Waste Management of Canada Corporation

Environmental Assessment for a New Landfill Footprint at the West Carleton Environmental Centre

GEOLOGY AND HYDROGEOLOGY EXISTING CONDITIONS REPORT

DRAFT FOR DISCUSSION AND COMMENT

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1. Introduction

This technical memorandum provides a description of the existing geology and hydrogeology conditions, on regional and site-specific scales, in the area around the proposed West Carleton Environmental Centre (WCEC). An understanding of the existing conditions forms the basis for the comparative evaluation of alternative landfill footprints, as described in the Minister-approved Terms of Reference (ToR) for the Environmental Assessment (EA) being undertaken for the landfill component of the WCEC.

In accordance with the approved ToR, study areas for the description of existing geology and hydrogeology conditions have been developed. These study areas are as follows (see **Figure 1** for reference to the study areas):

Existing Landfill........... the lands owned by WM and currently approved for the establishment and use of a waste disposal site, in accordance with Provisional Certificate of Approval No. A461002, including the Contaminant Attenuation Zones;

Detailed Study Area..... the lands on and surrounding the Existing Landfill and the North and West Envelopes being considered for alternative landfill footprints, extending 500 metres (m) in all directions; and,

Regional Study Area ... the lands within natural hydrogeologic boundaries, including Huntley Creek to the north, Feedmill Creek to the south, and extending to Carp River in the east. The upgradient boundary of the Regional Study Area coincides with the boundary of the Detailed Study Area.

A more comprehensive layout of the Detailed Study Area, showing features on the Existing Landfill, the North Envelope and the West Envelope is presented on **Figure 2**.

The following description of the existing geology and hydrogeology conditions begins with an overview of the Regional Study Area (Section 2.1). The information used to develop this section was gathered from published geologic and hydrogeologic reports, maps, data, websites, and from local knowledge. Section 2.2 of this report presents a description of the existing conditions within the Detailed Study Area. In both sections, the discussion is divided into topics such as topography and drainage (physiography), geology (surficial and bedrock), physical hydrogeology, and groundwater quality.

2. EXISTING GEOLOGY & HYDROGEOLOGY CONDITIONS

2.1 REGIONAL STUDY AREA

In this section, a description of the physical setting of the Regional Study Area is presented. This includes a discussion of the physiography and topography, geology, physical hydrogeology and groundwater quality.

2.1.1 Physiography and Topography

The Regional Study Area lies within the Ottawa Valley clay plain physiographic sub-region, part of the Ottawa-St. Lawrence Lowlands, as classified by Chapman and Putnam (1984). The physiography in the area ranges from sandy upland areas in the northwest and west to poorly drained swampy areas, clay plains and the Carp River floodplain toward the northeast. The primary natural topographic feature in the area is a northwest-southeast trending sand and gravel ridge, which has historically been exploited for aggregate extraction. This feature is described in more detail in Section 2.1.2.4.

Within the Regional Study Area, the natural topography, which has been modified by extraction and waste disposal activities, ranges from an elevation of approximately 131 metres above sea level (mASL) southwest of the existing landfill site to less than 100 mASL along Carp River. The dominant man-made topographic features in the study area are the WM Ottawa Landfill, which extends to an elevation of approximately 172 mASL, and the Huntley Quarry, which has been mined to a floor elevation of less than 75 mASL (**refer to Figure 3**).

The Regional Study Area is situated within the Carp River watershed. The watershed drains approximately 306 km^2 of land in the northwestern portion of the City of Ottawa (Robinson Consultants, 2004). Carp River is located approximately four kilometres northeast of the existing landfill (see **Figure 1**), and discharges to the Ottawa River at Fitzroy Harbour, approximately 20 km northwest of the landfill property. Surface drainage within the area is controlled by the ground surface topography and small tributaries of Carp River, as modified by the surrounding quarry operations and the Highway 417 drainage system. North and west of the existing landfill site, surface drainage flows within the Huntley Creek subwatershed, and discharges via Huntley Creek to Carp River east of Huntmar Road, approximately 1 km north of Richardson Side Road. The Huntley Quarry, operated by AECON, is located within this subwatershed and pumps groundwater from the quarry into Huntley Creek.

East and southeast of the existing landfill site, surface drainage flows within the Feedmill Creek subwatershed. Feedmill Creek discharges to Carp River east of Huntmar Road, approximately 0.3 km north of Highway 417. Surface water flow along Highway 417 within the study area is controlled by a system of ditches, catch basins and culverts, and discharges into Feedmill Creek.

Because of these drainage features, surface water downgradient of the existing landfill property does not flow from north to south across Highway 417. A more detailed description of local surface water flow is provided in Section 2.2.1.

The topography on the North Envelope rises from approximately 120 mASL in the east to approximately 125 mASL in the west. The land generally consists of well-drained sandy upland areas. The West Envelope is relatively flat-lying, with ground surface elevations ranging from 125 mASL to 130 mASL. A provincially significant wetland (part of the Goulbourn Wetland Complex) is situated along the southwestern border of the West Envelope; other areas are generally well-drained. The wetland serves as a headwater for Huntley Creek, which flows eastward and northward across the West Envelope.

2.1.2 Geology

2.1.2.1 Surficial Geology

The Regional Study Area lies within the upper Ottawa clay plains region. The surficial deposits in this region consist of glacial and related materials from the late Wisconsian glaciation. During this glacial period, thick sequences of sand and gravel were deposited along the Ottawa River valley, followed by deposits of silt and clay during encroachment of the Champlain Sea. The surficial geology within the study area is shown on **Figure 4**.

The materials observed in the vicinity of the WM Ottawa Landfill are interpreted to be ice-contact stratified drift sediments, consisting of a mixture of poorly to well-sorted, stratified gravels and sands, interbedded with lenses of silty sand-gravel till (GSC, 1982; Natural Resources Canada, 2002). The deposits are interpreted to have been submerged during the Champlain Sea encroachment, and therefore show indications of re-working in a nearshore, subaqueous environment. The deposits are horizontally bedded and often display evidence of cross-bedding, as observed in excavation faces on and near the existing landfill property. Across the North Envelope sand and gravel are the predominant surficial deposits to the east; these grade into sand and till deposits to the west. Along the Highway 417 alignment west of the West Envelope, shallow organic and till deposits overlie the limestone bedrock.

Closer to Carp River, thick deposits of silt, clay and organic materials (peat and muck) have been deposited in a lower energy, offshore marine environment consistent with the deeper waters of the Champlain Sea. Organic deposits are found on the southeastern portion of the quarry property, east of Carp Road.

2.1.2.2 Bedrock Geology

The Regional Study Area is underlain by several carbonate rock-types. Throughout the majority of the portion of the Regional Study Area that encompasses the Detailed Study Area, bedrock consists of grey, fine to medium-grained fossiliferous limestone with some shaly or sandy interbeds. The bedrock is classified as the Bobcaygeon Formation, a member of the Middle Ordovician-aged Ottawa Group, and is described regionally as a limestone with shaly partings with intermittent sandstone (Derry Michener Booth & Wahl and OGS, 1989; Natural Resources Canada, 2002; Williams, 1991). Geologic mapping of the Huntley Quarry northeast of the landfill has interpreted the quarry to extend within the lower member of the Bobcaygeon Formation (Derry Michener Booth & Wahl and OGS, 1989). The bedrock is horizontally-bedded and discretely-fractured, with the fracture frequency decreasing with depth. The total estimated thickness of the Bobcaygeon Formation is approximately 95 m, with the upper, middle and lower members being approximately 40, 25 and 30 m thick, respectively.

