beneath the eastern portion of the site. Bedrock core samples collected from the Michigan Formation at well DB-28 include 18 feet of laminated gray shale overlain by approximately 10 feet of massive yellowish gray gypsum (see Cross Section C-C'; Figure 10).

3.2.2 Glacial Deposits

Surficial deposits consist of uncemented or weakly consolidated earth materials that have been reworked by natural or artificial means. At the site they include cover soils, refuse, access roads, berms, and stockpiled earth materials within and adjacent to the site.

Glacial sediments are exposed around the perimeter of the site and underlie the entire site at depth. The glacial stratigraphy controls groundwater conditions in the upper aquifer. Geological Cross Sections A-A′ through F-F′ (Figures 8 through 13) illustrate the subsurface distribution of glacial sediments beneath the site.

The following discussion is based on boring logs and drill core recovered from 24 exploratory borings drilled during this investigation and 71 exploratory boring drilled during previous subsurface investigations. The exploratory borings encountered approximately 165 to 205 feet of glacial sediments above a relatively flat bedrock surface. The contact between the glacial sediments and the underlying bedrock is not a barrier to groundwater flow. The glacial sediments consist of interbedded slit, sand, and gravel interlayered with massive beds of clay. The low-permeability clay beds restrict vertical groundwater movement.

The glacial sediments are divided into four stratigraphic units based on their hydrogeological characteristics and stratigraphic position. From the surface down they include a continuous upper clay unit, an upper sand unit, a lower discontinuous clay unit, and a lower discontinuous sand unit (see Cross Sections A-A′ through F-F'; Figures 8 through 13). Groundwater conditions in the glacial sediments are addressed in Section 5. A detailed description of the sediments and their soil classification are provided on the boring logs (Appendix B). Below is a generalized description of each unit followed by its laboratory derived soil classification and approximate thickness.

The upper clay unit consists of massive clay beds (CL) interstratified with poorly-graded silt and sand lenses. The upper clay unit is approximately 60 to 170 feet thick. The upper sand unit is 5 to 75 feet thick and consists of poorly-graded, fine- to medium-grained sandy silt (SP-SC). The average thickness of the upper sand unit is approximately 25 to 35 feet. The lower clay unit consists primarily of sandy clay (SC) with minor silt (ML) and sandy silt lenses. The unit is discontinuous with a maximum thickness of approximately 45 feet beneath the northern portion of the site (Cross Section D-D'; Figure 11). The lower sand unit consists of poorly graded, medium- to coarse-grained sand and includes a well-graded gravel (GW) to clayey gravel (GC) at the base of the section. The lower sand and gravel beds contain clasts derived from the underlying bedrock. The lower sand unit is discontinuous ranging from 20 to 35 feet thick beneath the eastern portion of the site. Beneath the south-central portion of the site, the upper and lower sands form one unit approximately 60 feet thick (Cross Section E-E'; Figure 12).

The low-permeability upper clay unit described above thickens to the west and is characteristic of sediments deposited in a moraine environment. The laterally continuous upper clay unit restricts surface water infiltration to the upper aquifer. The water-bearing sand units thin to the west and are characteristic of glacial outwash deposits. The upper sand unit is approximately 5 feet thick beneath the southwestern portion of the existing landfill, and the lower sand pinches out beneath the northeastern part of the site (Cross Section D-D'; Figure 11). The upper and lower sand units form one continuous stratigraphic unit beneath the south-central part of the site. Exploratory borings drilled for water wells west of the site indicate that the water-bearing sands are absent downgradient from the site. Groundwater conditions in the glacial sediments are discussed in Section 5.

The geology of the eastern expansion is similar to the existing site with the exception of the bedrock surface and the depth to the upper sand unit. The bedrock surface rises beneath the eastern expansion and forms a structural high in the vicinity of well DB-28 (Cross Section D-D'; Figure 11). The top of bedrock in this area consists of approximately 10 feet of gypsum underlain by 18 feet of shale.

A contour map of the upper sand unit is shown on Figure 19. The upper sand unit is at its deepest elevation beneath the southeastern corner of the expansion area (approximately 503 ft MSL at well DB-25). The sand rises to its highest elevation beneath the northeastern portion of the site at well DB-28, approximately 592 feet MSL (Cross Section C-C'; Figure 10). In this area, sand verification and clay confirmation borings SB-31, SB-32, SB-38, SB-40, SB-41, and SB-42 (Figure 3) confirmed the thickness of the upper clay and depth to sand (Cross Section B-B'; Figure 9). The proposed landfill subgrade for the eastern expansion has been designed to accommodate for the variations in clay thickness (*Engineering Report*; Weaver Consultants Group, 2016) (Cross Section B-B'; Figure 9). Consistent with OWMRP-115-26 (Appendix D), additional clay confirmation borings will be proposed, as needed, to verify the natural soil barrier beneath the eastern expansion (see Section 5.2.1.1).

