May 12, 2015

WESTSIDE LANDFILL, WEST KELOWNA, BC

Closure Plan

Submitted to:
Regional District of Central Okanagan
1450 KLO Road
Kelowna, BC

REPORT

Report Number: 1406505-003-R-Rev0-5000

Distribution:

1 Copy - Regional District of Central Okanagan
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Golder Associates

Executive Summary

Introduction

This report provides an update to the landfill closure plan prepared in 2011 by CH2M HILL Canada Ltd. (CH2M HILL), and consolidates the various proposed changes into a single, updated closure plan. The background of the closure planning process is provided below, followed by discussion of the main components of the plan.

Westside Landfill, which is managed by the Regional District of Central Okanagan (RDCO), received municipal solid waste from the late 1960s to June of 2010. The landfill stopped receiving waste before it reached its full design capacity, in part because of increasing urbanization near the landfill. One of the consequences of this decision was that a significant portion of the central area of the landfill (over 5 hectares) was not completed to a configuration that would satisfy Ministry of Environment (MoE) criteria for minimum grades for the cover system and that would not satisfy the requirements outlined in a closure plan developed by Reid Crowther and Partners Ltd. in the early 1990s (Reid Crowther, 1993). To achieve these grades, clean fill would need to be obtained and placed on site, which if purchased would have cost implications, and if obtained from free sources, could result in significant delays in final closure of the landfill since free fill is only available sporadically.

The RDCO retained CH2M HILL to develop a new closure plan (CH2M HILL, 2011), in part to explore options that would might allow for lower minimum final grades for the landfill and also to address recent changes in regulations regarding landfill gas emissions. The RDCO retained Golder Associates Ltd. (Golder) to assess the option of using what is sometimes referred to as an "evapotranspiration" cover at this site. There are precedents for using such cover systems in semi-arid areas such as the Okanagan, where evaporation and transpiration exceed rainfall on an annual basis.. Evapotranspiration covers "hold" most of the moisture from rain and snowmelt over the cooler parts of the year when the input from these sources exceed evapotranspiration, and "release" it later during the summer when the converse is true. Golder (2012) explored this option, and found that it should be appropriate at this site, and provided specifications for such a design, which the MoE has indicated is acceptable for use at this site. The design also allows for final slopes that are shallower than the usual criteria, thus reducing the amount of additional clean fill that is required to be brought to site, and thereby reducing the cost and/or time required to close the site compared with alternate approaches.

The substitution of and evapotranspiration cover system for that envisioned in CH2M HILL's (2011) closure plan affected other parts of the plan, including the approach to landfill gas and surface water management. A number of additional reports were developed by Golder in 2012, 2013 and 2015 that discuss these proposed modifications. In addition, Golder (2013) developed a landfill gas management plan for Westside Landfill and, based on review of monitoring data for landfill gas and groundwater, proposed modification to those programs. This report consolidates all of these proposed changes to the approach for closure into a single document for consideration by the MoE. The key component of the updated closure plan, the evapotranspiration cover, is incorporated into this report. The other components of the closure plan are also discussed in the main body of this report, but in some cases, earlier stand-alone reports are included in appendices to provide additional detail.

Components of the Closure Plan

Evapotranspiration Cover System

The final cover system for the landfill will be an evapotranspiration cover system. It will consist of a "soil" cover that has sufficient water holding capacity to store excess precipitation and snow melt from cooler parts of the year, when evapotranspiration is low, and release it through evaporation and transpiration (essentially evaporation through plants) in the warmer months, when evapotranspiration is typically much higher than precipitation. On an annual basis, the potential for evapotranspiration in this area is much higher than precipitation, thus if the surface soil layer has sufficient water holding capacity, there will be very little infiltration of water (rain and snowmelt) through the cover layer, and hence very little generation of leachate. The water holding capacity of the soil cover depends on the characteristics of the soil cover (grain size distribution, primarily) and the thickness of the layer. The detailed requirements for an evapotranspiration cover are provided in the report, but the main requirements are that the cover soils have sufficient fine grained material to hold water effectively though the dry season, but yet not be so fine that it is subject to cracking in the summer or promoting significant runoff during winter rains and snowmelt in the spring. Vegetation established on the cover system plays a role, since the plants support transpiration of water stored in the cover system to the atmosphere. The vegetation also serves to limit erosion from storm runoff and wind.

Grading Plan

Based on assessments by CH2H HILL (2011) and Golder (2012), the minimum surface grade for the landfill is 2.5%. The maximum grade remains at 3x33%. A grading plan for the upper surface of the landfill has been developed. The final grades will be achieved through redistribution of material already placed on site as interim cover, plus importation of approximately 8,000 cubic metres of clean fill suitable for use in the cover system, a considerable portion of which has already been transported to and stockpiled on site. Under the current plan, no bulk filling is required; all of the imported material will be used in the cover system. There are already approximately 4000 cubic metres of compost stockpiled on site that will be selectively mixed into portions of the cover where the imported soil may require improvement.

The remainder of the landfill has cover in place that generally meets the requirements for an evaporation cover, with the following exceptions. There is a portion of the west side of the landfill that is steeper than the maximum design grade. This area will receive some bulk fill and final cover will be placed over that slope, and then vegetated. There is a portion of the landfill on the northwest section that requires placement of some additional cover material. This will be completed in conjunction with surface water drainage works that are to be located in that area.

Surface Water Management

CH2M HILL (2011) developed a surface water management plan, based in part on the assumption that the cover system would include a low permeability barrier layer, which would be expected to limit infiltration of water and promote runoff more readily than would be expected for an evapotranspiration cover system. Another important change is that with development to the west of the site, there are now storm sewer systems that are expected to limit run-on to the site from the west. Given these changes, Golder has modified the surface water management plan, although surface water drainage works are still required on a portion of the northwest side of the landfill.

These works to install these works, which are mainly to limit run-on entering the landfill from the northwest, would also include placing additional cover in the vicinity of these drainage works, where the cover is locally thinner than required for the evapotranspiration cover system.

Landfill Gas Management

Currently there is a landfill gas management plan in place that includes regular monitoring at a number of monitors located around the perimeter of the landfill. Methane levels above set levels for specific monitors trigger specific actions that are outlined in the landfill gas management plan. The results are communicated to a qualified professional within 24 hours of collection of the data for comparison with the requirements of the landfill gas management plan. As well, the overall results for all landfill gases are reviewed annually by a qualified professional to assess trends and make recommendations for modifications to the program, as appropriate. Some recommendations for modification of the monitoring program have been developed based on the assessment of landfill gas monitoring results to date, and recommendations for further investigation have also been completed.

Monitoring Programs

At present, there are established programs for groundwater sampling, groundwater level measurements, landfill gas sampling, and annual inspection and monitoring. Based on assessment of results to date, recommendations are included in the report for modifications to these programs to reflect post-closure requirements. Monitoring results are to be assessed annually by a qualified professional and an annual site inspection should be completed annually after closure, although the requirements for monitoring, inspection and reporting will be reviewed periodically, and may be modified subject to approval by the Ministry of Environment.

Proposed Timeline for Closure

The completion of grading and placement of cover on the upper portion of the landfill is scheduled for completion in 2015. Initial seeding would take place either in fall of 2015 or spring of 2016, depending on the construction schedule. Completion of other works, including addressing the over-steepened portion of a slope on the west side by bulk filling and placement of cover, surface water works on the northwest side and associated placement of cover in that area and seeding of these areas would take place in 2016. Some additional landfill gas investigation is to take place in 2015; any additional work arising for assessment of the investigation results would take place later in 2015, or in 2016. Thus, the main closure works are to be completed by the end of 2016. Additional work may be required after 2016 to fully establish vegetation. Monitoring and inspection will continue beyond 2016, but are expected to be modified over time based on continuing assessment of the results.

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1.0 INTRODUCTION

The Regional District of Central Okanagan (RDCO) retained Golder Associates Ltd. (Golder) to complete an updated Closure Plan for Westside Landfill, which is no longer active. This updated Closure Plan builds on an earlier closure plan completed in 2011 by CH2M HILL Canada Ltd. (CH2M HILL, 2011), which in turn builds on an operations and closure plan completed in 1993 by Reid Crowther and Partners Ltd. (Reid Crowther, 1993).

As will be discussed further in Section 2.1, placement of waste was halted at the site in 2010, before the design capacity of the landfill was reached. This resulted in requirements for changing the closure design. CH2M HILL (2011) provided a revised design, and Golder was subsequently retained to consider additional options for the cover system (Golder, 2012), develop a landfill gas management plan (LGMP), develop and update the grading and surface water management plan, provide recommendations for updated post-closure monitoring and inspection requirements and complete an updated landfill gas management assessment. The primary purpose of the current report is to consolidate this additional work into an updated Closure Plan.

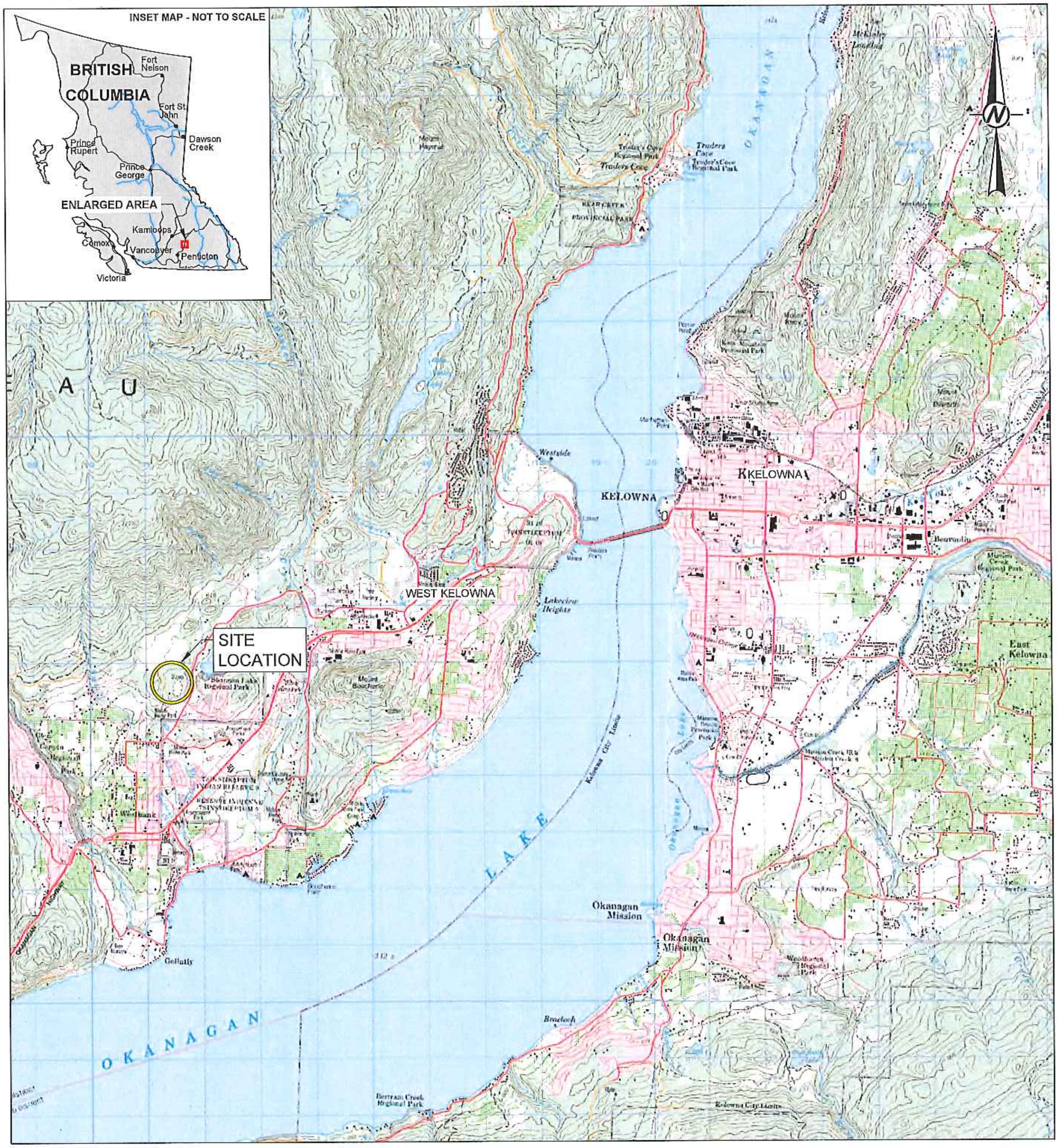
This report summarizes the main elements of these additional reports, in some cases including the original reports as appendices so that the additional details contained in those reports are available to the reader. In Section 2.0 of this report, additional background information is provided, including summaries of landfill and closure plan history, regulatory and planning considerations and some key site characteristics are provided. In Section 3.0, the key elements of the Closure Plan are discussed, including the cover system design, grading requirements, surface water management, landfill gas management and the end use for the site. In Section 4.0, monitoring requirements are discussed for groundwater, landfill gas, surface water, site inspection, as well as recommended reporting requirements. A proposed timeline for closure is provided in Section 5.0. This report should be read taking into consideration the limitations discussed in Appendix E.

2.0 BACKGROUND

2.1 Landfill and Closure Plan History

The location of Westside Landfill is provided in Figure 1, and a site plan is provided in Figure 2. Westside Landfill started operating in the late 1960s (CH2M HILL, 2011). A permit (PR12217) was first issued in 1973. In 1993, an operations and closure plan was developed by Reid Crowther (1993). In 1997 an Operational Certificate (PR12217) was issued, and in 2001 was updated to modify monitoring requirements.

Filling ceased before the design capacity of Westside Landfill was reached, in large part because the landfill was located in an area that was becoming increasingly urban. One of the consequences of the early cessation of filling was that the central portion of the landfill, where more waste would have been accepted, is fairly "flat" such that the surface slopes are at a lower angle than specified in the original closure plan and less than the minimum (4%) that is specified in the guidance document, *Landfill Criteria for Municipal Solid Waste* (British Columbia Ministry of Environment, 1993), hereafter referred to as the Landfill Criteria.



REFERENCE

OF CANADA, DEPARTMENT OF NATURAL RESOURCES. ALL RIGHTS RESERVED.
PROJECTION: TRANSVERSE MERCATOR DATUM: NAD83
COORDINATE SYSTEM: UTM ZONE 10

0 2,500 5,000
1:100,000 METRES

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

PROJECT
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	G. BARRETT
PREPARED	J. FARAH
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

TITLE
KEY PLAN

PROJECT NO.	PHASE	REV.	FIGURE
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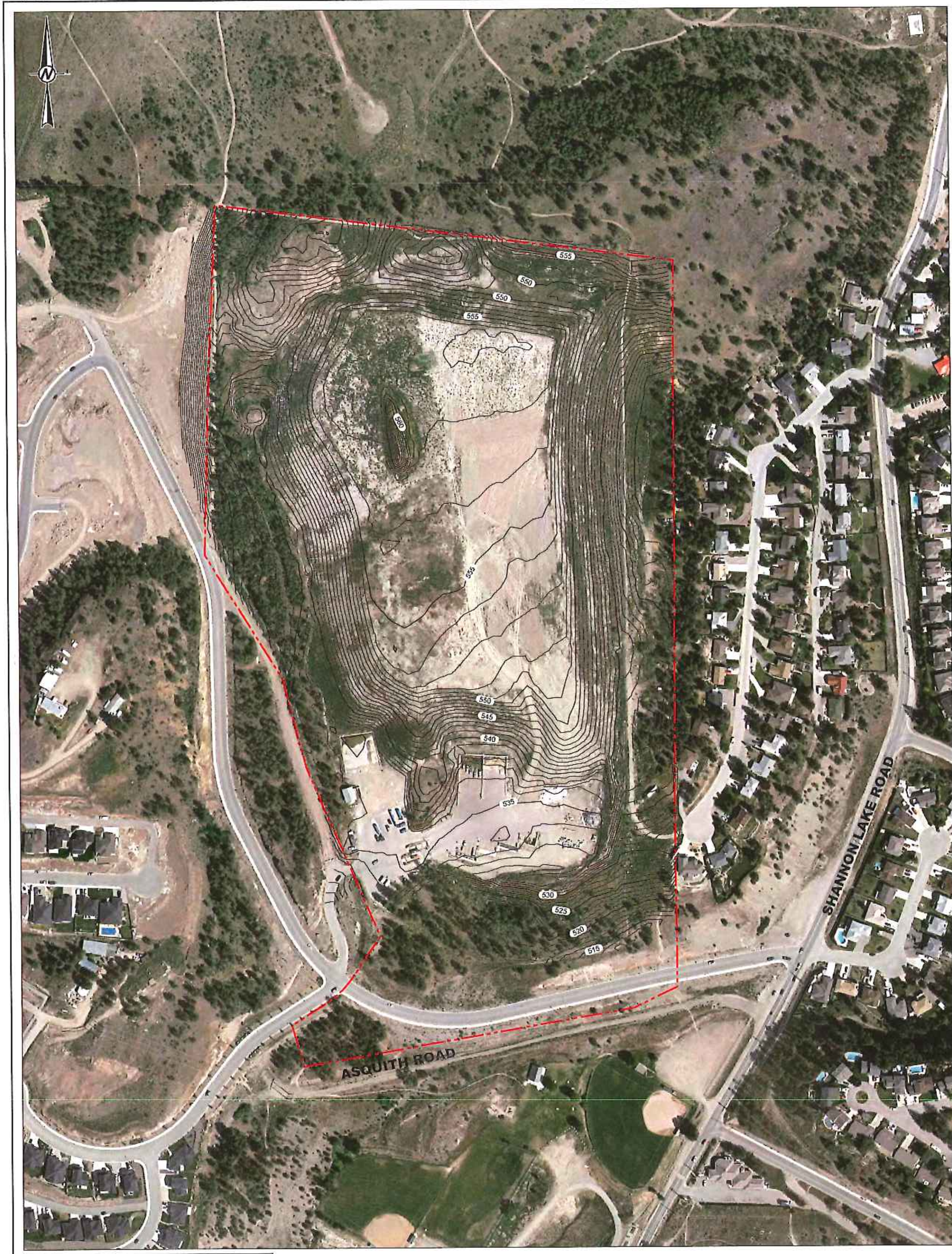

LEGEND

LANDFILL BOUNDARY

MAJOR TOPOGRAPHIC CONTOUR (INTERVAL = 5 m)

MINOR TOPOGRAPHIC CONTOUR (INTERVAL = 1 m)

0 50 100

1:3,000 METRES

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT

REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT

LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE

SITE PLAN

PROJECT NO.	PHASE	REV.	FIGURE
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In order for the central portion to meet the minimum slope requirement specified in the Landfill Criteria, clean fill would be required to create a conical "peak" on the landfill that has the required side slopes. The steeper the slope requirement, the greater the amount of additional clean fill needed and, typically, the greater the expense. Site specific deviations from general guidelines provided in the Landfill Criteria may be allowed by the Ministry of Environment (MoE), but generally only after consideration of supporting documentation provided.

CH2M HILL (2011) assessed several alternatives to the standard design outlined in the Landfill Criteria (a 1.0 metre thick barrier layer topped by 0.15 metres of topsoil, with slopes on the upper surface no less than 4.0% and maximum slopes no greater than 33%), but in the end focused on two alternate cover designs, one assuming a grading plan with minimum slopes of 2.5% and the other with minimum slopes of 1.5%. In both cases, CH2M HILL included the 1.0 metre thick barrier layer recommended in the Landfill Criteria, but with an additional 0.3 metre thick "vegetative" layer placed above the barrier layer and then a 0.15 metre thick topsoil layer. CH2M HILL used the US Environmental Protection Agency's (EPA's) Hydrologic Evaluation of Landfill Performance (HELP) model to assess the performance of these alternatives (Schroeder, Lloyd and Zappi, 1994). The HELP modelling suggested that both of these alternate covers would perform better with respect to leachate generation than a standard cover system as outlined in the Landfill Criteria (CH2M HILL, 2011).

Golder was asked by the RDCO to consider, in consultation with CH2M HILL, the use of an evapotranspiration (ET) cover system at Westside Landfill. In semi-arid areas, such as this part of the Okanagan Valley, ET covers are often feasible alternatives to conventional cover systems with barrier layers. The HELP model is not always the most appropriate tool for assessing the potential performance of an ET cover system, however, since it is designed for evaluation of systems with barrier layers, which ET covers do not have. In the case of ET cover systems, which "rely" on soil storage and evapotranspiration to limit leachate production, water balance modelling can provide a more effective tool for estimation of the likely performance, and that is the approach that was used by Golder (2012).

Golder completed a preliminary analysis of the likely performance of an ET cover system, and reviewed the results with the RDCO and CH2M HILL, before meeting with representatives of the MoE to discuss the potential offered by this approach. In short, Golder's analysis suggested that an ET cover system would likely be effective at this site and that lower grades than those specified in the Landfill Criteria were expected to be acceptable. The MoE indicated that as part of a formal proposal for use of an alternate cover system at this site, that a means of performance assessment be recommended. The proposed cover and a system for performance assessment were included in *Cover System Options* report (Golder, 2012).

2.2 Regulatory and Planning Considerations

CH2M HILL (2011) provided a review of the key regulatory documents that pertain to closure of Westside Landfill; including:

- Permit PR 12217 – original MoE permit, PR12217, issued in 1973, but superseded by an Operational Certificate issued in 1997 (see next entry);
- Westside Landfill Operating Certificate (PR 12217) – Issued in May, 1997 - includes requirements that are generally in agreement with the MoE's *Landfill Criterial for Municipal Solid Waste* (1993), but includes a number of site specific requirements for monitoring, operational requirements, and so forth (Appendix A), with revision to the groundwater monitoring requirements by the MoE in 2001;

- Westside Official Community Plan – Adopted as Schedule A to Bylaw 1050 in February, 2005 – has implications for end use, includes principals such as the use of native vegetation in reclamation of disturbed areas and the use and management of topsoil specifically designed for water retention purposes;
- Westside Parks and Recreation Master Plan (WPRMP) - completed by RDCO in 2000 – identifies a potential future use of Westside Landfill as the site of a new community park, and recommends that the closure plan be updated to include this end use;
- RDCO Solid Waste Management Plan - updated in 2006 – no direct references to Westside Landfill, although it should be noted that waste collection and transfer facilities are located on site; and,
- The Landfill Gas Management Regulation - in force since January 1, 2009 under the Greenhouse *Gas Reduction (Emissions Standards) Statutes Amendment Act*, 2008 – outlines reporting and assessment requirements related to landfill gas emissions (see Section 3.6 and Appendix B).

2.3 Site Characteristics

2.3.1 General

The location of the site is provided in Figure 1. A general site map showing the approximate topography of the site and the location of monitoring well and vapour probes is provided in Figure 2.

2.3.2 Climate

Climate normals are available for Environment Canada's Kelowna PC Burnett's Nursery for the period 1981 to 2010. In Figure 3, the average monthly rain and snow are plotted as stacked bars, along with an estimate of potential evapotranspiration (shown as negative values since they represent a possible loss of water versus the gain from rain and snowmelt) made using the Thornthwaite approach, corrected for latitude (see, for example, Dunne and Leopold, 1978). The "Balance", which is the sum of rain plus snow less potential evapotranspiration, is also shown in Figure 3, by month. Potential evaporation exceeds rain and snow over the period April to October, and for the year totals over 662 mm, versus combined rain and snow of about 345 mm. In the Köppen classification system, this would be a BS climate, sometimes referred to as a steppe climate, or semi-arid climate.

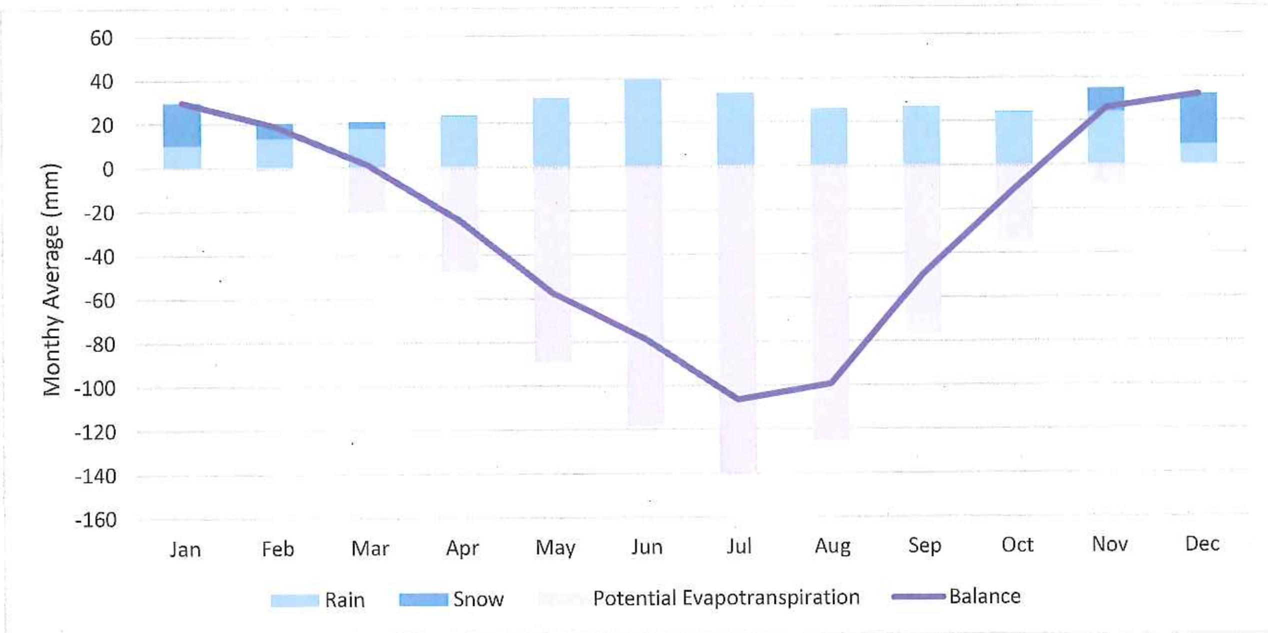


Figure 3: West Kelowna Climate Data (PC Burnett's Nursery)

2.3.3 Geology

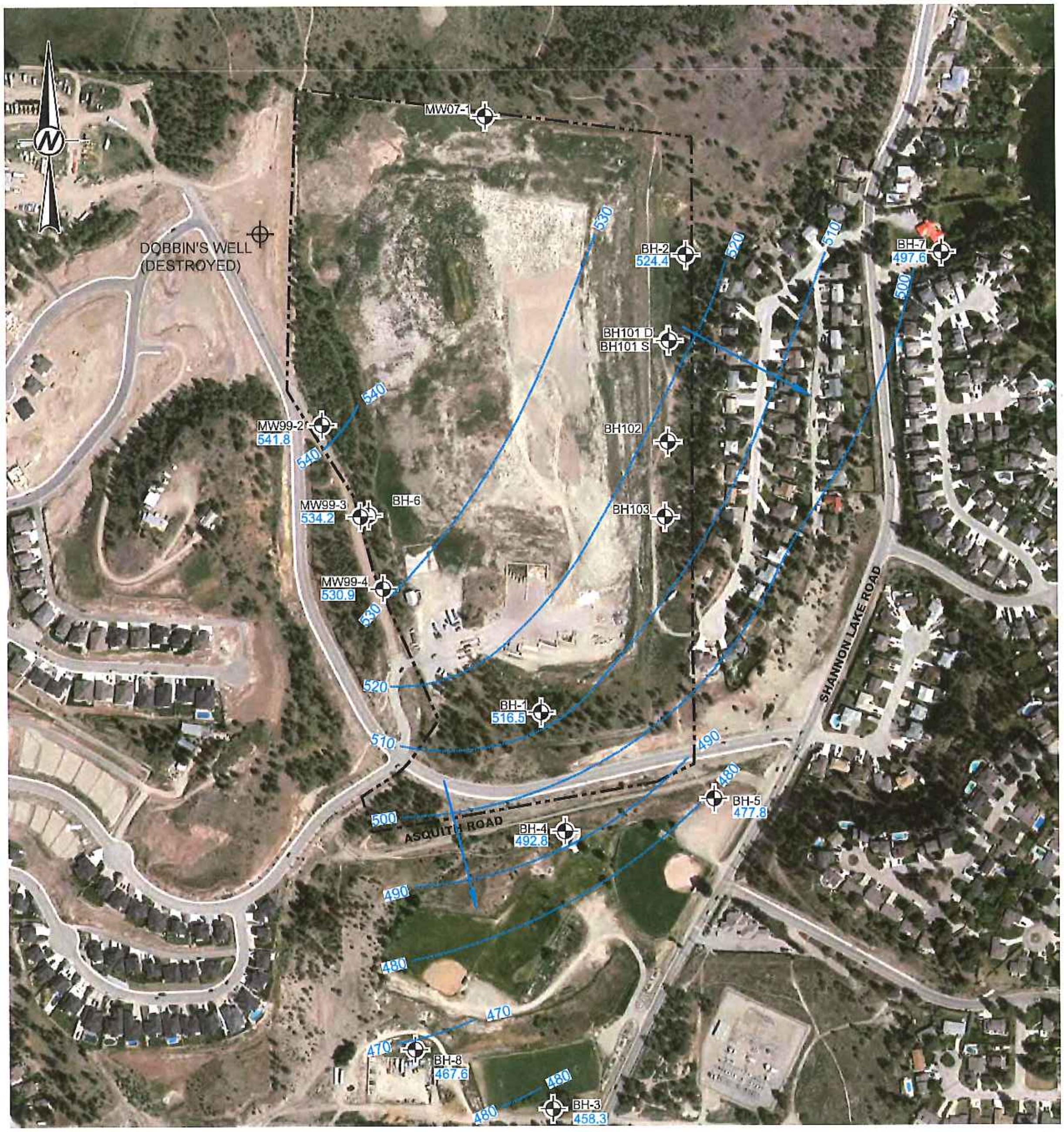
CH2M HILL (2011) stated that it appeared that there was relatively little trench filling at this site, with the majority of the waste being placed above grade up to depths of about 20 metres on the south side of the landfill and up to 8 metres on the north side. Soil mapping (Experimental Farm Service, 1948) suggest that the surface materials were likely till (a glacial deposit), which is consistent with more recent mapping that also characterizes the original surface as till (Paradis, et.al., 2010). Underlying the glacial deposits, the bedrock has been identified as volcanic (British Columbia Department of Energy and Mines, Minfile website, July, 2012).

2.3.4 Soils

Soils at the site of the landfill were identified in a 1948 map as "Kelowna Gravelly Sandy Loam" (Experimental Farm Service, 1948). The Kelowna Gravelly Sandy Loam is associated with weathered till, is typically dark brown, and consists generally of sands with some gravel and coarser material, and is associated with a semi-arid climate (Ibid.).

2.3.5 Hydrogeology

Based on information accessed online from the BC Water Resources Atlas (British Columbia Ministry of Environment, 2014), beneath the site there is a bedrock aquifer (Aquifer Number 0305) of low productivity and moderate vulnerability. The southern portion of the site overlies part of the gravel and sand Shannon Lake Aquifer (Aquifer Number 0301). The Shannon Lake Aquifer is located above the bedrock aquifer (0305) where the two overlap. Based on water level data from groundwater monitors located on and off-site and historical data from selected wells, groundwater level contours suggest flow is to the southeast to south, as illustrated in Figure 4.



LEGEND

- LANDFILL BOUNDARY
- GROUNDWATER MONITORING WELL LOCATION
- DOMESTIC WATER WELL LOCATION
- 458.3 MONITORING WELL GROUNDWATER ELEVATION (JAN 2013)
- INFERRED DIRECTION OF GROUNDWATER FLOW
- — 470 — INFERRED GROUNDWATER CONTOUR (10m INTERVAL)

REFERENCE(S)

2009 BASE ORTHOPHOTO OBTAINED FROM RDCO.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING, DATED MAY 2013.

0 100 200

1:6,000 METRES

CLIENT

REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

PROJECT

LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-11
PREPARED	J. FARAH
DESIGN	G. BARRETT
REVIEW	G. BARRETT
APPROVED	R. PELESHYTYK

SITE PLAN DEPICTING GROUNDWATER FLOW DIRECTION

PROJECT No.	PHASE	Rev.	FIGURE
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2.3.6 Surface Water

There is surface water located on the west side of the landfill that is fed by seeps. The location of ponding has appeared to change over time in response to some excavation on the west side, as will be discussed further in Section 3.4. The only major surface water body near the landfill is Shannon Lake to the east, but it appears that groundwater flow is toward Okanagan Lake to the south, such that any contamination of groundwater from landfill leachate would not impact Shannon Lake.

