Memorandum

December 31, 2017

To:	Maureen Bilawchuk (ENV)	Ref. No.:	11149336
From:	Ben Kempel – Senior Hydrogeologist/cs/02	Tel:	604-214-0510
cc:	AJ Downie (ENV) James Reid (GHD)		

Subject: Supplementary Review of Monitoring well MW-6
Cobble Hill Landfill
460 Stebbings Road, South Shawnigan Lake Area, BC

As requested, GHD Limited (GHD) has prepared this memorandum to provide the BC Ministry of Environment and Climate Change Strategy (ENV) with a supplemental expert opinion concerning the location of monitoring well MW-6 at a quarry/landfill site located at 460 Stebbings Road in the South Shawnigan Lake area, BC (Site). The MOE specifically requested GHD's opinion regarding the suitability of MW-6 as a background monitoring well for the Site. A memorandum responding to this request was provided to ENV on October 5, 2017. Based on a meeting on December 12, 2017 attended by ENV, GHD, and interested third parties, GHD understands that there are concerns expressed regarding the suitability of MW-6 as a background monitoring well. The concerns are related to suspicions that MW-6 has been impacted by landfilling activities. The opinions presented in this memorandum supplement those provided in the October 5, 2017 memorandum and are based on an additional evaluation of various lines of evidence regarding the suitability of MW-6 as a background monitoring well.

Groundwater Flow Direction

A background monitoring well is used in a monitoring program to define groundwater quality prior to the effects of the contaminant source being introduced, in this case the landfill. By defining groundwater quality prior to the effects of the contaminant source, it is possible to identify and often quantify the effects of the contaminant source on groundwater resources.

Understanding the groundwater flow direction is important in determining a suitable location for a background monitoring well. At a landfill site a background monitoring well should be located upgradient of the landfill so that it is not subject to the effects, if any, of the landfilling activities. The background monitoring well can be used to define not only the natural, un-impacted groundwater quality, but also the natural variability in groundwater in a given hydrogeologic setting.

The groundwater flow direction within an aquifer is determined by measuring static groundwater elevations at various points within the aquifer. The groundwater flows under the force of gravity from points of higher static groundwater elevation to lower static groundwater elevation. The most common method for determining the groundwater flow direction on a macro scale is to draw contours along lines of inferred equipotential

hydraulic head (groundwater elevation). The groundwater flow direction is perpendicular to the contour lines in the direction from highest static elevation to lowest static elevation.

GHD reviewed the groundwater elevations on Site from several sources including a professional opinion letter prepared by Mr. Dennis Lowen, P.Eng. dated February 23, 2012, a geotechnical assessment letter report prepared by Active Earth Engineering Ltd. (October 2013), and the 2016 static groundwater elevation data from the on-Site monitoring well network (4 quarterly monitoring events). All sources reviewed interpret the on-Site groundwater flow direction within the bedrock aquifer to be to the northwest.

Therefore, on the basis of the natural groundwater flow direction within the bedrock aquifer, MW-6 is suitably located to be a background monitoring well for the monitoring network at the Site as it is located upgradient of the landfill.

Geochemical Fingerprint

In order to investigate the possibility that MW-6 has been impacted by landfilling activities, GHD prepared a trilinear piper plot of groundwater quality from monitoring wells included in the monitoring program and leachate. A piper plot presents the major ions as percentages and is used to determine patterns in the geochemical character of water samples. Cations (positive ions) and anions (negative ions) are potted in two triangles at the base of the plot. The compositions from the base triangles are then projected up to the central diamond. This central diamond therefore presents the data from all of the major ions in one plot. On a piper plot, samples with similar geochemical character (similar sources) will plot relatively close to one another. Because the major ions are used, a piper plot is useful for detecting differences in the geochemical character between water samples.

Figure 1 provides the piper plot generated using water quality samples from on-Site monitoring wells MW-2, MW-3S, MW-3D, MW-4 and MW-6. In addition, leachate samples collected during the 2017 monitoring period have been plotted for comparison purposes. There are three important observations made from the piper plot:

- The geochemical characteristics of water quality from all on-Site monitoring wells are very similar, as they plot in the same portion of the diamond.
- The geochemical characteristics of water quality from water samples collected before landfilling are essentially the same as those collected after landfilling.
- The geochemical characteristics of leachate are very different than those of the groundwater quality samples.