4.0 REGIONAL HYDROGEOLOGY

An overview of the regional hydrogeologic setting is presented in this section to compare regional characteristics with local site conditions. The overview covers sufficient area to allow for a definition of the potential impact that site operations may have on area groundwater.

The regional characteristics of the sandstone bedrock and glacial sediments are the focus of the overview because they contain the primary aquifers beneath the site. A hydrogeological investigation of the Michigan Basin and its associated regional aquifer system was performed by Western Michigan University (Western Michigan University, 1981), Swain (1984), and Mandle and Westjohn (1988). The following is summarized from those reports.

Mississippian and Pennsylvanian sedimentary rocks and Quaternary sediments of the Michigan Basin contain a regional aquifer system that consists of three primary aquifer units. These regional aquifers include (1) a lower aquifer unit which is contained in sandstone of the Marshall and Michigan Formations, (2) a middle aquifer unit which is contained in younger sedimentary rocks not present beneath the site, and (3) an upper aquifer unit which is contained in glacial sediments. The glacial sediments contain numerous aquifers that are not regionally interconnected. Groundwater resources in the Marshall Formation and glacial sediments are the focus of this investigation because they underlie the site.

Regional groundwater flow in the Marshall Formation is generally from east to west consistent with topography in the western part of the basin. In the area surrounding the site, groundwater in the Marshall Formation generally flows west towards Lake Michigan (Mandle and Westjohn, 1988) which is consistent with observations at the site. Groundwater in the overlying glacial sediments generally flows southwest towards the Grand River drainage basin. Waste water treatment ponds for the City of Coopersville are located approximately 0.5 miles upgradient from the site, east of Deer Creek (Figure 2). The largest source of aquifer recharge in the area is surface water infiltration, groundwater flow from upgradient sources, and seepage from tributaries of Deer Creek (Figure 2).

The Marshall Formation consists of locally fractured and cemented to poorly cemented sandstone and minor limestone, shale, and siltstone. The lower bedrock aquifer is typically enhanced by recharge from smaller, localized aquifers in the overlying glacial sediments and by surface water bodies. The bedrock in highly productive throughout the Michigan Basin, supplying drinking water for both municipal and domestic needs. All of the known water wells within 0.5 miles of the site (Figure 7) are completed in the Marshall Formation except one, which is completed in the glacial sediments northwest of the site. None of these wells are utilized by a Type I or IIa public water supply.

There are no wells within 1,000 feet of the site that are utilized for a Type IIb public water supply. There is one Type III public water supply within 1,000 feet of the site at 8352 68th Avenue (Figure 7; 27-10). There are no known oil or gas wells within 0.5 mile of the site (MDEQ Wellogic System; *secure1.state.mi.us/welllogic*).

Transmissivity values for the Marshall aquifer where the bedrock is hydraulically connected to the glacial sediments range from 130 to 27,000 square feet per day (ft^2/d) (Mandle and Westjohn, 1988). Glacial sediments in the vicinity of the site consist of outwash deposits interbedded with moraine deposits (Figures 5). The regional geological cross section shown in Figure 6 illustrates the subsurface distribution of glacial sediments relative to the underlying bedrock formations. The outwash deposits contain the most extensive aquifers in the glacial sediments. These deposits thicken to the east, upgradient from the site and pinchout to the west downgradient from the site (Figure 6). Moraine deposits in the area consist of massive beds of clay that have low permeability and restrict groundwater flow. The clay beds thicken to the west downgradient from the site. Water well logs and deep exploratory borings drilled adjacent to the site confirm the subsurface distribution of glacial sediments (Figure 6).

5.0 SITE HYDROGEOLOGY

An evaluation of the hydrogeology is required by Rule 904 to characterize the upper aquifer beneath the site and determine the flow paths and hydraulic characteristics of the water-bearing zones. Data obtained during the original hydrogeological investigation conducted by Dell Engineering, Inc. *(Hydrogeologic Site Characterization for Ottawa County Farms Landfill,* 1995*)* and information collected during this hydrogeological investigation were used to meet these requirements. The monitoring well network, groundwater conditions, and conceptual hydrogeologic model are presented in this section.

5.1 MONITORING WELL NETWORK

The initial groundwater monitoring network was completed in August 1994 and included sixteen monitoring wells. Three of these monitoring wells were screened in the lower aquifer, seven wells were screened in the upper sand unit (upper aquifer), and two of the wells were screened in discontinuous silt and sand lenses that contain perched water in the upper clay unit. The monitoring network also included four monitoring wells installed during previous site investigation (1987 and 1993). These wells were also screened in discontinuous silt and sand lenses that contain perched water in the upper clay unit. The groundwater monitoring network approved for the 1995 Environmental Monitoring Plan included the following sixteen monitoring wells. A summary of well construction details is provided on Table 2.

