May 3rd, 2019 PRJ19002

Thompson Nicola Regional District
300-465 Victoria St.
Kamloops, B.C. V2C 2A9

Attention: **Kory Ryde**
EHS Technologist

Dear Mr. Ryde,

Re: Heffley Creek Landfill 2019 Greenhouse Gas (GHG) Emissions Reduction Quantification

Sperling Hansen Associates (SHA) is pleased to submit this letter report on *2018 greenhouse gas (GHG) emissions reduction for the Heffley Creek Landfill.*

1 LANDFILL INFORMATION

The Heffley Creek Landfill is located approximately 5 km east of Heffley Creek and Highway 5 on Tod Mountain Road, then 700 m north into the site (7381 Sullivan Valley Road). Based on the 2016 Census Data, the Heffley Creek site serves approximately 20,350 people. The landfill footprint, which encompasses slightly more than 13 Ha, is surrounded by the Thompson-Nicola Regional District (TNRD) land currently under a grazing permit to a local cattle rancher. The landfill was originally permitted as a waste management site in 1974 for the disposal of municipal refuse from the Heffley Creek and Rayleigh areas. Originally, the landfill operated under a Waste Management Permit (PR-3447). Currently the TNRD has a License of Occupation with the Province of BC under License Number 342120 for a term of ten years, which commenced on July 14th, 2006. This License of Occupation is currently undergoing a renewal process.

Historically, waste filling activities at the Heffley Creek Landfill have been performed in the central and southern portions of the site and have been completed by way of the 'Trench Filling' method. The current active face of the landfill is located in the south west corner of the landfill footprint as shown in Figure 3 and the enclosed Figure 4.

Figure 1 shows location of the Heffley Creek Landfill.

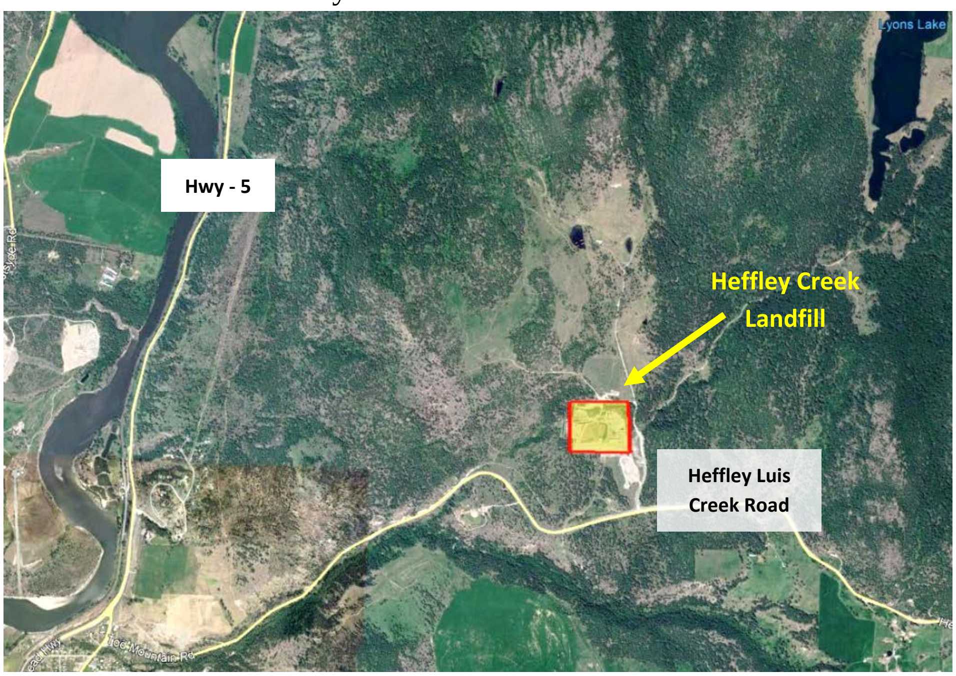

Figure 1. Heffley Creek Landfill Location

2 LANDFILL GAS GENERATION ASSESSMENT

In 2014, SHA completed a landfill gas (LFG) generation assessment for the Heffley Creek Landfill. The LFG generation estimates showed that the annual methane generation at this site was approximately 227 tonnes/year. Methane generation rate in 2018 was estimated to be approximately 263 tonnes/year. Figure 2 shows the methane generation estimate at the Heffley Creek Landfill from 1984 to 2018.