Within the Regional Study Area, the Bobcaygeon Formation is in contact with interbedded silty dolostone, limestone, shale and sandstone of the underlying (older) Gull River Formation and overlying (younger) Verulam Formation, which are classified as limestone with shale interbeds. Both formations are also members of the Middle Ordovician-aged Ottawa Group. Within the Regional Study Area, lateral contacts between the bedrock formations are primarily along faults, with the exception of the contact between the Bobcaygeon and Gull River Formations in the southeast portion of the study area. The bedrock geology within the study area is shown on **Figure 5**.

The bedrock surface generally slopes at less than 1 degree in a northeasterly direction under the Regional Study Area.

2.1.2.3 Structural Features and Seismic Activity

The Ottawa River Valley rift zone, which developed from tectonic extension several million years ago, was created through the occurrence of block faulting to form the regional structural feature known as the Ottawa-Bonnechere graben. The Paleozoic formations in the Ottawa area are transected by steeply dipping normal faults associated with the rift zone, three of which are found within the Regional Study Area oriented from northwest to southeast (refer to **Figure 5**).

Carp River follows the orientation of the Hazeldean Fault, which separates the Paleozoic bedrock found within the Regional Study Area from the much older Precambrian rocks that compose the Carp Ridge northeast of the study area. Another one of the regional faults (unnamed) is exposed in the Bobcaygeon Formation as a result of excavation in the Clarke.

Quarry located southeast of the West Envelope. This fault is described as a steeply-dipping normal fault system with a total downthrow of approximately 9 m to the northeast (Derry Michener Booth & Wahl and OGS, 1989).

Regionally, joints commonly occur close to faults and are parallel to them, suggesting a genetic relationship between the joints and faults (Natural Resources Canada, 2002).

Compared to active seismic areas around the world (e.g., Western North America, Eastern Asia), Eastern Canada is located in a stable continental region and, as a result, has a relatively low rate of earthquake activity. The Regional Study Area lies within the Western Quebec Seismic Zone (WQSZ), which covers the Ottawa Valley from Montreal to Temiscaming, as well as the Laurentians and Eastern Ontario (Natural Resources Canada, Earthquake Zones of Eastern Canada, http://earthquakescanada.nrcan.gc.ca). The urban areas of Montreal, Ottawa-Gatineau and Cornwall are located in this zone. The WQSZ is described as a zone of moderate seismic activity, with earthquakes occurring at an average frequency of once every five days. However, those large enough to be felt occur once every couple months. Within the WQSZ, the pattern of seismic activity is concentrated in two sub-zones: one along the Ottawa River and the second along a more active Montreal-Maniwaki axis (see ***Figure 6***). The largest recorded earthquake in the zone occurred near Temiscaming in 1935, at a magnitude of 6.2.

The seismic activity in the Ottawa region is not associated directly with any specific fault line. Rather, the activity in stable continental areas such as Eastern Canada and the WQSZ are believed to be related to the regional stress fields, with the earthquakes concentrated in general zones of weakness in the earth's crust (Natural Resources Canada, Earthquake Zones of Eastern Canada, http://earthquakescanada.nrcan.gc.ca).

2.1.2.4 Aggregate Resources

Aggregate resources, including sand, gravel and bedrock formations are found within the Regional Study Area. A detailed aggregate assessment was completed in 1993 by Gorrell Resource Investigations (GRI, 1993) within the former Regional Municipality of Ottawa-Carleton. A summary of the aggregate resources and restrictions identified within the study area is provided below.

Bedrock found within the western portion of the Regional Study Area consists of the Bobcaygeon Formation, a limestone with shaley interbeds. Parts of the formation are alkalide reactive and cannot be used for concrete aggregate (GRI, 1993). However, these portions of the formation are suitable for use as crushed stone. The formation is ranked as a Class 3 bedrock deposit (a ranking of 1 is a high value aggregate, a ranking of 5 is low value). Properties immediately east of Carp Road (Concession II of the Geographic Township of Huntley, Lots 3, 4 and the south half of Lot 5) are designated as a Limestone Resource Area in the City of Ottawa Official Plan (City of Ottawa, 2006). This area includes the Huntley Quarry as well as the concrete and aggregate production areas on the east side of Carp Road operated by AECON, Tomlinson Ltd., West Carleton Concrete, and CBM. The Clarke Quarry, located outside of the study area to the southwest of the landfill property and operated by AECON, is also designated as a Limestone Resource Area.

The remainder of the Regional Study Area toward Carp River is primarily underlain by the Verulam Formation, with a small area to the south underlain by the Gull River Formation. The Verulam Formation is a limestone with shale interbeds. Because of the thickness of the shale zones and beds, the formation is generally not suitable for use as concrete and asphalt aggregate, and is used as crushed stone only. The formation is ranked as a Class 5 (low value) bedrock deposit, and is not quarried within the Regional Study Area. The small area underlain by the Gull River Formation along Highway 417 is also not quarried at present; however, the western portion of the deposit is located within the designated Limestone Resource Area. The Gull River Formation, a silty dolostone with limestone, shale and some sandstone, is ranked as a Class 2 (moderate-high value) bedrock deposit. The eastern portion of the area underlain by Gull River Formation is within the City of Ottawa Urban Area (City of Ottawa, 2006) and is not suitable for the development of a quarry.

Sand and gravel resources are associated with glaciofluvial and nearshore beach ridge deposits oriented along the Carp Road corridor and underlying the eastern half of the WM Ottawa Landfill. These aggregate resource deposits have been identified as part of the much larger Galetta-Stittsville Ridge System (GRI, 1993). The portion of the ridge system from south of Stittsville to north of the WM Ottawa Landfill is classified as a Class 1 overburden deposit, which is defined as a high value sand-gravel resource with sufficient reserves and gradational characteristics to potentially support a large-scale aggregate operation (GRI, 1993). However, large areas of this Class 1 deposit have already been exhausted or are restricted from future extraction because of alternate land uses (roads, urban areas, subdivisions, existing landfill site, etc.), or because the remaining reserves are below the water table. Within the Detailed Study Area, the sand and gravel deposits are not designated as mineral resources in the City of Ottawa Official Plan (City of Ottawa, 2006).

Elsewhere in the Regional Study Area toward Carp River, the overburden deposits consist of glacial till, silt, clay and organic deposits (peat and muck), which are not viable as an aggregate resource. There are no designated sand and gravel resource areas within the Regional Study Area. Clay has been identified as a potential overburden resource, primarily for use as landfill cover material (GRI, 1993); however, the market for the material is considered small and not sufficient to support a stand-alone operation.

2.1.3 Hydrogeology

2.1.3.1 Physical Hydrogeology

Groundwater occurs within the unconsolidated overburden units and the Paleozoic bedrock fracture systems found within the Regional Study Area. The general direction of regional groundwater flow is northeast toward Carp River. Water table elevations range from approximately 135 m southwest of the existing landfill to between 92 and 105 m along Carp River (Robinson Consultants, 2004). On a larger regional scale, **Figure 7** illustrates the groundwater elevations (also known as the *hydraulic heads*) obtained from the MOE Water Well Record inventory. In general, groundwater flows from areas of higher hydraulic head toward areas of lower head. The highest groundwater elevations are observed southwest of the Regional Study Area, in Lanark County, with lower water table elevations along the Carp River corridor.

Locally, groundwater recharge occurs along the sand and gravel ridge and upland areas extending north and south of the existing landfill (Dillon, 2004; Robinson Consultants, 2004). Overall, the North and West Envelopes are interpreted as having strong to weak downward gradients, indicating that these areas are considered recharge zones.