2.3.7 Sensitive Areas

As noted in Section 2.3.6, the closest major surface water body that could be affected by leachate is Shannon Lake, but the evidence available suggests that groundwater that is potentially impacted by the landfill does not flow towards Shannon Lake.

Leachate from the landfill could potentially impact the aquifers beneath the site. A groundwater monitoring system is in place to assess the possibility and reports are completed and submitted annually to the MoE.

There is a residential area located relatively close to the landfill (see Figure 2). Given that the landfill is no longer in operation and has at least partial cover over the site, with the exception of a small area on the west side of the landfill (see Section 3.3.2), issues such as odour and litter are not expected to be issues. During the actual closure works, noise and dust are potential issues; the detailed work plans should include measures to limit the impact on residents in nearby residential areas.

3.0 LANDFILL CLOSURE

3.1 General

In the following sections of this report, the key requirements for closure are discussed, including cover system design (Section 3.2), grading requirements (Section 3.3), surface water management (Section 3.4), landfill gas management (Section 3.5) and end use of the site (Section 3.6). Monitoring, inspection and reporting requirements are discussed in Section 4.0).

3.2 Cover System Design

In the following subsections, the cover system options are reviewed (Section 3.2.1), recommendations for a preferred cover system are provided (Section 3.2.2), cover system specifications are provided (Section 3.2.2) and cover system performance assessment is discussed (Section 3.2.4).

3.2.1 Cover System Options

An ET cover system was not included in CH2M HILL's assessment of alternate cover systems, but such a cover system is, at least in principle, an option in semi-arid climates such as the Okanagan Valley. As summarized in the United States Environmental Protection Agency's (2013) *Evapotranspiration Landfill Cover Fact Sheet*, ET covers typically include: "... fine grained soils such as silts and clayey silts, that have a relatively high water holding capacity; native vegetation to increase evapotranspiration; and locally available soils to streamline construction and provide for cost savings".

As further discussed in the United States Environmental Protection Agency's (EPA's) fact sheet, a number of cover systems were included in a field trial of cover systems; the most relevant covers for the present discussion are the ET cover and the Subtitle D cover (Subtitle D covers are effectively a standard cover system for municipal solid waste landfills in the US). The ET cover system consisted of a 105 cm thick cover, of which "... 90 cm of native soil was compacted while the top 15 cm of topsoil was loosely placed". The Subtitle D cover was 60 cm thick and constructed of two principal layers: the "... top vegetation layer is 15 cm of loosely laid topsoil ... [and the] bottom layer is a 45 cm thick compacted soil barrier layer". The results of the multi-year field trial are provided in Table 1 for the ET and Subtitle D cover systems.

Table 1: Summary of Key Results from a Field Comparison of Landfill Cover Systems.

Year	1997*	1998	1999	2000	2001	2002	Average
Annual Precipitation (mm)**	267	292	225	300	254	144	247
ET Cover Percolation (mm)	0.08	0.22	0.01	0.00	0.00	0.00	0.05
Subtitle D Cover Percolation (mm)	3.56	2.48	1.56	0.00	0.00	0.74	1.39

*for May to December only ** rounded to the nearest mm

The results presented in Table 1 suggest that under appropriate conditions, an ET cover system can perform as well or better than a conventional municipal solid waste cover system with respect to limiting percolation into the landfill, which is a key factor in limiting leachate production in landfills.

ET cover systems are most appropriate in areas with a semi-arid to arid climate, such as found in the Okanagan. Kelowna has three Environment Canada Climate Stations for which "30 year normals" have been generated for the period: Kelowna A (airport), Kelowna East and Kelowna Burnett's Nursery. Using the Thornthwaite approach (see, for example, Dunne and Leopold, 1978, and additional discussion in Appendix A), potential evapotranspiration was estimated for each of these stations using the values from the 30 year normals and is compared to average annual precipitation in Table 2. As can be seen from Table 2, there is some variation between sites with respect to precipitation, from a low of 340 mm per year for Kelowna PC Burnetts Nursery to 416 mm per year for Kelowna East, but for all sites potential evapotranspiration exceeds annual precipitation by over 200 mm per. An excess of potential evapotranspiration over precipitation is one of the prerequisites for an evapotranspiration cover.

Table 2: Precipitation and Estimated Potential Evapotranspiration.

Station	Annual Precipitation (mm)	Annual Potential Evapotranspiration (mm)
Kelowna East	416	637
Kelowna PC Burnetts Nursery	340	637
Kelowna A	381	601

Of the three stations for which we have 30 year normal information, the Kelowna A station has the longest record of monthly data, extending from late 1968 to 2005, but with a significant amount of missing data early and late in the record, leading us to only using data from 1969 and 2005, and only using data from 1969 for initiation of the model runs, as described in Appendix C.

As discussed in Appendix C, a water balance model based on an approach outlined in Dunne and Leopold (1978) was used to estimate the water balance for the cover system as well using a model recently developed by the United States Geological Survey (USGS), as described by McCabe and Markstrom (2007), and hereafter referred to as the USGS water balance model. The approach outlined by Dunne and Leopold (1978) represents what might be considered to be a standard approach to water balance modelling, and is referred to hereafter as the standard water balance, or SWB model (see Appendix C for further discussion). The general approach used in the SWB model has been well documented and variants of this approach have been used for many years. The variations between versions of the SWB related to the particulars of how some estimated parameters in the water balance, such as snow melt, are estimated.

In order to develop design parameters for an ET cover, the SWB model and two variants of the USGS water balance model were used to estimate the amount of water that would percolate from the cover system into the waste and thus potentially form leachate for different values of the water holding capacity of the cover system. As discussed in Appendix C, the two version of the USGS model differ in assumptions related to what fraction of the rain and snowmelt is assumed to be lost as surface runoff and the maximum fraction of snow that can melt in a month. The USGS model's default values for the fraction of rain and snowmelt that are lost as surface runoff and the limit on the snowmelt that can take place in a month result in estimates of "percolation" (or "surplus" as it is referred to in the USGS model) that are lower than what is predicted by the SWB. As discussed further in Appendix C, if the default values are adjusted to values more in line with similar parameters in the SWB, the results are very similar to those predicted by the SWB. This latter version of the USGS model is referred to as the "USGS (specified values)" model to distinguish it from the "USGS (default values)" model. In Figure 5, the results of water balance modelling, using the Kelowna Airport data as input, is shown for water holding capacities from 50 mm to 200 mm (using steps of about 25 mm). The results for CH2M HILL's HELP modelling for the "standard cover" (as specified in the Landfill Criteria) and for the 1.5% and 2.5% slope options are shown for comparison.

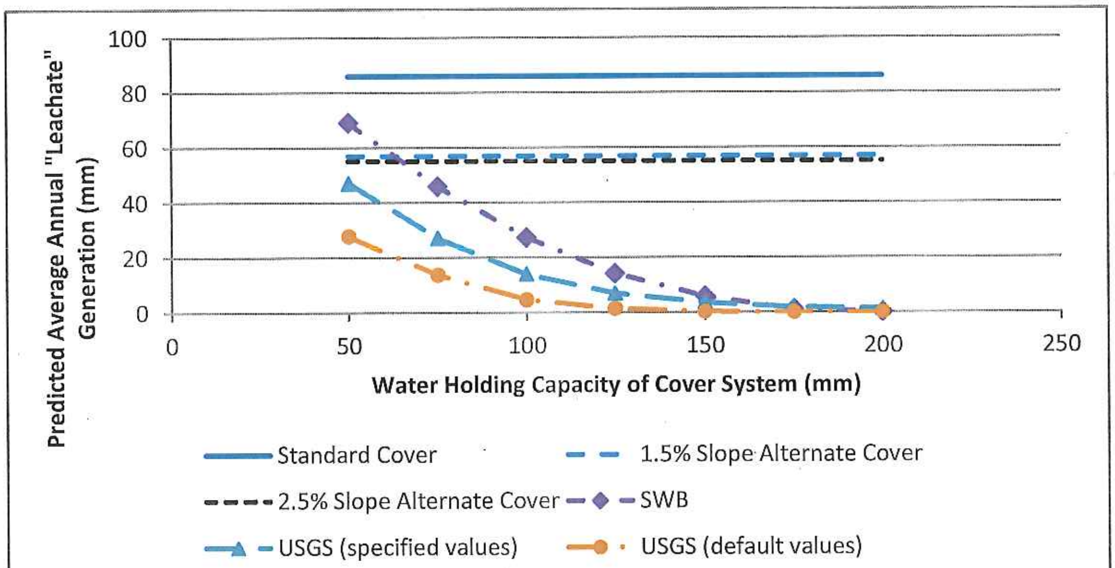


Figure 5: Predicted Leachate Generation for Selected Cover Systems

As can be seen from the results presented in Figure 5, all versions of the water balance model suggest that an ET cover will perform better than would be predicted by the HELP model for a standard cover system (as defined in the Landfill Criteria) or by either of the two variants considered by CH2M HILL. In fact, the standard cover system and the two variants (the 1.5% and 2.5% slope) models might perform better than predicted by the HELP model since the water holding capacity of the barrier layer is not taken into account by the HELP model, but the HELP model is a standard, widely used model that provides a performance benchmark against which to compare alternatives.

3.2.2 Cover System

Golder (2012) previously recommended that an evapotranspiration cover system be considered for use at this site, given that in this semi-arid environment it should perform as well or better than the standard design outlined in the LCMSW, provided that an appropriate design is adopted. The MoE has accepted the proposal to use an evapotranspiration cover system at this site, but performance monitoring (see Section 3.2.4) is to be conducted with results issued to MoE for their review. In addition, through consultation with the MoE, the minimum grade for the final surface cover was set at 2.5%.

3.2.3 Cover System Specifications

Three key components of the cover system are specified in the following subsections: water holding capacity (Section 3.2.3.1), soil specifications (Section 3.2.3.2) and establishment of vegetation (Section 3.2.3.3).

3.2.3.1 Water Holding Capacity

As noted in Section 3.2.1, an evapotranspiration (ET) cover system can offer performance that meets or exceeds the options for a cover system based on design criteria provided in LCMSW or either of the options discussed by CH2M HILL (2011) using lower slope alternatives (they considered a 2.5% minimum slope and 1.5% minimum slope designs), provided that the water holding capacity of the cover system is sufficiently high. As discussed in Section 3.2.1 and in Appendix C, Golder used a water balance model based on the Thornthwaite approach to model performance, along with two versions of a water balance developed by the USGS (2007) to assess the likely performance of an ET cover system.

Using the most conservative model (referred to as the SWB model in Appendix C), the water holding capacities of an ET cover system required to match the predicted (using the HELP model) performance of the standard MoE cover system and the two CH2M HILL variants, as described in Section 2.2, were as follows:

- Standard MoE Cover System as described in LCMSW based on HELP modelling completed by CH2M HILL (2011) – an ET cover would require 33 mm of water holding capacity to match the predicted performance of this cover system;
- CH2M HILL's (2011) modified cover system with minimum slopes of 2.5% - an ET cover would require 64 mm of water holding capacity to match the performance of this cover system; and,
- CH2M HILL's (2011) modified cover system with minimum slopes of 1.5% - an ET cover would require 62 mm of water holding capacity to match the performance of this cover system.

Thus, to match the predicted performance (using the HELP model) of the "best" of the options considered by CH2M HILL, a water holding of at least 64 mm would be required, while a water holding capacity of only 33 mm of water would be required to match the predicted (again, using the HELP model) of a standard MoE cover.

The water holding capacity of the cover system is a function of the properties of the material used in the cover system and its depth. Given that the cover system acts in part to cover the waste, it is desirable to have a certain minimum thickness for the cover system, no matter what the physical characteristics might be. As noted in Section 3.2.1, the ET cover systems tested by the US EPA consisted of 90 cm of compacted local soil (about 3 feet) topped by 15 cm (about 0.5 feet) of loosely placed local soil, for a total cover system thickness of just over one metre (1.05 metres). Currently there is local "soil" placed over much of the landfill to a depth of 1.0 metre or more. Thus, a reasonable specification for the total thickness of the cover system is that it be at least 1.0 metre thick. To satisfy the water holding capacity requirement, then, the material that the cover system is composed of should have a water holding capacity of at least 33 mm per 1.0 metre (or 3.3 cm / 100 cm, a commonly used unit for water holding capacity) to match the performance (as predicted by HELP modelling) for a standard MoE cover, or about 65 mm per 1.0 metre to match the performance (again, as predicted by HELP modelling) for the best of the two additional options considered by CH2M HILL (the 2.5% slope option).

The water content of seven samples of the material already used as cover was estimated by Golder; the results are summarized in Table 3.

Table 3: Water Holding Capacity Estimates.

Method	No. Samples	Average (mm/m)	Minimum (mm/m)	Maximum (mm/m)
1	7	141	100	200
Noble	7	129	90	150
Ramsey	7	119	80	160

As the results recorded in Table 4 indicate, the water holding capacity of all samples tested, even using the most conservative of the approaches (Ramsey's) met or exceeded 80 mm per metre thickness of material. This implies that a 1.0 metre (or more) thick ET cover system composed of this material would exceed the minimum water holding capacity and perform better than the HELP model predicts a standard MoE cover would perform (with respect to limiting leachate generation), and better than the HELP model predicts either of the two alternate cover systems considered by CH2M HILL would perform. Thus, the data suggests that the material already in place at Westside Landfill is suitable for use in an ET cover system.

3.2.3.2 Soil Specifications

Additional material must be brought on site to bring the cover system up to a minimum thickness of 1.0 metre. It is important that the material have sufficient water holding capacity to meet the requirement of an ET cover that is 1.0 metre thick. The clay and silt sized materials in soil generally contribute much of the soil water holding capacity, but the proportion of fine grained material should not be so high that the infiltration capacity of the soil is reduced to such an extent that surface runoff becomes significant, since that can lead to erosion.

An approximate range of suitable material types was identified by Anthony Schori, a Professional Agrologist with Golder to provide field level guidance to allow the RDCO to identify material that is likely to be appropriate for use in the cover system. Since decisions on whether or not material is acceptable often needs to be made quickly by RDCO staff or technicians working for the RDCO, the criteria needs to be simple enough to be judged in the field. Golder has recommended that soils judged to consist of about 50% fines and 50% sands and gravels should be appropriate, and would be expected to have a water holding capacity of about 13 to 15 centimetres per metre (about 130 to 150 millimetres per metre). Some variation from this half and half split is acceptable, from about what would be judged to be 40% fines and 60% sands and gravels, to about 60% fines and 40% sands and gravels. Material outside of this range could be acceptable as well, but it should be subject to inspection by a suitably qualified professional.

The approximate range of the most desirable textures is depicted in Figure 6, for the clay, silt and sand sized fractions of the soil (the coarser material is excluded). This is a guideline, and soils outside this range may be suitable as well, but should be subject to additional professional consideration. However, within the identified range, soils are likely to have infiltration characteristics and water holding capacities that are suitable for use in construction of an ET cover system. The material that is accepted will typically be dumped and then later spread to achieve a minimum thickness of 1.0 metre. The spreading process will result in mixing, as well as some compaction of the material. In addition to laboratory testing to characterize the cover with respect to water holding capacity, we recommend that a qualified professional should complete a walkover of the site and complete further assessment, as required.

3.2.3.3 Establishment of Vegetation

A testing program will be required to confirm the approximate nutrient status of the cover soil, which in turn will determine what nutrients should be added to support establishing vegetation similar to the native mix. Based on preliminary sampling and testing of cover material already in place, some enrichment of the soil with organic matter is desirable. There is some organic material stockpiled on site that may be suitable for this purpose, pending additional testing. The existing cover material appears to have limited nutrients, thus we anticipate that additional fertilization will be necessary, probably 18-18-18 fertilizer (with 50% slow release nitrogen) will be recommended at a rate of 450 kg/ha. It is anticipated that it may be necessary to provide additional rounds of fertilization as vegetation is being established on site.

We recommend that seeding be conducted in spring or fall. An appropriate seed mix would be approximately 10% bluebunch wheatgrass, 8% Idaho fescue, 2% Sandburgs bluegrass, 20% crested wheatgrass, 15% hard fescue, 20% tall wheatgrass, 20% tall fescue, and 5% drylander alfalfa, (applied at a rate of 75 kg /ha). Additionally, a cereal such as fall rye should be added to the seed mix at rate of 50 kg/ha. We recommend that the seed mix be revisited after completion of the cover and additional testing (of nutrient status and texture) has been completed.

The number of soil samples that will need to be tested to adequately assess the soil nutrient status will depend in part on how heterogeneous the soil cover is when completed and thus how much spatial variability we might expect. A qualified professional would make the final assessment of the number required, and the assessment may require multiple rounds of testing, depending on the variability of the results from any initial testing. As well, the qualified professional would make additional recommendations for fertilizing and seeding, as required. For example, it may be advantageous, depending on the degree of compaction of the cover material, to "loosen" the upper 150 mm of the cover before seeding. Other possible advice might be related to measures to control or limit invasive weeds.

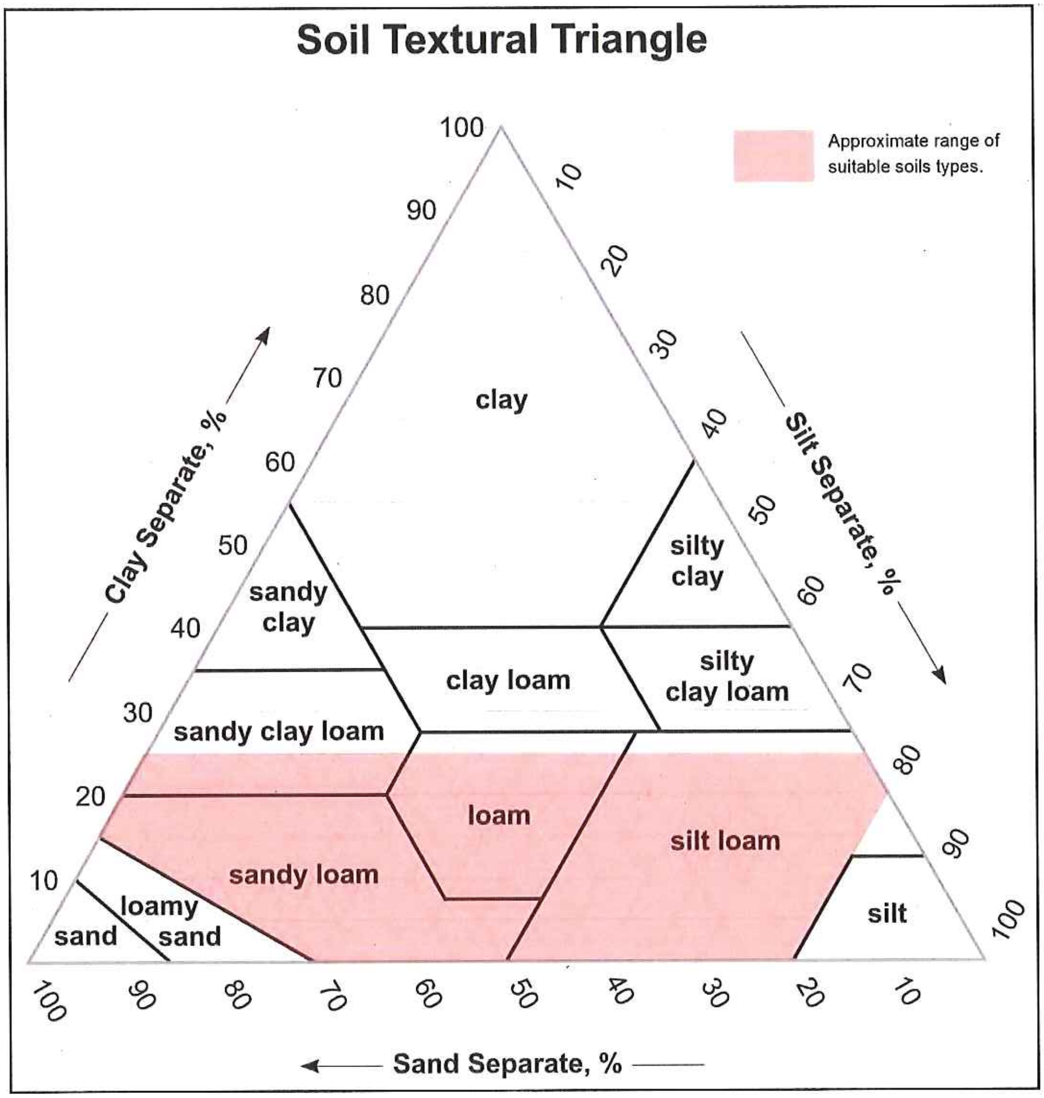


Figure 6: Approximate range of acceptable soil properties

Weed control will be essential in order to establish successful grass and legume vegetation. Although we note that herbicide use would probably be effective, we anticipate that other means of control would be preferred for this site. Thus, cutting before seed set to limit reseeding by annual weeds might be considered. This may need to be done for several years in succession.

3.2.4 Cover System Performance Assessment

An ET cover should limit infiltration and thus leachate generation from percolation of rain and snowmelt through the cover system into waste to a level similar to or better than what is expected from the standard cover system discussed in the LCMSW. The key factors in the performance of an ET cover system include:

- Construction of the cover system using material with appropriate physical characteristics, including most importantly, the water holding capacity of the soil. It is proposed that testing be conducted to confirm that the cover system has been constructed of appropriate material. This would be done through sampling, textural analysis and estimation of water holding capacity (using accepted estimation procedures based on texture) and a visual inspection during a walkover by a qualified professional.
- Construction of the cover system to an appropriate thickness. This would be completed based on analysis of existing test pit and survey data from areas that already have an appropriate cover thickness, supplemented by additional test pitting and surveying in areas where filling is not yet complete.
- The cover system should have positive grades with convex contours (plan view) as discussed in Section 3.3.2 that would not lead to concentration of surface flow (this also avoids any closed depressions on the surface). This can be confirmed by survey. Since waste may settle over time, physical site inspections by a qualified professional are required periodically, and may be supported by additional surveys as required.
- Ensuring that the soil is suitably prepared for establishment of vegetation by determining an appropriate fertilization regime, appropriate species for planting and appropriate timing for planting. Additional requirements, such as "loosening" of an upper layer of the cover prior to seeding, would be established by a qualified professional.

The ongoing performance of the cover system will be assessed in part by the results of the groundwater monitoring program. One of the functions of the cover system is to limit infiltration. Thus, groundwater quality should not be worse than it was during the active life of the landfill, and should improve over the long term, provided that infiltration of water through the cover system is the only source of leachate. In the short term, however, the results at a given location, especially an off-site location, may not improve immediately, and may even get worse, since there can be a significant lag between when groundwater was contaminated and when it appears at a given location. As well, water quality may be impacted by other factors, including the lateral flow of groundwater through waste placed in the landfill.

3.3 Grading Plan

3.3.1 Grading Requirements

As previously discussed, CH2M HILL (2011) explored two alternatives to the standard MoE cover system; both included adding a 300 mm thick "vegetative" layer (CH2M HILL's terminology) above the existing barrier layer followed by a 150 mm layer of topsoil. The two alternatives differed in that one option involved slopes on the upper portion of the landfill assumed to have a minimum grade of 1.5%, and the other option assumed slopes with a minimum grade of 2.5%. CH2M HILL used the HELP model to compare the performance of these two alternatives to that of the standard MoE cover system, and presented a summary of the results in Exhibit 4-4 of their 2011 report. Some of the key results from Exhibit 4-4 are summarized in Table 4.

Table 4 - HELP Modelling Results for Selected Cover System Designs.

Parameter (mm/yr)	Landfill Criteria / OC Requirements	Low Slope Barrier Layer - Minimum Slope 1.5%	Low Slope Barrier Layer - Minimum Slope 2.5%
Precipitation	416	416	416
Runoff	50	16	16
Evapotranspiration	279	348	350
Percolation	86	57	55

Based on CH2M HILL's HELP modelling, the lower slope solutions are expected to perform better than the standard MoE cover at this site with respect to "percolation", which is the water that seeps from the cover system to the waste below, and would therefore contribute to leachate production. Furthermore, the performance (with respect to percolation / leachate production) of the lower slope (1.5%) alternative based on the HELP modelling is almost identical to that of the higher slope (2.5%) alternative. Thus, the alternate cover systems considered by CH2M HILL (2011) would meet or exceed the performance of a cover based on Landfill Criteria guidelines.

The results above are based on HELP modelling, which assumes a conventional cover design with a barrier layer. Based on the documentation for the HELP model (Schroeder, Aziz, Lloyd and Zappi, 1994), evapotranspiration is considered and estimated in the model, but only the layers above the barrier layer are considered to be able to store and release water to the environment. At Westside Landfill, there is currently a layer of material over much of the landfill that was considered as the "barrier layer" in the HELP model runs and therefore its water holding capacity was ignored. The water holding capacity of the material considered to be a "barrier layer" in the HELP modelling was taken into account in the design and evaluation of an ET cover system.

As discussed in Section 2.1 filling ceased at Westside Landfill before the design capacity was reached, leaving a portion of the landfill with slopes at a grade somewhat less than the 4% minimum recommended in *Landfill Criteria for Municipal Solid Waste* (British Columbia Ministry of Environment, 1993). Analyses completed in *Westside Landfill Closure Plan, Final Report* CH2M HILL (2011) suggested that cover systems with lower grades could provide performance as good as that of the standard cover system recommended in *Landfill Criteria for Municipal Solid Waste*, with some modifications to the standard design. Further consideration of cover system options suggested that an evapotranspiration cover system with grades lower than 4% could be expected to perform satisfactorily at this site (Golder, 2012). The Ministry of Environment (MoE) considered the proposal to have an evapotranspiration cover system at grades lower than 4%, and then approved the approach in principle. In discussions with Golder and the RDCO, the MoE indicated that 2.5% would be the minimum acceptable grade.

Golder has produced a grading plan where the maximum slopes are 33.3% and the minimum are 2.5%. There is one portion of the western slope of the landfill where grades are currently steeper than 33% and as already discussed, a portion of the upper surface where slopes are less than 2.5%.

3.3.2 Grading and Slope Stabilization

As discussed in Section 3.2, if an ET cover is used at Westside Landfill, having slopes shallower than the 4% minimum specified in the LCMSW is not likely to be significant with respect to performance of the cover system in terms of leachate generation (from percolation from the base of the cover system). However, there must not be closed depressions in the surface where snow may accumulate to a greater than average depth (from drifting, in particular) or where water might pond under particularly intense rainfall events, or if there is concrete frost (which reduces the infiltration capacity of the surface soils when present). Thus, there is a general requirement that final surfaces should not contain closed depressions of significant extent (more than a few metres in extent).

As well, the surface should be graded in such a way that there are no areas that would tend to result in significant concentration of any surface water runoff that may occur. In short, there should be no "catchments" within the landfill, except those that may be designed to divert surface water from the site, thus it follows that final contours for the landfill will be convex outward or linear in plan view; such that any surface runoff that does occur is not concentrated.

The exact grading does not need to be specified fully in advance, but it should satisfy the following criteria:

- Slopes should have a positive slope of at least 2.5% and less than 33%;
- There should be no closed contours (that is, no closed depressions);
- Contours should all be planer or convex when viewed in plan; and,
- In Figure 7, areas where additional grading, slope stabilization and additional fill placement may be required are identified. These areas are discussed in greater detail in the subsections that follow.

LEGEND

- LANDFILL BOUNDARY
- AREA BOUNDARIES
- APPROXIMATE FOOTPRINT OF SURFACE WATER DETENTION / SEDIMENT
- 2013 MAJOR TOPOGRAPHIC CONTOUR (INTERVAL = 5 m)
- 2013 MINOR TOPOGRAPHIC CONTOUR (INTERVAL = 1 m)
- PROPOSED MAJOR TOPOGRAPHIC CONTOURS
- PROPOSED MINOR TOPOGRAPHIC CONTOURS (INTERVAL = 0.5 m)

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.
EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

0 50 100
1:2,500 METRES

CLIENT REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)			PROJECT LANDFILL CLOSURE PLAN WESTSIDE LANDFILL WEST KELOWNA, B.C.
CONSULTANT Golder Associates	YYYY-MM-DD	2015-05-11	TITLE GRADING PLAN
	DESIGNED	J. FARAH	
	PREPARED	G. BARRETT	
	REVIEWED	G. BARRETT	
	APPROVED	R. PELESHYTYK	PROJECT NO. 1406505 · PHASE 5000 · REV. 0 · FIGURE 7

3.3.2.1 Area A

A plan showing the proposed final surface contours using the 2.5% grade is provided in Figure 7. The final grade contours are superimposed over the existing contours. The plan shows the grading slope direction, which is generally to the southeast. The grading plan is designed, in part, to divert most surface runoff that may form away from a depression to the northwest where groundwater seepage and ponding exists. The grading plan takes advantage of the thicker cover at the southwest corner to help reduce the additional filling volume and still maintain a 2.5% grade. The plan requires the import of about 8,000 cubic metres (m^3) of clean fill suitable for use in the cover system to achieve a thickness (before amendments to improve the soil properties for establishment of vegetation) in the range of 0.9 to 1.0 metres (m) and achieve a minimum slope of 2.5%. A compost pile is located on the site, but this material is provisionally designated for use as a soil amendment rather than as general fill, and thus was not factored into this volume estimation. As a result of placing material from the compost pile, the final surface in the area to be graded will be slightly greater in elevation than shown in Figure 7.

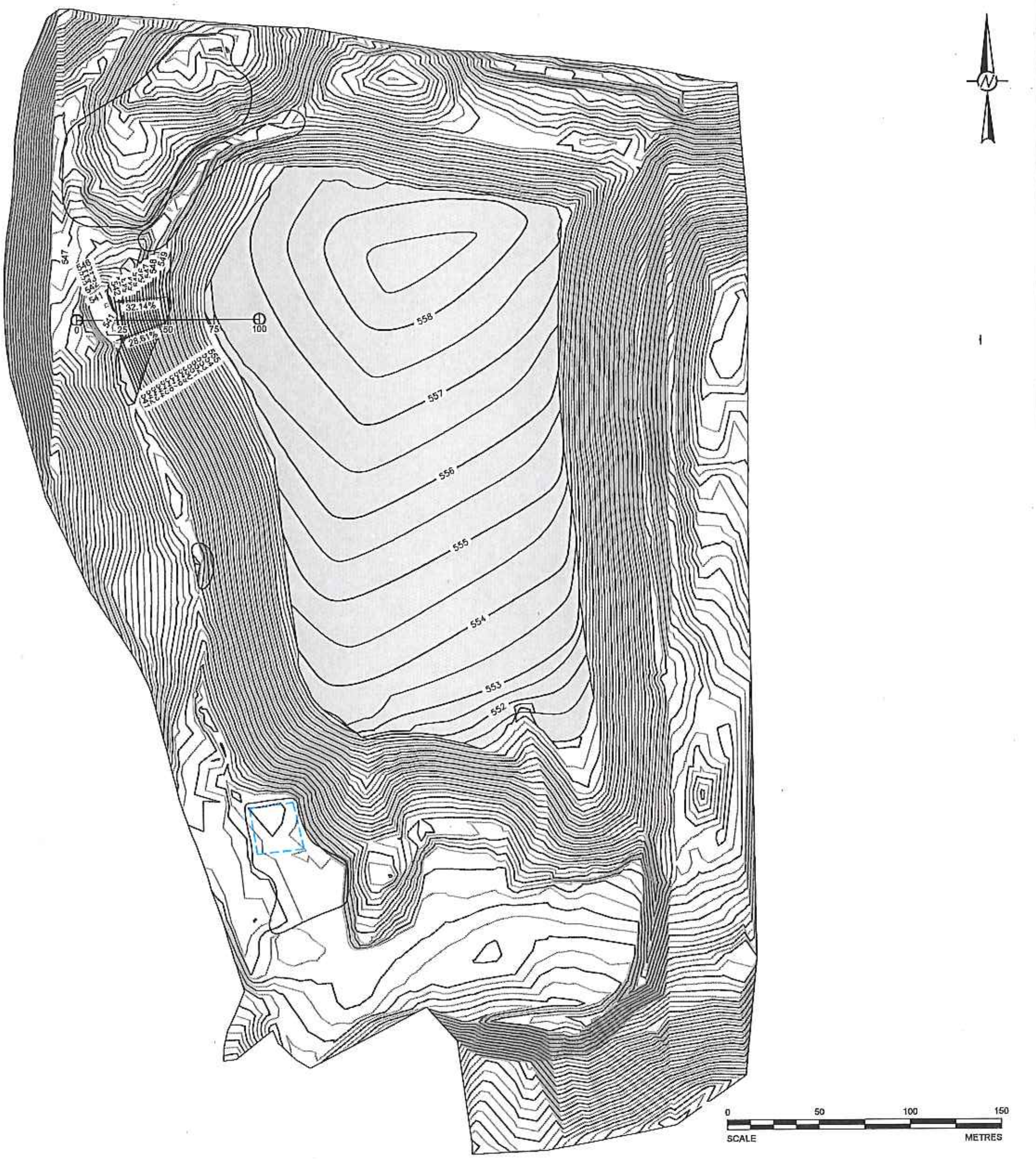
In 2014, much of the additional fill required for regrading Area A was imported to site and stockpiled on the northern portion of Area A. Golder envisions that filling in Area A will begin with completion of the central mound (highest elevation portion of the site) to the final 558.7 m crest height. Once the northern "mound" is completed, filling would continue to the south until final grades are achieved. Golder recommends that "grade stakes" be placed on a 10 m grid by a surveying firm using the 3D model developed by Golder as a guide. This would be used to guide cutting, filling and final grading.