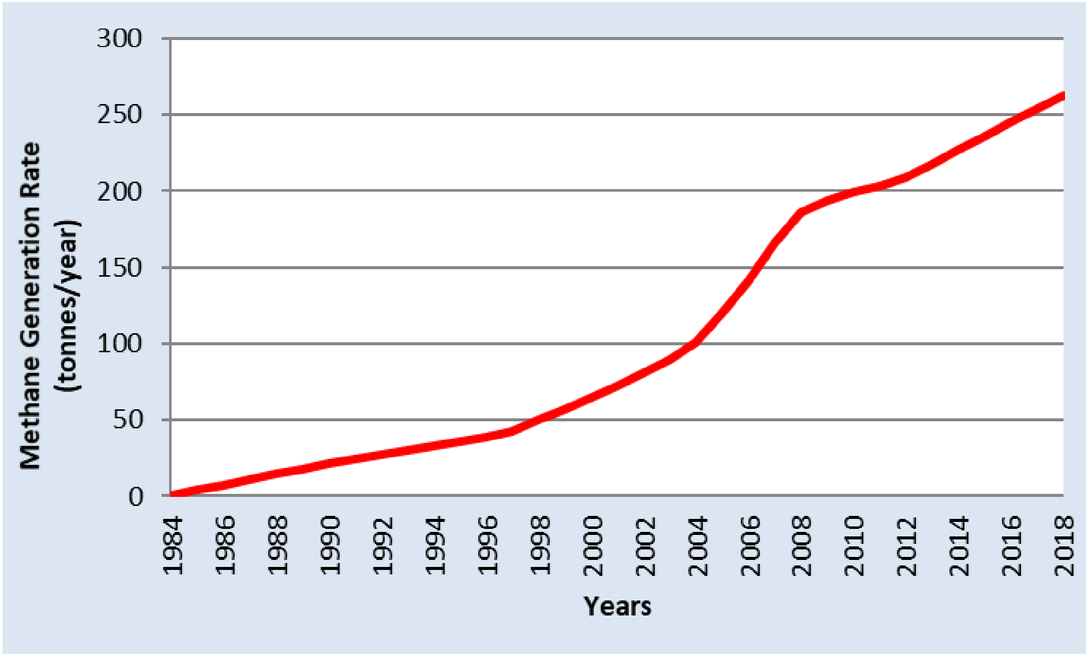

Figure 2. Methane Generation Estimate at Heffley Creek Landfill (Based on 2014 LFG Assessment)

A summary of estimated methane generation rates for the Heffley Creek Landfill is presented in Table 1.

Table 1. Summary of Methane Generation Modeling Results (ENV Model)

Item	**Year of Estimate**	**Mass of Methane (tonnes/year)**
Estimated Quantity of Methane Produced in the Year Preceding the Assessment	2013	218
Estimated Quantity of Methane Produced in the Year of Assessment	**2014**	**227**
Estimated Quantity of Methane Produced one Year after the Assessment	2015	236
Estimated Quantity of Methane Produced two Years after the Assessment	2016	245
Estimated Quantity of Methane Produced three Years after the Assessment	2017	254
Estimated Quantity of Methane Produced four Years after the Assessment	**2018**	**263**

3 GHG EMISSIONS REDUCTION INITIATIVE

As the methane generation at the Heffley Creek Landfill is estimated to be well below the 1,000 tonnes per year threshold set by the BC Ministry of Environment (ENV) as per LFG Management Regulation (2008), this site is not required to install an active LFG management system. Therefore, the relatively small amount of the generated methane can be released to the atmosphere without any active LFG management. Nevertheless, SHA suggested that the TNRD can reduce the GHG emissions from this site and benefit from the carbon credits. We suggested that one of the most feasible options of generating carbon credits for small sites, such as the Heffley Creek Landfill, is biological oxidization of methane using a biocover system.