In a regional aquifer vulnerability study completed for the City of Ottawa, the glaciofluvial and beach ridge deposits in the study area are identified as having a high to very high intrinsic vulnerability (Waterloo Hydrogeologic Inc. and CH2M Hill, 2001). A high groundwater recharge potential and relatively shallow depth to the water table are the principal factors in this determination of aquifer vulnerability.

The Mississippi-Rideau Source Protection Region has also completed an analysis of aquifer vulnerability within the Mississippi River and Rideau River watersheds as part of the Drinking Water Source Protection Program (Mississippi-Rideau Source Protection Region, 2009a). The Regional Study Area, with the exception of the clay plains found east of Oak Creek Road toward Carp River (refer to **Figure 4**) is classified as a high vulnerability aquifer, due to the shallow water table and permeable soil conditions. The area is also classified as a significant groundwater recharge area (Mississippi-Rideau Source Protection Region, 2009b).

Closer to Carp River, groundwater discharge zones occur, with upward hydraulic gradients becoming more pronounced in proximity to Carp River (Dillon, 2004). Intrinsic aquifer vulnerability in this area is classified as low to medium (Waterloo Hydrogeologic Inc. and CH2M Hill, 2001).

The hydrogeological unit of prime interest with regard to groundwater resource potential is the overburden-shallow bedrock zone. In areas of aggregate extraction, much of the overburden unit has been removed, and it is generally not considered to be a viable resource for groundwater supply. However, in localized areas, where the sand-gravel has not been removed and there is a sufficient saturated thickness, groundwater may be encountered and extracted from the overburden unit. The Paleozoic bedrock aquifers (primarily limestone, dolostone and sandstone) supply over 90% of the water wells within the Carp River watershed, whereas less than 5% of the wells are supplied by the overburden unit (Robinson Consultants, 2004).

Within the Regional Study Area, the largest permitted use of groundwater authorized under a Permit to Take Water (PTTW) from the Ontario Ministry of Environment is to dewater the Huntley Quarry, which is operated by AECON. The maximum allowable groundwater taking for this permit is 11.78 million litres per day (Dillon, 2004). The purge well system for the WM Ottawa Landfill is permitted to take 2.5 million litres of groundwater per day, and the Thunderbird Athletic Club at 1927 Richardson Side Road reportedly has a PTTW with a maximum allowable taking of 156,900 L/day. These are the only significant users identified under a PTTW in the Regional Study Area.

In the Carp River watershed study report (Robinson Consultants, 2004), it is noted that groundwater use from domestic wells in the watershed comprises less than 1% of the annual recharge, and that usage from all takings combined is estimated to be less than 10% of total recharge in the watershed.

2.1.3.2 Groundwater Quality

Groundwater quality within the Carp River watershed is generally acceptable for potable usage, and is free from recognizable regional-scale groundwater impact (Robinson Consultants, 2004). In a recent groundwater study along the Carp Road corridor, no widespread problems of health related parameters were detected in the groundwater (Dillon, 2004). Non-health related water quality parameters, such as total dissolved solids, hardness, iron, sulphate and chloride commonly exceeded the Ontario Drinking Water Standards, although the concentrations in the groundwater tend to vary considerably with the type of bedrock formation. Natural groundwater quality appears to be better in areas where the Verulam Formation aquifer is used for water supplies as compared to areas where the Bobcaygeon and Gull River Formation aquifers are used (Dillon, 2004). In general, the regional groundwater quality reflects the characteristics of the limestone bedrock, being dominated by calcium carbonate (hardness) and also containing iron and sulphur compounds (sulphate, hydrogen sulphide) from the shaley interbeds.

Elevated concentrations of sodium and chloride observed in groundwater along Carp Road and the Highway 417 corridor may be the result of road salting practices (Dillon, 2004; WESA, 2005). Extensive use of road salt along Carp Road, Highway 417 and the interchanges, combined with the high groundwater recharge potential, make aquifers in these areas particularly susceptible to impacts from road salting operations.

Impacts from other anthropogenic activities such as private sewage systems, industrial activities and agricultural operations are sometimes seen in isolated occurrences, but do not appear as widespread problems within the study area (Dillon, 2004; Robinson Consultants, 2004).

2.2 Detailed Study Area

In this section of the report, more detail is provided on the existing geologic and hydrogeologic conditions specific to the Detailed Study Area. The existing site conditions form the basis of the information that will be used in the comparative evaluation of alternative landfill footprints.

2.2.1 Topography and Drainage

Within the Detailed Study Area, the natural topography, which has been modified by extraction and waste disposal activities, ranges from an elevation of approximately 131 mASL southwest of the landfill site to less than 110 mASL on the Huntley Quarry property. As noted for the Regional Study Area, the WM Ottawa Landfill extends to an elevation of approximately 172 mASL, and the Huntley Quarry has been mined to a floor elevation of less than 75 mASL (refer to **Figure 3**).

From within the boundaries of the existing landfill property, there is no direct off-site discharge of surface water that is in contact with waste that has been landfilled; internal surface water drainage is contained within the landfill property and is directed to on-site ponds, which are engineered, natural or remain following extraction of aggregate. The exceptions to this are the external slopes of the vegetated site perimeter berms along the east and south boundaries of the landfill property; however, this amount of surface runoff is very minor and is not in contact with operational activities at the landfill. Runoff from the vegetated berms flows into the Carp Road and Highway 417 drainage systems. There is also a small area of drainage from the extreme western end of the site, north of the service entrance, which flows into the ditch along William Mooney Road, and then northward into a tributary of Huntley Creek. The surface water drainage pattern in the vicinity of the landfill is shown on **Figure 8**.

The above-noted tributary of Huntley Creek originates from the wetland situated along the western boundary of the West Envelope. Surface water flow on the West Envelope is in a north-northeasterly orientation, from the higher ground surface elevations of 129 to 130 mASL in the south and west to approximately 123 mASL in the northeast. The wetland feeds a drainage course that flows across the west portion of the Detailed Study Area, collecting surface drainage from the agricultural and residential properties along William Mooney Road, west of the WM Ottawa Landfill. Flowing from west to east under William Mooney Road, the drainage course then bends to the north and flows toward Richardson Side Road. Along the south side of Richardson Side Road, the creek is aligned as a roadside drainage ditch, flowing eastward to a point approximately 450 m east of William Mooney Road. Surface water from the agricultural land east of William Mooney Road and south of Richardson Side Road is controlled by drainage ditches and flows northward to the roadside ditch along Richardson Side Road.

The Huntley Creek tributary then flows northward through a culvert under Richardson Side Road. Here the creek collects drainage from the area north of Richardson Side Road, including several residential and commercial/industrial properties. Approximately 250 m west of Carp Road, Huntley Creek flows in a southeasterly direction under Richardson Side Road and bends toward the northeast, where it passes under Carp Road. From there, the creek flows eastward, parallel to Richardson Side Road, then northward through a culvert under the road, eventually discharging in Carp River approximately 3.8 km northeast of the landfill property. Ditches along both sides of Carp Road between the landfill property and Richardson Side Road also drain into this tributary.

The surface water flow pattern on the North Envelope can be divided into two areas. On the south half of the envelope, adjacent to the existing landfill, surface water flow is controlled by a series of ditches and a stormwater recharge pond. Surface flow is generally from southwest to northeast. Because the east end of the property was used for aggregate extraction, the ground surface elevation is now lower than the surrounding area. Consequently, there is no direct off-site surface water runoff from this area. On the residential properties located beyond the eastern limit of the former extraction area, surface water flow is northeastward, following the slope of the land surface.