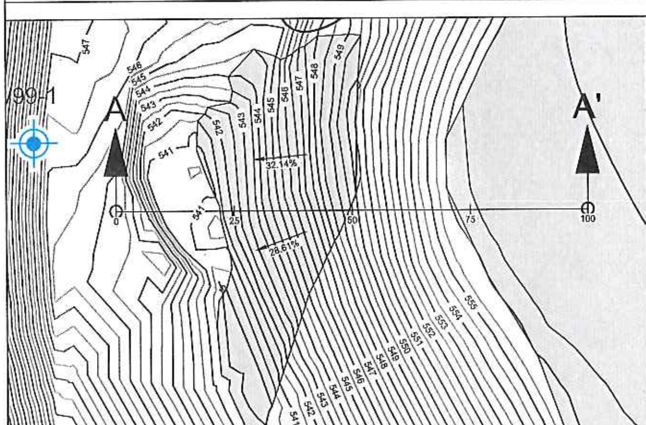
Some portions of the landfill, particularly to the southwest, have more cover than is necessary and can be cut and pushed to the east to increase the cover thickness in areas that where it is not yet at the design thickness. Again, the grade stakes would be used as guides to redistribute this material.

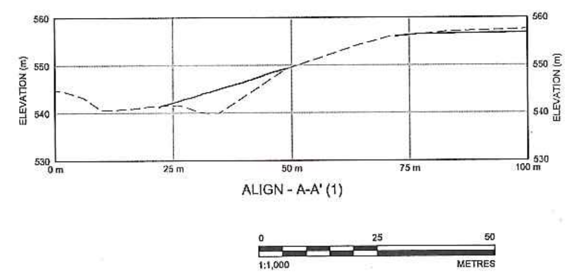
3.3.2.2 Area B

The slopes in Area B are steeper than the 33.3% maximum final grade and need to be "flattened". Cutting back the top portion of the slope would involve moving waste material and depositing such material elsewhere on the site, which is not the preferred approach for a variety of reasons, including cost. The preferred option is to add material to the lower portion of the slope. However, there is a closed depression near the base of the landfill slope in Area B that currently has water ponded in it. This closed depression appears to have been formed by excavation of soil for use as cover. Prior to excavation of this material, there were some seeps and ephemeral ponding to the north.

As shown in Figure 8, it is proposed that the slope in Area B be regraded to a shallower slope and that the depression that was formed at the base of the slope be filled. It proposed that clean fill be used. The upper 0.9 to 1.0 metre of the fill would need to meet the cover material specifications, and additional soil amendment would be undertaken such that this area meets the specifications for the cover as outlined for Area A (see Section 3.3.2.1).







LEGEND

- ORIGINAL GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 1 m)
- ORIGINAL GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 0.5 m)
- PROPOSED GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 1 m)
- PROPOSED GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 0.5 m)

PROFILE LEGEND

- EXISTING GROUND
- PROPOSED GROUND

REFERENCE

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY, 2013.

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE
STEEP AREA REGRADING PLAN

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	8

3.3.2.3 Area C

Area C is located on the west side of the landfill and, based on existing mapping, appeared to have over-steepened slopes. Given the resolution of the current mapping, it was unclear if the apparent over-steepening was real or not. Golder undertook further inspection of the area to confirm the extent of over-steepened slopes in May of 2015. It appears that Area C is relatively well vegetated and does not show signs of instability. Slope stabilization works do not appear to be necessary.

3.3.2.4 Areas D and E

The extent of Area D in Figure 3 is schematic, but represents a portion of the site where some reworking of the landfill is required. In some locations, refuse will need to be "pulled back" from the area where Area D is adjacent to Area E, and then final cover placed in those areas. Area E is an area outside the area of waste disposal where there is little to no cover material above bedrock. The bedrock in Area E slopes generally toward Area D, and is divided from it by a topographic low. In the event of rain or snowmelt, surface water from Area E would be expected to drain toward the divide between it and Area D. Runoff from rainstorms and/or snowmelt would be rarer from Area D than from Area E, but would not be impossible. After landfill cover is complete in Area D, any surface water runoff would be expected to be clean.

The main issue with surface runoff from Area E, and to a lesser extent from Area D, would be that after collecting in the divide between Area D and Area E, some water could infiltrate into waste in Area D and contribute to leachate generation. Thus, we envision a lined drainage channel in this area that would convey surface storm runoff to the south and tie into the overall surface water drainage system to be constructed on the west side of the landfill (see Section 3.4).

3.3.2.5 Area F

Area F is an area where a surface water detention, sediment collection pond could be located, if required. As will be discussed in Section 3.4.2, it does not appear that such a system will be required, but the option is available if further observation and/or analysis suggests that it is required.

3.4 Surface Water Management

CH2M HILL provided a conceptual plan for surface water drainage works, with some sizing information, in their Closure Report (CH2M HILL, 2012). For the purpose of sizing, CH2M HILL divided the landfill site into three catchments: 1) a "north catchment" estimated to be 2.0 hectares in extent; 2) a "southeast catchment" estimated to be approximately 5.1 hectares in extent; and 3) a "southwest" catchment (mostly to the west) estimated to be approximately 15 hectares in extent, including 3 hectares on site and an additional 12 hectares upslope from the site.

CH2M HILL's assessment, however, assumed that a cover system with a barrier layer would comprise the final cover. An evapotranspiration cover does not include a barrier layer and is designed to have a significant water holding capacity, and thus is not expected to have the same runoff generating characteristics. As well, there has been development to the west, including road development and storm sewer installation that limits the potential for surface water run-on.

In the following subsections, the assessments of the three catchment areas identified by CH2M HILL are revisited in light of the changes in cover design and local conditions.

3.4.1 North and Southeast Catchments

In CH2M HILL's Closure Plan, the "north catchment" and the "southeast catchment" would include a surface water collection system that includes a "dry" pond on the north side (essentially an existing closed depression). This pond would connect to a ditch system that leads to the east face of the landfill, run along the east face and then along a portion of the south side to a retention/infiltration pond. Golder notes that this plan was developed prior to the development of the evapotranspiration cover system, which does not include a low permeability barrier layer and thus may not promote surface water runoff to the same extent as a conventional cover. There were no signs of surface water erosion observed during a site inspection completed in May of 2015. The eastern side slopes are currently well vegetated in most areas, which helps limit surface erosion. As well, the current topography is such that in the event of an extreme rainfall, snowmelt or combined rainfall and snowmelt event, significant concentration of flow is not expected, although there could be rill or gully formation on the side slopes.

It is anticipated that after completion of landfill closure, the main risk from extreme storm events is localized erosion of the cover system. The cost of installing and maintaining surface water works on the north and east sides of the landfill should be weighed against the cost of repairing the side slopes after an extreme event. It should be noted that an evapotranspiration cover system is generally easier to repair than a barrier layer cover system, and thus the cost of repairs are limited.

Golder also notes that since the surface water drainage system recommended in the Closure Plan is located on a side slope, in some locations well above the foot of the slope, failure of the surface drainage system due to inadequate maintenance or some other issue could result in greater localized flows. These could occur because water from a much larger catchment would be discharging than would be the case if locally generated surface water flowed down the side slopes. Such failures could be more significant than natural surface runoff.

Taking the points outlined above into consideration, Golder recommends that surface water drainage works not be installed on the northeast and east sides of the landfill. Repairs would be completed as required if there were damage to the cover from surface water erosion.

3.4.2 Southwest Side Catchment

Observations made during a site visit in May of 2014 indicate that a storm sewer system has been put in place along Asquith Road to the west of the site, which is inferred to considerably reduce the area of catchment to the west of the site from that assumed by CH2M HILL (2011). Based on additional observations made during the May 2014 site visit, it is anticipated that if there were run-on, it would collect along the west side of the landfill. If there were discharge from the area, it would be expected to be towards Area F (see Figure 7). Given the much reduced catchment area from that assumed by CH2M HILL, and the greater water holding capacity expected for an evapotranspiration cover system as compared with a barrier system, it expected that surface water discharge will be much less than estimated by CH2M HILL under similar conditions. Golder recommends not disturbing the vegetation that currently exists any more than necessary for closure works and that surface water works not be installed on the west side of the landfill.

As previously discussed, Area E (Figure 7) has little surface soil and hence has limited water holding capacity. As a consequence there is expected to be greater generation of surface water runoff during rainfall and snowmelt events than areas with thicker soils and more vegetation. Runoff from this area would flow towards a natural divide between Area E and Area D. At present a portion of this runoff could seep into the landfill itself, and thus the runoff must be intercepted. While further detailed design is required, construction of a lined channel is likely to be the preferred solution. The water would drain to a low area located to the west of the landfill, as illustrated in Figure 9.

As indicated in Figure 9, there are several additional areas on the sides slopes of the landfill where the contours are such that surface water flow (as might be generated from "heavy" rainfall and/or snowmelt) would tend to be concentrated and thus potentially subject to more erosion by the surface water than would otherwise be the case. If filling were continuing on site, then placing additional fill in these areas would be the preferred solution, however, at this point fill would need to be imported specifically for this purpose. Given the anticipated high cost of adding such fill, Golder suggests that these areas be inspected regularly for signs of erosion and if there appear to be erosion issues, then various approaches to erosion control could be considered. In Figure 9, the main access road to the upper portions of the site is also highlighted. Since filling and other closure activities will be required for a number of years, Golder recommends that the access road be inspected annually and issues corrected on an as-required basis. The road will likely remain commissioned for some time after closure works are completed to allow access for site repairs.

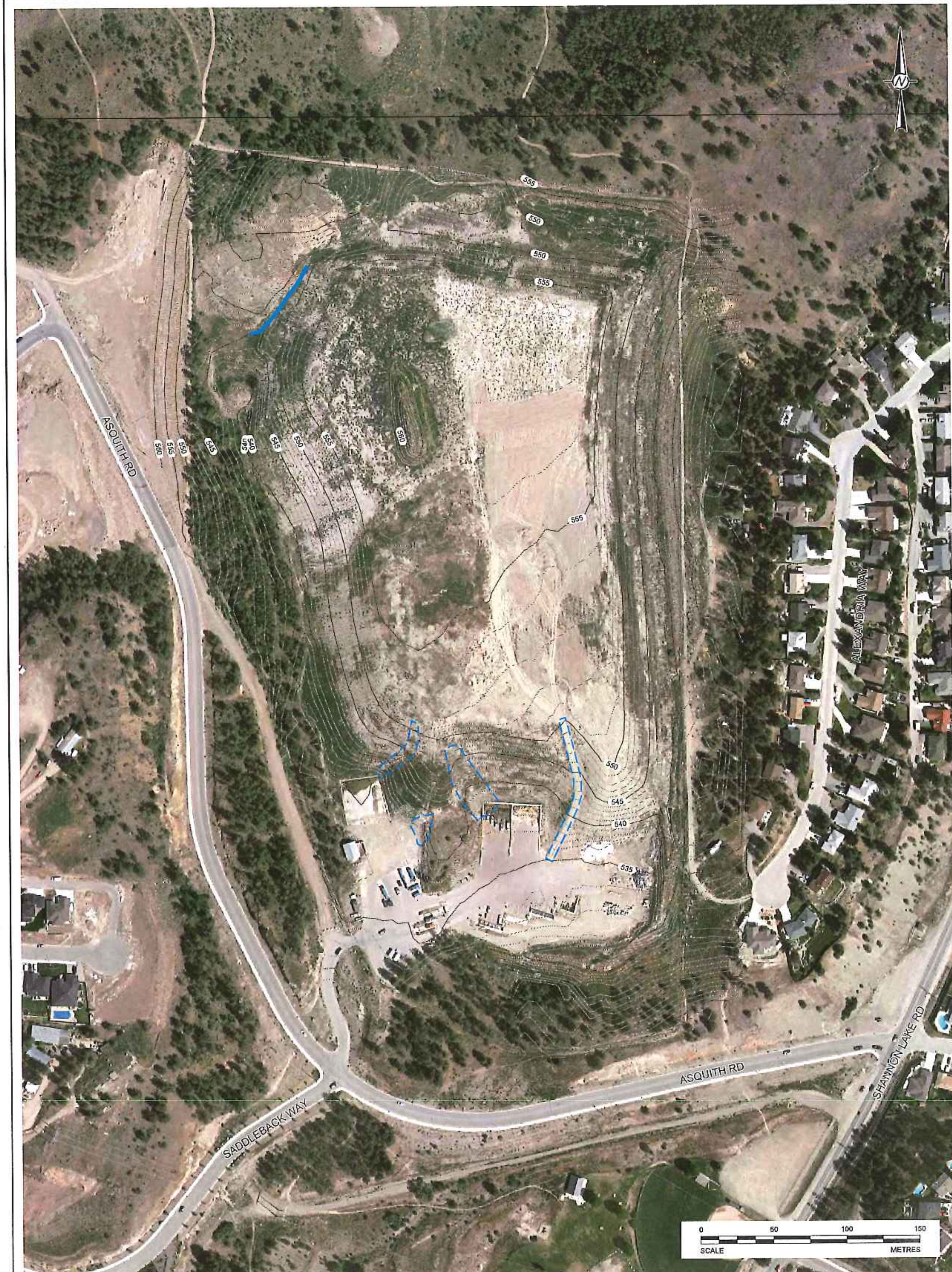
3.5 Landfill Gas Management

There are two aspects to Landfill Gas Management: (1) overall emission of landfill gas, particularly methane, but also non-methane organic compounds (NMOCs); and (2) possible migration of landfill gas, particularly methane, off-site in concentrations that are not acceptable to the MoE based primarily on their potential hazard to human health.

A preliminary assessment of the emission of methane, which is a greenhouse gas, was completed by CH2M HILL (2010) as required under the MoE's Landfill Gas Management Act (December 8, 2008), hereafter referred to as the LGMA. As specified in the LGMA, a reassessment by a qualified professional was required by March 31, 2015. This assessment was completed by Golder (2015) and is included as Appendix B (which also includes the preliminary assessment by CH2M HILL). As discussed by Golder (2015) in the follow-up assessment, there was no new filling beyond that included in the initial assessment by CH2H HILL (2010), which indicated that methane emissions were likely below 1000 tonnes per year. Additional assessment of landfill gas monitoring results in the follow-up assessment by Golder (2015) suggests that methane makes up a much smaller proportion of the landfill gas emitted than assumed in the preliminary assessment, and thus methane emissions are likely lower than previously estimated. The data suggests that aerobic decomposition of waste, which does not produce methane, is likely more dominant than anaerobic decomposition (which does produce methane), at Westside Landfill.

Westside Landfill Closure Plan, Final Report (CH2M HILL, 2011) included plans for a passive landfill gas system to be installed that could be converted to an active system, if required. It was envisioned that the landfill gas control system would be installed to vent a cover system that included a barrier layer. The evapotranspiration cover system that is now planned for the site would not pose the same limitations to venting, although it is possible that seasonally, venting through the cover may be limited due to saturation or near-saturation of surface soils, possibly promoting lateral migration of landfill gas.

Path: \\golder.gds\gal\Victoria\CAD-GIS\Client\RDCO\WESTSIDE LANDFILL\03_PROJECTS\1406505_Westside_Landfill_Closure_Plan\02_PRODUCTION\Phase_5000\ | File Name: 1406505-5000-09.dwg



LEGEND

- ORIGINAL GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 1 m)
- ORIGINAL GROUND TOPOGRAPHIC CONTOUR (INTERVAL = 0.5 m)
- APPROXIMATE LOCATION OF SURFACE WATER CONTROL WORKS
- AREAS WHERE ADDITIONAL SURFACE WATER CONTROL WORKS MAY BE REQUIRED

REFERENCE(S)
2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.
EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE
SURFACE WATER CONTROLS

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	9

25 mm
IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

Golder developed a preliminary LGMP that took into account the potential impact of the change of cover system to an evapotranspiration cover and the results of landfill gas monitoring that was presented to the MoE for discussion. Golder completed a LGMP that incorporated updated procedures developed in consultation with the MoE and RDCO in *LGMP, Westside Landfill (Golder, 2013),* hereafter referred to as the 2013 LGMP, a copy of which is included in Appendix D. The 2013 LGMP included recommendations for landfill gas monitoring. Based on assessment of continued monitoring to the end of 2014, some modifications to the landfill gas monitoring program are proposed in Section 4.1.

One of the purposes of ongoing monitoring of landfill gas is to identify areas where off-site migration of landfill gas could pose a potential hazard. In addition to the monitoring results, Golder recommended to the RDCO that a three-dimensional (3D) computer model of the site be developed using existing information from borehole logs (which show the type of material encountered with depth during drilling) with groundwater elevation data, surface topography and topography from older maps. It was found during a preliminary attempt to develop this model that location data for many of the boreholes (which are now the site of groundwater wells and vapour monitors) were not sufficiently accurate for this exercise, which led Golder to further recommend that the borehole (monitor) locations be resurveyed. This survey work was completed in 2015, and a preliminary 3D computer model has been developed. This model is being used in conjunction with monitoring results to assess the current monitoring network and to identify locations where additional investigation or controls may be required.

A plan for investigating specific locations is in preparation and will be completed in the spring of 2015. The results of the investigation will be used to assess the need for additional monitors and/or additional investigation.

3.6 End Use

The proposed end use identified in CH2M HILL's (2011) Closure Plan is natural open space, with grassland vegetation similar to that which would exist in this area naturally, to serve as a community or regional park, possibly with a network of "gravel walking trails". An ET cover system is consistent with this end use and since it does not depend on an intact barrier layer for its performance, shrub and tree growth should not compromise the performance of the system.

4.0 MONITORING, INSPECTION AND REPORTING

Monitoring at site currently includes the sampling and analysis of groundwater for selected parameters, determination of groundwater levels and landfill gas monitoring. The results are reported annually, and recommendations for changes to the program may be made to MoE from time to time, as continuing assessment of the results suggests. Golder is recommending some changes to the groundwater and landfill gas monitoring programs, and recommends annual site inspections by a qualified professional after closure, to be re-evaluated annually.

In Sections 4.1 and 4.2, the monitoring programs for groundwater and landfill gas are reviewed, respectively, and recommendations for changes are provided. In Section 4.3, recommendations for post-closure site inspections are provided and in Section 4.4, post-closure reporting requirements are proposed.

4.1 Groundwater Monitoring

Groundwater monitoring is currently conducted quarterly at six "down-gradient" locations: BH-1, BH-2, BH-3, BH-4, BH-5, and BH-7 (see Figure 10). Water samples are tested for a defined set of parameters. Water level measurements are also recorded for these six wells, and sometimes for other monitors that are no longer sampled. The results of analyses to 2005 for a residential well that no longer exists, generally referred to as "Dobbin's Well", was located on the "upgradient" side of the landfill, were used to represent possible background groundwater conditions. At present there are no "background" monitors being sampled, but a proposed replacement is discussed in Section 4.1.1.

In the following subsections, Golder proposes some changes to the groundwater monitoring program with respect to monitoring background conditions, the frequency of sampling and analysis and the frequency of groundwater level measurements.

4.1.1 Background Monitoring

Dobbin's Well was formerly used as a background well, but it no longer exists. According to information from the Ministry of Environment's Water Well Database, Dobbin's was completed to a depth of 180 feet, or just less than 55 m. This is considerably deeper than the currently active groundwater monitors, which range from less than 1 m in depth to just over 17 m in depth. It is quite likely that Dobbin's Well is associated with the deeper bedrock aquifer (Aquifer Number 0305) discussed in Section 2.3.5, while the other monitors are expected to be associated with shallower groundwater flow systems. Thus, even though Dobbin's Well may have been upgradient of the site, it was not necessarily representative of the near surface groundwater quality upgradient from the landfill.

The MW99 series of wells are relatively close to the landfill, and vary between 6 and 7 metres in depth. These wells were not previously considered as candidates for use as background wells since there may be "mounding" of the water table underneath landfills, resulting in near surface flows opposite to the general groundwater gradient. However, given the semi-arid climate and the evapotranspiration cover that will be put in place, it is expected that there will be little recharge from the landfill, and thus little or no mounding. Golder recommends adding MW99-2 to the sampling program as a potential new background well. The suitability of MW99-2 for this purpose would be evaluated after collection of at least one year of data.

0 50 100
1:3,000 METRES

LEGEND

- LANDFILL BOUNDARY
- MONITORING WELL LOCATION
- SOIL VAPOUR WELL LOCATION
- WELL LOCATION

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE
GROUNDWATER AND SOIL VAPOUR MONITOR LOCATIONS

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	10

4.1.2 Monitoring Frequency

Groundwater sampling currently takes place on a quarterly basis. Since the landfill no longer receives waste, has interim cover in place, and construction of a final cover system is underway, the risk that something will be introduced into the landfill that results in a sudden change in leachate generation and thus produce a "spike" in values is expected to be lower than it might be when the landfill was actively in operation. However, it is still necessary to assess trends over time. The key issue is whether such trends can reasonably be assessed with less than quarterly monitoring.

Golder has completed a limited analysis of historical data for selected parameters for the monitors currently included in the monitoring program. As discussed in the *2013 Annual Operations and Monitoring Report* (Golder Associates Ltd. 2014), chloride, ammonia, nitrate, iron and manganese are considered as key indicators of "possible" impacts on groundwater quality. They are described as indicators of "possible" impacts since there are factors other than leachate that can influence the concentration of each one of these. Perusal of the results to date that for most of the key indicators suggested that where there are temporal trends, the variation within years appears, qualitatively at least, to be limited relative to the longer term trends.

Golder recommends that the MoE consider a phased reduction in groundwater monitoring. The first phase would involve moving to two rounds per year until the current landfill works are completed. At some point after closure works are completed, the matter would be revisited to consider reducing to annual monitoring, assuming the results support such a change, and continuing until such time as the results warrant considering removing groundwater monitoring requirements.

If the monitoring frequency is reduced to twice per year, Golder suggests that the rounds be spaced approximately six months apart, with sampling either in Q1 and Q3, or in Q2 and Q4. Golder reviewed historical data to determine if one of these possibilities should be preferred to the other. To gain more insight into this issue, the correlation between the readings in a given quarter and the average of the results for the other three quarters was estimated for selected parameters for results from each of BH-1, BH-2, BH-4, and BH-5. There were too few results for BH-2 and BH-7 to include them in this analysis. The parameters used for this analysis were chloride and manganese, two of the key parameters discussed in detail in the *2013 Annual Operations and Monitoring Report*. The other key parameters – ammonia, nitrate and iron – were excluded since for some monitors at least there were a significant number of results below the detection limit, which compromises the estimation of a correlation coefficient. Only years with results from all four quarters were included in the analysis (four to six years of data, depending on the monitor). The results are summarized in Table 5, below.

Table 5: Correlation of Average in Quarter to Average for Remaining Quarters for Selected Parameters

Period	Q1	Q2	Q3	Q4
Chloride				
BH-1	0.49	0.28	0.13	0.46
BH-2	0.88	0.98	0.93	0.95
BH-4	0.53	0.86	0.78	0.16
BH-5	0.92	0.98	0.97	0.81
Top Ranked	1	3	0	0
Average	0.70	0.77	0.70	0.59
Manganese				
BH-1	0.94	0.88	0.96	0.83
BH-2	0.36	0.74	0.21	-0.58
BH-4	0.25	0.91	0.37	0.88
BH-5	-0.38	0.57	1.00	-0.47
Top Ranked	0	2	2	0
Average	0.29	0.78	0.63	0.17

As summarized in Table 5, the results from Q2 show the highest correlation with the average for the remaining three quarters. The data analyzed is limited, and therefore the results are not definitive, but the results suggest that Q2 would be the best time to sample if monitoring eventually reduces to annual sampling. On this basis, it is recommended that Q2 be one of the quarters in which sampling takes place if the frequency is reduced to twice per year, which implies sampling in Q2 and Q4. Thus, for a phased reduction the sequence would be sampling and analysis in Q2 and Q4, followed by sampling in Q2 only at some point after closure works are completed, if continuing results suggest that is reasonable.

In Figures 11 through 15, the time series for the annual average value of chloride, ammonia, nitrate, iron and manganese are shown along with the time series for the average of Q2 and Q4 values. For some years, there is not data for all four quarters, or not all four sets collected in the year are in separate quarters (for example, there may be two rounds within a quarter if there are delays due to weather or other issues). Hence, Figures 9 through 13 do not perfectly represent how well the average for Q2 and Q4 tracks the annual average, but the results suggest that long term trends in these parameters would be captured reasonably well by a monitoring program that consists of two rounds per year, in Q2 and Q4 of each year.

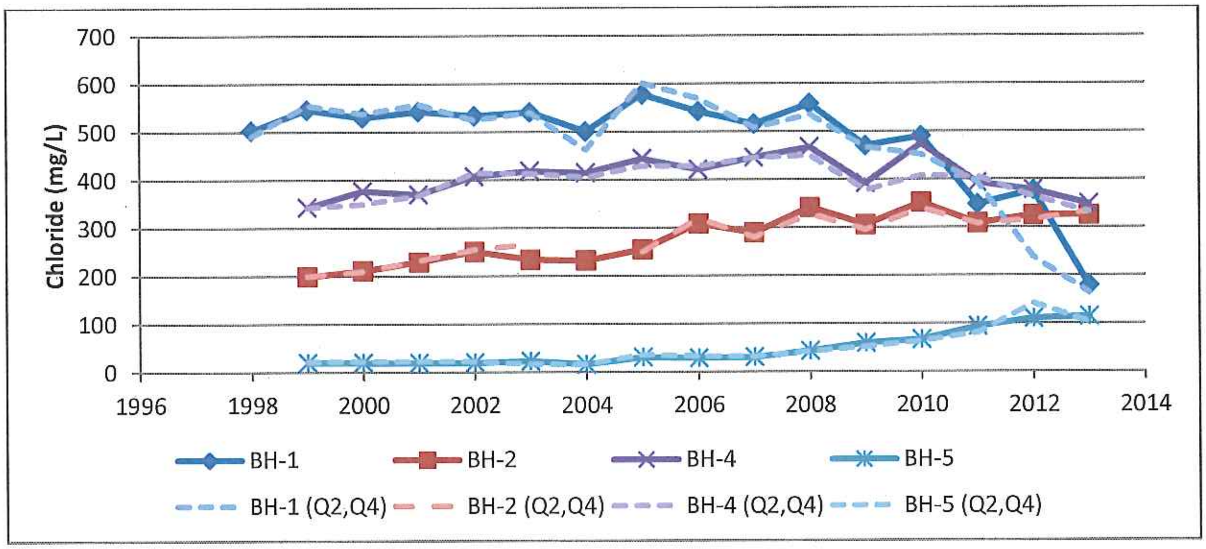


Figure 11: Chloride - Average Concentration based on Annual and Q2 plus Q4 results

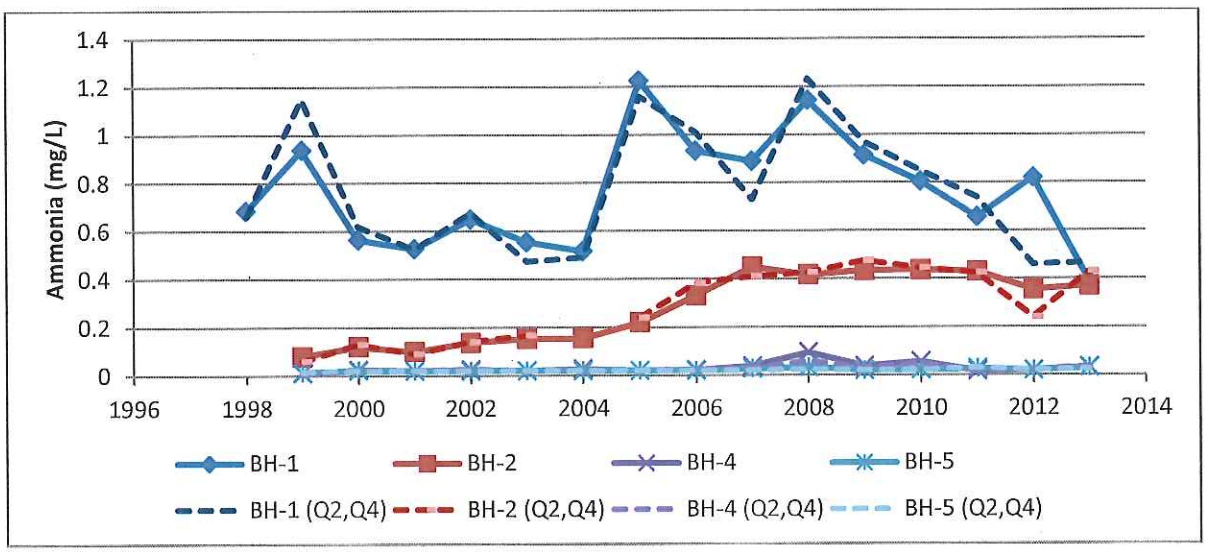


Figure 12: Ammonia - Average Concentration based on Annual and Q2 plus Q4 results

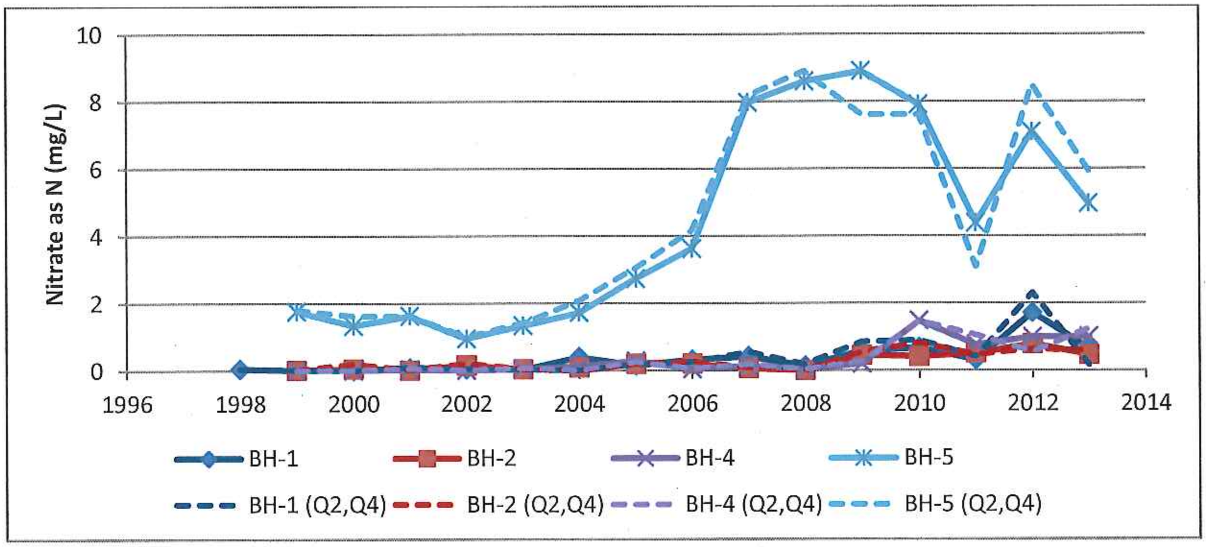


Figure 13: Nitrate as N - Average Concentration based on Annual and Q2 plus Q4 results