In 2015, the TNRD adopted this approach and implemented biocover system over top of the closed areas of the Heffley Creek Landfill in the central portion of the site. The implementation of the biocover system at the Heffley Creek Landfill started after a baseline GHG emission measurement was completed at this site by SHA in November 2014. Subsequently, SHA completed additional rounds of GHG emissions measurement in the following years to assess efficiency of the biocover system in methane oxidization and to quantify the GHG emissions reduction achieved in each year. In 2016 and 2017 SHA concluded average biocover efficiencies of 49% and 32%, respectively. We estimated total GHG emissions reduction of 312 and 144 tonnes of carbon dioxide equivalent (CO_2-e) for 2016 and 2017, respectively.

The TNRD retained SHA to conduct another round of field measurement at the Heffley Creek Landfill, to evaluate effectiveness of the biocover system and to quantify the GHG emissions reduction achieved at this site throughout 2018.

4 LITERATURE REVIEW ON BIOLOGICAL OXIDATION OF METHANE

Methane oxidation in landfill cover soil reduces GHG emissions from landfills. There are a number of published and peer reviewed scientific research papers that have reported methane oxidation fractions through operational soil cover at 22-55% (Whalen et al., 1990; Chanton et al., 2009; Chanton et al., 2011). Abedini et al. (2016) showed average methane oxidation values of 28% and 34% occurring at the cover soils of two different areas of the Vancouver Landfill in BC.

The U.S. Environmental Protection Agency (USEPA, 2004) also reported an average methane oxidation rate of 10% to 25% with lower rates for clay cover soil and higher rates for topsoil. However, due to the challenges of accurately measuring methane oxidation and lack of standard quantifying methods, the U.S. EPA recommends a default average value of 10% methane oxidation for cover soil (USEPA, 2004). This minimum baseline methane oxidation rate for landfill cover soil is also adopted by Climate Action Reserve (CAR) protocol, Pacific Carbon Trust (PCT) LFG management protocol, as well as the Intergovernmental Panel on Climate Change (IPCC) guidelines and protocols for national GHG inventories. In the following analysis, because the baseline methane emissions measurement was completed after placement of the cover soil, the baseline methane oxidation was already factored in the calculations. Therefore, additional deductions were not applied.

For engineered fabricated biocovers, the methane oxidation rate is reported to be between 50% and 100%, depending on the biocover design, climate, and the methane loading rate on the biocover (Barlaz et al., 2004; Stern et al., 2007; Abichou et al., 2009). Proper installation and maintenance of the biocover system is required to ensure effectiveness of the system and to avoid methane displacement, rapid advection of the gas through the cracks and creation of emission hot spots.

5 BIOCOVER APPLICATION AND MONITORING

The Baseline emission monitoring was completed on cover soils as shown in Photo 1 below. During the baseline methane emission sampling, the Heffley Creek Landfill was divided into different zones on the crest and the side slopes. The total area that was scanned for methane emissions and was envisioned to receive biocover was approximately 2 hectares.

Photo 1. SHA Staff conducting baseline methane emission sampling at Heffley Creek Landfill

After this first round of field measurements, the TNRD placed fabricated biocover on the slope and crest areas of Phase A (Crest Biocover (C1) and Slopes 1, 2, 3, and 4). However, based on the landfill's filling plan, in 2016 and 2017 waste disposal continued in south and west of Phase A, and as the result, Slopes 3 and 4, as well as a portion of the crest (C1) were buried under next lift of deposited MSW. Following SHA recommendations and to maximize the GHG emissions reduction from this site, the TNRD has continued to place additional biocover on the south and west slopes of the current active cell. These areas, shown as Slope 6 and Slope 7 in enclosed Figure 3, received biocover in early 2018. Therefore, the offset credits resulted from application of biocover in these areas will be included in next year's assessment for 2018 GHG emissions reduction quantification.