Upper Clay Unit (perched water)

MW-11	MW-12	DB-5	DB-15

Upper Sand Unit (upper aquifer)

DB-11	DB-14	DB-16	DB-17
DB-18	DB-19	DB-20	MW-1R
MW-2R			

Marshall sandstone (lower aquifer)

DB-1	DB-2	DB-3

An updated construction permit and accompanying Hydrogeological Investigation Report for the facility was submitted in August 1995. At that time, monitoring wells DB-17 and DB-19 were replaced with wells DB-17R and DB-19R. Monitoring well MW-11 was abandoned in July 1996 for the Phase I landfill expansion and monitoring well MW-1R was removed from the monitoring program because it had been damaged and was no longer functional. Monitoring well MW-12 was abandoned for the Phase 2 landfill expansion. In July 2000, monitoring wells DB-21 and DB-22 were included in the monitoring program as part of the landfill expansion for Phases 3 and 4. These

wells were screened in the upper aquifer (Cross Section F-F'; Figure 13). Monitoring well DB-2 was abandoned for the Phase 3 and 4 landfill expansion.

Monitoring well DB-23 was installed in 2003 to further characterize groundwater conditions in the upper aquifer upgradient from the landfill. This well was installed as part of the county consistency requirements for the eastern expansion. Monitoring well DB-5 was abandoned in October 2015.

The monitoring network was expanded as part of the hydrogeological investigation for the eastern expansion and includes an additional six monitoring wells (DB-23, DB-24, DB-25, DB-26, DB-27, and DB-28; Figure 3). Monitoring wells DB-28 is screened in the lower bedrock aquifer and monitoring wells DB-23, DB-24, DB-25, DB-26, and DB-27 are screened in the upper aquifer. Monitoring wells DB-3 and DB-16 are scheduled to be abandoned to allow for the eastern expansion.

Well construction details and survey coordinates are summarized in Table 2, and details of drilling and well installation are presented in Appendix D. The monitoring well network presented in this report combines the eastern expansion well network with the site's existing detection monitoring well network. Below is the list of monitoring wells proposed for the detection monitoring program (*Environmental Monitoring Plan*, E&E Solutions, 2016).

DB-11	DB-19R	DB-22	DB-25
DB-15	DB-20	DB-23	DB-26
DB-17R	DB-21	DB-24	DB-27
DB-18	MW-2R		

5.2 GROUNDWATER CONDITIONS

Groundwater occurs in sandstone bedrock and glacial sediments beneath the site.

Groundwater conditions in the bedrock have been evaluated at four deep wells screened in the lower aquifer (DB-1, DB-2, DB-3, and DB-28). Groundwater in the overlying glacial sediments which contain the upper aquifer have been evaluated at 17 wells screened in the upper sand unit (MW-1R, MW-2R, DB-11, DB-14, and DB-16 through DB-27). Perched water has been evaluated at six wells (DB-5, DB-15, MW-11, and MW-12). These wells are screened in discontinuous sand and silt lenses in the upper clay unit above the upper aquifer. Consistent with previous site investigations, perched water in the upper clay unit is not considered an aquifer.

Groundwater elevations have been monitored at the site since 1994. Historical groundwater elevations collected at site monitoring wells are provided in Table 3.

The upper aquifer at the site is approximately 60 to 170 feet BGS and is contained in the upper sand unit. The water bearing unit consists of well-sorted, medium- to fine-

grained sand which is approximately 60 feet thick beneath the south-central portion of the site at well DB-2 and thins to less than 5 feet thick beneath the southwest portion of the site at well DB-17R (see Cross Section F-F'; Figure 13). Fractured limestone and sandstone bedrock of the Marshall Formation contains a lower aquifer approximately 190 to 205 feet BGS. The bedrock aquifer is several hundred feet thick (Mandle and Westjohn, 1988) and underlies the entire site.

The upper aquifer is hydraulically connected to the lower bedrock aquifer beneath the southeastern portion of the site. In this area, the lower clay unit is absent and the sand units which contain the upper aquifer are in direct contact with bedrock (see Cross Section F-F'; Figure 13).

Three deep wells (DB-1, DB-3, and DB-28) and three wells screened in the upper sand unit (DB-14, DB-16, and DB-27) (Figure 3) are used as well pairs DB-1/DB-14, DB-3/DB-16, and DB-28/DB-27). The deep wells are screened in the lower bedrock aquifer and the adjacent wells are screened in the upper aquifer (see Cross Section D-D'; Figure 11). The well pairs are constructed so that the upper and lower aquifers can be sampled independently and the vertical gradients between the aquifers can be measured.

Shallow Wells/Soil Borings

Four shallow wells (DB-5, DB-15, MW-11, and MW-12) were screened across discontinuous silt and sand lenses that are contained within thick layers of low-permeability clay (upper clay unit). The discontinuous silt and sand lenses contain perched water. Wells screened in the perched water zone are located along the western and north-central portions of the site, west of the eastern expansion. Perched water in the discontinuous silt and sand lenses was encountered 30 to 40 feet BGS and rose to within 10 to 15 feet BGS indicating it is confined or semi-confined by the low-permeability clay. Perched water in the silt and sand lenses flows northeast (Dell 1995), opposite to the flow in the upper aquifer (see Section 5.2.2). The perched water is not considered an aquifer and is not hydraulically connected to the upper aquifer. Northeast flow in the perched silt and sand lenses is consistent with site surface drainage which generally flows towards the east into western tributaries of Deer Creek (Figure 2).