The pattern of water quality distribution on this plot supports the interpretation that water quality samples from the on-Site monitoring well network are not affected by leachate. If the water quality at a monitoring well was affected by leachate, the geochemical characteristics would bear a closer resemblance to leachate and the sample would plot closer to the leachate samples on the diamond. In typical circumstances where samples from a variety of monitoring wells are variably affected by a single contaminant source, the wells that are more affected by the contaminant source plot closer to the contaminant source samples on the diamond. As the water quality samples from all monitoring well sources over time plot far from the leachate

source samples, and close to each other, the piper plot suggests that none of the monitoring well water quality samples have been affected by leachate.

An argument could be made that all water quality samples have been affected equally by a leachate source, which would result in all samples being affected equally with respect to their position on the diamond. However, considering the variable distances from the on-Site leachate source (or sources) and the single documented flow direction within the bedrock aquifer (northwest), it is extremely unlikely that all monitoring wells could be equally affected by a leachate source at any given time.

Further, GHD reviewed a piper plot prepared by Mr. Dennis Lowen in a professional opinion letter dated August 1, 2013. Mr. Lowen's piper plot illustrates the geochemical characteristics of water quality samples from on-Site groundwater quality samples collected from 2013, prior to landfilling activities. The pre-landfilling piper plot produced by Mr. Lowen plot in the same area on the diamond as the 2012, 2016 and 2017 samples plotted on GHD's Figure 1. This similarity in geochemical characteristics pre and post-landfilling further supports the interpretation that groundwater at the Site has not been affected by landfilling.

Concentration Vs. Time Plots

In order to further investigate the possibility that MW-6 or other monitoring wells on-Site are affected by leachate, GHD reviewed water quality samples for monitoring wells collected pre and post-landfilling activities. The complete set of available monitoring data was reviewed and concentration vs. time plots for major ions were prepared to identify temporal trends in water quality evolution. The 2011 and 2012 pre-landfilling data was obtained from the Active Earth Engineering Ltd report titled "*Technical Assessment for Authorization to Discharge Waste*" dated August 2012. The 2015, 2016 and 2017 data was obtained from various environmental monitoring submissions provided by the Named Parties to the MOE.

Figures 2 and 3 illustrate the concentrations of alkalinity, calcium, chloride, magnesium, potassium, sodium and sulphate over time at MW-6, MW-2 and MW3S/D. The concentration vs time plots illustrate that, although there is some minor variability in water quality, the concentrations of these indicator parameters are largely stable over time. If there were impacts from landfilling activities migrating vertically through the subsurface and affecting groundwater quality at these monitoring points, clear trends of increasing indicator parameter concentrations would be apparent.