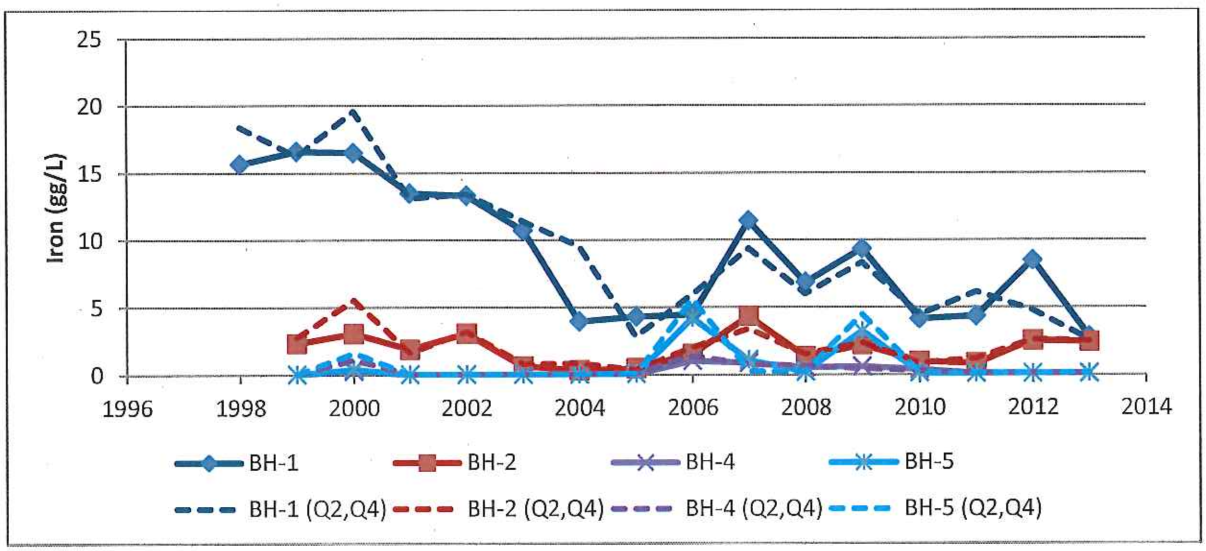


Figure 14: Iron - Average Concentration based on Annual and Q2 plus Q4 results

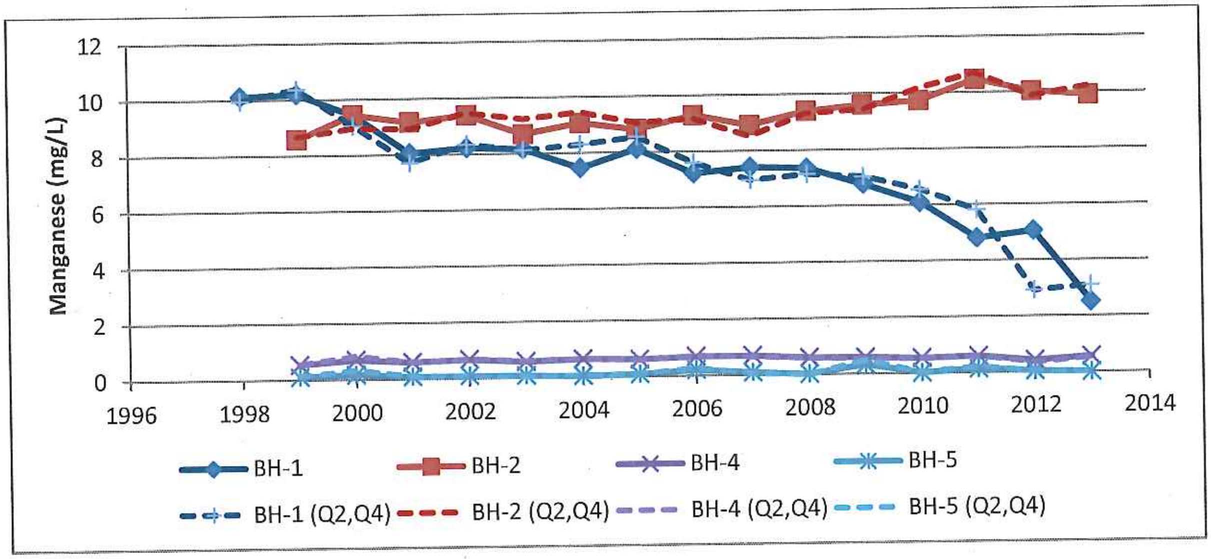


Figure 15: Manganese - Average Concentration based on Annual and Q2 plus Q4 results

4.1.3 Water Level Measurements

Water level measurements are currently taken at the monitors that are part of the current sampling and analysis program (BH-1, BH-2, BH-3, BH-4, BH-5 and BH-6) and from some monitors (MW99-2, MW99-3 and MW99-4) that were formerly sampled (Figure 10). Golder suggests that monitoring water levels in the MW99 series wells be continued in 2015 and then re-evaluated. The water levels would be determined at the same time as the proposed sampling rounds.

4.1.4 Parameters

Golder recommends that the current parameter list be retained, with minor revisions. There are a suite of parameters included in the "metals scans" typically offered by analytical laboratories. Not all of the parameters in these suites are necessarily pertinent at a particular site, and the parameters included in those suites may not all be identical. Based on review of historical results to the end of 2013, it appears that antimony, beryllium, tellurium and tungsten have not been identified at levels above the detection limit of the associated analytical procedure. Given that there is no reason to suspect that any of these parameters should be elevated in leachate from Westside Landfill and that there is no evidence that they ever have been, Golder recommends that it be recognized that these parameters do not need to be part of any "metals suite" chosen for analysis of groundwater samples at Westside Landfill.

Golder further recommends that the parameter list be reviewed by a qualified professional annually, with recommendations for modifications to be included in the annual report (see Section 4.4).

4.2 Landfill Gas Monitoring

4.2.1 General

Regular monitoring of landfill gas has been in place since 2000. Additional monitors have been added in several rounds of installation since 2000. The currently active network is illustrated in Figure 16, which also shows the location of groundwater monitors.

The landfill gas monitoring program was modified most recently in 2013 to begin implementing the approach outlined in the LGMP (Appendix B), and documented further in the report, *2012 Annual Operations and Monitoring Report, Westside Landfill, West Kelowna, BC* (Golder Associates Ltd. 2013b), hereafter referred to as the 2012 Annual Report. The key changes to the monitoring program were made to bring the landfill gas monitoring program into alignment with the recommendations outlined in the LGMP, as follows:

- The number of rounds of gas monitoring was increased to take place monthly from October to April inclusive, and once in either July or August.
- An "Action Plan" was developed that defined the response if methane readings above set thresholds were measured, with different actions being required depending on the proximity of the monitor to the property boundary. Some actions were to be completed within one week of a methane measurement being recorded, which meant that the process for recording and transmitting the readings to a qualified professional needed to be completed in much less than one week to allow appropriate responses to be implemented.
- Based on continuing assessment of the historical and recent (2013) landfill gas monitoring results, and experience with implementation of most elements of the revised landfill gas monitoring program from May to December, Golder proposes some modifications to the LGMP. These proposed revisions are related to the following:
- Schedule for monitoring rounds, based on review of results from 2013 and earlier;
- Criteria for classification of monitors;
- The Action Plan; and,
- The approach to data collection, review and reporting.

These proposed revisions are discussed in Sections 4.2.2 through to Section 4.2.5 of this report.

4.2.2 Proposed Changes in Landfill Gas Monitoring Schedule

The landfill gas monitoring schedule proposed in the LGMP was based in part on recommendations initially made in the *Westside Landfill Closure Plan, Final Report* (CH2M HILL Canada Ltd. 2011). The Closure Plan suggested quarterly monitoring, increased to monthly during the "winter" months. Climate data were reviewed in the LGMP, and winter was provisionally defined as the period from October to April, based mainly on monthly snowfall and data during "days <= 0C". An additional round of sampling would then take place in July or August. An assessment of historical methane measurements to the end of 2013 suggested that the proposed monitoring program would have "captured" the historical exceedances of the proposed action levels, although the number of data points was very limited for some months of year, and therefore the results were considered to be preliminary.

In consultation with the British Columbia Ministry of Environment (MoE), action levels were developed that varied by the location of the monitor with respect to the property boundary. As discussed further in Section 4.2.3, the monitors were classified as being "inside boundary", "near boundary" or "outside boundary" for the purpose of defining action levels. The locations of the landfill gas monitors and their original classification are illustrated in Figure 16. In the case of "near boundary" monitors and "outside boundary" monitors, actions were specified for methane levels that equalled or exceeded 10% LEL (lower explosive limit). For the "inside boundary" monitors the action level was 25% LEL.

Since completion of the LGMP, historical methane levels have been compiled and analyzed for results from 2000 to 2013. The data were compiled primarily from tables used in annual reports up to 2012, and after that directly from data collected in 2013. The data set may not include some methane results recorded for programs other than the monitoring program, and is not identical to the data set used for the preliminary assessment of results reported in the LGMP; however, it does represent the largest set of landfill gas data yet analyzed for Westside Landfill.

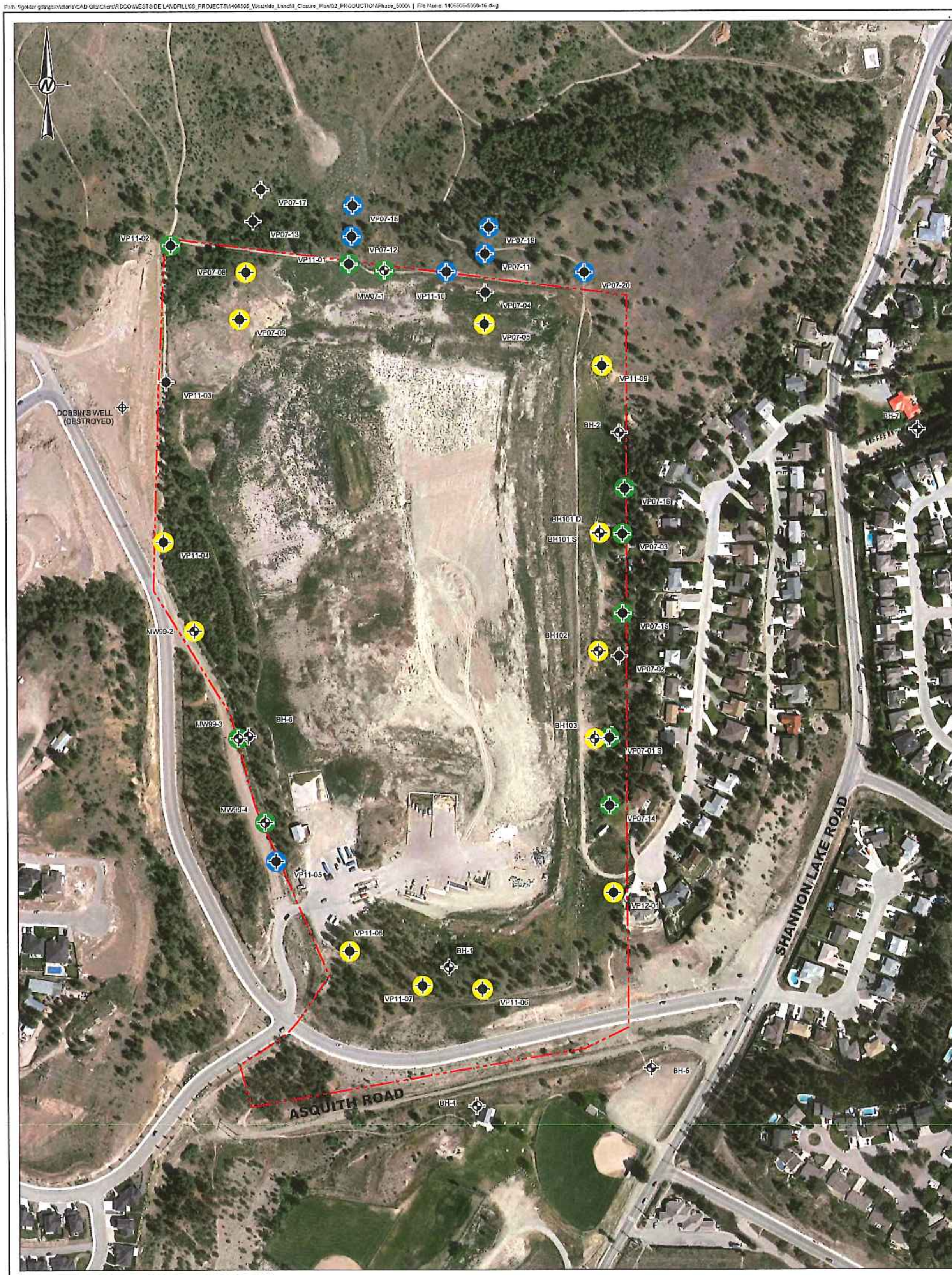
The percentage of methane readings that exceeded the 10% LEL action limit (the lowest limit that applies) is shown in Table 6 by month, along with the total number of measurements made in each month, and grouped by the side of the landfill that the measurements were associated with. To date, the only exceedances of the 10% LEL action limit have been on either the east or north side of the landfill, with most being associated with monitors on the east side. The cells' shading varies with the % LEL to make patterns easier to visualize.

Table 6: Summary of the Percentage of Methane Readings that Exceed the 10% LEL Action Limit (for all data to the end of 2013)

	Fall			**Winter**			**Spring**			**Summer**		
Side	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**
East	0%	0%	9%	9%	0%	6%	12%	6%	6%	0%	0%	0%
North	0%	0%	0%	0%	0%	0%	6%	6%	0%	0%	0%	0%
South	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
West	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cover Water Content*	0%	0%	25%	36%	44%	61%	100%	75%	21%	0%	0%	0%
Sample Size	33	65	31	210	42	13	33	32	173	42	32	32

*MC = predicted moisture content, as a percent of the maximum water holding capacity

All of the exceedances of 10% LEL in Table 6 were recorded in the period from November to May, with the highest frequency of readings exceeding 10% LEL being in March.



LEGEND

LANDFILL BOUNDARY

MONITORING WELL LOCATION

SOIL VAPOUR WELL LOCATION

WELL LOCATION

ACTIVE OUTSIDE BOUNDARY MONITORS

ACTIVE NEAR BOUNDARY MONITORS

ACTIVE INNER BOUNDARY MONITORS

0 50 100
1:3,000 METRES

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT
Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE
MONITOR LOCATIONS AND ORIGINAL CLASSIFICATION

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	16

25 mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM ANSI B

Water balance modelling completed for the assessment of cover options (Golder, 2012) suggested that the peak water content would typically be expected in March. While the cover system is not completed, much of the landfill already has cover that is close to that required for final closure and therefore it is anticipated that the water balance for the existing cover will approximate that of the modelled moisture content for much of the landfill. The predicted moisture content for the cover system is included in Table 6 by month, for a "normal" year. Cell shading by value has been used to make variations in moisture content easier to visualize.

As can be seen from the results presented in Table 1, the percentage of values of methane that exceed the 10% LEL level show an apparent correlation with the predicted water content of the cover soils. There is potentially a causal link between water content and methane levels in the subsurface. As the water content of soil increases, the gas permeability will decrease, becoming very low as the water content approaches and reaches saturation (100% water content). Thus, as the water content of surface soils increases, venting through the landfill cover is expected to be impeded; this may account for the apparent correspondence between the expected water content of the cover soil and the frequency that a reading of 10% LEL was exceeded.

As can also be seen from the results in Table 6 methane levels exceeding 10% LEL were only observed on the east and north sides of the landfill. In fact, exceedances of 10% LEL have only been recorded at five of the existing monitors, including BH-1, BH102, BH103, VP07-11 and VP11-09. The methane results for these five monitors are summarized in Table 7. Note that with over 684 measurements of methane in the remaining monitors, no exceedances of a 10% LEL have been recorded. The one exceedance for BH-1 was recorded in 2004, and there were no further exceedances to the end of monitoring in 2013. Two landfill gas monitors, VP11-06 and VP11-07, were established in the immediate vicinity of BH-1 and replace it in the monitoring system. Another monitor, VP11-08, is also located on the south side of the landfill and provides additional coverage of this portion of the landfill (see Figure 16).

Table 7: Summary of Exceedances, by Monitor (for all data to the end of 2013)

Monitor	>10% LEL	>25% LEL	>100% LEL	Total
Number of exceedances of specified % LEL levels				
BH 102	11	7	6	36
BH 103	2	0	0	36
VP07-11	2	1	0	12
BH-1	1	1	1	24
VP11-09	1	0	0	12

No readings from any monitor have exceeded 10%LEL in the period from June to October (Table 6). Golder recommends that a full round be collected in August and that partial rounds be completed in June, July, September and October, on an interim basis. The partial rounds would include the four monitors in the existing program where exceedances have been recorded, including BH102, BH103, VP07-11 and VP11-09. The three monitors closest to BH-1 (VP11-06, VP11-07 and VP11-08) would also be included in the partial rounds. If exceedances of action levels are noted, additional measurements might be required at other monitors, including VP07-1, VP07-2 and VP07-19, following the protocol that will be described in Section 4.2.5.

The proposed change to landfill gas monitoring outlined above would be an interim measure, with further revision likely after the results from 2015 have been assessed and additional work is completed to further assess options for landfill gas migration control.

4.2.3 Proposed Revisions to the Classification of Monitors

In the LGMP, three classes of monitor were defined:

- Inside boundary monitors – these are monitors located more than 5 metres (m) from a property and had an associated action threshold for methane of 25% LEL;
- Near boundary monitors – these are monitors located inside the landfill property, but located 5 m or less from the property boundary and had an associated action threshold for methane of 10% LEL; and,
- Outside boundary monitors – these are monitors located outside the boundary and no specific action thresholds were defined for these monitors, but provisionally the action limit has been set as being the same as that for the near boundary monitors (10% LEL) and the actions are similar.

As can be seen in Figure 16, there are a number of monitors that are fairly close to the property line that were classified as being "inside" and "outside" monitors based on being inside or outside the 5 m limit set in the LGMP. It should be noted that the classification was completed before a resurvey of the site was completed in January of 2015. Golder recommends modifying the definitions of monitors by position such that "inside boundary" monitors are those monitors located within the landfill boundary and more than 15 m inside that property boundary, using locations established in the January 2015 survey. "Near boundary" monitors would comprise those monitors within 15 m of the property boundary, and "outside boundary" monitors would comprise those located more than 15 m outside the property boundary. This change results in lowering the action threshold for some monitors from 25% LEL to 10% LEL. The change does not lead to an increase in the action threshold for any monitor. The proposed change is consistent with provisions of the original Action Plan that indicate that actions should be taken to determine the geographic extent of methane levels that are greater than 10% LEL (as will be discussed further in Section 4.2.5).

In the Action Plan outlined in the LGMP, if a monitor exceeds the associated action level, then a series of actions are triggered that may include assessing the levels in a "step-out" monitor, if one exists, or establishing such a monitor if one does not exist. A "step-out" monitor is a monitor that is located further from the landfill than another monitor on a line extending at right angles (approximately) to the property boundary. There are a number of monitors where associated "step-out" monitors are already in place. Under the existing Action Plan, no additional actions are required if the outermost "step-out" monitor in a set is under the appropriate criteria for that monitor. There are six such sets of monitors; sets A to F, as illustrated in Figure 17. A "step-out" monitor exists for every currently active monitor that has exceeded an associated action level specified in the current LGMP.

As can be seen in Figure 19, there are some "near boundary" and "outside boundary" monitors that have no associated "step-out" monitors. The associated action level for "near boundary" monitors is 10% LEL and this has been held to apply for the "outside boundary" monitors as well. There are several "inside boundary" monitoring wells that do not have associated "step-out" monitors, including VP11-07, VP11-08, VP11-09 and VP12-01. Since these are "inside boundary" monitors, under the current LGMP the action level would be 25% LEL. However, since there are no associated "step-out" monitors, adopting an action level of 10% LEL is recommended for these monitors unless a new "step-out" monitor is installed. Essentially, an overarching "rule" is being applied: if there are no monitors further from the centre of the landfill approximately in line with a given monitor, then the action level for that monitor is 10% LEL, irrespective of position relative to the landfill boundary. If there are associated step-out monitors, then the action level is set at 10% LEL for all near and outside boundary monitors, and at 25% LEL for inside monitors. This rule is illustrated in Figure 19.

As noted, under the proposed new rule the action level for several monitors would change from 25% LEL to 10% LEL, including VP11-09, which is significant since the highest methane level recorded for this monitor in 2013 was equivalent to 20.5% LEL in March of 2013. A reading of 20.5% LEL is under the action level currently outlined in the LGMP for this monitor because it is an "inside boundary" monitor, but would exceed the proposed 10% LEL limit recommended because there is currently no associated "step-out" monitor. Thus, an additional step-out monitor that would be associated with VP11-09 might be required if the proposed modification to the LGMP is adopted and if the 10% LEL is exceeded again. However, it should be noted that since starting implementation of the LGMP in May 2013, the highest methane level recorded at VP11-09 was only 1.1% LEL.

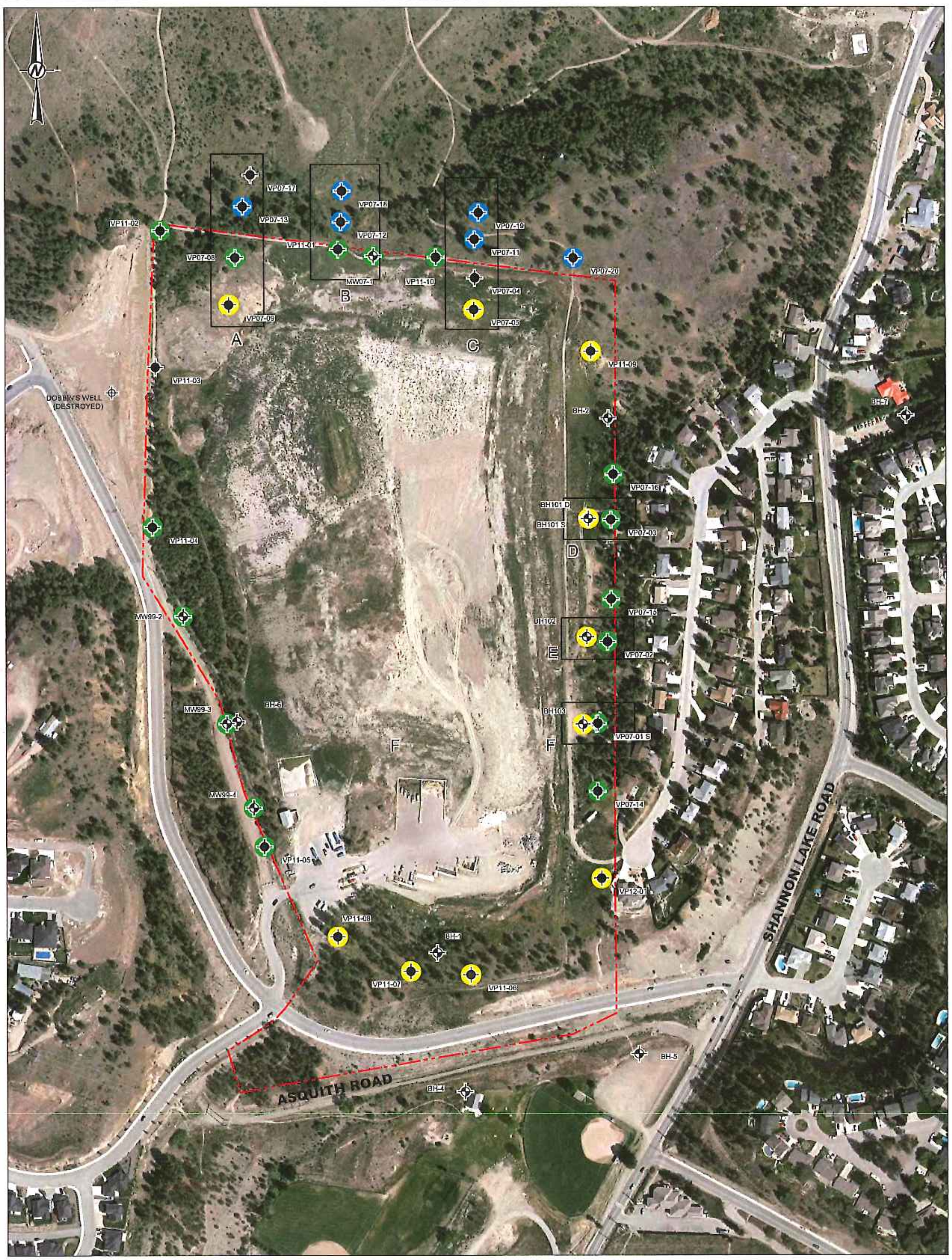
Golder envisions that post-closure monitoring requirements may change significantly after closure works are completed, depending in part on future results and upon the nature of any landfill gas control works implemented. The monitoring program will continue to be evaluated as new information is gathered, and recommendations for modifications, if any, will be part of the annual landfill reports.

4.2.4 Revision to Data Collection Procedure

The methods of data collection were reviewed after completion of the LGMP and modified to allow results to be assessed more quickly. Data is still recorded manually on paper forms, but a digital collection system that can be used on "smartphones" was implemented. Data is recorded in the field and sent from the field to a qualified professional, who can then compare the results against action levels, and then implement the Action Plan, which may involve notification of the MoE and development of a detailed plan by a qualified professional, in consultation with the RDCO and MoE.

4.2.5 Proposed Revision to the Action Plan

As discussed in Section 4.2.3, Golder has proposed that action levels for monitors be set following the procedure summarized in the flow chart presented in Figure 18, and the action levels for each of the current monitors is summarized in Figure 19. In the LGMP, the first step to take if a methane level above the action level was to recalibrate instruments and retest within a week. However, as discussed in Section 4.2.4, with changes in how quickly field data can be assessed and how quickly possible calibration issues can be assessed, the revised procedure assumes that recalibration and repeating the measurements will take place within 24 hours rather than within one week, and thus is now considered a step completed as an integral part of the sampling round rather than as part of a follow-up round. Given that "step-out" monitors have already been established for most of the monitors that have historically exhibited methane levels above their associated action level, the next action is to determine the levels in the "step-out" monitors. If the methane levels in the "step-out" monitor furthest from the landfill are less than 10% LEL, then under the LGMP no further action is required. The proposed revised methane Action Plan is summarized in the flow chart presented in Figure 20.



LEGEND

- LANDFILL BOUNDARY
- MONITORING WELL LOCATION
- SOIL VAPOUR WELL LOCATION
- WELL LOCATION
- ACTIVE OUTSIDE BOUNDARY MONITORS
- ACTIVE NEAR BOUNDARY MONITORS
- ACTIVE INNER BOUNDARY MONITORS
- F MONITOR SETS

0 50 100

1:3,000 METRES

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT

REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT

LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

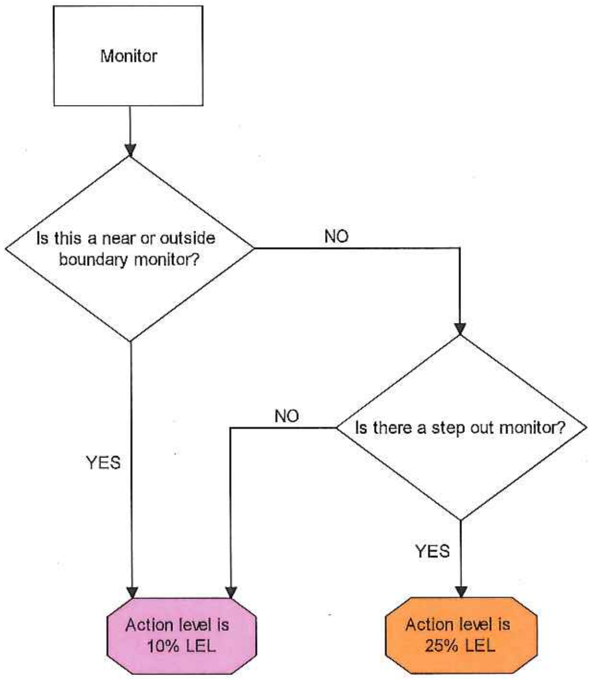
TITLE

MONITOR LOCATIONS AND REVISED CLASSIFICATION

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	17

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B

25 mm



All monitors have an associated action level of 10% LEL except for inside bounary monitors with an associated step-out monitor, which have an action level of 25%.

CLIENT
REGIONAL DISTRICT OF CENTRAL OKANAGAN

PROJECT
MONITORING PROGRAM REVISION
WESTSIDE LANDFILL

CONSULTANT: Golder Associates

YYYY-MM-DD	2014-02-17
PREPARED	GB
DESIGN	GB
REVIEW	RP
APPROVED	RP

TITLE
ESTABLISHING ACTION LEVELS

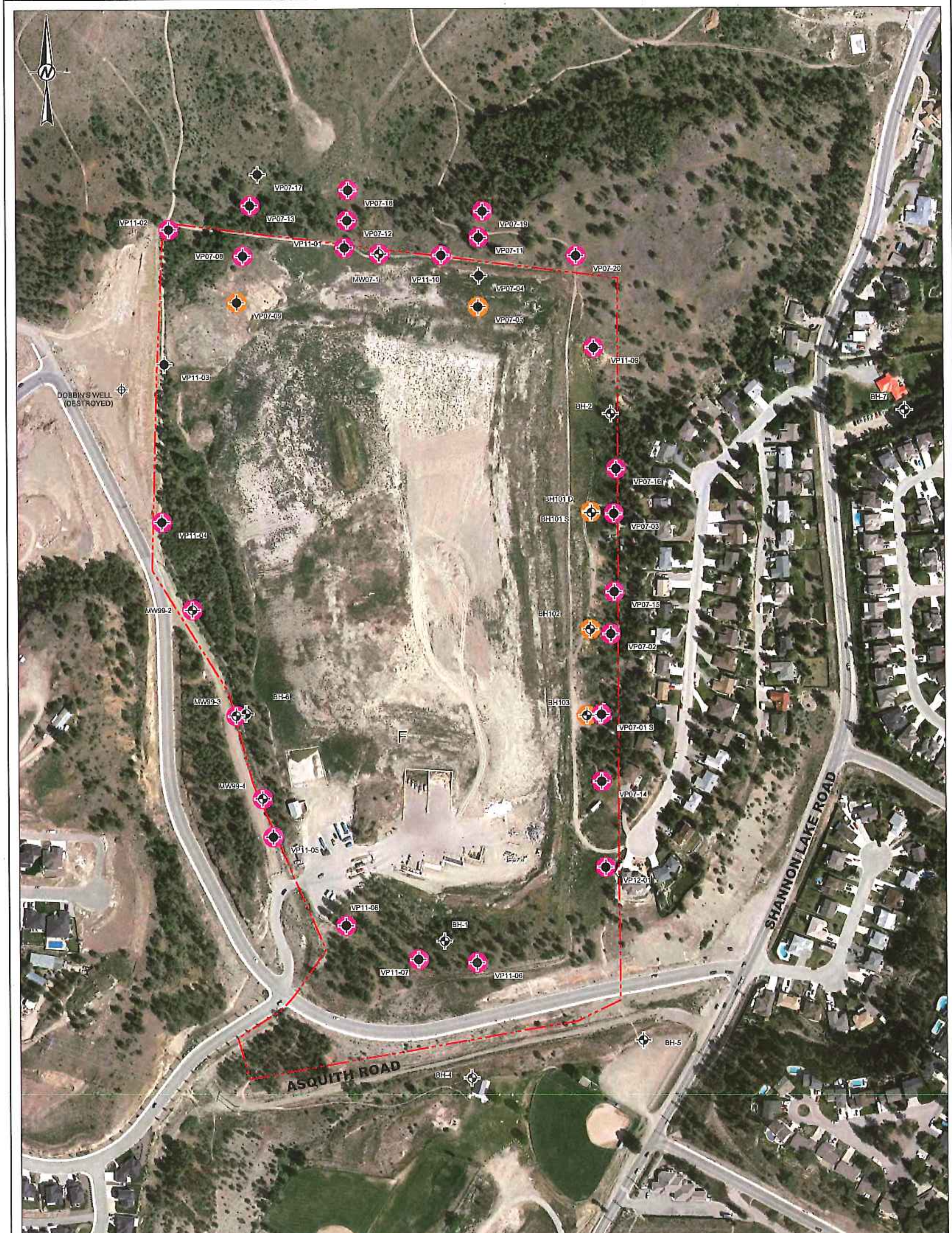
PROJECT No	PHASE	Rev	FIGURE
1406505	5000	0	18

Path: \\golder.gds\gal\kelowna\active\2004\1440 - kelowna\04-1440-062 rdco westside landfill\phase 4001 - 2013 reports\deliverables\figure 4.docx File Name: Figure 4.Docx

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

25 mm

Path: \\golder.gds\gal\Victoria\CAD-GIS\Client\RDCO\WESTSIDE LANDFILL\99_PROJECTS\1406505_Westside_Landfill_Closure_Plan\02_PRODUCTION\Phase_5000\ | File Name: 1406505-5000-19.dwg



LEGEND

LANDFILL BOUNDARY

MONITORING WELL LOCATION

SOIL VAPOUR WELL LOCATION

WELL LOCATION

MONITORS WITH ACTION LEVEL OF 25% LEL

MONITORS WITH ACTION LEVEL OF 10% LEL

0 50 100

1:3,000 METRES

REFERENCE(S)

2012 BASE ORTHOPHOTO OBTAINED FROM DISTRICT OF WEST KELOWNA ONLINE MAPPING.

EXISTING CONTOURS BASED ON SURVEY BY FRITSCH LAND SURVEYING INC. DATED MAY 2013.