Shallow silt and sand lenses and associated perched water and was not encountered in the upper clay beneath the eastern expansion. In this area, the clay confirmation borings confirmed a continuous low-permeability clay unit above the upper aquifer (see Cross Section A-A' through E-E'; Figures 8-12).

Upper Aquifer Wells

Groundwater conditions in the upper aquifer were evaluated at 16 wells (MW-1R, MW-2R, DB-11, DB-14, DB-16, DB-17R, DB-18, DB-19R, and DB-20 through DB-27). The

wells are screened in the upper sand unit approximately 75 to 180 feet BGS. The groundwater potentiometric surface for the upper aquifer is approximately 35 to 65 feet BGS (see Cross Section F-F'; Figure 13). The potentiometric surface is the elevation to which groundwater will rise due to confining conditions in the aquifer.

During the January 2016 sampling event, groundwater elevations were measured in the upper aquifer monitoring wells (Table 3). Groundwater elevations ranged from approximately 621 feet MSL along the northeast edge of the site to approximately 612 feet MSL along the southwest edge of the site. The depth of the existing and proposed landfill liner system meet the groundwater separation requirements of Part 115. The static groundwater elevations were used to generate hydraulic head contours and determine the direction of groundwater flow beneath the site (Figure 14). Contours generated from the wells indicate that groundwater in the upper aquifer flows to the south and southwest (Figure 14). Southwest flow is consistent with regional flow patterns and past site characterizations.

Bedrock Wells

Groundwater conditions in the sandstone bedrock of the Marshall Formation were evaluated at four deep wells (DB-1, DB-2, DB-3, and DB-28). The wells are screened near the top of the bedrock aquifer approximately 196 to 212 feet BGS. The groundwater potentiometric surface in the lower bedrock aquifer is approximately 40 to 60 feet BGS (Wells DB-28 and DB-1). Groundwater in the lower bedrock aquifer is confined. Groundwater elevations in the lower aquifer range from approximately 617 feet MSL along the northeast edge of the site to approximately 610 feet MSL along the northwest edge of the site (Figure 15). Static groundwater levels measured in the lower bedrock aquifer are approximately 2 to 5 feet below the groundwater elevations in the upper aquifer indicating a downward vertical gradient (Table 3). Contours generated from the deep wells indicate that groundwater in the lower aquifer flows to the west and northwest (Figure 15). The northwest direction of flow is believed to be associated with groundwater pumping at farm and non-residential production wells west of the site (see water well logs 27-7 and 27-10; Figure 7 and Appendix C).

5.2.1 Aquifer Hydraulic Characteristics

The aquifer testing program is summarized in this section. Details of the testing methods and procedures are provided in Appendices D and E. A summary of hydraulic conductivity test results for the glacial sediments and sandstone bedrock of the Marshall Formation are presented in Table 4 and a comparison of the results is provided in Figure 16. These data were obtained from laboratory testing, field testing, and grain size analysis.

During the 1995 investigation, rising- and falling-head slug tests were performed at 12 site monitoring wells (DB-1, DB-2, DB-3, DB-5, DB-11, DB-14 through DB-17, MW-11,

MW-12, and MW-2R). The testing was conducted to estimate the hydraulic conductivity of the saturated zone adjacent to the wells. A summary of the test results is presented in Table 4 and details of the aquifer testing are provided in Appendix E.

Shelby tube samples were collected from the low-permeability clay units that overlie the upper aquifer. A total of 21 samples of the upper clay unit were analyzed in the laboratory to determine the hydraulic properties. Seven Shelby tube samples were tested during the 1995 investigation and 14 Shelby tube samples were tested during the 2015 investigation. Their undisturbed hydraulic conductivities were determined in accordance with ASTM D5084 as modified by Part 115. A summary of the laboratory hydraulic conductivity test results is presented in Tables 1 and 4 and details of the testing procedures are provided in Appendix E.

The hydraulic conductivity data were compiled to evaluate groundwater conditions in the glacial sediments and sandstone bedrock. The following describes site conditions with respect to geologic units and aquifers.

5.2.1.1 Glacial Deposits

The hydraulic conductivity data obtained from the field and laboratory tests were used to evaluate groundwater conditions beneath the site and to verify a natural soil barrier for the landfill liner system. The hydraulic conductivity values obtained from the glacial sediments are discussed with respect to the upper and lower clay and sand units.