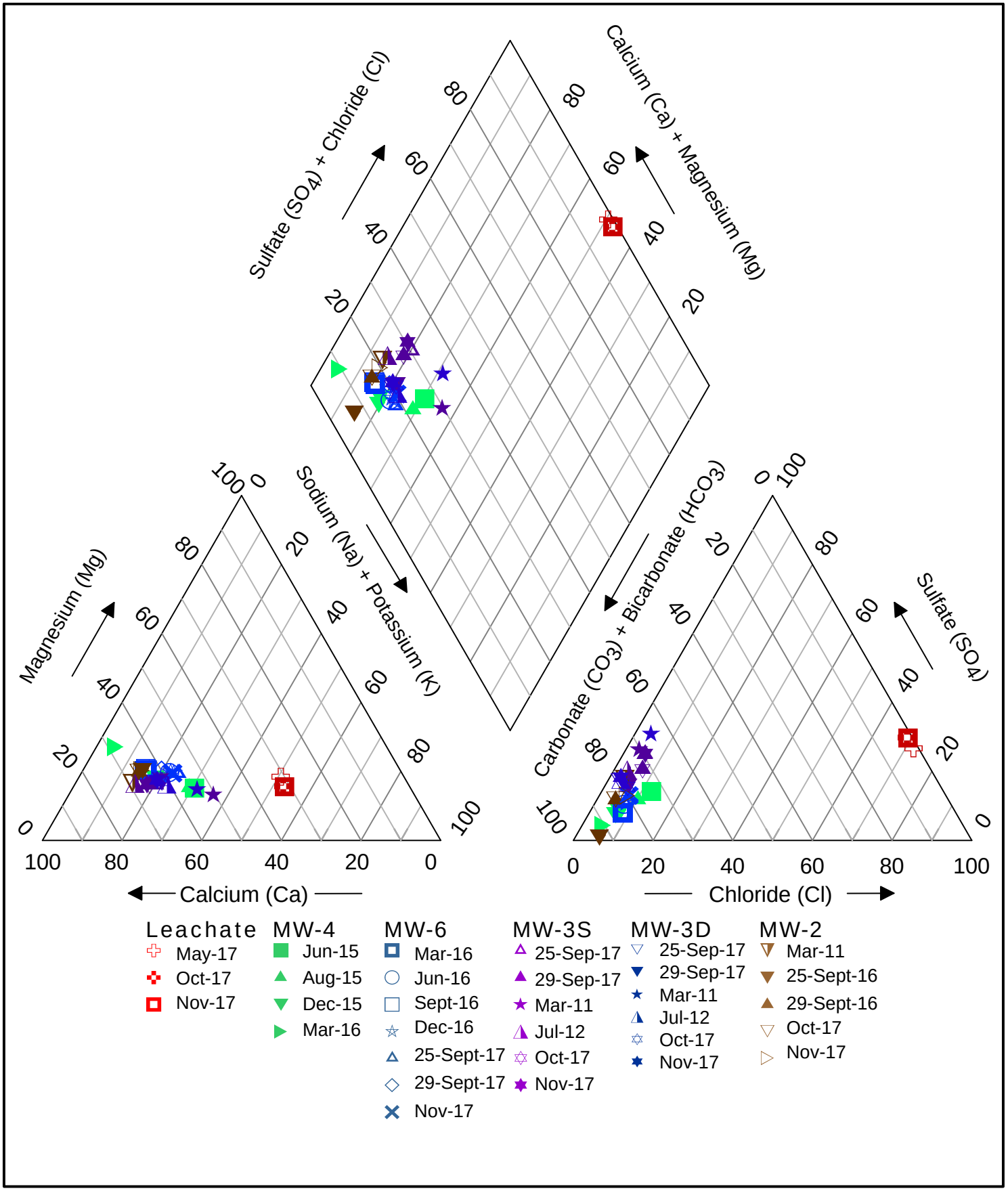
The patterns of concentration vs time illustrated on Figures 2 and 3 support the interpretation that groundwater quality in the on-Site monitoring well network has not been affected by landfilling activities.

Conclusions

On the basis of the data reviewed and the interpretations presented above, monitoring well MW-6 is considered a representative background monitoring well for the Site. This conclusion is based on the following summary points:

1. MW-6 is located upgradient of the landfilling area.
2. Water quality at the on-Site monitoring wells, including MW-6, is geochemically uniform and different from leachate generated within the landfill.

3. Concentrations of leachate indicators in the on-Site groundwater monitoring wells have remained relatively stable since landfilling began indicating that progressive deterioration of water quality from a leachate source has not occurred.