CLIENT

REGIONAL DISTRICT OF CENTRAL OKANAGAN (RDCO)

CONSULTANT

Golder Associates

YYYY-MM-DD	2015-05-11
DESIGNED	J. FARAH
PREPARED	G. BARRETT
REVIEWED	G. BARRETT
APPROVED	R. PELESHYTYK

PROJECT

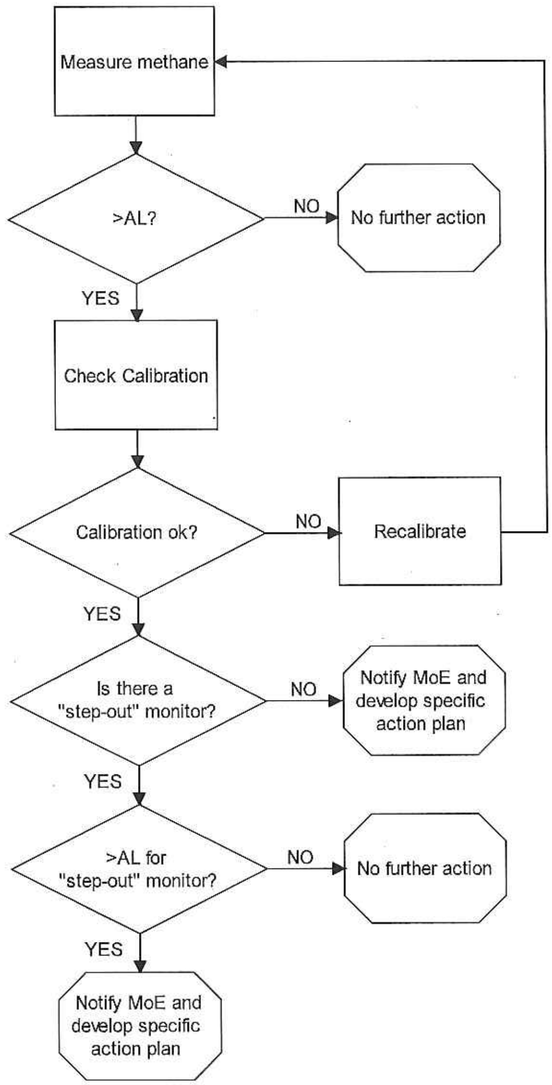
LANDFILL CLOSURE PLAN
WESTSIDE LANDFILL
WEST KELOWNA, B.C.

TITLE

CURRENT VAPOUR MONITOR ACTION LEVELS

PROJECT NO.	PHASE	REV.	FIGURE
1406505	5000	0	19

0 25 mm IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI B



Notes: AL = Action Level

CLIENT	REGIONAL DISTRICT OF CENTRAL OKANAGAN
PROJECT	MONITORING PROGRAM REVISION WESTSIDE LANDFILL
CONSULTANT	Golder Associates
YYYY-MM-DD	2014-02-17
PREPARED	GB
DESIGN	GB
REVIEW	RP
APPROVED	RP
TITLE	METHANE MONITORING ACTION PLAN
PROJECT No	1406505
PHASE	5000
Rev	0
FIGURE	20

Path: \\golder.gds\gal\kelowna\active\2004\1440 - kelowna\04-1440-062 rdco westside landfill\phase 4001 - 2013 reports\deliverables\figure 6.docx File Name: Figure 6.Docx

25 mm

IF THIS MEASUREMENT DOES NOT MATCH WHAT IS SHOWN, THE SHEET SIZE HAS BEEN MODIFIED FROM: ANSI A

4.3 Site Inspection

Operational Certificate PR12217 (Section 3.4) includes the requirement that vegetation be inspected at least once per year during the growing season to determine if environmental impacts are occurring. Golder recommends that a site walkover be completed annually, focusing in particular on identifying areas of surface erosion, differential settlement and the "health" of vegetation. It is recommended that the inspection be completed in the period from April to October to satisfy the requirement that the vegetation inspection be completed within the "growing period".

Golder recommends continuing annual post-closure site inspections initially, with recommendations for inspection frequency being reassessed with each inspection. The inspection requirements, including the frequency and scope, must ultimately be approved by the MoE.

4.4 Reporting

Groundwater and landfill gas monitoring results are currently reported annually. It is proposed that the results of surface water monitoring and the annual site inspection also be included in the annual report. As noted in Section 3.2.4, the monitoring program and site inspection results comprise part of the cover performance assessment, and thus a qualified professional should review the results to assess whether the results are consistent with the anticipated performance of the cover system. As well, the qualified professional should provide recommendations for modification of the monitoring or inspection program, as required.

In addition to the above, as discussed in Section 3.5 and Section 4.2, there are "action levels" set for landfill gas measurement results that may require additional assessment and possibly reporting to the MoE. Thus, assessment of landfill gas results by a qualified professional is required after each landfill gas monitoring round, generally within 24 hours of the measurements being taken.

As well, if any observations of conditions or assessment of any monitoring result suggests that there is a significant imminent hazard to human health or the environment, then the MoE should be notified of those observations or assessments, as soon as practical (24 hours if possible).

4.5 Summary of Monitoring Recommendations

The current monitoring program and the proposed changes to that program are summarized in Table 8. The revised program will not be implemented until reviewed by the Ministry of Environment, although voluntary additions to the current programs are assumed to be acceptable. Note that it is recommended that MW99-02 be added to the monitoring program provisionally and evaluated as a possible long-term background groundwater monitor. The monitoring program should be reviewed annually going forward, and recommendations for modifications to the program be made as appropriate and submitted to the Ministry of Environment for consideration.

Table 8: Summary of Monitoring Program Recommendations

Month	Landfill Gas		Groundwater Sampling		Site Inspection		Reporting	
	C	R	C	R	C	R	C	R
Jan								
Feb								
Mar								
Apr								
May								
Jun		p						
Jul		p						
Aug								
Sep		p						
Oct		p						
Nov								
Dec								

C = current program **R** = proposed revised program

p = partial round (BH102, BH103, VP07-11, VP11-09, VP11-06, VP11-07 and VP11-08)

5.0 PROPOSED TIMELINE FOR CLOSURE ACT

The RDCO has provisionally planned to complete the main closure works in 2015; including, but not limited to:

- Completion of sourcing, placement and grading of appropriate fill for the upper portion of the landfill (Area A, Figure 7) in fall of 2015;
- Completion of slope stabilization works in 2016 (Area B, Figure 7);
- Completion of initial seeding in either fall of 2015 or spring of 2016;
- Completion of addition of local fill and surface water works on the northwest portion of the landfill (Area D and part of Area E, Figure 7, and as illustrated in Figure 9) in 2016;
- As discussed in Section 3.5, additional investigation is required in the vicinity of BH102 (see Figure 10), which has shown methane levels that are elevated. The results for a monitor, VP07-02, located further from the landfill in the direction of expected gas flow, suggests venting is occurring between the two monitors. However, Golder recommends, and the RDCO concurs, that further investigation be completed in the vicinity of BH102. This work is scheduled to be completed in 2015; and,
- The results of this additional information would be used in conjunction with existing information to develop a plan for mitigation. The plan would be presented to the MoE for consideration before implemented.

6.0 CLOSURE

If there are any questions about the updated Closure Plan in this report, please contact Golder Associates Ltd.

Yours truly,

GOLDER ASSOCIATES LTD.

Gary Barrett, Ph.D., P.Geo.
Senior Consultant

Rick Peleshytyk, P.Eng.
Principal

GB/RP/kv

https://capws.golder.com/sites/1406505westsidelandfillclosureplan/phases and tasks/07 deliverables/1406505-003-r-rev0-5000-westside landfill operations and closure plan-12may_15.docx

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APPENDIX A

Ministry of Environment, Lands and Parks - Operational Certificate PR 12217

POLLUTION
PREVENTION

Suite 201
3547 Skaha Lake Road
Penticton
British Columbia V2A 7K2
Telephone: (250) 490-8200
Fax: (250) 492-1314

BRITISH COLUMBIA

MINISTRY OF ENVIRONMENT,
LANDS AND PARKS

OPERATIONAL CERTIFICATE
PR 12217

Under the provisions of the Waste Management Act and in accordance with the Approved Regional District of Central Okanagan Solid Waste Management Plan,

Regional District of Central Okanagan

1450 KLO Road

Kelowna, British Columbia

V1W 3Z4

is authorized to manage recyclable materials and to discharge refuse to the ground at a landfill facility located approximately 2.5 km north of Westbank, British Columbia, subject to the conditions listed below. Contravention of any of these conditions is a violation of the *Waste Management Act* and may result in prosecution.

1 AUTHORIZED DISCHARGES

1.1 The discharge of refuse to which this Sub-Section is applicable is shown on the attached Site Plan A. The reference number for this discharge is E223888.

1.1.1. The maximum rate at which refuse may be discharged to the landfill is 20,000 tonnes per year.

1.1.2 The type of refuse which may be discharged is municipal solid waste and other wastes as authorized by the Regional Waste Manager.

1.1.3 The works authorized are a sanitary landfill and related appurtenances.

1.1.4 The location from which the discharge originates is generally the area on the west side of Okanagan Lake within the boundaries of the Regional District of Central Okanagan.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

Date Issued: May 28, 1997
Amendment Date:
(most recent)

1.1.5 The location of the approximate area of discharge is that Part of District Lot 3794 ODYD shown on Plan C11135 Except Plan KAP46607 as shown on Site Plan A.

2 GENERAL REQUIREMENTS

2.1 Maintenance of Works and Emergency Procedures

The holder of the Operational Certificate shall inspect the landfill, any related pollution control works and designated areas for managing recyclable or reusable materials regularly and maintain them in good working order. In the event of an emergency or condition beyond the control of the holder of the Operational Certificate which prevents continuing operation of the authorized method of pollution control, the holder of the Operational Certificate shall immediately notify the Regional Waste Manager and take appropriate remedial action.

2.2 Process Modifications

The holder of the Operational Certificate shall notify the Regional Waste Manager prior to implementing changes to any process that may affect the quality and/or quantity of the discharge.

2.3 Plans - New Works

Plans and specifications of any new works related to this facility shall be submitted to the Regional Waste Manager and his consent obtained before construction commences. The works shall be constructed in accordance with such plans. Review of the submitted plans and specifications is for the purpose of administration of the Operational Certificate and only implies that the works specified therein meet the appropriate guidelines, criteria or standards.

2.4 Operational and Closure Plan

2.4.1 An *Operational and Closure Plan*, prepared by a suitably qualified professional shall be submitted for authorization by the Regional Waste Manager, on or before July 31, 1997.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

2.4.2 The *Operational and Closure Plan* shall include the following:

- Anticipated total waste volumes and tonnage, and life of the landfill (ie: closure date);
- A topographic plan showing the final elevation contours of the landfill and surface water diversion and drainage controls;
- Design of the final cover including the thickness and permeability of barrier layers and drainage layers, and information on topsoil, vegetative cover and erosion prevention controls;
- Procedures for notifying the public about the closure and about alternative waste disposal facilities;
- Rodent and nuisance wildlife control procedures;
- Proposed end use of the property after closure;
- A plan for monitoring groundwater, surface water and landfill gas, erosion and settlement for a minimum post-closure period of 25 years;
- A plan and accompanying design for the collection, storage and treatment/use of landfill gas for a minimum of 25 years;
- A plan for operation of any required pollution abatement engineering works such as leachate collection and treatment systems, for a minimum post-closure period of 25 years;
- A schedule of reserve funds or security to be collected each year until closure; to cover estimated costs of closure, post-closure and a contingency for remediation;
- A screening plan, ie: vegetative or berm, designed by a landscape architect with particular focus on the east side of the landfill;
- A detailed fill plan for the east side of the landfill;
- A perimeter and electric bear control fencing design;
- Litter and odour control measures;
- Design of gas monitoring wells for lateral migration and the proposed gas monitoring program;
- Final cover design and a schedule to cover previously filled areas that are no longer going to receive waste, particularly on the east side of the landfill;
- Contingency plan & notification procedures in the event of an emergency;
- Training procedures for operators; and
- Any other site specific concerns as identified by the Regional Waste Manager.

2.4.3 Terms of reference for the Operational and Closure Plan are subject to authorization by the Regional Waste Manager.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

2.4.4 The Regional Waste Manager may request revisions to the *Operational and Closure Plan.* Terms of reference for the revisions to the *Operational and Closure Plan* are subject to authorization by the Regional Waste Manager.

2.4.5 Operation of this landfill is to be in substantial accordance with the authorized *Operational and Closure Plan.*

2.4.6 If there is an inconsistency between this Operational Certificate and the authorized *Operational and Closure Plan*, the Operational Certificate shall take precedence.

2.5 Ground and Surface Water Quality Impairment

2.5.1 Landfills must not be operated in a manner such that ground or surface water quality decreases beyond that allowed by the *Approved and Working Criteria for Water Quality* dated 1995 prepared by the Water Quality Branch of the Ministry of Environment, Lands and Parks at or beyond the landfill property boundary. The appropriate water quality criteria will be specified by the Regional Waste Manager after reviewing uses of the ground and surface water resources.

2.5.2 If excursions result to the specified water quality criteria, the Regional Waste Manager may require that leachate management control measures or works be undertaken. Terms of reference for any leachate management study and/or design work is subject to the authorization of the Regional Waste Manager.

2.6 Landfill Gas Management

2.6.1 An assessment of the emissions of non-methane organic compounds (NMOCs) is required for landfills exceeding a total capacity of 100,000 tonnes. If NMOCs are determined to exceed 150 tonnes/year, landfill gas recovery and management systems will be required to be designed, installed and operational within 3 years. If NMOCs are projected to be less than 150 tonnes/year for the operating life of the landfill, an assessment for the need of passive gas venting will be required. Terms of reference for any landfill gas study or design is subject to the authorization of the Regional Waste Manager.

2.6.2 The gas monitoring wells, designed by a suitably qualified professional, are to be installed on or before August 31, 1998.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

Date Issued: May 28, 1997
Amendment Date:
(most recent)

2.7 Property Boundary

The buffer zone between any municipal solid waste discharged after the issuance of this Operational Certificate and the property boundary is to be at least 50 metres of which the 15 metres closest to the property boundary must be reserved for natural or landscaped screening (berms or vegetative screens). Depending on adjacent land use and environmental factors, buffer zones of less than 50 metres but not less than 15 metres may be authorized by the Regional Waste Manager.

2.8 Other Facilities

The distance between the discharged municipal solid waste and the nearest residence, water supply intake, hotel, restaurant, food processing facility, school, church or public park is to be a minimum of 300 metres. Greater or lesser separation distances may be authorized where justified. For those landfills designed to collect and recover methane gas generated, the issue of potential on-site or off-site users of the energy should be addressed in siting the landfill, consistent with the preceding regarding public places. An exemption is granted to discharge municipal solid waste closer than 300 m to the existing residences located in the subdivision to the east of the landfill.

2.9 Natural Control Landfill

2.9.1 The bottommost solid waste cell is to be at least 1.2 metres above the seasonal high water table. Greater or lesser separation depths may be authorized based on soil permeability and the leachate renovation capability of the soil.

2.9.2 There is to be at least a 2 metres thick layer of low permeability soil with a hydraulic conductivity of 1 x 10-6 cm/s or less (i.e. silt or clay), below each of the bottommost waste cells. Lesser thicknesses or no layer of low permeability soil may be authorized based on the potential for leachate generation and the unsaturated depth, permeability and leachate renovation capability of the existing soil.

2.10 Water

The disposal of municipal solid waste into water is unacceptable. Surface water diversion to restrict storm water runoff from contacting the wastes is required.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

Date Issued: May 28, 1997
Amendment Date:

2.11 Final Cover

Final cover for landfill sites is to consist of a minimum of 1 metre of low permeability (<1 x 10-5 cm/s) compacted soil plus a minimum of 0.15 metre of topsoil with authorized vegetation established. The depth of the topsoil layer should be related to the type of vegetation proposed (ie rooting depth). Soils of higher permeability may be authorized based on leachate generation potential at the landfill site. Final cover is to be constructed with slopes between 4% and 33% with appropriate run-on/run-off drainage controls and erosion controls. An assessment of the need for gas collection and recovery systems shall be made so that, in the event such systems are required, cover can be appropriately designed and constructed. Final cover is to be installed within 90 days of landfill closure or on any areas of the landfill which will not receive any more refuse within the next 12 months. Completed portions of the landfill are to progressively receive final cover during the active life of the landfill.

Additional layers of natural materials including earth and aggregate and/or synthetic materials may be necessary for inclusion in the final cover design due to site specific conditions and the presence of management systems for leachate and landfill gas.

2.12 Access Road

An appropriately constructed and maintained access road to, and a road system within the landfill site capable of supporting all vehicles hauling waste, are required during the operating life of the landfill.

2.13 Fencing and Access

2.13.1 Fencing is required to be installed around the perimeter of the landfill on or before April 1, 1998. The type and extent of fencing will depend on the existing natural vegetation and topographic features and is to be authorized by the Regional Waste Manager. All access points are to have locking gates.

2.13.2 Bears shall be prevented from accessing any and all putrescible refuse from April to November inclusive through the use of electric fencing. Electric fencing is to be installed on or before April 1, 1998 and maintained thereafter.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

2.13.3 The holder of the Operational Certificate is to conduct a public relations campaign 3 months prior to the installation of electric fencing. The purpose of the campaign is to inform the public of the impacts of installing electric fencing around the landfill. The Conservation Officer Service is to be consulted in the development of the public relations campaign.

2.13.4 Signage is to be attached to the electric fence at regular intervals with an appropriate safety warning indicating that the fence is electrified.

2.14 Design by Qualified Persons

All landfills are to be designed by persons qualified in landfill site selection, design and operation. All plans, specifications, and reports are to be sealed by a professional engineer or geoscientist licensed to practice in the province of British Columbia.

2.15 Prohibited Wastes

The co-disposal of the following wastes with the rest of the municipal solid waste is prohibited unless specifically authorized by the Regional Waste Manager:

- Special Wastes other than those specifically authorized in the *Special Waste Regulation*
- Bulk liquids and semisolid sludges which contain free liquid;
- Liquid or semisolid wastes including septage, black water, sewage treatment sludge, etc.;
- Automobiles, white goods, other large metallic objects and tires;
- Biomedical waste as defined in the document *Guidelines for the Management of Biomedical Waste in Canada* (CCME, February 1992); and
- Dead animals and slaughter house, fish hatchery and farming wastes or cannery wastes and byproducts.

Burial of these wastes in dedicated locations (i.e. avoiding co-disposal) at a landfill site may be authorized by the Regional Waste Manager only if there is no other viable alternative such as treatment/disposal, recycling, reprocessing or composting. The viability of alternatives is to be determined by the Regional Waste Manager based on submission of cost data by the holder of the Operational Certificate. For those cases in which the dedicated disposal of otherwise prohibited wastes is authorized, the specific on-site location of the disposal shall be recorded to allow ready access to the waste should corrective or further action pertaining to the management of these wastes be required by the Ministry at some time in the future.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

2.16 **Hydrocarbon Contaminated Soils**

The deposit of hydrocarbon contaminated soils below the ***Special Waste Regulation*** criteria is authorized at this landfill subject to the following conditions:

- Soil contaminated with hydrocarbons shall be deposited in layers less than 0.3 meters; and
- Soil contaminated with hydrocarbons shall be deposited a minimum of 1.2 meters above the seasonal high groundwater level and a minimum of 2.0 meters below the final grade of the landfill to prevent the impact on groundwater and any future vegetation on the site.

2.17 **Designated Areas**

Maintain areas for the separation, handling and storage of recyclable or reusable materials where applicable.

When a separated recyclable material is a special waste it is to be stored and managed in accordance with the ***Special Waste Regulation.***

Composting of yard waste is to be in accordance with the ***Production and Use of Compost Regulation.***

2.18 **Signs**

A sign is to be posted at each entrance of the landfill with the following current information:

- Site name
- Owner and operator
- Contact phone number and address for owner and operator
- Phone number in case of emergency (such as fire)
- Hours of operation (if applicable)
- Materials/wastes accepted for landfill and recycling
- Materials/wastes banned
- Tipping fees (if applicable)

Additional signs which clearly indicate the directions to the active tipping face, public disposal area, recycling and waste separation areas, etc. should also be displayed.

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2.19 Supervision

Fulltime, trained operators on-site are required at this landfill during operating hours. The gates are to be locked to prevent unauthorized access during non-operating hours. Properly designed and maintained public waste disposal and/or recyclable material bins situated outside the main gate may be provided for after hours use. The operator is required to be familiar with the Operational Certificate, inspection records, the authorized *Operations and Closure Plan* and all annual reports.

2.20 Scavenging

Scavenging of waste is to be prevented. The salvaging of wastes should be encouraged by providing areas and facilities for separation of recyclable or reusable materials.

2.21 Dust Control

Dust created within the landfill property is to be controlled, using methods and materials acceptable to the Regional Waste Manager, such that it does not cause a public nuisance.

2.22 Waste Compaction and Covering

2.22.1 Wastes are to be spread in thin layers (0.6 m or less) on the working face and compacted. The working face area should be minimized as much as possible. A compacted layer of cover material of at least 0.15 metre of soil or functionally equivalent depth of other cover material, as authorized by the Regional Waste Manager, is to be placed on all exposed solid waste at the end of each day of operation. If the landfill should operate continuously 24 hours per day, 0.15 m of cover material is to be applied at a frequency authorized by the Regional Waste Manager. Under specific circumstances, such as during bear season, the Regional Waste Manager may specify more stringent cover requirements. During periods of extreme weather conditions, such as those that cause the ground to freeze, an exemption to the normal cover requirements may be authorized at a frequency authorized by the Regional Waste Manager.

2.22.2 An intermediate cover consisting of a compacted layer of at least 0.30 metre of soil or functionally equivalent depth of other cover material is to be placed where no additional solid waste has been deposited or will be deposited within a period of 30 days.

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Assistant Regional Waste Manager

2.23 Litter Control

Litter is to be controlled by compacting the waste, minimizing the working face area, applying cover, providing litter control fences and instituting a regular litter pickup and general good housekeeping program or any other measures required by the Regional Waste Manager.

2.24 Vectors

Vectors are to be controlled by the application of cover material at a specified frequency or by other control measures as required and authorized by the Regional Waste Manager.

2.25 Wildlife

The landfill is to be operated so as to minimize the attraction of wildlife such as bears and birds by applying cover at required frequencies and instituting a good housekeeping program. Further control measures, such as bear control fences, and bird control devices, may be specified by the Regional Waste Manager.

2.26 Fire Protection

Adequate fire fighting equipment is to be available to extinguish surface or underground fires. Recyclables and reusable materials are to be stored in such a manner to not constitute a fire hazard.

3 MONITORING AND REPORTING REQUIREMENTS

3.1 Municipal Solid Waste Measurement

3.1.1 Provide and maintain a weigh scale and record the weight of refuse discharged to the landfill over a 24-hour period.

3.1.2 Record the weight of recyclable and reusable materials not being discharged and that are being separated, stored or processed at the landfill over a 24-hour period.

3.1.3 Density tests are to be performed utilizing a known scaled volume of representative compacted refuse at a frequency of at least once per year and reported in kg per m3.

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Assistant Regional Waste Manager

3.2 Water Levels

Measure the water level and determine the elevation, on a quarterly basis, in monitoring wells BH1 (E224611), BH2 (E224612), BH4 (E224617), BH5 (E224618), BH6 (E224620), BH7 (E224621), BH8 (E224623) and Dobbin's Well (E224624) as shown on Site Plan B.

3.3 Water Quality

3.3.1 Install a suitable sampling facility and obtain a grab sample on a quarterly basis, of the groundwater, in monitoring wells BH1 (E224611), BH2 (E224612), BH4 (E224617), BH5 (E224618) and Dobbin's Well (E224624) as shown on Site Plan B.

3.3.2 Obtain analyses of the samples in section 3.3.1 for the following:

conductivity, total alkalinity ($CaCO_3$), chloride, sulphate, ammonia nitrogen, nitrate nitrogen, aluminum, antimony, arsenic, barium, beryllium, bismuth, cadmium, calcium, chromium, cobalt, copper, iron, lead, lithium, magnesium, manganese, molybdenum, nickel, phosphorous, potassium, selenium, strontium, thallium, tin, titanium, tungsten, vanadium, and zinc.

3.3.3 Obtain grab samples, every two years, of the groundwater in monitoring wells BH1 (E224611) and BH4 (E224617) as shown on Site Plan B.

3.3.4 Obtain analyses of the samples in section 3.3.3 for the following:

total dissolved solids, boron, total purgeable hydrocarbons, total extractable hydrocarbons, volatile organics (EPA 624) and acid and base/neutral extractable organics (EPA 625), BOD, COD, and phenolics.

3.3.5 Obtain suitable grab samples, on an annual basis, of the groundwater in all domestic water wells being used for drinking water purposes within 1000m down-gradient of the landfill subject to obtaining permission from the water well owner.

3.3.6 Obtain analyses of the samples in section 3.3.5 for conductivity and chloride.

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Assistant Regional Waste Manager

3.4 Vegetation Monitoring

Inspect vegetation during the growing season in the vicinity of the landfill at least once per year to determine if any environmental impacts are occurring.

3.5 Sampling and Analytical Requirements

3.5.1 The sampling and monitoring requirements specified above shall be carried out in accordance with the appropriate procedures listed in the table below. Alternative test methods may be used provided that the alternative test methods are authorized by the Regional Waste Manager prior to performing the actual source testing. Test methods for parameters not listed below require the consent of the Regional Waste Manager.

DISCHARGES TO AIR, AMBIENT AIR:		
Parameter	**Source Testing Procedure**	**Analytical Procedure**
Particulate Matter Rate of Discharge (flow rate) Gaseous emissions	Stationary Emission Testing Code - contained in British Columbia Field Sampling Manual for Continuous Monitoring plus the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples, 1996 Permittee Edition	A Laboratory Manual for the Chemical Analysis of Ambient Air, Emissions, Precipitation, Soil and Vegetation, 3rd edition, April, 1983, 253 pp.
LIQUID EFFLUENTS, SURFACE WATER, GROUND WATER, SOILS, SEDIMENTS, VEGETATIVE MATTER:		
Parameter	**Source Testing Procedure**	**Analytical Procedure**
Metals Nutrients Organics Toxicity	British Columbia Field Sampling Manual for Continuous Monitoring plus the Collection of Air, Air-Emission, Water, Wastewater, Soil, Sediment, and Biological Samples, 1996 Permittee Edition	British Columbia Environmental Laboratory Manual for the Analysis of Water, Wastewater, Sediment and Biological Materials, March, 1994, Permittee Edition

The above manuals are available from Queen's Printer Publications Centre, P.O. Box 9452, Stn. Prov. Govt, Victoria, BC, V8W 9V7 (1-800-663-6105 or (250) 387-4609). The above manuals are also available for inspection at all Pollution Prevention offices.

3.5.2 Proper care should be taken in sampling, storing and transporting the samples to adequately control temperature and avoid contamination and breakage.

3.5.3 Maintain the groundwater monitoring wells including provisions to ensure protection from damage due to vehicles or vandalism.

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Assistant Regional Waste Manager

3.5.4 Groundwater monitoring wells are to be covered with lockable caps, fitted with locks all keyed alike, and a key is to be provided to the Regional Waste Manager.

3.5.5 Three well bore volumes are to be pumped from each monitoring well prior to sample collection.

3.6 Changes to Sampling and Monitoring Program

On the basis of findings during routine inspections and any other information related to the effect of the discharge on the receiving environment, the Regional Waste Manager may allow reductions or require additional sampling and monitoring of the discharge and receiving environment.

3.7 Annual Report

An annual operations and monitoring report is to be submitted to the Regional Waste Manager within 60 days of the end of the calendar year. The first annual report is due on March 1, 1998. These reports are to contain at least the following information:

- Total volume and/or weight of waste discharged into the landfill for the year;
- Service population and waste discharge rate for the year (in tonnes per capita per year) and a trend analysis with a comparison to the 1990 baseline waste discharge rate of 1.20 tonnes per capita per year ;
- Authorized design volume;
- Remaining site life and capacity;
- Operational plan for next 12 months;
- Operation and maintenance expenditures;
- Monitoring data compilation, interpretation and trend analysis prepared by a suitably qualified professional regarding landfill gas, vegetation and leachate/water quality including a review of groundwater elevations and flow direction and a comparison made to the drinking water parameters found in the *Approved and Working Criteria for Water Quality* dated April 1995.;
- Amounts of leachate collected, treated and disposed;
- Any changes from authorized reports, plans and specifications;
- any changes to the contingency plan;
- Amount of landfill gas collected and its disposition;
- Review of the closure plan and associated estimated costs, including an update of the schedule of reserve funds or security to be collected each year until closure;. to cover estimated costs of closure, the 25 year post-closure period and a contingency for remediation; and
- Any other data relevant to this Operational Certificate

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Assistant Regional Waste Manager

3.8 Format of Submission

Monitoring and/or reporting information shall be submitted in an electronic and/or printed format which is suitable for review by the public and/or other government agencies and is satisfactory to the Regional Waste Manager.

3.9 Financial Security

Provide a future financial security of the operations at and beyond closure by establishing a Closure Fund in a form acceptable to the Regional Waste Manager, such as upfront security or a fund financed on a charge per tonne of waste disposed basis. Such a fund would be analogous to the provincial Waste Management Trust Fund which the Minister may establish under Section 53 of the *Waste Management Act*. The ultimate amount of the financial security shall meet or exceed the currently estimated closure and post-closure costs as outlined in the closure plan plus a reasonable contingency for any remediation which may be required. For municipally owned landfills, the financial security can be built up over time according to a schedule authorized by the Regional Waste Manager.

3.10 Legal Survey

Landfills sited on titled land must register a covenant that the property was used for the purpose of waste disposal as a charge against the title to the property as provided for under Section 215.1 of the *Land Title Act*. Landfills located on crown land are to have a "notation on file" registered that the property was used for the purpose of waste disposal.

3.11 Buildings and Structures

The construction of buildings and other structures on landfills containing putrescible wastes is not recommended for a minimum period of 25 years after closure due to concerns about combustible gas and excessive settlement. Such activity will only be considered and /or authorized after an investigation and report by qualified persons. The report is to be submitted for authorization to the Regional Waste Manager prior to initiating construction activities.

3.12 Operation of Gas Recovery and Management System

Where landfill gas recovery and management is required, operation of the system should be considered an integral part of overall landfill management. The system should be planned for from the early design stage of the landfill and arrangements made for its operation for a minimum 25 year life after closure.

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

3.13 Operation of Other Control Systems

Operation of other environmental control systems for leachate and run-off as well as monitoring of leachate, groundwater and surface water must be continued during the entire post-closure period unless the early suspension of such operations or monitoring is authorized by the Regional Waste Manager.