The north half of the North Envelope is used primarily as agricultural land and residential properties, with the southeast corner used by a manufacturing facility (Laurysen Kitchens Ltd.). The western portion of the North Envelope is flat-lying and surface drainage follows the land contours and agricultural ditches in a northerly to northwesterly orientation toward Richardson Side Road and into the tributary of Huntley Creek described above.

On the eastern portion of the North Envelope, the land slopes in a north-northeasterly orientation along the edge of the post-glacial beach ridge. Surface drainage follows the slope of the land surface into ditches along Carp Road. These ditches drain northward into the Huntley Creek tributary. Immediately north of the Laurysen Kitchens plant is a former aggregate extraction area, approximately 5 hectares in size. Where the land surface in the former extraction area is depressed, surface water collects in localized ponds. The water level in these small depressions reflects the local groundwater table elevation.

The Highway 417 drainage system controls surface water flow immediately south of the existing landfill property. Surface water drainage south of the landfill property is controlled by ditches, catch basins and culverts along Highway 417 and generally flows from west to east, eventually reaching Feedmill Creek and ultimately Carp River (see **Figure 8**).

Along the north side of Highway 417, east of the landfill property, shallow groundwater discharges into the highway drainage ditch and provides the baseflow for the ditch. This ditch flows eastward along the north side of Highway 417, and empties into Feedmill Creek at a point approximately 1.5 km east of the landfill property, where Feedmill Creek flows through a culvert from south to north under the highway. Feedmill Creek continues to flow eastward from that point and discharges into Carp River approximately 3.6 km east of the landfill property.

Surface water drainage on the quarry property on the east side of Carp Road is influenced by a series of excavated ponds that are used as a recirculation system for on-site aggregate washing and dust control. The recirculation pond system is located on the eastern side of the property and consists of six ponds connected through a series of culverts. Water used for dust control and aggregate processing flows through the pond system and is recirculated back for re-use at the crushing/screening plant.

There are no flood hazard zones located within the Detailed Study Area. The elevated topography and high recharge potential of the beach ridge deposits along the Carp Road corridor negate the potential for surface flooding.

2.2.2 Geology

The following detailed site geology description is based on the observations made during drilling investigations conducted on the landfill property and within the Detailed Study Area. The stratigraphy interpreted from the drilling investigations is illustrated on four cross-sections, whose locations are shown on **Figure 3**. These sections include the interpreted geologic units on the North and West Envelopes as well as the existing landfill property, and are presented in **Figures 9(a)** and **(b)**. The bedrock surface elevation, interpreted from all available borehole logs, is shown in **Figure 10**.

2.2.2.1 Surficial Geology

The surficial geology across the Detailed Study Area reflects the same glacial history as the Regional Study Area (see Section 2.1.2.1). The unconsolidated deposits observed during subsurface investigations consist principally of sand, silt, gravel and glacial till, and range in thickness from approximately 3 to 17 m. An overburden thickness map is presented on **Figure 11**. The surficial deposits are interpreted to be ice-contact stratified drift sediments, consisting of a mixture of poorly to well-sorted, stratified gravels and sands, interbedded with a silty sand-gravel till. The deposits are interpreted to have been submerged during the Champlain Sea encroachment, and therefore show indications of re-working in a subaqueous environment. The deposits are horizontally bedded and often display cross-bedding features. The stratigraphic units overlying the bedrock within the Detailed Study Area include (from ground surface down):

Topsoil .... Organic deposits, including peat & muck deposits.

Sand .... Uniform, fine grained, silty, well sorted, non-cohesive.

Silt.......................... Generally uniform and well sorted, non-cohesive to slightly cohesive.

Sand and Gravel ... Silt to very fine or coarse grained sand with gravel and cobble size rounded to sub-rounded rock fragments, often as discrete layers.

Glacial Till .... Very abundant rock fragments, mainly of limestone and becoming increasingly abundant with depth, in a matrix of poorly sorted sand, silt and clay.

Overburden deposits were found to be relatively heterogeneous across the site, both laterally and vertically. The till unit is generally less than 3 m thick, and is found as a discontinuous layer overlying bedrock. It is most abundant in the northwestern portion of the study area. Overlying the till is a sand and silt deposit, varying in thickness from 2 to over 10 m. Generally the thickness of this deposit increases from west to east. A sand and gravel deposit is interlayered with the silt and sand, primarily in the eastern portion of the area.

The unconsolidated deposits observed on the North Envelope consist principally of sand-gravel and sand. The deposits were found to be relatively homogeneous across the envelope, grading from sand-gravel in the eastern portion along the post-glacial beach ridge to fine sand further west, away from the edge of the ridge. At borehole locations on the North Envelope, the overburden deposits ranged in thickness from 4.3 to 15.6 m. The overburden thickness was greatest in the southeast corner of the area, and least in the northwest corner.

The unconsolidated deposits observed during the drilling investigation on the West Envelope ranged from fine sand and silty sand to sand-gravel. At W77, on the southern side of the West Envelope, a thin (1.5 m) lens of clay was observed between the layers of sand. Elsewhere, this clay layer was not observed. At the borehole locations, the overburden deposits ranged in thickness from 2.6 to 9.2 m. The overburden thickness was greatest in the east-central portion of the area, and thinnest along the northern side.

2.2.2.2 Bedrock Geology

The bedrock sections observed during drilling investigations generally consist of light to medium grey, fine to medium-grained fossiliferous limestone with some shaly and sandy interbeds. The bedrock is classified as the Bobcaygeon Formation which is described regionally as a limestone with shaly partings and intermittent sandstone (Natural Resources Canada, 2002). The bedrock is generally most fractured in its upper few metres, while the frequency of fractures in the bedrock decreases starting at depths of approximately 6 to 8 m below the bedrock surface. The highest average fracture frequencies (9 to 10 fractures per 1.5 m of bedrock core) are found in the west-central portion of the study area at boreholes W76-1, W77-1 and W78-1. At these locations, the trend in decreasing fracture frequency with depth is also less apparent. Other boreholes average between 2 and 8 fractures per 1.5 m of core. The fractures are generally found along horizontal to sub-horizontal discontinuities such as bedding planes, shaley layers and mud seams, although some high-angle fractures were observed in the bedrock core samples.

The Rock Quality Designation (RQD) of the bedrock was recorded during bedrock coring investigations. The RQD can be classified according to the following:

0-25%.....................Very Poor
26-50%...................Poor
51-75%...................Fair
76-90%...................Good
91-100%.................Excellent.

In general, the RQD was observed to be poor to fair near the top of the bedrock (upper 2 to 4 ms), and at discrete intervals at greater depths (from approximately 6 m to more than 10 to 12 m below bedrock surface). These less competent (lower RQD) intervals also correspond loosely to depth intervals where fracture frequency is increased.

The bedrock surface generally slopes toward the northeast across the Detailed Study Area, ranging between elevations of 125 mASL and 108 mASL. The bedrock surface features two apparent topographic highs: one located near the southwest extremity of the study area, and the other in the western portion of the existing landfill site (see **Figure 10**). Across the North Envelope, the bedrock surface generally slopes toward the north and northeast, ranging from elevations of 121 to 123 mASL in the south portion to 113 mASL in the northeast. The bedrock surface slopes in a northerly to northeasterly direction across the West Envelope, with elevations of the top of bedrock ranging from 125 to 117 mASL.