Hydraulic conductivity values obtained from the upper clay unit were derived from laboratory testing of 21 Shelby tube samples The samples were collected from borings DB-1, DB-2, DB-3, DB-5, DB-7, DB-13, DB-24 through DB-27, SB-31, SB-33, SB-35, SB-37, SB-38, SB-40, SB-41, and MM-21. The samples were analyzed in the laboratory to determine their vertical hydraulic properties (Flexible-Wall Permeability - ASTM D5084). The samples were collected from the upper clay unit 20 to 90 feet BGS (Table 4). A summary of the test results are presented in Tables 1 and 4, and laboratory data sheets are provided in Appendix E. Hydraulic conductivity values obtained from laboratory testing of the clay unit beneath the eastern expansion ranged from 5.8×10^{-8} to 9.4×10^{-9} centimeters per second (cm/sec) (Table 4). These values satisfy the hydraulic conductivity values required for a natural soil barrier (1.0×10^{-7} cm/sec) A graphical illustration showing the range of hydraulic conductivity values for the clay unit is provided on Figure 16.

Results of this investigation along with a demonstration of homogeneity will be used to propose an alternate frequency for future borings to verify a natural soil barrier consistent with OWMRP-115-26 (Appendix D). Future subsurface investigations with additional clay confirmation borings will be conducted, as needed, for new cell certification. Based on the lateral consistency and uniform characteristics of the upper

clay unit, as documented, one clay confirmation boring is recommended for every 2 acres of natural soil barrier for the eastern expansion.

Groundwater occurrence in the upper clay unit is restricted to thin discontinuous silt and sand lenses beneath the north-central portion of the site west of the eastern expansion. The thin silt and sand lenses were not encountered in the upper clay unit beneath the eastern expansion. The upper clay unit is 60 to 170 feet thick and has been confirmed beneath the entire site.

To evaluate the hydraulic characteristics of the upper aquifer, rising- and falling-head slug tests were performed at four wells screened in the upper sand unit (DB-11, DB-14, DB-16, and DB-17). The wells were tested during the 1995 investigation (Dell 1995). The monitoring wells are screened in medium- to fine-grained sand that contains the upper aquifer. Hydraulic conductivity values for the slug tests ranged from 1.31×10^{-2} cm/sec in well DB-16 to 5.08×10^{-6} cm/sec in well DB-17 (Table 4). The lower value obtained from well DB-17 represents a more clayey portion of the upper sand unit. Hydraulic conductivity values estimated from the sieve analyses confirm the slug tests, ranging from 3.8×10^{-2} to 6.8×10^{-3} cm/sec (Table 4). Figure 16 illustrates the range of hydraulic conductivities in the upper sand unit.

Hydraulic conductivity values of 3.0×10^{-2} to 7.1×10^{-3} cm/sec were estimated for the lower sand unit based on sieve analyses. Figure 16 illustrates the range of hydraulic conductivities for the lower sand unit. Values ranging from 3.0×10^{-1} to 8.0×10^{-3} cm/sec are typical of gravelly sand (Driscoll, 1986).

Hydraulic conductivity values were not obtained from the lower clay unit but are expected to be similar to those obtained from the upper clay unit (Table 4).

5.2.1.2 Sandstone Bedrock

Hydraulic conductivity values obtained from the sandstone bedrock of the Marshall Formation (lower aquifer) were derived from slug tests performed in deep monitoring wells DB-1, DB-2, and DB-3. These wells were tested during the 1995 investigation. Values obtained from the slug tests ranged from 5.7×10^{-3} to 5.1×10^{-3} cm/sec (Table 4) and transmissivity values ranged from 2,572 to 3,245 ft^2/d. Figure 16 illustrates the range of hydraulic conductivities for the lower bedrock aquifer. These values are similar to those reported by Western Michigan University (1981) for a water well completed in the Marshall aquifer north of the site, in the City of Coopersville.

5.2.1.3 Vertical Hydraulic Gradient

The direction and rate of the vertical hydraulic gradient beneath the site is required by Rule 904. This section addresses those requirements.

Aquifers are typically divided into areas of recharge, lateral flow, and discharge (Figure 17). In recharge areas, groundwater has a downward component of movement because the hydrostatic pressure of the water column is greater than the hydraulic pressure of the aquifer. That is, the downward force of groundwater in a recharge area is greater than the ability of the aquifer to support the water; and groundwater moves down and away from the source of recharge. The recharge area illustrated in Figure 17 shows equipotential lines dipping away from the direction of horizontal flow. These conditions are similar to those observed at the site (Figure 18).

Vertical hydraulic gradients between the upper and lower aquifers underlying the site were evaluated at three locations by installing well pairs screened in each aquifer. Well pair DB-27/DB-28 is screened in the upper and lower aquifers upgradient from the eastern expansion. Well pair DB-16/DB-3 and DB-14/DB-1 are screened in the same aquifers upgradient and downgradient form the existing landfill (Figures 14). The aquifers are hydraulically connected beneath the south-central portion of the site. The subsurface distribution of geologic units at well pairs DB-16/DB-3 and DB-27/DB-28 is illustrated on Geologic Cross Section D-D′ (Figure 11). The well pairs were constructed so that the upper and lower aquifers can be sampled independently and vertical gradients between the aquifers can be measured.