Date Issued: May 28, 1997
Amendment Date:
(most recent)

T.R. Forty, P.Eng.
Assistant Regional Waste Manager

APPENDIX B

Landfill Gas Generation Assessment Report Update, 2015-Five Year Follow-Up Report, Golder Associates Ltd. (2015)

March 18, 2015

2015 - FIVE YEAR FOLLOW-UP REPORT

Landfill Gas Generation Assessment Report Update

Submitted to:
Regional District of Central Okanagan
1450 KLO Road
Kelowna, BC
V1W 3Z4

REPORT

Report Number: 1406505-002-R-Rev1-8001

Distribution:

1 Copy - Regional District of Central Okanagan
1 E-Copy - Ministry of Environment
2 Copies - Golder Associates Ltd.

Golder Associates

Table of Contents

1.0 INTRODUCTION

The Regional District of Central Okanagan (RDCO) has retained Golder Associates Ltd. (Golder) to complete a supplementary assessment report for Westside Landfill to satisfy Section 15 of the Province of British Columbia Ministry of Environment's (MoE's) *Landfill Gas Management Regulation* (December 8, 2008, Order in Council No. 903). The Regulation requires that such a report be completed between January 1 and March 31 of the fifth calendar year after the preliminary assessment, which was completed by CH2M Hill Limited (CH2M Hill) in 2010 (See Appendix A). The current report is submitted to satisfy that requirement.

Section 15 of the *Landfill Gas Management Regulation* applies in cases where the estimated emission of methane was less than 1000 tonnes annually in the initial assessment, which is the case for Westside Landfill (CH2M Hill Canada Ltd., 2010). Section 15, under 15 (1), requires that a qualified professional either:

- Conduct a supplementary assessment that includes the assessments required under 4 (2) (a) to (c) and (e), and an estimate of the quantity of methane generated at the landfill site each of the calendar years preceding the calendar year in which the supplementary assessment is conducted; or,
- Reviews the previous assessment to determine whether there have been any material changes in the information since the previous report.

Given that CH2M Hill included estimated filling at Westside Landfill, up to the end of 2010, and that acceptance of waste at the site ceased as planned in June of 2010, Golder has elected to complete a review of the previous assessment to determine whether there have been any material changes in the information since the previous report.

CH2M Hill used the Landfill Gas Calculation Tool provided by the MoE in conjunction with the *Landfill Gas Management Regulation*, and as described in the estimate emissions. Any "material" changes to the inputs would be expected to change the estimated gas emissions, although the change could be either a decrease or increase in the estimate. In Section 2.0 of this report, each of the key inputs required for operation of the Landfill Gas Calculation Tool are reviewed, along with specific recommendations provided by CH2M Hill. Section 3.0 includes additional assessment based on review of landfill gas monitoring program results for the period from late 2000 to the end of 2014, review of the additional analysis completed for the 2010 assessment, and discussion of recommendations from the 2010 assessment. Section 3.0 includes a brief summary of the key points from the 2015 supplementary Landfill Gas Assessment.

2.0 REVIEW OF KEY PARAMETERS

The inputs required for the Landfill Gas Calculation Tool include:

- Annual totals of waste disposed at site;
- Waste Characterization, including classification by percentage composition; and,
- Methane generation parameters (a set of three).

The original selection of values for each of these inputs, and whether or not there have been any substantive changes or new information, is discussed in Sections 2.1 through 2.3.

2.1 Annual Totals of Waste Disposed at Site

CH2M Hill prepared estimates of the total waste disposed at site up to the scheduled end of filling in 2010. Golder understands that waste disposal did in fact stop at the site in 2010 as planned, and thus no additional filling took place. Golder is not aware of any revisions in the estimates of waste disposed at site. Thus, there does not appear to be any reason to modify the estimate of annual disposal rates at the site that CH2M Hill used in their 2010 assessment.

It should be noted that methane generation rate from waste disposed in a given year is assumed to decline exponentially in the equations used in the Landfill Gas Calculation Tool. Thus, since no waste has been disposed at the site in the last five years, the total emissions estimated from Westside Landfill would be lower, if redone in 2015, because of this exponential decay in contributions.

2.2 Waste Composition

CH2M Hill used the results of a Waste Audit for Glenmore Landfill completed by the Regional Waste Reduction Office in 2008 as a basis for assigning the proportions of "decomposable", "moderately decomposable" and "relatively inert" waste. However, CH2M Hill increased the proportion of waste in the "decomposable" category by 5% to 42% of the total waste stream, which resulted in decreasing the assumed percentage for "relatively inert" waste by 5% to 23%. The proportion of "moderately decomposable" waste was set to 35%, the same value found in the Waste Audit.

Glenmore Landfill serves a nearby "waste catchment" area and it appears reasonable to assume that waste disposed at Westside Landfill would be similar in catchment. By increasing the assumed percentage of "decomposable waste", CH2M Hill would get a higher emission rate estimate than would have been the case if they had used the Waste Audit results for Glenmore Landfill as the basis for their estimate. Golder is not aware of any new information that suggests that the original composition estimates should be modified such that the percentages of either "decomposable" or "moderately decomposable" waste be increased, which would be the only change that would lead to an increase in the emission rate.

2.3 Methane Generation Parameters

There are three methane generation parameters included in the model: (1) the methane generation potential (commonly represented as Lo); (2) the methane generation rate (commonly represented as k); and (3) the water addition factor.

2.3.1 Methane Generation Potential

The Landfill Gas Guideline sets methane generation potential (Lo) for each of the three types of waste – "decomposable", "moderately decomposable", and "relatively inert". Thus, this factor is not adjusted independently, but rather its effect on the emission estimate simply follows from the waste disposal and waste composition estimates discussed in Section 2.2.

2.3.2 Methane Generation Rate

The methane generation rate (k) depends on both the relative amounts of the different classes of wastes ("decomposable", "moderately decomposable", and "relatively inert") and the annual precipitation. CH2M Hill selected values for k for the different classes of wastes from those described in the Guidelines, assuming that annual precipitation at Kelowna was on average 415 mm, which falls within the 250 mm to 500 mm class. Environment Canada's 30-year normal precipitation is 344.5 mm annually for the period from 1981 to 2010 for the Kelowna PC Burnetts Nursery Station, which is the closest station to Westside Landfill. This result falls into the same 250 mm to 500 mm annual precipitation band selected by CH2M Hill, thus, there does not appear to be any rationale for adjusting CH2M Hill's selection of "k" values.

2.3.3 Water Addition Factor

The water addition factor, which based on criteria in the Guidance document, can vary from 0.9 to 1.1, depending on site conditions. This factor is used to modify "k", the methane generation rate constant. CH2M Hill selected a water addition factor of 0.9, based primarily on their judgement based on the storm water management practices in place at the site and the fact that there is no leachate recapture and recirculation on site. The factor k is a constant in an exponential decay function in the model, and thus there is not a linear change in the estimated generation of methane. Golder is not aware of any questions being raised regarding CH2M Hill's selection of "k" in the original assessment. Golder notes that the estimate of methane generation provided by CH2M Hill would have been somewhat higher had a water addition factor of 1.0 been selected instead of 0.9. However, as discussed in the following section, the assumptions regarding the percentage of methane in landfill gas generated at Westside Landfill included in the calculation procedure can be refined based on data collected over the period 2000 to 2014, which suggest much lower rates of methane production than suggested using the Landfill Gas Calculator.

3.0 ADDITIONAL CONSIDERATIONS

In Section 3.1, additional considerations based on the results from the landfill gas monitoring program are discussed. In Section 3.2, the additional analysis included in the 2010 is discussed, and in Section 3.3, recommendations from the 2010 assessment are discussed.

3.1 Additional Considerations Based on Monitoring Results

Landfill gas monitoring has been taking place at the site since late in 2000. The program has evolved somewhat over time. Currently, and for most of the monitoring events since 2000, measurements of methane, carbon dioxide, carbon monoxide, hydrogen sulphide and oxygen have been made. Golder has assembled the data for the period from December of 2000 to December of 2014. Over that period of time, some 1439 landfill gas measurements have been made, of which 1006 readings include values for methane and carbon dioxide. Of these 1006 readings, some 208 had methane or carbon dioxide levels that were either at or so close to zero (lower than the level expected in the atmosphere) that they are considered to be non-detectable.

For the readings with detectable levels of methane and carbon dioxide, the percentage of methane to the combined total of methane and carbon dioxide was estimated. The Landfill Gas Calculation Tool estimates are based on the assumption that methane and carbon dioxide will each comprise 50% of the landfill gas generated, which is what is expected with anaerobic decomposition of waste. Since there is some methane and carbon dioxide in the atmosphere, these ambient levels were subtracted from the measured values in the landfill gas to better reflect the concentration that could be attributed to generation from decomposition of waste. After making these corrections, only 2.3% of the gas generated was methane, with the other 97.7% being carbon dioxide. This result is the same as results for the period from 2000 to 2014, and for 2014.

The monitors are primarily located along the perimeter of the landfill and not across the entire surface, and thus the results may not be fully representative. However, the source of the methane and carbon dioxide would be from decomposition of waste (adjustments were made to take into account the amounts normally present in the atmosphere), and thus provide some indication of the processes that are at work in the landfill. Based on the data from the landfill gas monitoring program, it appears that percentage of methane in the landfill gas that is generated in Westside Landfill is likely much lower than 50%, indicating that aerobic decomposition or oxidation of methane may be significant at this landfill. This is plausible since the landfill is located in a semi-arid area, and that most or all of the waste appears to lie above the water table. In order to further assess the issue of whether or not aerobic decomposition is more significant than anaerobic at this site, some additional analysis of monitoring data has been completed.

Aerobic decomposition is expected to result in "consumption" of oxygen and "production" of carbon dioxide. Thus, potting the "consumption" of oxygen, which is taken as the level of oxygen in the atmosphere less the amount measured in the soil vapour, against the carbon dioxide produced, which is the carbon dioxide measured in the soil vapour less the amount naturally in the atmosphere, should result in a 1:1 relationship. Some 753 of the soil vapour measurements used in the analyses presented above had oxygen measurements as well as the carbon dioxide measurements. These data were used to estimate the amount of oxygen consumed (the atmospheric value less the measured value) and the amount of carbon dioxide produced (the measured value less the level in the atmosphere). The resulting estimates of carbon dioxide "produced" against the corresponding estimate of the amount of oxygen "consumed' are plotted in Figure 1, as a bubble chart, with the bubble area being proportional to the methane level.

As can be seen in Figure 1, much of the data is scattered around the 1:1 line, as would be expected from aerobic decay. As oxygen "Consumption" approaches the approximately 21% maximum (the amount of oxygen in the atmosphere), methane levels tend to increase, as indicated by the bubble size (which reaches an artificial limit at the upper resolution limit of the methane detectors typically used). The results in Figure 1 are consistent with aerobic decomposition being the dominant form of decomposition for much of the data.

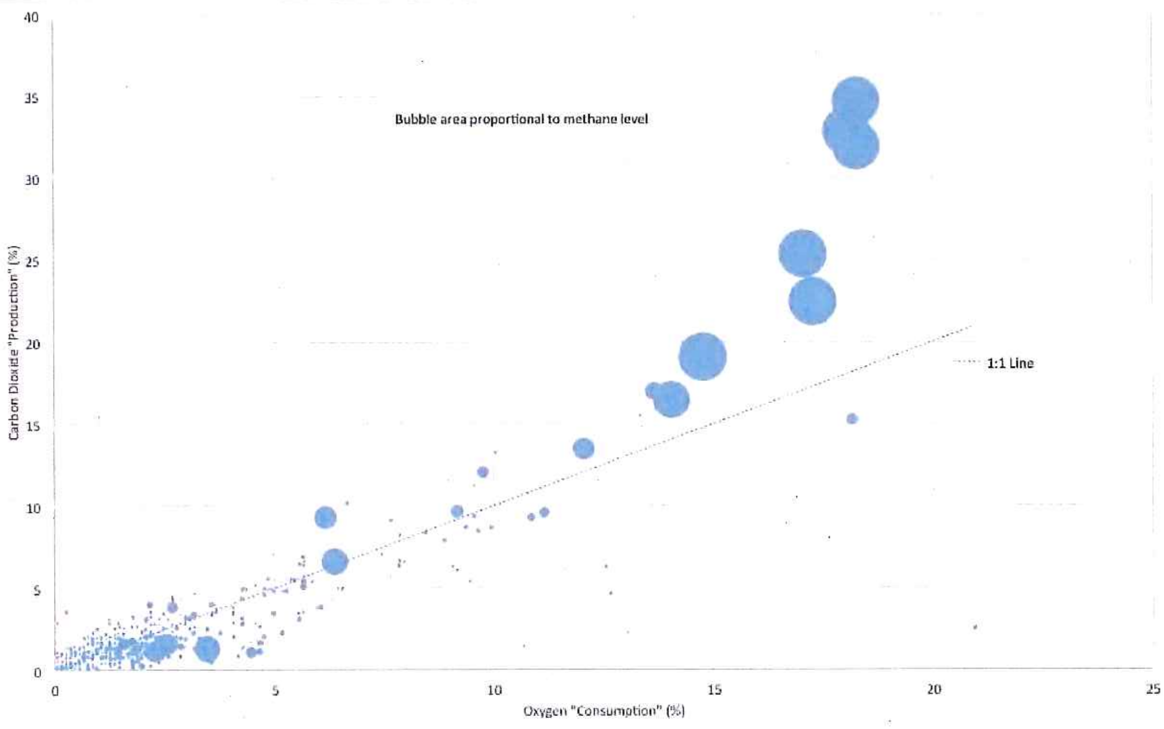

Figure 1: Carbon Dioxide "Production" versus Oxygen "Consumption"

3.2 Discussion of Additional Analysis from the 2010 Assessment

The 2010 assessment also included an estimate of emissions of non-methane organic compounds (NMOCs), using the United States Environmental Protection Agency's Landfill Gas Emission Model (LandGEM). CH2M Hill used version 3.02 of the LandGEM model, which is still the most current version of the model. They estimated that emissions of NMOCs would be between 31 and 54 metric tonnes, depending on the selection of parameters. One of the key input parameters for the model is the amount of waste disposed by year. There has been no additional placement of waste on site beyond that assumed by CH2M Hill in the 2010 assessment. One of the variable parameters in the LandGEM model is the percentage of methane in the landfill gas. The default is 50%, which as discussed in Section 2.4, is much higher than the percentage estimated from monitoring results. However, the model only accepts values for the percentage of methane levels in the landfill gas in the range from 40% to 50%, hence rerunning the model would not allow use of significantly more accurate values.

3.3 Discussion of Recommendations from the 2010 Assessment

CH2M Hill noted that given the proximity of the landfill to residential areas to the east and taking into consideration a preliminary assessment of risks related to possible migration of landfill gas (Golder, 2009), that there should be additional investigation to determine whether or not LFG collection and treatment is required.

Golder concurs, and a proposed plan for further investigation will be included in an updated closure report that is in preparation by Golder.

4.0 CLOSURE

This report reviews a Landfill Gas Assessment report by CH2M Hill completed in 2010, to fulfil the requirements outlined in the Landfill Gas Management Regulation for a review after five calendar years for landfills that in a preliminary assessment were estimated to emit less than 1000 tonnes of methane annually. The 2010 assessment included estimated waste disposed to closure in 2010. Since there has been no additional placement of waste beyond the closure in 2010, the assessment primarily included a review of the selection of parameters for use in estimation of the methane. As discussed, the parameter values selected for the earlier assessment appear to be reasonable. As further discussed, however, the monitoring results now available suggest that aerobic decomposition of waste is much more significant at the site than anaerobic, with methane probably comprising less than 3% of the landfill gas generated on average, rather than 50% assumed in the screening level modelling. Based on the landfill gas monitoring completed at the site, it appears likely that the actual methane emissions are considerably lower than estimated in the 2010 assessment.

The Landfill Gas Management Regulation does not specify that there is a requirement for additional assessment after the completion of a supplementary assessment. Given the results of the supplementary assessment presented herein and the fact that the landfill no longer receives waste, it is suggested that no further assessment under the Landfill Gas Management Regulation appears to be required. It should be noted that landfill gas monitoring is ongoing, but the focus is on assessing potential off-site migration of landfill gas, rather than estimation of methane emissions to the atmosphere. The landfill gas monitoring program will continue, with results being reported to the Ministry of Environment regularly (currently annually).

Yours truly,

GOLDER ASSOCIATES LTD.

Gary Barrett

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Principal

GB/RP/kv

https://capws.golder.com/sites/1406505westsidelandfillclosureplan/phases and tasks/07 deliverables/1406505-002-r-rev1-8001-landfill gas generation assessment update-18mar_15.docx

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United States Environmental Protection Agency, LandGEM 3.02 Excell spreadsheet: http://www.epa.gov/ttn/catc/dir1/landgem-v302.xls

APPENDIX A

2010 Landfill Gas Assessment

Findings of Initial Landfill Gas Generation Assessment Report – Westside Landfill, Regional District of Central Okanagan (RDCO)

PREPARED FOR:	Chris Radford, RDCO
PREPARED BY:	Caroline Théoret, P.Eng., CH2M HILL
REVIEWED BY:	John Muller, P.Eng., CH2M HILL
COPIES:	Scott Gamble, P.Eng., CH2M HILL
DATE:	May 25, 2010
PROJECT NUMBER:	401157

At the request of the RDCO, CH2M HILL Canada Limited (CH2M HILL) has prepared the following Technical Memorandum (TM) to summarize findings associated with the initial Landfill Gas (LFG) generation assessment (the Assessment) conducted as part of the ongoing Detailed Closure Plan being developed for the Westside Landfill (Site). The Assessment was completed in accordance with the British Columbia Ministry of Environment (BC MOE) Landfill Gas Management Regulation (Regulation) that was approved on December 8, 2008.

1. Background

The Site began receiving Municipal Solid Waste (MSW) in 1960 and currently operates under the Operational Certificate (OC) PR12217 issued by the BC MOE on May 28, 1997. The Site primarily services residents and businesses on the west side of Lake Okanagan (municipalities of Westside and Peachland) and RDCO's west electoral area. The Site is scheduled to close in the summer of 2010. The total waste buried at the Site in 2008 was 33,659 metric tonnes (Golder Associates, 2009). Based on a 3-percent population increase, approximately 36,800 metric tonnes of waste will be diverted in 2011 for disposal to the Glenmore Landfill in Kelowna, British Columbia (BC) following Site closure. CH2M HILL was retained in 2010 by RDCO to prepare the Detailed Closure Plan for the Site.

2. Regulation

On December 8, 2008, a new regulation for the management of LFG at BC-regulated landfill sites was ordered and approved. The Regulation describes a regulated landfill site as a site with 100,000 metric tonnes or more of MSW in place, or that has received 10,000 or more metric tonnes of MSW annually for disposal into the landfill site in any calendar year after 2008 (BC MOE, 2008). Since a total of 10,624 metric tonnes of MSW was buried at the Site in 2009 (Rotheisler, 2010), the Site is considered a regulated landfill and subject to the Regulation. The total quantity of waste buried at the Site was estimated to be approximately 778,000 metric tonnes, which also falls under a regulated landfill.

The Assessment and report must be conducted in accordance with Regulation requirements and submitted to the BC MOE Director no later than January 1, 2011. An LFG management facilities design plan must be prepared for the Site if the generation of methane is estimated to be 1,000 metric tonnes or more in the calendar year immediately preceding the Assessment. This plan must be submitted no later than 1 year after the date the Assessment Report was submitted to the director. The Regulation defines LFG management as including managing LFG migration, collection, storage, and flaring. The LFG management facilities and practices must be installed and implemented no later than 4 years after the LFG management facilities design plan submittal date.

The Regulation states that the Assessment must be conducted in accordance with the most recent edition of LFG guidelines as approved by the BC MOE Director. The LFG Generation Assessment Procedure Guidance Report (CRA, 2009) is the LFG Guideline used by the BC MOE. It is available on the BC MOE Regulation official website and must be used to guide the Assessment. The Regulation further states that the Assessment must be prepared by a qualified professional who will use his or her knowledge with respect to solid waste and LFG management to select models for LFG estimation, assess results, and provide required recommendations.

3. Initial LFG Assessment

The Assessment has been conducted according to the Regulation. The report will be included in the Detailed Closure Plan for the Site. This TM prepared by CH2M HILL summarizes findings of The Assessment. This section details the methodology used to complete the Assessment, the annual waste buried at the Site, the references for the selected methane generation input parameters, the results, and an overview of the next steps required by the Regulation.

3.1 Methodology

LFG production at the Site was estimated using the calculation tool available on the BC MOE Regulation official website and according to the BC MOE LFG Guideline.

The model is based on a first-order decomposition rate equation for quantifying emissions from the decomposition of wastes in MSW landfills. Exhibit 1 presents the parameters required to run the model.

EXHIBIT 1
Input Parameters used in the BC MOE LFG Guideline Calculation Tool

Input Parameters or Constants	LFG Generation Model
	BC MOE LFG Guideline, Calculation Tool
Landfill first year	1980
Landfill closure year	2010
Annual waste tonnage	Annual waste acceptance for 30 years (from 1980 to 2010) Annual waste tonnages for relatively inert waste and moderately decomposable and decomposable wastes
k	methane generation rates
methane generation rates	for relatively inert, and moderately decomposable and decomposable wastes
Lo	potential methane generation capacity
Waste types	relatively inert, moderately decomposable, and decomposable wastes

k = Methane Generation Rate per year

Lo = Potential Methane Generation Capacity (m^3 methane / Mg of waste) or (m^3 methane / metric tonne of waste)

m^3/Mg = cubic meters per megagram

m^3/ metric tonne = cubic meters per metric tonne

The model accounts for different factors associated with the generation of LFG and contains a matrix that requires the user to define historical waste characteristics.

3.2 Waste Characteristics

Characterization according to Waste Types is required to conduct the simulation using the BC MOE LFG Guideline calculation tool. Waste must be characterized into three categories: relatively inert, moderately decomposable, and decomposable. As is the case for most BC landfill sites, waste composition studies have not been conducted at the Site. A Waste Audit was conducted by the Regional Waste Reduction Office in conjunction with the Glenmore Landfill between April 28 and May 2, 2008 at the Glenmore Landfill. Considering the proximity of both landfills, the above-mentioned Glenmore waste composition study has been selected to define the Waste Type for the Westside Landfill. Considering that, as is the case for most BC landfill sites, waste composition studies have not been conducted every year or on a regular basis, it should be noted that the Waste Type percentages have been used to characterize the waste for every year of landfill development, from beginning to closure.

Based on the above-mentioned study and on Appendix A, Categorized Waste Types, from the BC MOE LFG Guideline, decomposable waste represents the most significant component of the waste stream, with 37 percent; followed by relatively inert waste, with 28 percent; and a quantity of moderately decomposable wastes of approximately 35 percent.

In a landfill, methane generation is directly linked to waste decomposition and its organic content. Considering this and that there is no waste composition study for the Site, in order to conduct a conservative assessment, Waste Type percentages were modified, and the following were used in the simulation:

- Decomposable waste: 42 percent (was increased by 5 percent)
- Moderately decomposable: 35 percent
- Relatively inert waste: 23 percent (reduced by 5 percent)

3.3 Annual Waste Buried

Exhibit 2 presents the estimated annual amount of MSW disposed at the Site from years 1960 to 2010. The waste history estimates are based on the annual quantity of waste buried at the site between 2000 and 2008 (Susan, 2008), the estimated remaining quantity of waste to be disposed in 2010 in order to reach closure capacity for the Site, the estimated total volume of waste buried at the Site, and the following assumptions:

- Population increase of 3 percent after 1960
- Tonnages per capita per year (tcy) of 0.70 from 1960 to 1990
- Tonnages tcy of 0.65 from 1991 to 1999

The estimated total amount of waste buried at the Site was based on the following site data and waste factors:

- Estimation of total landfill volume using the May 20, 2009 topographic survey that was conducted by Ansell Construction Ltd.
- 30 percent volume for cover material
- Waste density of 0.7 metric tonne/m^3

EXHIBIT 2
Annual Quantity of Waste Disposed at the Site

Years	Waste Disposed	Cumulative Waste Disposed	Population	tcy
	Metric tonnes	Metric tonnes		
1960	7,041	7,041	10,059	0.70
1961	7,259	14,301	10,370	0.70
1962	7,484	21,784	10,691	0.70
1963	7,715	29,500	11,022	0.70
1964	7,954	37,453	11,363	0.70
1965	8,200	45,653	11,714	0.70
1966	8,453	54,107	12,076	0.70
1967	8,715	62,821	12,450	0.70
1968	8,984	71,806	12,835	0.70
1969	9,262	81,068	13,232	0.70

EXHIBIT 2
Annual Quantity of Waste Disposed at the Site

Years	Waste Disposed	Cumulative Waste Disposed	Population	tcy
	Metric tonnes	Metric tonnes		
1970	9,549	90,617	13,641	0.70
1971	9,844	100,461	14,063	0.70
1972	10,148	110,609	14,498	0.70
1973	10,462	121,072	14,946	0.70
1974	10,786	131,858	15,408	0.70
1975	11,120	142,977	15,885	0.70
1976	11,463	154,441	16,376	0.70
1977	11,818	166,258	16,883	0.70
1978	12,183	178,442	17,405	0.70
1979	12,560	191,002	17,943	0.70
1980	12,949	203,951	18,498	0.70
1981	13,349	217,300	19,070	0.70
1982	13,762	231,062	19,660	0.70
1983	14,188	245,250	20,268	0.70
1984	14,626	259,876	20,895	0.70
1985	15,079	274,955	21,541	0.70
1986	15,545	290,501	22,207	0.70
1987	16,026	306,527	22,894	0.70
1988	16,522	323,048	23,602	0.70
1989	17,033	340,081	24,332	0.70
1990	17,559	357,640	25,085	0.70
1991	16,809	374,450	25,861	0.65
1992	17,329	391,779	26,661	0.65
1993	17,865	409,644	27,485	0.65
1994	18,418	428,062	28,335	0.65
1995	18,987	447,050	29,211	0.65
1996	19,575	466,624	30,115	0.65
1997	20,180	486,804	31,046	0.65
1998	20,804	507,609	32,006	0.65
1999	21,448	529,056	32,996	0.65

EXHIBIT 2
Annual Quantity of Waste Disposed at the Site

Years	Waste Disposed	Cumulative Waste Disposed	Population	tcy
	Metric tonnes	Metric tonnes		
2000	19,939	548,995	34,017	0.59
2001	19,460	568,455	35,069	0.55
2002	24,030	592,485	36,154	0.66
2003	24,040	616,525	37,272	0.64
2004	30,498	647,023	38,424	0.79
2005	28,244	675,267	39,613	0.71
2006	28,857	704,124	40,838	0.71
2007	31,429	735,553	42,101	0.75
2008	33,659	769,212	43,364	0.78
2009	10,624	779,836	44,665	0.24
2010	2,562	782,398	46,005	0.06

Notes:

1: Waste disposed at the Site between 2000 and 2007 (Susan, 2008).

2: Waste disposed at the Site in 2008 (Golder Associates, 2009).

3: Waste disposed at the Site in 2009 (Rotheisler, 2010).

4: Estimated waste quantity to be buried in 2010 considering the Site closure.

3.4 Methane Generation Parameters

3.4.1 Methane Generation Potential (Lo)

The input parameters used for the Lo value are based on the BC MOE LFG Guideline calculation tool (Table 5.1). For this Site, the model uses a Lo-value of 20 m^3 methane (CH_4)/ metric tonnes of waste for relatively inert waste, 120 m^3 CH_4/metric tonnes of waste for moderately decomposable waste, and 160 m^3 CH_4/metric tonnes of waste for decomposable waste.

3.4.2 Methane Generation Rate (k)

Input parameters used for the methane generation rate constant (k) are based on the BC MOE LFG Guideline calculation tool (Table 5.2), which are based on annual precipitation. For this Site, the model uses a k-value of 0.01/year (yr) for relatively inert waste, 0.02/yr for moderately decomposable waste, and 0.05/yr for decomposable wastes. The annual precipitation for the Site has been estimated at 415 millimeters (mm) based on the selected Environment Canada weather station located in East Kelowna.

3.4.3 Water addition factor

According to the BC MOE LFG Guideline, Section 5.4, the selected k-value should be corrected based on the landfill operation and maintenance practices, including: stormwater management, cover properties, and the extent of leachate recirculation or stormwater injection. Based on Table 5.3 of the BC MOE LFG Guideline, the water addition factor appropriate for the Site conditions in 2009 is 0.9.

Low-permeability final cover has been installed on a portion of the Site, and the landfill stormwater management works have been implemented partially across the Site. An additional assessment has been conducted using the BC MOE LFG Guideline calculation tool with a water addition factor of 1.0 to estimate the methane generation, assuming low-permeability final cover installed across the entire Site and stormwater best management practices fully implemented across the Site. The result is discussed in the following section.

3.5 Results of the Assessment

The estimated LFG generation rates for the Site are shown in Exhibit 3.

EXHIBIT 3
Estimated LFG Generation Rates for the Site

		LFG Generation Model		
Parameters	**Units**	**BCMOE guideline, calculation tool, (Note)**		
		Waste Characteristics		
		Relatively inert 23 %	**Moderately decomposable 35%**	**Decomposable 42 %**
k	per yr	0.01	0.02	0.05
Lo	m^3 CH_4 / metric tonnes of waste	20	120	160
Results	**Units**			
Methane generated in 2009	metric tonnes CH_4/yr	953		

Note:
(Regional Waste Reduction Office, 2008)

According to the BC MOE LFG Guideline calculation tools, the quantity of methane generated in 2009 at the Site is 953 metric tonnes, using a water addition factor of 0.9, the waste characteristics according to the Waste Audit Report for the Glenmore Landfill (Regional Waste Reduction Office, 2008), and increasing the decomposable waste content by 5 percent to be conservative, as discussed in Section 3.2.

3.6 Additional Assessment

A simulation was conducted using the LandGEM - Landfill Gas Emission Model, version 3.02 (LandGEM), United State (U.S.) Environmental Protection Agency (EPA) to estimate the Non-methane Organic Compounds (NMOCs). Results of the Assessment show that the emissions included 31 and 54 metric tonnes of NMOCs in 2009, using a k-value of 0.02 /yr and Lo-value of 100 and 170 m^3 CH_4/metric tonnes of waste. References for the Lo-value are described as follows:

- Reference for Lo of 170 m^3 CH_4/metric tonnes of waste: Clean Air Act (CAA) default. The CAA defaults are based on requirements for MSW landfills.
- Reference for Lo of 100 m^3 CH_4/metric tonnes of waste: Inventory defaults are based on emission factors in EPA's Compilation of Air Pollutant Emission Factors (AP-42) and can be used to generate emission estimates for use in emission inventories and air permits in the absence of site-specific test data.

4. Conclusion and Next Steps

This TM summarizes findings associated with the Assessment conducted as part of the Detailed Closure Plan that is currently being developed for the Site. The Assessment has been completed in accordance with Regulation requirements. According to the BC MOE Guideline calculation tools, the quantity of methane generated in 2009 is not greater than 1,000 metric tonnes.

It should be noted that the result of the Assessment is based on methane generation input parameters as recommended in the BC MOE LFG Guideline. Also, historical data prior to 2000 were not available to estimate the total quantity of waste buried at the Site, which has been estimated based on the May 20, 2009 topographic survey conducted by Ansell Construction Ltd and assumed density. Finally, the Waste Type percentages are based on the Waste Audit Report (Regional Waste Reduction Office, 2008), and have been used to characterize the waste for every year of landfill development from beginning to closure. Considering the above, the estimated methane generation calculated in 2009 for the Site could vary based on actual tonnage of waste landfilled and different site-specific input parameter assumptions.

It should be noted that the rate of LFG direct emission to the atmosphere could be lower than the LFG generation rate considering methane oxidation through the landfill cover which has been installed over a large area of the landfill's slopes. The LandGEM assessments conducted for this Site show the emission of NMOCs is below 150 metric tonnes/yr.

According to the Regulation, if the estimate of methane generated in 2009 is not greater than 1,000 metric tonnes, a LFG management facilities design plan for the Site is not required. The Regulation states that if the estimate of methane generated in 2009 is not greater than 1,000 metric tonnes, a supplementary assessment following Section 15 of the Regulation must be conducted during the fifth calendar year following the calendar year of the previous assessment (2010). The supplementary assessment report must be submitted to the Director no later than March 31, 2015.