Along the western and southern sides of the West Envelope, at boreholes W77 and W78, the top of the underlying Gull River Formation was observed at elevations ranging from 112.5 to 115.5 mASL. The upper member of the Gull River Formation consists of a light grey, microcrystalline to fine-crystalline, thinly bedded limestone with shale interbeds (Derry Michener Booth & Wahl and OGS, 1989). Regional geologic mapping (Natural Resources Canada, 2002; see **Figure 5**) indicates the presence of a faulted contact between the Bobcaygeon and Gull River Formations in this area. The presence of the Gull River Formation at higher elevations in W77 and W78 relative to other boreholes is consistent with the interpretation of an ancient faulted zone within the West Envelope, which has caused upward movement of the bedrock stratigraphy west of the fault. There is no evidence of post-glacial movement along the fault.

2.2.3 Physical Hydrogeology

2.2.3.1 Hydrostratigraphic Units and Interconnectivity of Aquifers

A hydrostratigraphic unit is defined as a distinct unit of the geologic sequence that displays physical and chemical continuity. The unit may be shown to be extensive laterally but it is typically well defined and bounded vertically. The unit will typically show both physical hydraulic continuity and connection as well as consistent groundwater geochemical quality in its natural or undisturbed state. For these reasons the hydrostratigraphic unit will act as a potential pathway for contaminants in the presence of a contaminant source(s) and a driving force (gradient).

Previous hydrogeologic investigations conducted at the WM Ottawa Landfill and on surrounding properties have led to the development of a conceptual model for the hydrogeology of the Detailed Study Area. These investigations have been supplemented with the available geologic information from the Regional Study Area. The Detailed Study Area is interpreted to be underlain by two hydrostratigraphic units:

a) the unconsolidated ice contact sands, gravels, and glacial till, and the hydraulically connected weathered upper bedrock surface; and
b) the deeper bedrock fracture systems.

These units are described in further detail below.

Unconsolidated Deposits and Weathered Bedrock Surface (Overburden-Shallow Bedrock Zone)

The unconsolidated deposits across the Detailed Study Area have a variable thickness ranging from approximately 3 to 17 m. In the higher topographic elevations along Carp Road, the water table in the unconsolidated deposits (i.e., sand, silty sand and silty sand-gravel till) is generally found at over 10 m depth, indicating that the majority of the unconsolidated deposits are unsaturated. The saturated thickness of these deposits, which represents the water table aquifer, is generally limited to 5 m or less. In areas where the bedrock is closer to the surface or where the topographic elevations decline, the depth to the water table decreases, however, the saturated thickness remains limited. Groundwater is also found in the weathered bedrock at the overburden-bedrock interface. This part of the unit extends to a depth of approximately 6 to 8 m below the bedrock surface.

The unit has good vertical and lateral hydraulic connection due to a lack of any continuous confining layers in the sequence of unconsolidated deposits and the upper bedrock. Low vertical gradients are typically measured within the unit, which is also an indication of good hydraulic connection. This zone, herein termed the overburden-shallow bedrock zone, can therefore be interpreted to act as a single hydrostratigraphic unit. It ranges in saturated thickness from approximately 5 to 10 m.

Based on the frequency of fractures observed in the shallow bedrock and the relatively higher hydraulic conductivities, the overburden-shallow bedrock zone is the primary groundwater-bearing formation across the study site and potentially the primary pathway for the transport of dissolved phase constituents.

Deep Bedrock Zone

Groundwater flow in the limestone bedrock is controlled by open joints and fractures. Consequently, the fractured bedrock unit does not always behave as a continuous porous medium, and traditional methods of hydraulic analysis must be adjusted to successfully evaluate the physical characteristics of the unit. Data collected during investigations on and around the WM Ottawa Landfill provide a reasonable understanding of the physical flow characteristics in the deeper bedrock within the Detailed Study Area.

Investigations have indicated that the deeper bedrock, below approximately 6 to 8 m from the bedrock surface, contains fewer fractures than above, and produces significantly lower groundwater yields in monitoring wells developed into this unit. As discussed in Section 2.2.2.2, lower fracture frequencies are generally observed beginning approximately 6 to 8 m below bedrock surface during investigations within the Detailed Study Area.

Although it is reasonable to predict that there is some vertical fracturing from the upper bedrock to the deeper zone, the results from site investigations within the Detailed Study Area suggest that the connection is limited. Low groundwater yields observed in the deeper bedrock in combination with the hydraulic head separations between the shallow and the deep bedrock units demonstrate that this deeper zone is not well connected vertically to the overburden-shallow bedrock unit above or laterally within the deep bedrock. Overall, the water level and hydraulic conductivity data obtained during these studies further supports the distinctiveness of the two hydrostratigraphic units (overburden-shallow bedrock and deep bedrock units).

Across the western portion of the Detailed Study Area, where the bedrock is found at shallower depths, the hydraulic heads in the deep bedrock zone are generally more consistent with those in the overburden-shallow bedrock zone than they are on the eastern portion of the study area. This indicates that there may be more hydraulic connectivity between the shallow and deep hydrostratigraphic units in this area.

2.2.3.2 Direction of Groundwater Flow and Hydraulic Gradients

Site-wide groundwater levels are measured as part of the landfill environmental monitoring program once annually each spring. Groundwater levels are also measured monthly at selected monitoring wells as part of the purge well monitoring program. The water level measurements (converted to groundwater elevations or hydraulic heads) are used to interpret the flow directions on and around the landfill site. The interpreted hydraulic head contours and flow directions for the overburden-shallow bedrock from the January, April, and August 2011 data are shown on **Figures 12(a)** to **12(c)**, respectively. The groundwater elevations from April 2011 are also shown on the geologic cross-sections presented in **Figures 9 (a)** and **(b)**.

The groundwater contours and interpreted flow direction are presented each year in the Annual Report for the landfill site. The current (2011) conditions are representative of the existing groundwater conditions in the Detailed Study Area around the landfill site. Comparison of the January (winter), April (spring) and August (summer) contours illustrates that there is seasonal variation in the groundwater elevations; however, the general characterization of the flow directions and gradients remains consistent.

Shallow groundwater flow generally follows the bedrock topography (see **Figure 10**), with a water table elevation varying from 128 to 129 mASL in the southwest portion of the landfill property and on the West Envelope to less than 112 mASL east of Carp Road. The direction of groundwater flow within the overburden-shallow bedrock in the southwest portion of the site and on the south side of the West Envelope is towards the north. Further to the north on the West Envelope, the groundwater flow is toward the north-northeast. Groundwater flow in this area exhibits a horizontal hydraulic gradient of approximately 0.005 to 0.010. In the northwest corner of the existing landfill site, the topographic high present in the bedrock appears to influence shallow groundwater flow and induces an area of localized northwesterly flow toward the northwest corner of the site. Across the majority of the landfill site, the direction of groundwater flow in the overburden-shallow bedrock is towards the northeast, with an average gradient of approximately 0.006.

On the western half of the North Envelope, groundwater flow in the overburden-shallow bedrock is northerly with a horizontal hydraulic gradient of approximately 0.007. Toward the eastern half of the North Envelope the flow trends more northeasterly, influenced by the topographic decline along the edge of the post-glacial beach ridge. The horizontal hydraulic gradient on this portion of the North Envelope is approximately 0.015. Slightly larger hydraulic gradients are observed along the eastern boundary of the existing landfill site where the gradient is approximately 0.020 to 0.025. This area corresponds to the location of purge well system.

The groundwater flow directions remain relatively consistent between seasons, which is seen by comparing the orientations of the groundwater contours on **Figures 12(a)** to **12(c)**. The hydraulic heads vary from approximately 0.3 to 2 m between winter and spring 2011, with higher heads generally found in the spring. The August groundwater elevations are generally 0.5 to 1.5 metres lower than the spring measurements. The largest variations are seen around the surface water ponds and features on the existing landfill (PW13 and PW15), the North Envelope (W63 and W64), and the West Envelope (W78-2). This is typical of a recharge area, where runoff collects in surface water bodies during wetter periods of the year, and gradually infiltrates into the subsurface.