Vertical hydraulic gradients were calculated using water-level measurements taken January 2016 (Table 3). The vertical hydraulic gradient for each well pair was estimated based on differences in groundwater potentiometric elevations and the elevations of the screened intervals for each well pair. The groundwater elevation in well DB-27 (upper aquifer) was 4.13 feet higher than the groundwater elevation in adjacent well DB-28 (lower aquifer) (Table 3), indicating a downward gradient at this location. Similarly, the groundwater elevation in well DB-16 (upper aquifer) was 5.27 feet higher than the groundwater elevation in adjacent well DB-3 (lower aquifer) (Table 3), indicating a downward gradient at this location. A downward gradient was also measured at well pair DB-14/DB-1. The downward hydraulic gradient between the upper and lower aquifers was calculated to be 0.032 foot per foot (ft/ft) at well pair DB-27/DB-28; 0.058 ft/ft at well pair DB-16/DB-3; and 0.043 ft/ft at well pair DB-14/DB-1. The qualitative flow net for the site illustrated in Figure 18 shows equipotential lines dipping away from the direction of flow, indicating a downward gradient. Gradients measured beneath the existing landfill have remained relatively consistent since groundwater measurements began in 1994 (Table 3).

5.3 CONCEPTUAL HYROGEOLOGIC MODEL

A conceptual hydrogeologic model of the site is presented in the following section. The model is based on groundwater hydraulic head contours generated from historical groundwater elevations (Table 3) and data obtained from the aquifer and laboratory tests. The conceptual model is the foundation on which the site's Environmental Monitoring Plan is based.

5.3.1 Groundwater Flow Direction

Groundwater in the site's lower aquifer flows west- northwest and groundwater in the upper aquifer flows south- southwest consistent with regional flow patterns (Mandle and Westjohn, 1988). The flow direction in the confined lower aquifer is likely influenced by aquifer drawdown caused by groundwater pumping from farm and non-residential production wells completed in the same aquifer west of the site.

The qualitative flow net shown in Figure 18 illustrates the conceptual model for groundwater flow beneath the site. The flow net consists of equipotential lines of equal hydraulic head. The slope and direction of the lines were determined by the vertical hydraulic gradients established at the site's well pairs. The groundwater flow direction is perpendicular to the equipotential lines and is represented by the arrows (Figure 18). Groundwater in the upper and lower aquifers is confined and the aquifers are hydraulically connected. A comparison of groundwater flow in the aquifers is summarized below.

Static water-levels measured at the wells were used to generate hydraulic head contour maps and determine the direction of groundwater flow beneath the site. The hydraulic gradient for the upper aquifer was calculated using the head difference (4.24 feet) divided by the distance (1,980 feet) along the known flow direction (Three-point problem using wells DB-27, DB-24, and DB-17R). The hydraulic gradient for the lower aquifer was calculated using the head difference (7.28 feet) divided by the distance (4,600 feet) along the known flow direction between wells DB-28 and DB-1. Based on the January 2016 groundwater elevations, the horizontal gradient in the upper aquifer is approximately 0.0021 ft/ft beneath the site (existing landfill and eastern expansion). The horizontal gradient in the lower aquifer is approximately 0.0015 ft/ft beneath the northern portion of the entire site. The hydraulic head contours and flow net indicate that groundwater moves under a slightly steeper hydraulic gradient in the upper aquifer than in the lower bedrock aquifer. The direction of groundwater flow in the upper aquifer is toward the south- southwest and flow in the lower aquifer is toward the west- northwest (Figures 7 and 8). The vertical gradient across the aquifers is approximately 0.032 ft/ft downward along the northeastern edge of the eastern expansion, 0.058 ft/ft downward along the western edge of the eastern expansion, and 0.043 ft/ft downward along northwestern edge of the existing landfill. This means that for every foot of vertical movement downward through the aquifers, the hydraulic head elevation falls approximately 0.03 to 0.06 feet.

5.3.2 Groundwater Flow Velocity

The groundwater flow velocities in the upper and lower aquifers were determined using the groundwater gradients calculated for the January 2016 sampling event. The average hydraulic conductivities were derived from the 1995 aquifer testing. The

average groundwater flow velocity in the upper and lower aquifers was calculated from the following equation:

$$V = Ki/n_e$$

Where:
- V = average flow velocity of groundwater,
- K = hydraulic conductivity,
- i = hydraulic gradient, and
- n_e = effective porosity of the aquifer medium.

The average groundwater flow velocity for the upper aquifer beneath the site (existing landfill and eastern expansion) was calculated using a hydraulic gradient of 0.0021 ft/ft and a hydraulic conductivity of 7.68×10^{-4} cm/sec. Because the hydraulic conductivity values in an aquifer have the characteristics of log normal distributions and the distributed across several orders of magnitude, the "average" hydraulic conductivity is best described by the geometric mean (Domenico and Schwartz, 1990). The hydraulic conductivity used in this calculation is the geometric mean of the aquifer test results. (see slug test results, Table 4). An estimated effective porosity of 20 percent was selected for the sand unit based on data obtained from soil testing program (Appendix D). The average groundwater flow velocity of the upper aquifer beneath the site is 8.3 feet per year (ft/yr).