Considering the east landfill footprint is at the property boundary and the proximity of the residential area, and based on CH2M HILL's evaluation of the Landfill Gas Monitoring and Preliminary Vapour Risk Assessment for the Westside Landfill (Golder, 2009), there are a number of issues that are a cause for concern and would make it very difficult to support the conclusions without additional investigation. Therefore, CH2H HILL recommends additional investigation to evaluate whether LFG collection and treatment is required for LFG migration and odor control.

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APPENDIX C
Water Balance Modelling

WATER BALANCE MODELLING

The United States Environmental Protection Agency's (EPA's) Hydrological Evaluation of Landfill Performance (HELP) model is often used for cover evaluation, but it is designed for systems that have barrier layers, which evapotranspiration (ET) covers do not have. Alternate approaches are therefore needed to evaluate ET covers. For design and evaluation of the probable performance of cover systems at Westside Landfill, water balance modelling was the primary tool used.

Water balance models are based on the following general conservation equation:

$$Input - Output = Change\ in\ Storage$$

In the case of ET covers, "storage" refers to the amount of water that is held in the cover system. For assessment of ET covers, the amount of water stored in the soil is expressed as a volume per unit area, which if dimensionally consistent units are used, can be expressed as a water equivalent depth. Since rain and total precipitation in Canada are typically expressed in millimetres, all of the terms in the water balance are expressed in millimetres (as a water equivalent depth) per a specified unit of time. The water balance calculations used here are all based on monthly values, since that is the period for which data is available.

The inputs are monthly values of rainfall and estimated snowmelt. The storage terms include soil moisture and accumulated snow on the surface of the earth. The outputs are estimated evapotranspiration, surface runoff and vertical drainage from the bottom of the cover system. It is the vertical drainage from the bottom cover that can lead to leachate generation and therefore is usually of most significance in evaluation of cover performance.

Of the components of the monthly water balance discussed above, rainfall is the only parameter that is generally available from climate records. All of the other parameters must be estimated. The estimates involve the values of other parameters (for example, temperature for some) and may also rely on previous values of parameters (such as snow accumulated in the previous month) and on physical limitations, such as the water holding capacity of the cover system (a function of soil type and depth). Dunne and Leopold (1978) describe a water balance based on monthly climate data, which forms the basis for what will be referred to here as the "Standard Water Balance" (hereafter referred to as the SWB). The United States Geological Survey (USGS) has developed a software model for monthly water balance estimation that can be used even if snowfall and snow accumulation data are not available; the basis for the model was described in a paper by McCabe and Markstrom (2007). The USGS model has been published and the code can be inspected, hence it provides a well documented approach that can be compared to other approaches to water balance modelling.

In the following we describe the general basis of the modelling, including data sources, inputs, outputs and storage changes.

DATA SOURCES

Historical monthly climate data are available from Environment Canada for a number of climate stations, including historical sites. The number of parameters available varies by station, but typically includes the rainfall, snow, total precipitation and average (mean) monthly temperature needed for water balance modelling by month.

The data set generally requires additional processing in order to use it in water balance modelling. In cases where a value is highlighted as an estimate by Environment Canada, that estimate will be used as the value for input to the model. Where the value of a parameter such as rain or snow is identified as a "trace", the value will be set to zero. In some cases, individual values are marked as missing. Provided that missing values do not constitute more than a small percentage of the total number of values, missing values are replaced with the monthly average for that parameter.

In the case of data from Kelowna Airport, reasonably complete data was available from 1970 to 2004. Missing values were present for a few parameters, but in no more than one of the years from 1970 to 2004; these were replaced by the period average. Data in 1969 was used from April of that year as an initiation year, but was not included in any of the averages since it was not a complete year, but also because initial values of some parameters, such as soil moisture storage, must be set arbitrarily for initiation of the model. Since the models tend to reach limiting values of soil moisture as the model runs, the impact of selecting the values of certain parameters has little impact on the results in later years of the model run.

INPUTS

Input to the cover system is modelled as rainfall plus snowmelt, less the amount of surface runoff that is generated.

Rainfall

Total monthly rainfall is typically available from climate records and it is used directly in the SWB. However, the USGS model is designed so that it partitions precipitation into rain and snow components, given the temperature.

Snow Melt

Snow melt in both models relies on two other estimates, one of which is the amount of snow available for melting and the other is the estimate of the potential snow melt, which is based in part on average monthly temperature. The amount of snow that is available for melting in a month is the sum of the amount of snow that fell in that month plus any snow from the previous month that was predicted not to have meltedAs discussed by Dunne and Leopold (1978), many algorithms for potential snow melt are simply linear functions of temperature; the coefficients may differ somewhat between sites, and the literature has published values that can be used. For sites in the Okanagan, it is our experience that any reasonable coefficients result in snow melt results that are quite similar to each other. The estimated snowmelt is equal to the potential snowmelt if the available amount of snow exceeds that value, or is set to the amount of snow available for melting if the potential snowmelt exceeds the amount of snow available for melting. Any snow that does not melt in a month is carried forward to the next month and the amount of snow that falls in the next month is added to it to provide the total amount of snow that is available for melting. As McCabe and Markstrom (2007) discuss, the USGS water balance model uses a more complex approach to estimation of snow melt, which includes a maximum melt function that is based on a percentage of the snow available to melt. The default value for the amount of snow that can melt is 50%, but it can be adjusted.

Surface Runoff

The SWB and the USGS water balance models have the soil cover as the storage system that the balance is developed for. From this perspective, surface runoff is not an input to the cover system, but rather a factor that must be taken into account in estimating the input of water into the cover system.

For the SWB model, it was assumed that there is ordinarily no surface water runoff since the components of an ET cover would generally be expected to be able to accept all of the input to the surface. Even a soil with a hydraulic conductivity of $1x10^{-5}$ cm/s can accept over 260 mm per month and over 3000 mm per year, without taking into account capillary forces which at the onset of a rainfall input can significantly increase the ability of soil to accept water without generation of surface runoff. While there may be intense, short duration storms that can generate surface runoff (depending on antecedent conditions) and unusual situations, such as the development of "concrete frost" whereby interstitial spaces (pores) in soils are filled with ice that can temporarily reduce the permeability of the soil, under most conditions we would not expect significant net surface runoff from an ET cover at Westside Landfill.

As noted by McCabe and Markstrom (2007), in the USGS Model surface runoff is estimated as a percentage of the sum of rain plus snowmelt. The default setting for surface runoff in the USGS model is 5% of the estimated total of rainfall and snowmelt. However, this default setting can be changed.

Input to the Cover System

The estimated total input to the cover system for a given month is equal to the sum of rainfall and estimated snow melt for that month, less the estimated surface runoff for that month, if any. As noted already, the SWB model assumes no surface runoff, so the input in a given month is simply equal to the sum of rainfall and estimated snowmelt in that month. For the USGS water balance model, one set of runs were completed with the default values for surface runoff (5%) as a percentage of rain plus snowmelt and for maximum snowmelt as a percentage of available snow (50%). Another set of runs were completed where the value for the fraction of input lost as surface water runoff was set to 0% and the maximum fraction of snow that could occur in a given month was set to 100% of the available snow or the potential snowmelt (estimated from temperature), whichever was less. This latter set of runs would be expected to yield results similar to those of the SWB model, since the underlying assumptions are similar, even if different algorithms are used for some components of the water balance.

Outputs

The outputs from the water balance equation for an ET cover are evapotranspiration, the combination of direct evaporation from the soil surface and from transpiration in plants, and the amount that would be expected to be lost to deep percolation, referred to as the "surplus" in the USGS water balance model. The amount of "surplus", or water lost to deep percolation, yields an estimate of the amount of water available for generation of leachate.

Evapotranspiration

Evaporation depends on the potential evapotranspirtion due to local climate conditions and the amount of moisture available for evapotranspiration. The estimates of potential evapotranspiration are based on Thornthwaite's (1948) approach. A fuller explanation of the approach can be found in Dunne and Leopold (1978) and it is also discussed by McCabe and Marstrsom (2007). Dunne and Leopold provide tables of correction factors for seasonal variations in day length, by latitude and month, while McCabe and Markstrom rely on a day length calculation. The two provide corrections that, as expected, are very similar to each other. For simplicity, linear interpolation between the values for selected months was used to estimate the values of monthly latitude correction factors for a given month.

For the SWB model, if the sum of inputs to the cover system in a given month and the available soil moisture is greater than or equal to the potential evapotranspiration for that month, then actual evapotranspiration will equal the potential evapotranspiration. If potential evapotranspiration is greater than the sum of inputs to the cover system and available soil moisture, the actual evapotranspiration is equal to the sum of the input and the available soil moisture.

The USGS water balance model is similar in general approach to the SWB model, but uses a more complex function to estimate the amount of soil moisture that is available to be withdrawn, with extraction of soil moisture becoming more difficult as the soil moisture declines. This approach would likely result in a somewhat more realistic estimate of soil moisture during the "dry" season than would the SWM model, but it is not expected to have a significant impact on the estimate of "surplus" (percolation to greater depth).

"Surplus"

The surplus, which is the water that flows from the soil cover to greater depth, and which therefore can generate leachate by flowing through the waste, is calculated as a residual term from all of the other terms in the water balance, whether it be for the SWB model or the USGS water balance model. All of the other parameters are either directly available as monthly data or estimated from selected monthly data. The only true variable in either the SWB or USGS water balance models is the water holding capacity of the cover system, which is a function of the characteristics and depth of the soil.

Comparison of Estimates of Leachate Production

The SWB approach was compared with two versions of the USGS water balance model, one with the default settings and one with the runoff coefficient set to zero (such that there is not loss to runoff) and also allowing snowmelt to take place up to the potential snowmelt limit (thus allowing a larger "pulse" of snowmelt in the spring). Both the modifications to the default settings of the USGS model result in the estimate of "surplus" (which leads to leachate production) to be larger than it would be otherwise.

The results of model runs calculating surplus from soil water holding capacities of the cover system, ranging from 50 to 200 mm in 25 mm steps, are shown in the table below.

Figure A 1 - Estimated "Surplus".

Model	Water Holding Capacity (mm)						
	50	**75**	**100**	**125**	**150**	**175**	**200**
Standard Water Balance Model	69	46	27	14	5.8	1.1	0.0
USGS (specified values)	47	27	14	6.9	3.6	1.8	1.2
USGS (default values)	28	14	4.6	1.3	0.3	0.0	0.0

The estimated surplus is in mm per year.

The SWB model provides the highest estimate of surplus (or potential leachate production) for a given water holding capacity. The USGS model, with specified values for the runoff coefficient and maximum snowmelt fraction, provides the next highest estimate. The USGS model with default values provides the lowest estimate of surplus (or potential leachate production).

https://capws.golder.com/sites/1406505westsidelandfillclosureplan/phases and tasks/07 deliverables/1406505-003-r-rev0-5000-attachments-11may_15/appendix c/appendix c - water balance modelling.docx

APPENDIX D

Landfill Gas Management Plan, Westside Landfill, Golder Associates Ltd. (2013)

February 13, 2013

WESTSIDE LANDFILL

LANDFILL GAS MANAGEMENT PLAN

Submitted to:
Mr. Chris Radford
Regional District of Central Okanagan
1450 KLO Road
Kelowna, BC
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REPORT

Report Number: 1114930084-R-Rev0-9100

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Golder Associates

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FIGURES

1.0 INTRODUCTION

The Regional District of Central Okanagan (RDCO) is currently working toward closure of Westside Landfill. In 2011, CH2M HILL Canada Ltd. (CH2M HILL) completed a report entitled *"Westside Landfill Closure Plan, Final Report"* (hereafter referred to as the Closure Plan) for the RDCO, in part based on an earlier 1993 closure plan prepared by Reid Crowther and Partners. Golder Associates Ltd. (Golder) was retained by the RDCO to consider additional options for a cover system for Westside Landfill, in consultation with CH2M HILL. Golder (2012) completed a report titled *"Options for Final Cover Systems, Westside Landfill"* in September of 2012 (hereafter referred to as the Cover Systems Report). The Cover Systems Report recommended that an "evapotranspiration" final cover (hereafter referred to as an ET cover) be used as part of closure of Westside Landfill, following earlier discussion of this option with representatives of the British Columbia Ministry of Environment (MoE). It is assumed for the purposes of this report that closure will proceed as outlined in the Closure Plan, incorporating additional recommendations provided in the Cover Systems Report.

Landfill gas management and the potential for offsite migration of methane were discussed in CH2M HILL's Closure Plan. Methane is potentially explosive when it is present in air in concentrations ranging from about 5% to 15%. The lower end of this range (5%), or a concentration of methane of 50,000 parts per million (ppm), is referred to as the lower explosive limit (LEL) and methane levels are often reported as a percentage of the LEL (a concentration of methane of 50,000 ppm is therefore equivalent to 100% LEL). Migration of methane to homes or other structures could pose a risk of explosion if it were present in sufficiently high concentrations.

Methane, along with some other potential landfill gases, is currently monitored at the landfill and the results are reported annually to the MoE. The Closure Plan recommends that a passive landfill gas collection system be installed and provides recommendations for post-closure monitoring. General guidance on contingency measures that could be put into place, should monitoring suggest that additional action is required to further limit the potential for off-site migration of methane, is also provided in the Closure Plan. This report addresses the MoE request for a landfill gas management plan that includes site specific criteria that would trigger particular contingency responses to possible migration of methane. In addition, this report provides discussion on possible modifications to the current monitoring program for future post-closure monitoring.

In Section 2.0 of this report, we provide a brief review of some of the relevant background information, including a brief summary of site conditions and regulatory requirements (related to landfill gas). In Section 3.0 of this report, a discussion of key post closure landfill gas issues is provided, setting the stage for a discussion of potential control, monitoring and mitigation measures in Section 4.0.

2.0 BACKGROUND INFORMATION

2.1 Site History

Westside Landfill is understood to have been in operation since the late 1960s, and was operated under Operational Certificate (OC) PR-12217 from May 28, 1997 (CH2M HILL, 2011) onwards. It is further understood that in June of 2009 waste disposal was restricted to waste that was direct hauled to the site by residents. All disposal is understood to have ceased in mid-2010 (Ibid.), with the exception of clean soil material to be used as a component of a cover system for the landfill.

2.2 Site Conditions

The location of the site is shown in Figure 1. A general site map showing the approximate current topography of the site and the location of monitoring wells and vapour pressure probes is provided in Figure 2.

CH2M HILL (2011) reports that waste was placed above grade to a depth of about 20 metres on the south side of the landfill and on the order of 8 metres at the north side. CH2M HILL (ibid.) estimated that about 778,000 tonnes of waste have been placed at the site and that most of this waste was placed above grade, with little waste placed in below grade trenches.

Based on mapping accessed from the British Columbia Ministry of Energy's Minfile site (July, 2012), the bedrock underlying the site is comprised of Eocene (approximately 56 to 34 million years before present) alkaline volcanic rocks that are part of the Penticton Group (mapped as undivided members of the Marron, Kettle River, Springbrook, Marama and Skaha Formations).

The site is semi-arid, with annual potential evapotranspiration being well above annual precipitation, on average (see Golder 2012 for further discussion). The water table has been inferred to flow generally southeast across the landfill. Groundwater quality and landfill gas monitoring is currently being conducted quarterly, with the results being reported annually (for additional discussion, see Golder 2012).

Additional discussion of site conditions is provided in the Closure Report (CH2M HILL, 2011) and the Cover Options Report (Golder, 2012).

2.3 Landfill Gas Monitoring Program

Methane monitoring began at the site in July of 2000. Beginning in spring of 2011, the recommendations for implementation of a landfill gas (LFG) monitoring program included in the Closure Plan (CH2M HILL, 2011) were put into effect. By the end of 2011, eleven new LFG probes had been installed at selected locations along the perimeter of the landfill, bringing the total number of monitors to 36 (see Figure 2 for the locations of historic and current monitoring locations). Monitoring at these locations is currently taking place quarterly. In addition to methane (expressed in ppm and/or as % LEL), oxygen, carbon dioxide, carbon monoxide and hydrogen sulphide are currently included in the monitoring program. Results are reported to the MoE annually (a listing of landfill gas monitoring reports is provided in the References section of this report).

Methane measurements from monitoring conducted in January, May and July of 2012 have been combined with the results of previously reported monitoring rounds at Westside Landfill to provide a data set that extends from the start of monitoring in 2000 to July 2012. There has been some variation in the equipment used over the years, with the result that detection limits and the units of measurement have not been the same over the period of record. Methane levels have been expressed as either a percentage of the lower explosive limit (% LEL) or as methane in parts per million (ppm). The lower explosive limit for methane is generally taken to be equivalent to 50,000 ppm. For this report, methane readings in ppm have been converted to the equivalent % LEL; this convention was followed because the relevant criteria and/or guidelines are expressed as % LEL.

The upper measurement limit for the instruments used is typically 100% LEL. In the few cases where readings have exceeded 100% LEL, a value of 150% LEL was used in calculations where a numeric value was required, such as calculating the median value. There are also some measurements taken where the upper limit was 20% LEL; in those cases a value of 30% LEL was used where numeric calculations were required. The lower limit for measurement has most often been 0.1% in the monitoring rounds, but in some cases it was 1% LEL.

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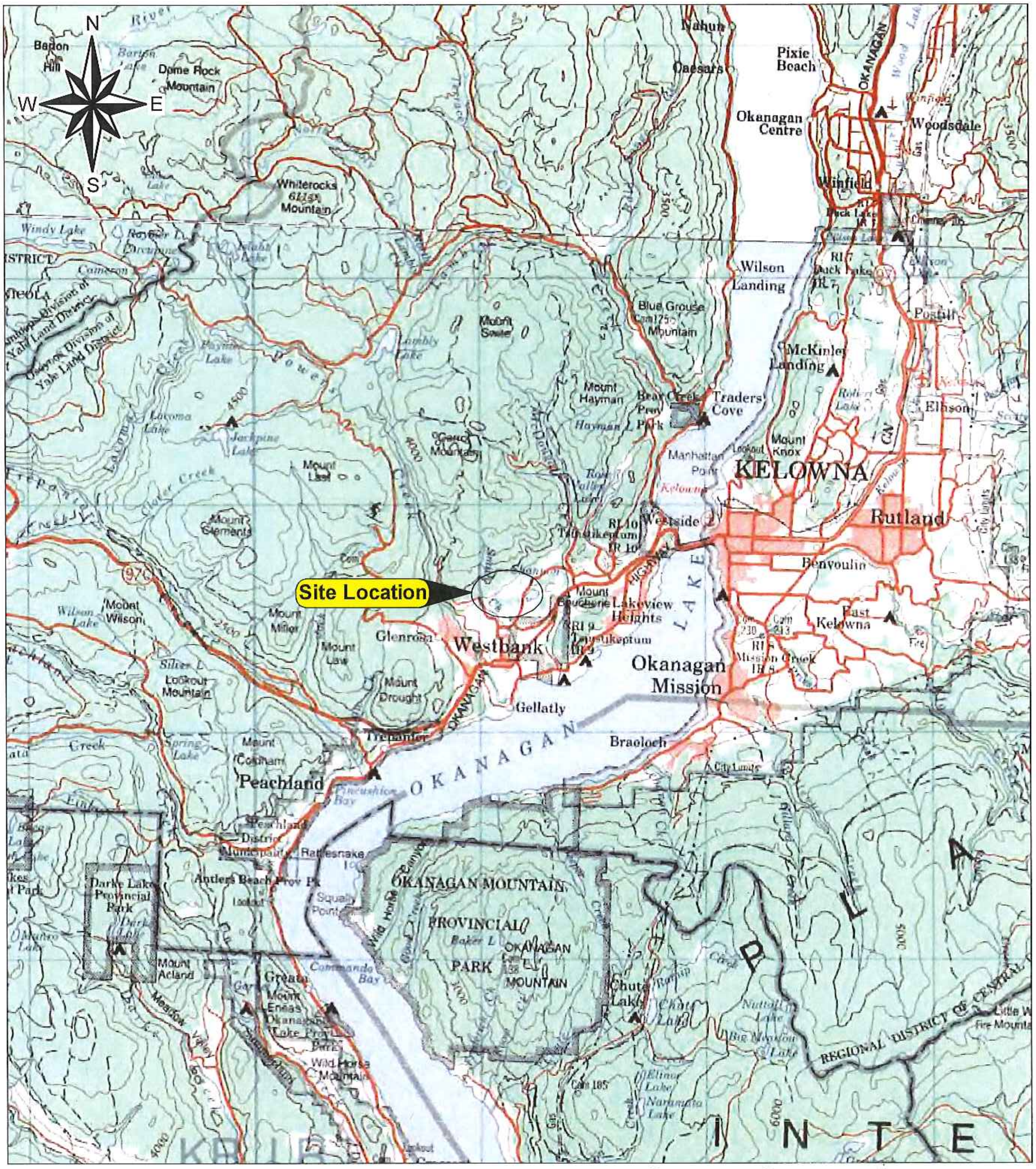


5 0 5
SCALE KILOMETRES

PROJECT

WESTSIDE LANDFILL
LANDFILL GAS MANAGEMENT PLAN
WESTBANK, B.C.

TITLE

KEY PLAN

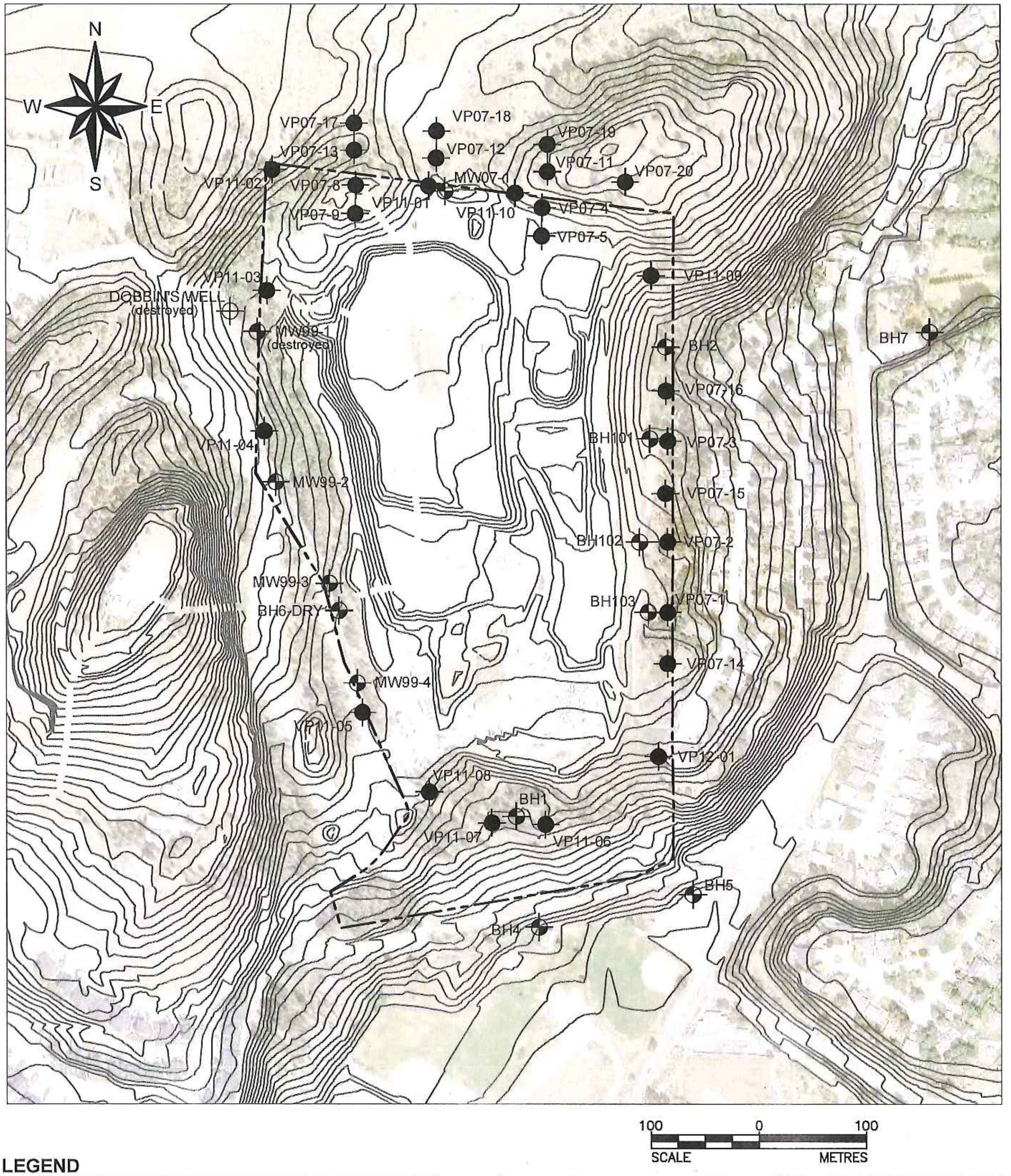
PROJECT No.		11-1493-0084	FILE No.	
DESIGN	AR	27JUL2012	SCALE 1:200,000	REV. 0
CADD	AR	27JUL2012	FIGURE: 1	
CHECK	GB	13FEB2013		
REVIEW	JH	13FEB2013		

Golder Associates

REFERENCES

1. MAP REFERENCE: PRODUCED UNDER LICENSES GRANTED BY HER MAJESTY THE QUEEN IN RIGHT OF CANADA, REPRESENTED BY THE DEPARTMENT OF NATURAL RESOURCES, AND BY SOFTMAP TECHNOLOGIES INC.

\\kel1-s-filesrv1\data\Active\2011\1493\11-1493-0084 RDCO Westside Landfill Closure\Drafting\CAD\GW Monitoring\2012\ Drawing file: Fig 2_1114930084_2012 GW mon_Vapour.dwg Feb 13, 2013 - 9:29am



LEGEND

APPROX. LANDFILL BOUNDARY

BH4 — APPROX. MONITORING WELL LOCATION

VP07-2 — APPROX. SOIL VAPOUR WELL LOCATION (2007)

PROJECT

WESTSIDE LANDFILL
LANDFILL GAS MANAGEMENT PLAN
WESTSIDE, B.C.

TITLE

VAPOUR MONITORING LOCATIONS

Golder Associates

PROJECT No.		11-1493-0084	FILE No.	Fig2_1114940084	
DESIGN	GB	27JUL2012	SCALE AS SHOWN	REV.	0
CADD	AR	27JUL2012	FIGURE: 2		
CHECK	GB	13FEB2013			
REVIEW	JH	13FEB2013			

REFERENCES

1. ORTHO PHOTOS OBTAINED FROM RDCO (2009).

In those cases where a numeric value was required for calculations, the value of the reading was set to one half of the detection limit; that is, at 0.05% LEL or 25 ppm for values that were less than 0.1% LEL and 0.5% LEL or 250 ppm for values less than 1% LEL.

The distribution of monitoring locations can be categorized on the basis of location. In this report, monitoring locations have been grouped by the side of the landfill where they are located, that is on the east, south, west and north sides. The locations are further grouped by whether they are located within the landfill boundaries, near the landfill boundary, or outside the landfill boundary. The distribution of monitors by location is summarized in Table 1. The landfill site itself is roughly rectangular and oriented with the long dimension roughly north-south. Currently, the area adjacent to the east side of the landfill is the most developed, with residences within the 300 metre setback for operating landfills recommended in the MoE's 1993 document, *Landfill Criteria for Municipal Solid Waste* (Landfill Criteria). However, it is noted that Westside Landfill is no longer in use, and the recommended 300 metre setback would no longer apply.

Table 1: Monitors by Location.

Boundary	Location with respect to the Landfill Boundary		
	Inside	Near (within 5 m)	Outside
East	BH 102, BH 103, BH 101D, BH101S, VP11-09, VP12-01	BH2, VP07-01D, VP07-01S, VP07-02, VP07-03, VP07-14, VP07-15, VP07-16	
South	BH 1, VP11-06, VP11-07, VP11-08		BH 4, BH 5, BH 8
West		BH99-1, BH99-2, BH99-3, BH99-4, VP11-03, VP11-04, VP11-05	
North	VP07-05, VP07-07	MW07-1, VP07-08, VP11-01, VP11-02, VP11-10	VP07-11, VP07-12, VP07-13, VP07-18, VP07-19, VP07-20

East Boundary

The maximum LEL levels recorded annually at monitors located on the east side of the landfill are provided in Table 2 for the period from 2000 to the end of 2012. A LEL reading of greater than 100% was measured in May of 2012 in BH102, and again in November and December of 2012. A reading in excess of the upper limit of the metre (20% LEL) was recorded in BH102 in 2009. BH102 is the only monitoring location on the east side of the landfill where a reading in excess of 100% LEL has been recorded. BH102 is located inside the landfill, approximately 25 metres west of the east landfill boundary.

The highest level of methane recorded in any of the monitors located "near" (within about 5 metres of the property boundary) the east boundary, was 8.8% LEL in VP07-15 in 2008. In 2011 and in 2012 thus far, the highest levels recorded in monitors located "near" the east boundary are about 1.2% LEL. A maximum reading of 0.1% LEL was recorded in BH7, outside of the landfill boundary, in 2007.

Table 2: East Side Monitors - Maximum Recorded LEL Values, by Year.

YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Inside Boundary													
BH 102	0.1	0.1	1.4	1.6	1.1	1.0	3.9	23.0	16.9	>20	10.3	4.0	>100
BH 103	0.1	0.1	1.2	1.6	1.3	1.2	19.7	1.1	10.3	1.5	0.8	0.1	1.1
BH101 D	0.2	0.1	2.2	1.7	1.7	2.0	4.2	1.3	4.0	4.1	1.1	0.1	6.0
BH101 S	0.2	0.1	1.4	1.6	1.1	1.4	5.0	1.3	4.4	3.2	0.9	0.1	0.8
VP11-09												9.0	2.2
VP12-01													0.8
Near Boundary													
BH 2	0.2	0.1	2.2	1.5	1.4	1.1	4.0	1.2	4.7	1.8	1.1		0.8
VP07-02								0.1	3.2	2.4	0.3	0.1	1.0
VP07-03								0.4	6.5	2.0	0.9	0.1	0.8
VP07-14								1.5	8.8	0.2	0.2	0.1	0.7
VP07-15								0.8	5.1	4.9	3.4	0.1	1.1
VP07-16								0.5	3.0	4.6	0.2	0.1	1.0
VP07-1D								0.8	2.0	3.2	0.5	0.1	1.0
VP07-1S								1.2	4.7	0.5	0.7	0.1	1.2
Outside Boundary													
BH 7								0.1					
All values in % LEL.													

South Boundary

The maximum annual LEL levels recorded at monitors located on the south side of the landfill are provided in Table 3. A value in excess of 100% LEL was recorded in 2004 at BH1, which is located within the landfill limits, approximately 50 metres north of the south boundary. For monitors located outside of the landfill, to the south of the boundary, the highest level recorded was 5.7% LEL in BH4 in 2006.

Table 3: South Side Monitors - Maximum Recorded LEL Values, by Year.

YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Inside Boundary													
BH 1	0.2	0.1	2.3	3.0	>100	1.9	5.0	0.2	3.8	0.6	1.2		
VP11-06												0.1	0.8
VP11-07												0.1	0.7
VP11-08												0.1	1.2
Outside Boundary													
BH 4	0.1	0.1	0.2	1.5	1.0	1.0	5.7	0.1	1.6	0.1	0.4		
BH 5	0.1	0.1	0.7	0.2	0.1	0.5	1.6	0.3	4.3	0.3	0.1		
BH 8	0.1	0.0	1.0	0.7	0.5	0.5	3.8	0.5	5.0	0.6	0.9		
All values in % LEL.													

West Boundary

The maximum annual LEL levels recorded at monitors located on the west side of the landfill are provided in Table 4. All of the monitors on the west side of the landfill are located close to the property line. The highest level recorded in any of these monitors was a reading of 4.6% LEL recorded in 2006 in MW99-4. In 2011 and thus far in 2012, all readings have been below 1% LEL.

Table 4: West Side Monitors - Maximum Recorded LEL Values, by Year.

YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Near Boundary													
MW 99-1	0.1	0.1	1.3	1.6	1.0	1.4	3.6	1.1	2.8	3.6	1.0		
MW 99-2	0.1	0.1	1.8	1.6	1.2	1.7	4.3	1.2	2.3	3.6	0.9	0.1	
MW 99-3	0.2	0.1	1.5	2.0	0.9	0.6	3.9	1.0	4.3	2.2	0.9	0.1	0.6
MW 99-4	0.1	0.1	1.2	1.3	2.0	2.1	4.6	1.3	3.7	3.8	0.9	0.1	0.8
VP11-03												0.1	
VP11-04												0.1	0.6
VP11-05												0.1	0.8

All values in % LEL.

North Boundary

The maximum annual LEL levels recorded at monitors located on the north side of the landfill are provided in Table 5. The data set is more limited for these monitors. A number of readings of over 100% LEL were recorded in monitors located inside the boundary in waste in 2007 and 2008. One reading of 49% LEL was recorded in 2007 for VP07-11, a monitor located outside of the property. Waste was moved in the north part of the site to achieve a minimum setback of water from the north property line of about 40 metres. Since that waste was removed, the highest reading has been 6.1% LEL in May of 2012 at VP07-11.

Table 5: North Side Monitors - Maximum Recorded LEL Values, by Year.

YEAR	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Inside Boundary													
VP07-05								>100	4.0			0.1	0.6
VP07-09								>100	>100			0.1	1.6
VP07-07								96	>100				
VP07-10								>100	>100				
Near Boundary													
MW07-1								2.6	4.5			0.1	0.1
VP07-04								0.6	2.1				
VP07-08								0.5	2.6			0.2	1.2
VP07-09								0.5	2.2			0.1	1.6
VP11-01												0.1	0.7
VP11-02												0.1	0.8
VP11-10												0.1	0.7
Outside Boundary													
VP07-11								49.0	3.7			0.1	6.1
VP07-12								0.8	2.3			1.0	0.4
VP07-13								0.6	2.6			0.1	0.9
VP07-17								0.8	1.8				
VP07-18								0.2	2.3			0.0	0.3
VP07-19								0.4	1.5			0.1	0.5
VP07-20								0.1	1.4			0.1	0.3

All values in % LEL.

The results by location are summarized in Table 6, which includes the number of readings taken in each set of monitors organized by location, the number of readings in each set for which a reading of greater than 100% LEL was recorded, the maximum reading obtained for any sample within that set, the number of readings in excess of 25% LEL, and the numbers of readings in excess of 25% LEL after the waste was moved on the northern boundary to achieve a larger setback from the property line (taken as readings made after 2008).

Table 6: Summary of Results by Location.

Location	Number of Readings	Maximum recorded LEL	Number of readings greater than 100% LEL	Number of readings greater than 25% LEL	Number of readings greater than 25% after 2008
	East				
Inside Boundary	139	>100%	3	5	5
Near Boundary	143	8.8%	0	0	0
Outside Boundary	1	0.1%	0	0	0
	South				
Inside Boundary	47	>100%	1	1	0
Near Boundary	-	-	-	-	-
Outside Boundary	70	6%	0	0	0
	West				
Inside Boundary	-	-	-	-	-
Near Boundary	124	5%	0	0	0
Outside Boundary	-	-	-	-	-
	North				
Inside Boundary	24	>100%	10	12	0
Near Boundary	53	4.5%	0	0	0
Outside Boundary	74	49%	0	1	0
	OVERALL				
Inside Boundary	210	>100%	14	19	5
Near Boundary	325	8.8%	0	0	0
Outside Boundary	145	49%	0	0	0

Several important points arise from the data analyses summarized in Table 6 and Tables 2 to 5 that precede it:

- A reading of greater than 100% LEL has been recorded only 14 times in the 680 methane readings completed to date, and all of these readings were recorded within or very close to the limit of filling ("Inside Boundary").
- No readings of 100% LEL or above have been recorded for any of the monitors near (within about 5 metres) the property boundary or outside of the landfill property.
- No readings of 25% LEL or above have been recorded for any of the monitors located near (within about 5 metres) the property boundary or outside of the landfill property after waste was moved to establish a minimum setback of 40 metres on the north side of the landfill (one reading of 49% was recorded offsite on the north side before the waste was moved).

Thus, the monitoring record to date indicates that there have been no readings of 100% LEL or greater at the property boundary; which meets the specification in the Landfill Criteria (see Section 2.4.3). No readings of greater than 25% LEL, which is the maximum reading for on-site or off-site structures or facilities, have been recorded at any of the monitors "near" the property line or outside of the limits of the landfill since waste was moved on the north side to establish a minimum 40 metre setback, but one reading of 49% LEL was made offsite before that time. The data available to date suggests that the regulatory requirements outlined in the Landfill Criteria for methane levels are being met presently.

The data that is available suggests that methane levels generally decline away from the area of waste placement (the landfill proper). In Table 7 the maximum, average and median values of methane levels are provided, along with the number of readings for sets of monitors based on whether they are located within the landfill property, approximately on the boundary (within about 5 metres), or outside of the landfill property. Given the highly variable nature of methane readings, the median is expected to be a reasonable indicator of the typical methane levels for monitors within a particular location. Where readings of greater than 100% LEL were made, averages were calculated assuming that the reading just exceeded 100% and calculated again, assuming that they equalled 150% LEL. These two assumptions were used to estimate a range for the average values of methane. Non-detect readings were assumed to be one-half of the detection limits for the purpose of estimating the average methane level.

Table 7: Methane Levels by Location.

Location	Maximum % LEL	Average % LEL	Median % LEL	Number of Readings
Inside Boundary	>100%	~9% to 12%	0.9%	210
Near Boundary	8.8%	1 %	0.6%	325
Outside Boundary	49%	1%	0.2%	145
ALL LOCATIONS	>100%	~3 to 5%	0.6%	680

The data presented in Table 7 suggest that under ordinary circumstances, methane (and other landfill gases) concentrations decline from inside the boundary to near the boundary to outside of the boundary. However, in developing a strategy to manage landfill gas, there is a need to consider how migration of methane (and other landfill gases) may be affected by closure activities or other factors, such as heavy rain, snow cover or the formation of concrete frost. There is also a need to consider whether or not the pathways are adequately characterized. These issues are discussed further in Section 3.3 of this report.

2.4 Regulatory Considerations

In addition to concerns regarding potential issues related to methane migration beyond the landfill boundaries, there are regulatory requirements related to landfill gas emissions; a brief review follows in Sections 2.4.1 to 2.4.4.

2.4.1 Non-methane Organic Compound (NMOC) Emissions

In the Landfill Criteria (MoE, 1993), if a municipal solid waste landfill emits more than 150 tonnes per year of non-methane organic compounds (NMOCs), there is a requirement to design and install a landfill gas capture system. CH2M HILL (2011) reported that they completed simulations of NMOC emission using the United States Environmental Protection Agency's (EPA's) Landfill Gas Emission Model (US EPA, 2005) using two selected values of the generation potential of the waste, resulting in estimated emission rates of 31 and 54 tonnes per year. These values fall below the action level set in the Landfill Criteria. However, since a gas collection system was recommended by CH2M HILL, they recommend testing the gas for actual NMOC levels after the collection system is installed.

2.4.2 Methane Emissions to Atmosphere

The *Landfill Gas Management Regulation* (LFG Guideline) came into force in British Columba on January 1, 2009. As discussed by CH2M HILL (2011), an assessment of methane generation was completed following the Landfill Gas Generation Assessment Procedure Guidelines (The Assessment) produced for the MoE by Conestoga-Rovers & Associates Limited (CRA), and issued in August of 2009. The Assessment indicated that methane emissions from the landfill would be below the 1000 tonne per year threshold that would trigger the need for a landfill gas management facilities design plan, but the LFG Guideline requires a supplementary assessment by March 31, 2015.

2.4.3 Methane Levels at Property Boundary

The British Columbia Ministry of Environment's (MoE) Landfill Criteria for Municipal Solid Waste (1993) (Landfill Criteria) specifies that the lower explosive limit should not be exceeded at the property boundary and should not exceed 25% of the lower explosive limit in any on-site or off-site structure or facility. Further, consideration must be given to the potential gas hazard with respect to the construction of any on-site building or structure or the installation of services such as water, storm sewer lines and other potential conduits of landfill gas.

2.4.4 Setbacks

In the Landfill Criteria (MoE, 1993) it is stated that: "The distance between the discharged MSW and the nearest residence, water supply well, water supply intake, hotel, restaurant, food processing facility, school, church or public park is to be a minimum of 300 metres." However, this setback is understood to apply during operation, and does not apply after a landfill is closed.

3.0 POST CLOSURE LANDFILL GAS ISSUES

As discussed in Section 1.0, Westside Landfill has ceased operation and is being closed. Closure works are to include completion of a cover system and installation of a passive landfill gas collection system. Methane and other landfill gases will likely be generated in appreciable concentrations for years to come. In this section of the report, the impacts of closure and some of the critical ongoing issues with respect to landfill gases, including methane, are discussed further to set the stage for the discussion of control, monitoring and mitigation measures provided in Section 4.0.

3.1 Continuing Generation of Landfill Gas

Methane generation rates are expected to generally decline after a landfill ceases to receive waste. Methane generation models, such as the LandGEM model produced by the US EPA (2005), which use the Scholl Canyon model, assume that methane generation rates decline exponentially after waste is placed. The rate constant (sometimes referred to as the biodegradation constant) for this exponential decay is generally held to be a function of how wet the site is, with higher rate constants for "wet" sites compared to "dry" sites. The "half-life", that is the time it takes for the gas generation to fall to half its former level, provides an easily understood measure of the expected rate of decline of methane generation rates with time. The half-life is approximately equal to 0.693/k (0.693 is the natural logarithm of 2 to 3 significant figures), where k is the rate constant for exponential decay. The rate constant is generally considered to vary from about 0.7 for a "wet" landfill to about 0.02 for a "dry" landfill; using these constants, the "half-life" is expected to be under a year for a "wet" landfill, but about 35 years for a "dry" landfill. Westside Landfill is located in a semi-arid area and thus is expected to be toward the "dry" end of the scale for landfill gas generation. Thus, methane generation may continue at appreciable rates for years, or even decades. However, methane generation rates are expected to decline over time and thus over the longer term reduce the risks associated with possible off-site migration of methane.

3.2 Potential Impacts of Closure

Closure may affect generation rates by limiting infiltration of water into the landfill, thus possibly leading the waste to become somewhat "drier" over time. This could, effectively, reduce the biodegradation constant and reduce the rate of methane generation somewhat over time. Cover systems that incorporated a low permeability layer may impede the venting of landfill gases and thus promote migration of landfill gases toward the periphery of the landfill. An ET cover, which does not require a particularly low permeability layer, has been proposed for this landfill but the cover materials will include soils that may have lower gas permeability than the waste and interim cover materials previously used. This can promote lateral migration of landfill gas. However, the Closure Plan (see CH2M HILL, 2011) does recommend installation of a passive landfill gas collection system. In simple terms, this provides pathways for landfill gas to vent through the cover of the landfill and thus should tend to reduce lateral migration of methane and other landfill gases. Such systems can be converted to active systems, if necessary.

3.3 Potential Pathways for Landfill Gas Migration

At Westside Landfill the waste fill has been placed such that it forms what amounts to a free-standing "pile"; waste does not appear to currently be placed against any pre-existing side slopes. Some waste was historically placed against pre-existing slopes on the north side of the landfill as was discovered during installation of vapour monitors on the north side in 2007. As discussed in Golder (March, 2009), this material was pulled back to re-establish a minimum 40 metre buffer from the properly line.

The water table acts as a barrier to migration of landfill gas. Thus, the main potential pathway from the landfill to surrounding areas would be through the unsaturated soils and fractured bedrock above the water table that are located around the perimeter of the landfill. We do not have complete information on the depth to water table in all areas, but based on the data available it appears that the thickness of this zone varies from close to zero at some locations on the east side (there are areas of standing water exposed in some locations) to possibly more than 10 metres at some locations on the north side. As will be discussed further in Section 4.2, some additional investigation is recommended to better characterize the potential pathways for landfill gas migration, particularly on the northern side of the property.

3.4 Other Potential Factors

Other factors that may impact the post closure migration of methane and other landfill gases include heavy rain, snow pack (particularly with an ice layer) and the formation of "concrete frost". These factors all act at the surface of the landfill cover. Rain can potentially result in a saturated layer forming temporarily near the surface, resulting in a barrier to the upward venting of landfill gas. Snow packs, especially those with ice layers, can also form a barrier to venting through the surface of the landfill and could potentially last for weeks, or even longer. Under some conditions, concrete frost, in which the pores of the soil become filled with ice, might also create a temporary barrier to venting. Falling barometric pressure can induce increased flow of landfill gas from the interior of the landfill to the surface. The landfill gas collection system proposed for the landfill (CH2M HILL, 2011) would, however, provide a pathway for gas to the surface and thus reduce the impacts of these temporary conditions on lateral migration of landfill gas. Whether the landfill gas collection system is sufficient to control lateral migration of landfill gas to the degree required, however, needs to be verified through monitoring.

Underground services and drainage systems can also provide potential pathways for the migration of landfill gas. Based on RDCO mapping (online reference) there may be a storm sewer system on the south end of the site. No other underground services were noted in the available mapping. As will be discussed in Section 4.2, further investigation and monitoring of this potential pathway will be recommended.

It should be noted that homes and other buildings may exhibit a "stack effect" which can result in the pressure inside the home or other structure dropping below the ambient atmospheric pressure, such that soil gases may tend to be drawn into homes. While the current data suggests methane levels at the property boundaries are typically below 25% LEL, and in fact only one exceedence of that value has been recorded, and that from the north side of the site before waste was moved to establish a minimum setback of 40 metres from the property line, if there were a preferred pathway, the "stack effect" might tend to draw soil gases into the home.

3.5 Summary of Key Post Closure Issues

In summary, the key post closure issue is the potential migration of methane offsite in concentrations high enough to be of concern. As discussed above, much of the landfill gas should vent from the cover and sides of the landfill, and when it is put into place, from the passive landfill gas collection system. The water table below the landfill provides a lower limit to the migration of landfill gas, with the result that the potential pathways from the landfill to homes or other structures would be through soils and fractured bedrock located adjacent to the landfill.

4.0 POTENTIAL CONTROL, MONITORING AND MITIGATION MEASURES

As discussed in Section 2.3 of this report, the available data is consistent with the proposition that methane levels at the boundary of the landfill are typically well below the regulatory limits. However, as also noted, relatively rare events (formation of concrete frost, for example) could potentially impact landfill gas migration at least temporarily, leading to migration off-site at higher levels than would otherwise be the case. Furthermore, there are some portions of the site where additional characterization of potential pathways for migration of landfill gas is required and where additional monitors may be required.

As noted previously, the Closure Plan already recommends that a passive landfill gas system be installed at the site to provide source control; the proposed control system is summarized briefly in Section 4.1. Recommendations for further investigation of potential pathways are provided in Section 4.2. In Section 4.3, recommendations for monitoring are provided. In Section 4.4, we provide recommendations for "next actions" that should be taken based on monitoring results reaching defined "Action Levels". We also summarize some contingency measures that could be taken if monitoring results suggest that further action is required to control off-site migration of methane. In Section 4.5, we outline some additional actions that local government may wish to consider to further mitigate risks.

4.1 Source Control

The first line of defence is source control. CH2M HILL (2011) has developed a passive landfill gas control system in their Closure Plan. If future monitoring indicates that this approach is not sufficient, then additional measures should be considered. The options should be re-evaluated at the time additional measures are put into place. One option might be to convert the passive system to an active system. Other options might include installation of gas collection trenches adjacent to the landfill where the depth to the water table or competent bedrock is not too great, or installation of gas collection wells along the perimeter of the landfill.

4.2 Further Characterization of Potential Pathways

In the "Landfill Gas Management Facilities Guidelines" (MoE, 2010), guidance is provided on the spacing of monitors, although it is noted that the spacing should be selected based on site specific conditions, including the nature of the materials through which landfill gas might potentially flow. As will be discussed further in Section 4.3, the required spacing is anticipated to be on the order of 40 to 50 metres, but tighter spacing could be required in some areas. At present, the spacing of monitors is greater than 40 to 50 metres in some locations, particularly on the north side. As new monitors are installed, the "logs" (record of materials encountered during drilling) will provide additional information that can be used to better define potential pathways for migration of landfill gas.

The water table, which forms a barrier to landfill gas migration, is not well characterized on the north side of the site. Thus, drilling in one or more locations on the north side should extend to the water table. It may be useful to install a groundwater monitor in at least one of these locations to better define the water table on the north side and provide at least one additional groundwater monitoring location.

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4.3 Monitoring System

4.3.1 Additional Monitoring Locations

In the "Landfill Gas Management Facilities Guidelines" (MoE, 2010), the recommended spacing varies from 5 metres in cases where there is likely to be fissure or fracture flow dominated strata and development within 150 metres, to 150 metres in the case of low permeability soils and no development within 250 metres. In the case of Westside Landfill, development currently exists at distances of less than 150 metres and it is understood that further development may take place within 150 metres of the limit of disposal. In some portions of the perimeter, the existing data suggests there are permeable sediments adjacent to the landfill; taking this into consideration, we anticipate that after further characterization of the materials and pathways, the recommended spacing will probably fall within the range of 10 to 50 metres. Along the east side, the existing spacing is on the order of 40 to 50 metres.

In areas that are not currently fully characterized, it would probably be most efficient to space monitors as a multiple of what might possibly be the ultimate spacing required. Since the recommended spacing could be 20 metres or 10 metres (or even 5 metres if we determine that there are areas, possibly on the north side, where there is likely to be fissure or fracture flow dominated strata present), then a spacing of about 40 metres would be a good starting point.

4.3.2 Monitoring of Underground Services

As discussed in Section 3.3, it is our understanding that a storm sewer line may be located on the landfill property, on the south side. We recommend that this be confirmed. We recommend that a potential monitoring site (or sites) be identified and that arrangements be made to allow a preliminary program of methane level measurements to be made in a storm sewer system, if it is present. The readings should be taken during periods of falling barometric pressure. We provisionally recommend at least four rounds of measurement to be conducted. The results would be reviewed by a qualified professional, who would make recommendations for additional investigation, monitoring or actions, as required.

4.3.3 Monitoring Frequency

Monitoring currently takes place quarterly, sometimes with considerable variation in methane levels between rounds. The distributions of all values observed in the monitoring program to date are summarized in Figure 3 by location following the conventions used in Section 2.3, whereby results from monitors located well within the property boundary are included in the "Inside Boundary" category, monitors located close to the boundary (within 5 metres) are included in the "Near Boundary" category and monitors located outside of the landfill property are included in the "Outside Boundary" category. The modal % LEL value for readings from monitors located in all three locations categories are all below 1%, and the frequency of readings in any category declines with increasing % LEL in all three location categories, but it is only at the "Inside Boundary" locations where there are any values recorded that are greater than 10% LEL (and the only location with any values greater than 100% LEL).

As discussed in Section 3.4, there are factors, such as the formation of concrete frost, snow, heavy rain and rapidly falling barometric pressure that can temporarily alter the migration of methane and other landfill gases within a landfill and may contribute to higher readings of methane than would otherwise be the case . Two of the three cases where a reading of 100% LEL was exceeded were in December, when snow or concrete frost could, at least in principle, be an issue, but we do not have sufficient information to know if such conditions existed at the time of the readings.

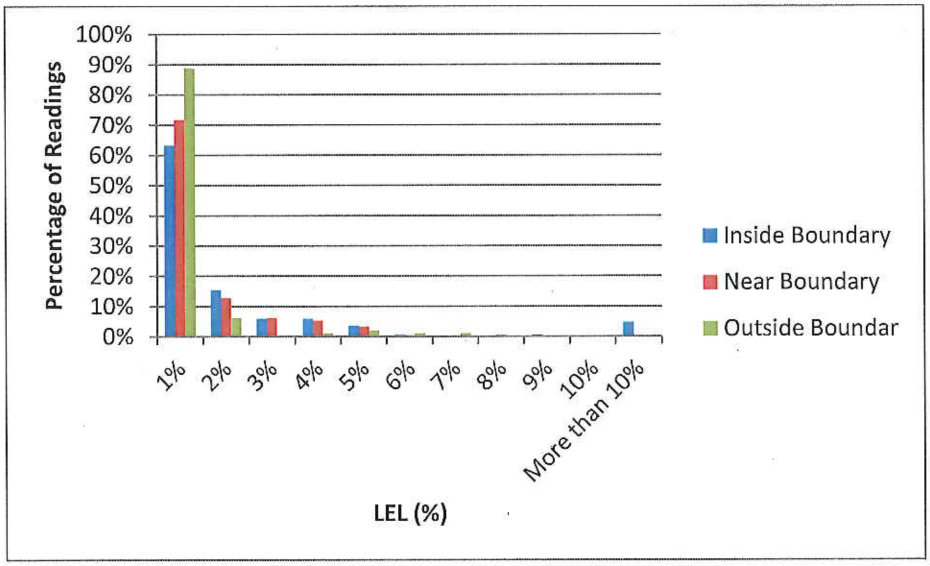

Figure 3: Frequency Distribution of LEL Values by Location.

It is the highest readings of methane that are of most concern, thus it would be valuable to better understand these relatively rare events where much higher methane levels may occur. To better understand the variability of methane levels, we suggest that additional information be collected during the sampling rounds, including ground conditions (for example, observations of snow on the ground or heavy frost) and any other observations that may be relevant. These observations should be made by suitably qualified personnel. Records of barometric pressure at hourly intervals have generally been available for at least one Environment Canada climate station located near or in Kelowna over the period of monitoring. However, the locations of stations have changed over the years and there will be spatial variations in pressure such that readings at other sites may not represent conditions at the site adequately. We suggest that barometric pressure be logged at the site at one hour intervals so that we develop a better understanding of the range of variation at site and to assist us in interpretation of the monitoring results.

CH2M HILL (2011) recommended that monitoring be conducted quarterly, but during "winter" months be increased to monthly, with re-evaluation after two years of post-closure monitoring. In Table 8, the average snowfall at Kelowna Airport for the 1971 to 2000 is provided, along with the extreme daily snowfall recorded over that period and the average number of days with temperatures less than 0°C. Based on the snowfall data, "winter" for the purposes of monitoring would probably be reasonably defined as extending from November to April. The temperature record suggests that there is the possibility of freezing conditions existing from September to May, and in rare cases to June, but the risk of extended periods of freezing conditions appears to be typically in the months from October to April. Thus, winter conditions in a typical year could be considered to extend from October to April. Following CH2M HILL's (2011) suggestion, monthly monitoring should be completed from October to April, although if winter conditions start earlier or later in a given year, this may be modified. July falls mid-way between April and October and would therefore be a logical time for the quarterly monitoring that CH2M HILL recommended for the remainder of the year.

Table 8: Selected Climate Data for Kelowna Airport.

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Snowfall (cm)	29	16	5	1	0	0	0	0	0	1	15	36
Extreme Daily Snowfall (cm)	26	19	9	4	1	0	0	0	0	7	20	24
Average number of days <= 0	28	25	23	13	3	<1	0	0	2	13	22	28

However, we note that a reading of greater than 100% LEL was recorded at one "Inside Boundary" location in May of 2012. In Table 9 the number and percentage of readings that exceeded 100% LEL and the number and percentage that exceeded 25% LEL are tabulated for the period of record, by month. Note that no readings have been made in February, April, or November. The results in Table 9 suggest that the highest probability of getting elevated methane readings is in March, with the next highest month being May.

Based on the results presented in Table 9, it would appear that monthly sampling should take place from October to May, with a round of sampling to take place in July or August.

Table 9: Number and Percentage of Readings in Excess of 100% LEL by Month.

	Jan	Mar	May	Jun	Jul	Aug	Sep	Oct	Dec
Number of Readings	41	28	61	30	215	22	13	56	138
Number greater than 100% LEL	0	4	3	0	3	0	0	1	1
Percent greater than 100% LEL	0%	14%	5%	0%	1%	0%	0%	2%	1%
Number greater than 25% LEL	1	4	6	0	3	0	0	1	2
Percent greater than 25% LEL	2%	14%	10%	0%	1%	0%	0%	2%	1%

4.3.4 Summary of Monitoring Program Recommendations

Recommendations for the post-closure monitoring program are summarized below:

- Establish a monitoring network, using existing and additional probes, that covers the following general areas:
  - Near-Boundary Monitors, located within 5 metres of the property boundary.
  - Inside-Boundary Monitors, located within the setback between the buried refuse and the property boundary.

The number and spacing of the monitoring probes will depend on the conditions at specific parts of the site, including the subsurface geology and proximity of the refuse to the property boundary. We recommend that in areas near current or future residential development along the east and north boundaries, respectively, monitors be installed along the property boundary to achieve a spacing of 40 to 50 metres. The need for even closer spacing of monitors would be assessed after the additional information gained during drilling of the new monitors and additional monitoring is assessed by a qualified professional.

- The initial monitoring frequency will be monthly for the period October to May, with an additional monitoring round in July or August. Monitoring would continue on this schedule until subsequent analysis of the results supports either less or more frequent monitoring.
- The following parameters will be measured in the field at each probe: methane, hydrogen sulphide, carbon dioxide, and oxygen. During each monitoring round, we also recommend that barometric pressure be logged at hourly intervals while on site, so that this information can be considered when interpreting results. Additional site observations should also be recorded for factors that could influence methane migration, including snow cover and evidence of concrete frost.
- After a passive landfill gas collection system is installed, implement CH2M HILL's (2011) recommendation to monitor the gas levels at the outflow vents.
- Install an additional groundwater well to monitor the elevation of the water table at the north side of the site, as the water table creates a lower barrier for landfill gas migration.
- We also recommend that conduits associated with underground services on site be included in the monitoring program. Underground services within 300 metres of the site should be identified and a program for a preliminary round of monitoring for methane be developed.

4.4 Contingency Plans

4.4.1 Action Levels

The monitoring data should be reviewed by a qualified professional after each collection round. The results will be compared with the regulatory requirements, as outlined in Section 2.4. In addition, the following methane concentrations will be used to trigger the actions listed below.

- Near-Boundary Monitors: methane >10% LEL (5,000 ppm).
- Mid-Boundary Monitors: methane >25% LEL (12,500 ppm).

We also recommend that the results be reviewed for apparent trends. This would be completed by a qualified professional on a monthly basis, with more rigorous assessment as part of the annual reporting. In addition to the threshold levels listed above, some key "flags" that further investigation and possibly action is required would include new high readings being reached in particular monitors, or apparent trends to increasing levels in particular monitors.

4.4.2 Actions

The nature of the investigation and action that would be required will clearly differ according to the results. In part this will be based on the judgement of the qualified professional reviewing the results, but some clear "actions" that can be identified by technical staff based purely on the data collected are desirable. A standard set of actions is outlined in Tables 10 and 11.

Table 10: Actions for Near-Boundary Monitors >10% LEL.

Action	Objective	Timeline (from previous action)
Re-measure specific monitor probe. Recalibrate field equipment.	Confirm methane >10% LEL	1 week
Notify MoE.	Provide data to MoE and develop a Specific Action Plan (SAP) to investigate and mitigate elevated gas levels.	3 days
Continue to regularly measure methane at monitor.	Assess upward or downward trend in methane level.	Developed in SAP
Collect air sample from monitor and submit for laboratory testing.	Confirm methane level is same as field measurement	Developed in SAP
Install step-out monitors 5-10 metres from initial location, and measure methane.	Attempt to bound the extent of methane >10% towards off-site buildings.	Developed in SAP
Notify resident(s). Monitor indoor vapour.	If methane not bounded to <10% LEL, confirm that elevated methane is not present inside building.	Developed in SAP
Install monitors on neighboring property and measure subsurface and indoor vapour.	Assess methane levels near off-site buildings	Developed in SAP
Implement additional control measures	See Section 4.4.3	Developed in SAP

Note: The SAP and associated timelines will be developed with input from MoE, based on the specific conditions including measured gas concentrations and proximity to off-site buildings.

Table 11: Actions for Mid-Boundary Monitor Probes >25% LEL.

Re-measure specific monitor probe Recalibrate field equipment.	Confirm methane >10% LEL	1 week
Notify MoE	Provide data to MoE and develop a Specific Action Plan (SAP) to investigate and mitigate elevated gas levels.	3 days
Continue to regularly measure methane at subject monitor and nearby near-boundary monitors.	Assess upward or downward trend in methane level.	Developed in SAP
Install step-out monitors toward boundary.	Attempt to bound the extent of methane >25% LEL	Developed in SAP
If step-out monitors at the boundary are >10% LEL, then proceed as per Table 10.	Confirm if methane >10% at nearby site boundary.	Developed in SAP
If step-out monitors at boundary consistently <10% LEL, then continue to monitor regularly.	Confirm that methane >25% LEL is bounded within site boundaries.	Developed in SAP
Consider additional control measures.	See Section 4.4.3	Developed in SAP

Note: The SAP and associated timelines will be developed with input from MoE, based on the specific conditions including measured gas concentrations and proximity to off-site buildings.

4.4.3 Additional On-Site Control Measures

CH2M HILL (2011) noted in their Closure Plan that if off-site migration of landfill gas at unacceptable levels is found to take place at a later date, then additional control measures may be required. These could consist of the following:

- Enhance the passive collection system with additional components at the landfill perimeter. These could consist of a gravel-filled trench or a series of vertical pipes to intercept vapour migrating between the refuse and property line.
- Upgrade the gas collection system to an active extraction system by installing a fan at one or more of the outflow vents.
- If elevated methane levels are due to migration along underground utility trenches, replace sections of granular backfill with lower permeability fine-grained soils and/or synthetic liner to impede the lateral migration of landfill gas.

4.5 Other Measures

Landfill gas has been known to migrate considerable distances, particularly in cases where there are pathways through fractured bedrock. The Canada Mortgage and Housing Corporation (CMHC) in their 1993 document, "Soil Gases and Housing, A Guide for Municipalities", suggest that the limit for gas migration could be a few metres to over half a kilometre (this potential for migration of landfill gas over long distances has been documented elsewhere). The first line of defence is source control, with monitoring to assess the effectiveness, which is the approach advocated in this report.

As noted by CMHC (1993), there are actions that local government can take to further mitigate risks and potentially limit their liability. It is beyond the scope of this document to advise local government on appropriate actions they might want to pursue.

5.0 CLOSURE

This report was prepared for the exclusive use of Regional District of the Central Okanagan (RDCO). Any use which a third party makes of this report, or any reliance on or decisions to be made based on it are the responsibility of such third parties. Golder Associates Ltd. (Golder) accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions taken based on this report.

The report, which includes all appendices and attachments, is based primarily on data and information provided to Golder by the RDCO, from earlier Golder reports and from third party sources, as identified in this report. Additional study, including further subsurface investigation, can reduce the inherent uncertainties associated with this type of study.

This investigation was performed according to current professional standards and practices in the environmental field. If new information is discovered during future work, including excavations, borings or other activities or studies, Golder should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

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CH2M HILL, August 25, 2011, *Westside Landfill Closure Plan, Final Report.*

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Conestoga Rovers & Associates on behalf of the British Columbia Ministry of Environment, March, 2009, *Landfill Gas Generation Assessment Procedure Guidelines.*

Golder Associates Ltd., September 19, 2012, *Options for Final Cover Systems, Westside Landfill.* US EPA (2005), United States Environmental Protection Agency, May, 2005, *Landfill Gas Emissions Model (LandGEM) Version 3.02 User's Guide*

Regulations

Landfill Gas Management Regulation, brought into force January 1, 2009, under the Authority of the *Greenhouse Gas Reduction (Emissions Standards) Statutes Amendment Act*, 2008, S.B.C. 2008, c. 20, s. 37 and the *Environment Management Act*, S.B.C. 2003, c. 53, s. 76.21.

APPENDIX E

Statement of Limitations

STATEMENT OF LIMITATIONS

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The report, which includes all appendices and attachments, is based on data and information collected during the investigation conducted by Golder Associates Ltd.'s personnel and upon third party information provided by the RDCO. The report provides a level of assurance commensurate with the level of study.

Golder has relied in good faith on information provided to us. We accept no responsibility for any deficiency, misstatements or inaccuracies contained in this report as a result of omissions, misinterpretations of fraudulent acts of the persons or agencies interviewed.

This work was performed according to current professional standards and practices in the environmental field. If new information is discovered during future work, including excavations, borings or other activities or studies, Golder should be requested to re-evaluate the conclusions of this report, and to provide amendments as required.

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