The regional direction of groundwater flow in the deep bedrock is interpreted to be toward the northeast. Hydraulic heads in the deep bedrock are plotted on **Figures 13(a)** to **13(c)** for the January, April, and August 2011 measurements. Hydraulic heads are found to be highly variable across the site, and are not contoured due to the lateral discontinuity in this hydrogeologic unit. Groundwater flow in the deep bedrock is interpreted to be influenced by isolated fracture zones, which do not appear to be well-connected across most of the Detailed Study Area. However, it is noted that upgradient of the existing landfill site and on the West Envelope where the bedrock is found at shallower depths, the hydraulic heads in the deep bedrock are generally more consistent with those in the overburden-shallow bedrock zone (e.g., W57, W76, W77 and W78). This indicates a higher degree of hydraulic connection between the shallow and deep bedrock in this area. Further to the east, the hydraulic heads in the deep bedrock are generally less consistent with the shallow bedrock, indicating less vertical and horizontal connectivity between the two units (e.g., W44, W50, W54 and W65). Overall, the hydraulic heads in the deep bedrock indicate that the groundwater flow orientation is consistent with the regional groundwater flow system toward Carp River (refer to **Figure 7**).

Vertical gradients between the overburden-shallow bedrock and the underlying deep bedrock are determined by comparing the water levels in adjacent monitoring wells screened at different elevations. Groundwater will flow with an upward or downward component depending on whether the water levels in the deep bedrock are higher or lower, respectively, than in the shallow bedrock. If the water levels in the shallow and deep bedrock are within a metre or two of one another, it implies that groundwater may flow between the two units. However, if there is a significant difference in hydraulic head between the shallow and deep bedrock, such as on the eastern side of the Detailed Study Area (e.g., W44, W50, W54, W55 and W56) where the heads differ by 10 m or more, it implies that there is little or no hydraulic connection between the shallow and deep bedrock.

With few exceptions, the vertical gradients across the Detailed Study Area are downward (see **Table 1**). This is consistent with the area being a zone of groundwater recharge, where flow is generally downward. In August 2011, more of the monitoring well locations were found to exhibit upward gradients. This is an indication of a higher magnitude of seasonal water level fluctuation in the overburden-shallow bedrock aquifer, relative to deeper bedrock. At monitoring wells W88, W89 and W90, located at the West Envelope, upward gradients were observed in April and August 2011.

2.2.3.3 Hydraulic Conductivity

The hydraulic conductivity (K) of a stratigraphic unit is a measure of the ability of a fluid to move through the pore spaces and along fracture pathways. Larger values of hydraulic conductivity (e.g., in sands and gravels, and highly fractured bedrock) imply faster movement of groundwater (depending on the hydraulic gradient) whereas smaller values of K generally indicate that the unit does not transmit water as readily (e.g., clays, and unfractured bedrock).

The hydraulic conductivity can be estimated from empirical data such as soil grain size, or it can be obtained using borehole tests such as slug or packer tests, or aquifer pumping tests. Within the Detailed Study Area encompassing the existing landfill, the North Envelope and the West Envelope, the hydraulic conductivity has been determined at 109 discrete locations including slug tests in 32 monitoring wells and 77 packer tests in thirteen monitoring wells. A summary of the hydraulic conductivity test results is presented in **Table 2**.

The range in hydraulic conductivity measurements in various borehole tests across the Detailed Study Area is from $>1x10^{-3}$ m/s (represented by a rapid response in slug tests) to $<1x10^{-11}$ m/s (a very slow response in bedrock packer tests). This is typical of geologic environments with highly permeable sands and gravels (large K) overlying bedrock that has zones of very little fracturing (small K).

The geometric mean of K calculated from slug tests in monitors completed in the overburden-shallow bedrock zone is $5.6x10^{-5}$ m/s. This represents a typical hydraulic conductivity in this unit within the Detailed Study Area. The geometric mean value of K calculated for the packer tests conducted in the upper two metres of bedrock was $1.7x10^{-6}$ m/s, indicating that the upper bedrock is somewhat less permeable than the overburden, but still moderately permeable. The geometric mean of K calculated from the packer tests conducted in the upper 8 m of the bedrock, where the fracture frequency is observed to be higher (see Section 2.2.2.2) is $2.8x10^{-7}$ m/s. At depths greater than 8 m below the bedrock surface, the average K is calculated to be slightly smaller at $1.6x10^{-7}$ m/s. From these results, it is seen that the limestone bedrock is consistently less permeable than the overburden across the Detailed Study Area.

A summary of the geometric mean values of K calculated from the tests conducted within the three areas in the Detailed Study Area (existing landfill, and the North and West Envelopes) is provided below:

Type of Test	Hydraulic Conductivity (geometric mean; m/s)		
	Existing Landfill	North Envelope	West Envelope
Slug tests (overburden and upper 8 m of bedrock)	3.0×10^{-5}	1.5×10^{-4}	1.3×10^{-4}
Packer tests (upper 8 m of bedrock)	1.8×10^{-8}	3.9×10^{-8}	1.9×10^{-6}
Packer tests (greater than 8 m into bedrock)	6.0×10^{-9}	6.2×10^{-9}	2.7×10^{-6}

From this summary it is seen that the slug testing, which represents the hydraulic conductivities measured in the monitoring wells screened in both the overburden and shallow bedrock, produced larger values of K than the hydraulic conductivities determined from the bedrock packer tests in all areas of the Detailed Study Area. The average hydraulic conductivities measured in the packer tests are relatively consistent between the existing landfill and the North Envelope (10^{-8} to 10^{-9} m/s), and are seen to decrease with depth below the bedrock surface. The average hydraulic conductivities obtained from depths greater than 8 m below the bedrock surface are 4 to 5 orders of magnitude less than those obtained in the overburden-shallow bedrock zone.

On the West Envelope, the pattern of hydraulic conductivity profiles is different from the other two areas. The average K in the overburden-shallow bedrock is 1.3×10^{-4} m/s, which is only two orders of magnitude greater than the packer test results in the bedrock. Also, the average hydraulic conductivities in the bedrock are fairly consistent with depth and do not exhibit a decrease at depths greater than 8 m below the bedrock surface. This observation is consistent with the observed fracture frequency profiles from the boreholes in the West Envelope, which did not show a pronounced decrease in frequency with depth, unlike the existing landfill and the North Envelope. This is further indication of a higher degree of interaction between the overburden-shallow bedrock unit and the deeper bedrock on the West Envelope, as seen from the similarities in the groundwater elevations between the two units (see Section 2.2.3.2).

2.2.3.4 Groundwater-Surface Water Interaction

The Detailed Study Area represents a zone of groundwater recharge, with a relatively shallow water table, an unconfined aquifer, and permeable hydrostratigraphic units. The area is classified as a significant groundwater recharge area (Mississippi-Rideau Source Protection Region, 2009b). In recharge areas, a higher proportion of surface water enters the subsurface to become groundwater, as opposed to groundwater discharging to become surface water. Groundwater gradients are generally downward in recharge areas.

Surface water features that interact with the groundwater regime within the Detailed Study Area include the provincially significant wetland on the West Envelope (part of the Goulbourn Wetland Complex), local wetlands along the northern edge of the North Envelope and south of Highway 417, and stormwater recharge ponds on the existing landfill. Precipitation will also directly infiltrate through the permeable surface soils, moving downward to the water table.