The average groundwater flow velocity for lower bedrock aquifer was calculated using a hydraulic gradient of 0.0015 ft/ft and an average hydraulic conductivity of 5.45×10^{-3} cm/sec. The hydraulic conductivity used in this calculation is the average value obtained from the 1995 aquifer test results (Table 4). An estimated effective porosity of 20 percent was selected for the sandstone bedrock based on literature sources (Driscoll, 1986). The hydraulic gradient was calculated using the hydraulic head difference (7.28 feet) divided by the distance (4,600 feet) along the known flow direction using wells DB-28 and DB-1. The average groundwater flow velocity in the lower aquifer is approximately 42 ft/yr.

5.3.3 Summary

Groundwater in the upper aquifer beneath the site flows towards the south- southwest with an average velocity of 8.3 ft/yr. Groundwater in the lower aquifer flows towards the west-northwest with an average flow velocity of 42 ft/yr. The site is in an aquifer recharge area. The aquifers are overlain by a continuous low-permeability clay unit.

6.0 SURFACE WATER

The site is located along the western edge of the Deer Creek water shed. Wetlands at the site are discussed in the Environmental Site Assessment (Weaver Consultants Group, 2016). Deer Creek and its tributaries form the only permanent surface-water body in the area other than the Grand River. The creek flows from north to south through the City of Coopersville across farmland east of the site (Figure 2) and empties into the Grand River 2.5 miles south of the site.

Runoff from the landfill that does not contact waste is collected by a system of storm-water channels and is directed to storm-water sedimentation basins. The basins are located along the northeastern and western sides of the site (Figure 14). Storm-water from the basins in the northeastern corner of the site is released an unnamed drainage that flows into Mosquito Drain, which connects to Deer Creek approximately 0.5 miles east of the site (Figure 2). Storm-water from the western basin is released to Sandler and Terpstra drain, which flows west across farmland to an intermittent stream known as Lucas Creek. Lucas Creek flows south and empties into the Grand River approximately 3 miles southwest of the site.

No groundwater mounding is anticipated beneath the sedimentation basins because of the low permeability clay that underlies the basins. There are no engineering modifications planned for the site that are intended to modify existing groundwater elevations and flow direction.

The proposed surface water monitoring program includes collecting samples from upstream and downstream locations along Mosquito Creek which flows across and adjacent to the northeast corner of the site. An upgradient sampling location (SW-1) is located south of I-96 where the creek turns to the west along the north side of the site. A downgradient sampling location (SW-2) is located along the east side of the site prior to where the creek flows under 60th Avenue. The proposed surface water monitoring program is intended to characterize the site's influence on surface water quality.

7.0 SAMPLING AND ANALYSIS PROGRAM

Rule 904 requires a site investigation to determine the existing groundwater quality and background quality in the upper aquifer and aquifers that are hydraulically interconnected to the upper aquifer. To satisfy these requirements, a groundwater sampling and analysis investigation is currently being completed for the eastern expansion to supplement existing groundwater quality and background quality database for the existing landfill. Background groundwater quality for the existing landfill was established based on 21 years of background sampling. Preliminary results for the eastern expansion are presented in this section. This Hydrogeological Investigation Report will be updated once the background sampling is completed for the eastern expansion.

7.1 GROUNDWATER QUALITY

To evaluate background groundwater quality for the eastern expansion (upper and lower aquifers), eight groundwater samples will be collected from six monitoring wells located around the perimeter of the expansion. A total of 48 background samples (8 samples collected at 6 wells) will be analyzed for the parameters listed in Part 115 (Rules 450 through 454). These parameters included primary and alternate inorganic indicators, heavy metals, and the primary and secondary volatile organic compounds (VOCs). The background samples will be collected during individual sampling events beginning in December 2015 and ending in December 2016. Analytical results for the background sampling events are provided in Appendix F.

The wells sampled included five detection monitoring wells (DB-23 through DB-27) screened in the upper aquifer and one bedrock well screened in the lower aquifer (DB-28). Well locations are shown on Figure 3 and details of sampling procedures are provided in the site's *Environmental Monitoring Plan*, (Engineering & Environmental Solutions, 2016). Field data sheets documenting the background sampling events are presented in Appendix F.

The only known sources of groundwater contamination within 0.5 miles of the landfill are located northeast of the landfill in the City of Coopersville (see Section 1.1). Groundwater contamination associated with these sites is downgradient from the proposed eastern expansion and is not known to have impacted the aquifers beneath the landfill.

7.1.1 Primary and Alternate Inorganic Indicators, and Heavy Metals

Primary and alternate inorganic indicators, and heavy metals detected at the new monitoring wells were plotted on time series graphs and compared to their Part 201 residential drinking water clean-up criteria (Appendix F). These graphs show background groundwater data from the first three sampling events.