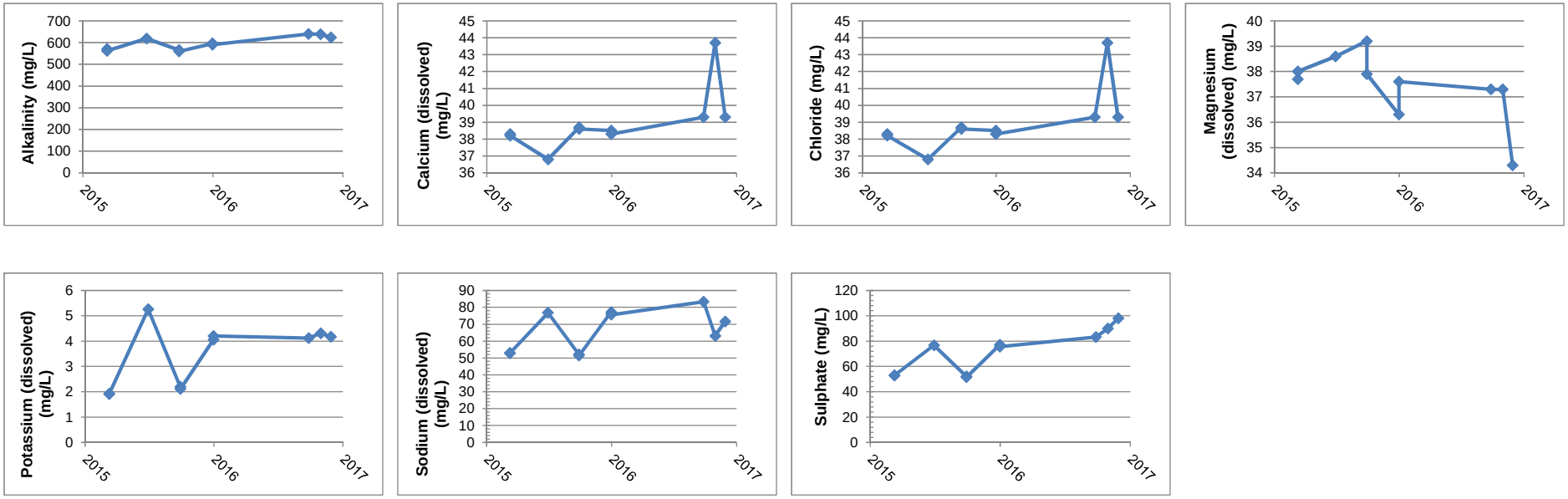


Geochemical Evaluation
Cobble Hill Landfill
Cobble HIll Holdings Ltd.

TRILINEAR PIPER PLOT

JOB NUMBER 11149336
DATE December 20, 2017

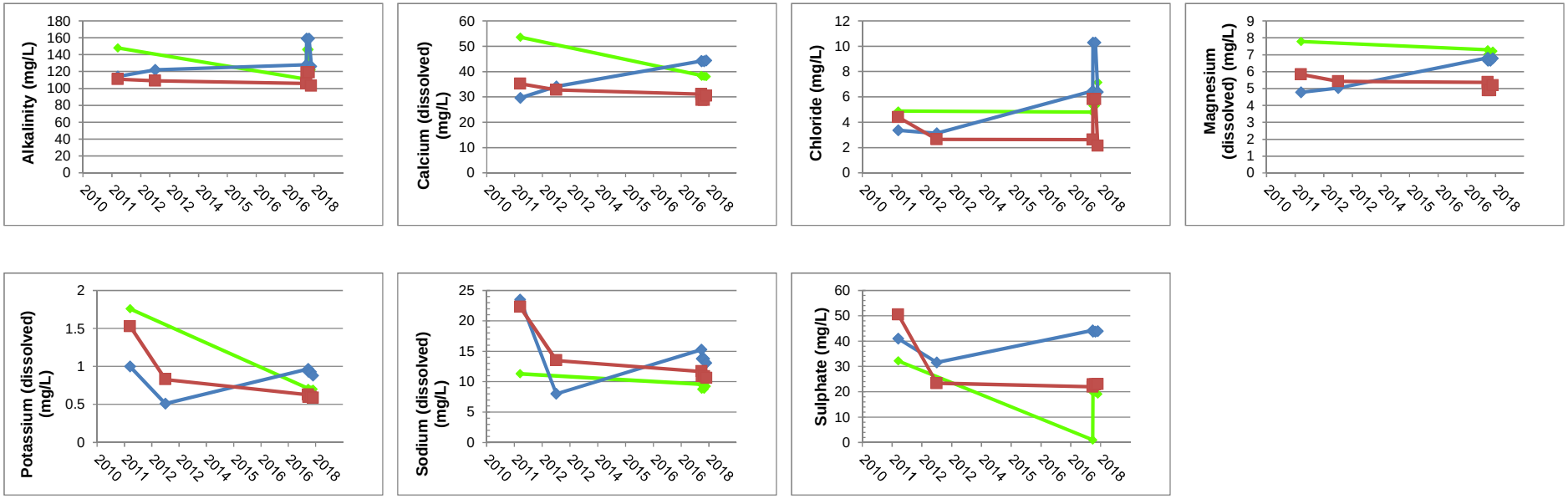
FIGURE 1



Notes:
Non-detects are shown as the full laboratory detection limit

MW-6

figure 2
Concentration versus Time
MW-6
Cobble Hill Landfill
Cobble Hill Holdings Ltd.



Notes:

Non-detects are shown as the full laboratory detection limit

- MW-2
- MW-3S
- MW-3D

figure 3
Concentration versus Time
MW-2, MW-3S, MW-3D
Cobble Hill Landfill
Cobble Hill Holdings Ltd.