On the West Envelope, surface water levels are measured at three locations around the provincially significant wetland. The wetland has a localized influence on the groundwater contours (see **Figure 12(b)**); however, at distances beyond the 120 m buffer zone, the influence is not apparent.

The stormwater recharge ponds on the south side of the existing landfill property and the local wetland south of Highway 417 also exert localized influence on the groundwater flow patterns in these areas (**Figures 12(a)** to **12(c)**).

East of the existing landfill site, shallow groundwater discharges into the drainage ditch north of Highway 417. This groundwater discharge provides the baseflow for the ditch which transmits drainage to Feedmill Creek, located further to the east. Groundwater discharge also provides baseflow to the dugout pond and ditch located on the property located southeast of the intersection of Carp Road and Highway 417 (known as the Metcalfe property), and to the dugout ponds and ditch located on the quarry property east of Carp Road (the dugout ponds are located east of W53 and W54, behind the CBM concrete batch plant).

2.2.3.5 Calibrated Numerical Model of Groundwater Flow

A three-dimensional numerical model of groundwater flow was developed for the Regional Study Area, using the USGS finite-difference MODFLOW computer application. The computer model extends to regional hydrologic boundaries beyond the Regional Study Area, while supporting a relatively high resolution for the analysis of the conditions in the Detailed Study Area. The computer model is based on the conceptual hydrogeologic model, which has been developed from the available hydrogeologic data, including published sources and data from site-specific investigations. Regional data that were used for the computer model includes the following:

- Regional topography from the Ontario Ministry of Natural Resources (OMNR);
- Ontario Base Map layers (including streams, lakes, wetlands, drainage lines, bedrock and surficial geology, etc.);
- Domestic well records from the Ontario provincial database, in particular lithologic information, water levels, and specific capacities contained therein;
- Hydrograph data available from the HYDAT monitoring network in the area; and
- Land use information derived from Landsat satellite imagery.

Site-specific data included:

- Local survey data (including waste mound topography);

- Physical data, including hydraulic properties of overburden deposits and bedrock;
- Historical hydrograph data, water levels, and water quality data for leachate and groundwater; and
- Borehole log data.

The three dimensional groundwater flow model was calibrated to the available field data, including hydraulic heads and baseflow estimates. The January 2011 water levels available from the landfill site monitoring program were used to provide accurate measurements of hydraulic head in the immediate vicinity of the site. Water level information from private water supply wells provided the broader geographical coverage needed for the remainder of the model area. Sensitivity analyses were conducted to develop the best-fit model and to assess the reliability of predictions in groundwater flow characteristics. For the sensitivity analyses, model properties were adjusted within reasonable ranges to match field observations.

The results of the simulation of groundwater elevations using the computer model are shown on **Figure 14**. Within the Regional Study Area, the simulated heads are in good agreement with the observed heads obtained from the MOE Water Well Records (**Figure 7**). In the Detailed Study Area, the groundwater elevation contours and flow directions are generally consistent with those developed from actual field measurements (**Figures 12(a)** and **12(b)**). Some of the localized details, such as the local flow regime around the higher bedrock surface topography in the northwestern corner of the existing landfill, are not as well-defined in the computer model; however, the general trends in groundwater elevations and flow directions can be seen in the computer-simulated conditions.

2.2.4 Overburden-Shallow Bedrock Groundwater Quality

The following discussion of the overburden-shallow bedrock groundwater quality within the Detailed Study Area is divided into the three areas previously described: the existing landfill (including the downgradient CAZ properties), the North Envelope, and the West Envelope. Groundwater samples from monitoring wells on all of these areas were collected in May 2011. In addition, historical results are available from monitoring wells used in the Environmental Monitoring Plan (EMP) for the existing landfill.

2.2.4.1 Existing Landfill Site

Recent information regarding the existing conditions of groundwater quality in the vicinity of the operating landfill site is presented in the 2010 Annual Report, which provides the results from the EMP conducted at the site. Historical groundwater quality information is also found in the annual report. A summary description of these conditions is presented below.

Note that potential groundwater impacts from the WM Ottawa Landfill are assessed using a suite of fifteen parameters, denoted Assessment Parameters or Primary Indicators. These parameters include nitrogen compounds (ammonia, total Kjeldahl nitrogen (TKN), nitrate and nitrite), potassium, chemical oxygen demand (COD), boron, and selected volatile organic compounds (VOCs). The parameters have low and relatively uniform background concentrations, elevated concentrations in the leachate, and no other apparent significant sources that affect groundwater concentrations at the monitoring locations.

<u>Background</u>

Background (upgradient) groundwater quality in the overburden-shallow bedrock zone is monitored at three locations as part of the existing landfill EMP:

- W57-2, W70 and W77-2.

The results for the background monitors indicate relatively low concentrations of water quality parameters.

Groundwater chemistry is also typically characterized using a Piper water quality diagram. This type of geochemical representation plots the major ions on two ternary diagrams representing the relative proportions of anions and cations, as well as on a quadrangle that combines all ions. The major ions include sodium (Na), calcium (Ca), magnesium (Mg), potassium (K), bicarbonate (HCO_3), sulphate (SO_4) and chloride (Cl), which typically account for the vast majority of the total dissolved solids present in natural groundwater. Different water quality types will plot in different areas of the central quadrangle. Therefore, Piper diagrams constitute a useful diagnostic chemical indicator of the various sources that combine to define the geochemical nature of a particular water sample. Natural background groundwater quality in the vicinity of the WM Ottawa Landfill plots on the left-hand side of the Piper quadrangle in the Ca-Mg-HCO_3 facies (see Piper diagrams on **Figure 15**). This is typical of shallow groundwater in areas underlain by carbonate (limestone) bedrock, which has a higher proportion of calcium and bicarbonate ions relative to other major ions.

<u>Western Boundary</u>

Groundwater quality in the overburden-shallow bedrock zone along the western boundary of the existing site is measured at the following locations:

- W60-2 and W61.

Monitoring well W60-2 is located in the northwest corner of WM property, and W61 is located at the northwest corner of the landfill footprint. Relatively low concentrations of dissolved solids, consistent with background concentrations, were observed in both of these monitors along the western boundary of the site. The Piper water quality diagrams are shown on **Figure 15**. The results for W61 plot in the area consistent with background groundwater quality, whereas the results for monitor W60-2 indicate a higher proportion of sodium ions relative to the other cations (calcium, magnesium and potassium).

North of Existing Landfill

Groundwater quality is monitored on-site at the following locations adjacent to the northern unlined footprint, and along the northern boundary of WM property:

- North of footprint – P79, P80-1 and W63
- Northern boundary – W62-2, W64.

The concentrations of leachate indicator parameters at P79, immediately adjacent to the unlined landfill, are elevated above background and indicate migration of leachate near the toe of the landfill. At P80-1, located to the west, the concentrations of some parameters are slightly elevated above background and have remained stable or have increased slightly since 2000 (e.g., iron, COD, conductivity).

Monitoring well W63 is located in the former Dibblee Pit area, north of the unlined landfill and east of the stormwater recharge pond. The concentrations of most dissolved parameters at this location have increased since the monitor was installed in 2004. It is noted that the concentrations of several water quality parameters are higher at W63 than at locations closer to the landfill footprint (e.g., alkalinity, ammonia, barium, chloride, hardness, sodium, TDS, etc.). This indicates that the source of the elevated concentrations at W63 may be due to other factors, such as the stormwater recharge pond or the former biosolids storage in this area.