Iron was detected above its clean-up criteria of 300 ug/L at monitoring wells DB-23 through DB-28. The highest background levels of iron were detected at monitoring DB-25, ranging from 1,900 to 2,500 ug/L (Appendix F). Similarly, total dissolved solids (TDS) was detected above its Part 201 clean-up criteria of 500 mg/L at six monitoring wells. The highest background levels of TDS were detected at monitoring well DB-25, ranging from 982 to 1,050 mg/L (Appendix F).

Manganese was detected above its Part 201 clean-up criteria of 50 ug/L at monitoring well DB-26. Background levels ranged from 77 to 100 ug/L (Appendix F).

No other inorganic indicators or heavy metals were detected above their Part 201 clean-up standards during the first three background sampling events.

7.1.2 Primary and Secondary VOCs

The background groundwater samples collected during the first three sampling events contained no detectable VOCs.

7.2 STATISTICAL EVALUATION OF BACKGROUND GROUNDWATER DATA

Part 115 requires that statistical procedures be developed for the site's groundwater monitoring program with the objective of providing an indication of a release from the landfill unit. Statistical tests proposed for the detection monitoring program include intrawell control charts and tolerance/prediction limits. Details of the proposed statistical tests are presented in the site's Environmental Monitoring Plan.

A minimum of 8 rounds of groundwater sampling will be collected from six new monitoring wells. Eight background samples from each new well will be collected over a one year period. Background groundwater analytical data from the first three sampling events is provided in Appendix F. After all of the background samples are collected, the background data will be evaluated and statistical methods will be proposed for each of the parameters selected for monitoring groundwater. New parameters from the primary (Rule 450) and alternate (Rule 451) inorganic indicator lists may be selected for the entire site.

Control charts are recommended for statistical evaluation of the inorganic indicators and tolerance/prediction limits are recommended for the heavy metals. Control charts are intended to be used for parameters that have a significant percentage of observations above the detection limit, conversely, tolerance/prediction limits (non-parametric) are intended for constituents that have a larger percentage of observations below the detection limit (non-detects). Time series plots will provide a visual representation of the analytical data over time. Trend tests will be used to identify any potential upward trends. VOCs detected at the site will be considered statistically significant if they exceed established detection limits.

Results of recommended statistical tests for each parameter selected for the all detection monitoring wells will be included as an addendum to site's Environmental Monitoring Plan. Once approved by the MDEQ, the recommended statistical methods for the selected parameters will be incorporated into the site's Environmental Monitoring Plan.

8.0 SUMMARY

The intent of this investigation was to address Part 115 requirements regarding surface and subsurface conditions at the site through hydrogeological characterization. Key items noted in Part 115 include (1) determining the soil and bedrock stratigraphy beneath the site, (2) identifying the upper aquifer and aquifers that are hydraulically interconnected to the upper aquifer, (3) defining the hydraulic properties of the soil and bedrock units, (4) determining the groundwater flow direction, flow rates, and the vertical and horizontal gradients, and (5) determining existing and background groundwater quality in the upper aquifer. The observations and findings that address the hydrogeological conditions are summarized below.

- The glacial and bedrock stratigraphy was evaluated at 24 exploratory borings during this investigation and 71 exploratory borings drilled during previous investigations. Bedrock consists of sandstone and limestone of the Marshall Formation and shale and gypsum of the Michigan Formation. The bedrock formations are overlain by approximately 200 feet of glacial sediments. The glacial sediments are divided into four stratigraphic units based on their hydrogeological characteristics. From the surface down, they include (1) a continuous upper clay unit approximately 60 to 170 thick, (2) a discontinuous upper sand unit approximately 5 to 75 feet thick, (3) a discontinuous lower clay unit which has a maximum thickness of approximately 45 feet, and (4) a lower discontinuous sand unit which has a maximum thickness of approximately 35 feet.

- Sedimentary rocks of the Marshall Formation have moderate permeability and contain a regional aquifer which is an estimated 200 to 300 feet thick in the area of the site. The sandstone bedrock contains the lower aquifer at the site. Sand units in the overlying glacial sediments contain the upper aquifer at the site. The sand units have moderate permeability and are hydraulically connected to each other and to the lower bedrock aquifer beneath the southeastern portion of the site.

- Groundwater in the lower aquifer flows west- northwest and groundwater in the upper aquifer flows south- southwest. Groundwater elevations in the lower aquifer are influenced by groundwater pumping from farm and non-residential production water wells located west of the site.

- The site is characterized by downward hydraulic gradients. Groundwater in the lower and upper aquifers is confined and moves under similar hydraulic gradients which range from 0.0015 to 0.0021 ft/ft. The average groundwater flow velocity in the lower aquifer is 42 ft/yr and the average flow velocity in the upper aquifer 8.3 ft/yr.

- To evaluate background groundwater quality for the eastern expansion's upper and lower aquifers, eight groundwater samples will be collected from six new monitoring wells installed around the perimeter of the expansion area. All samples will be tested for the full list of Part 115 parameters. Statistical analysis of the background groundwater data will be used to determine the most reliable parameters for the site's detection monitoring program.

9.0 REFERENCES

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