Monitoring wells W62-2 and W64 are located from west to east, respectively, along the central portion of the northern boundary of WM property. The concentrations of dissolved parameters at W62-2 generally reflect background groundwater conditions. Monitor W64 is situated at the downgradient end of an area of ponded water that collects runoff from a swale that originates at the northwest corner of the landfill footprint. The concentrations of indicator parameters at W64 are slightly elevated in comparison to background concentrations.

The Piper water quality diagrams are shown on **Figure 15** and the results for these wells plot in the area generally consistent with background groundwater quality, or slightly impacted.

Eastern Boundary & Downgradient

Groundwater quality in the overburden-shallow bedrock zone on the downgradient side of the existing landfill is represented by the following monitoring well locations:

- Purge wells – PW1 to PW10, and PW20
- On-site along eastern boundary – W65-2, W72, W80 and W81
- Off-site, CAZ properties – W44-3, W53-1, W53-2, W54-2, W55-2, W56-2, W79, W82, W84, W85 and WS2

- MTO property (Highway 417) – W48-2.

A brief discussion of each of these areas is provided below. Additional detailed information is contained in the 2010 Annual Report. The Piper water quality diagrams developed from the May 2011 sampling results are presented on **Figure 15**.

Concentrations of dissolved parameters observed in samples collected from the purge wells (denoted as PW) represent leachate-impacted groundwater that is being pumped from the subsurface and removed along the downgradient boundary of the landfill site. As expected, the concentrations of leachate indicator parameters are generally higher in the purge wells than in the downgradient monitoring wells. Along the alignment of the purge well system, the highest concentrations are generally observed around the closed south cell (PW7 and PW8), with lower concentrations to the north and south.

The monitoring wells located in the northeast corner of WM property (W65-2 and W72) have been sampled since 2004. The concentrations of indicator parameters remain at relatively low levels and do not show evidence of leachate impacts.

Monitoring wells W80 and W81, installed in 2008, are located immediately downgradient of the purge well system on WM property, and are within the hydraulic influence of the system. The concentrations of the leachate indicator parameters are elevated at these monitors relative to background conditions, as is expected.

The CAZ properties east of Carp Road are monitored at eleven locations (listed from north to south):

- W82, W53-1, W53-2, W54-2, WS2, W85, W79, W84, W44-3, W55-2, W56-2.

The monitoring wells located further to the south (i.e., W79, W84, W44-3, W55-2 and W56-2) generally have higher concentrations of inorganic parameters such as total dissolved solids, hardness, potassium, ammonia, etc. than the wells further to the north on the CAZ.

Monitoring well W48-2, located on MTO property north of Highway 417, shows elevated concentrations of leachate indicator parameters, specifically ammonia, TKN, COD and potassium.

The following eleven monitoring wells are sampled for VOCs in accordance with the EMP:

- W44-3
- W48-2
- W53-1
- W72
- W79
- W80

- W53-2
- W54-2
- W56-2
- W81
- WS2.

Low levels of VOCs are observed in some of these monitoring wells (chlorinated aliphatic hydrocarbons, chlorobenzenes and BTEX parameters). Year-to-year, the concentrations are consistent in terms of locations, constituents and concentrations.

2.2.4.2 Northern Envelope

For the discussion of groundwater quality, the North Envelope can be subdivided into its southern and northern halves, with the former being coincident with the area north of the existing landfill. Groundwater quality in this area is described above in Section 2.2.4.1 (North of Existing Landfill).

Groundwater quality on the northern half of the North Envelope is represented by monitoring wells W73-2, W75 and W76-2. The water quality parameters from the overburden-shallow bedrock monitoring wells on the northern half of the North Envelope are within the expected range of background concentrations. The concentrations at W76-2 are slightly higher than the other monitors further east, possibly as a result of its location immediately downgradient of William Mooney Road.

The groundwater samples from the overburden-shallow bedrock zone on the northern half of the North Envelope plot in a location on the Piper diagram that is consistent with natural background water quality.

Groundwater samples from the North Envelope have also been analyzed for VOCs. Trace levels of toluene (0.6 µg/L) were measured in one groundwater sample collected in 2007 from W75. However, no VOCs were detected in a sample from this well collected in 2011.

2.2.4.3 Western Envelope

Groundwater quality on the West Envelope is represented by monitoring wells W74, W77-2, W78-2, W88-2, W89-2, W90-2 and W91-2. Monitoring wells W74 to W78 were installed in 2007, whereas the remaining wells were installed in 2011. One round of samples has been collected from the monitoring wells installed in 2011; additional samples are to be collected later in 2011 to confirm these initial results.

Across the West Envelope, the observed groundwater concentrations in the overburden-shallow bedrock are generally within the range of expected background concentrations. Most of the groundwater samples from the overburden-shallow bedrock zone on the West Envelope plot in a location on the Piper diagram that is consistent with natural background water quality (W74, W77-2, W78-2 and W88-2). Samples from W89-2, W90-2 and W91-2 plot to the right of background water quality on the Piper diagram; additional sampling will be necessary to confirm whether these wells represent a different water quality or if the observed chemistry is an artifact of drilling and well installation.

The groundwater samples from the West Envelope were also analyzed for a suite of VOCs. At W74, W89-2 and W90-2, located from southwest to northeast across the central portion of the West Envelope, hydrocarbon parameters benzene, toluene and xylenes have been detected historically at trace levels of between 0.1 and 1.1 µg/L. In 2011, the observed parameters were toluene and xylenes, at concentrations ranging from 0.1 to 0.4 µg/L. Chloroform was also detected in 2011, ranging from 0.2 to 0.3 µg/L. The source of the VOCs in these samples is not known; however, the compounds may be related to isolated hydrocarbon spills from historical farming operations on the property.

2.2.5 Deep Bedrock Groundwater Quality

The deep bedrock zone is considered to be a secondary, discontinuous groundwater pathway controlled by open joints and fractures. The inorganic chemistry of the deep bedrock shows different characteristics than the overburden-shallow bedrock zone discussed above. Generally poor water quality and a higher degree of natural variability are observed in the deep bedrock groundwater across the Detailed Study Area.

At locations that are upgradient to the existing landfill, including W3-2, W41, W43-1 and W57-1, the deep bedrock groundwater exhibits a wide range in concentrations of inorganic parameters, such as alkalinity, calcium, chloride and iron. These results show that deep background groundwater can be more naturally mineralized than the shallower groundwater. At the same locations, the leachate assessment parameters such as ammonia, boron, COD, potassium and TKN are observed at relatively low concentrations (with the exception of the potassium concentrations at W43-1).

Similar variability is seen in deep bedrock monitoring wells located downgradient from the existing landfill. A wide range in parameter concentrations is observed, reflecting the natural variability in the deep bedrock water quality. The median concentrations of most water quality parameters, with the exception of alkalinity, calcium and iron, are higher at the downgradient monitoring locations than at the upgradient locations.

The various monitoring wells on the north half of the North Envelope and on the West Envelope were installed between 2007 and 2011; consequently, there is a smaller dataset available for the deep bedrock zone in these areas. However, there are sufficient data to establish the general water quality characteristics of the deep bedrock. On the North Envelope, the median concentrations of some parameters, such as alkalinity, boron, calcium and iron, are less than both the upgradient and downgradient concentrations on the existing landfill. The median concentrations of ammonia, potassium, TKN and fluoride are greater than both the upgradient and downgradient concentrations.

On the West Envelope, the median concentrations of water quality parameters are generally the same or less than the median concentrations upgradient of the existing landfill, and are all less than the median concentrations measured downgradient of the existing landfill. This may be due to the deep bedrock groundwater being mixed with the less-mineralized shallower groundwater on the West Envelope, where the deep bedrock zone is believed to have a higher degree of connection to the shallower unit.

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