Nevertheless, following SHA recommendations and to maximize the GHG emissions reduction from this site, the TNRD has been continuously placing new biocover systems on the finished slopes including biocover S3, S5 and S7 on the west and south slopes of the current active cell shown in the enclosed Figure 4. Figure 3 also shows the original S1 Biocover, the recently placed S3 and S5 biocovers, as well as the biocover material stockpile and blending area on top o fPhase A crest area at the Heffley Creek Landfill.

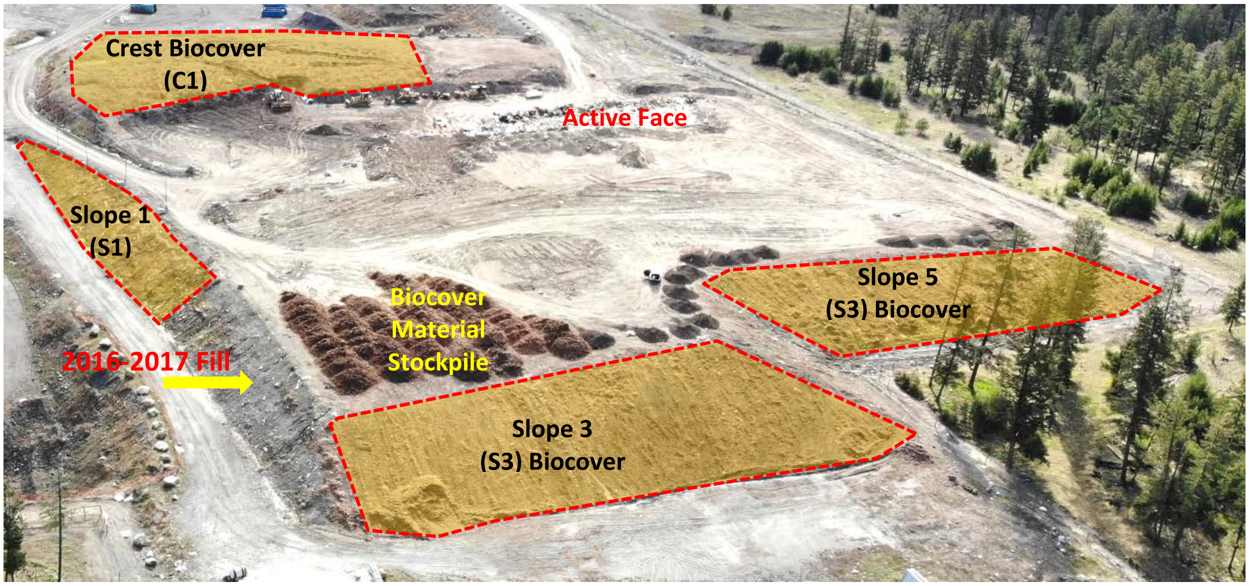

Figure 3. Slope 1 (S1), S3 and S4 Biocover Areas at the Heffley Creek Landfill

Photos 2 and 3 show the newly placed biocover material on slopes 5 and 7, respectively (Photo from May 2018).

Photo 2. Slope 5 area west of current active cell received biocover in early 2018

Photo 3. Biocover placed on the south slopes of Phase A (Slope 7 area) in early 2018

Continuous expansion of the biocover system ensures maximized GHG reductions are achieved. The finished side slopes on which biocover was placed in early 2018 at the Heffley Creek Landfill were sloped at 19.2˚ or approximately 3H:1V (3 Horizontal to 1 Vertical). This is the recommended angle for landfill external slopes and appropriate for placement of biocover media. Photo 4 shows slope of the area that received biocover in early 2018 at approximately 19° (i.e. ~ 3H:1V).

Photo 4. Proper side slope in Area Slope 4 (3H:1V)

Field monitoring for quantification of the GHG emissions reductions achieved in 2018 by application of biocover were completed in April 24th, 2019. Similar to previous years, SHA used an advanced technique to measure the fugitive methane emissions and compared the results with the baseline emission rates before application of biocover. The methodology and the results of these site investigations are explained in the next section.

5.1 Methane Emissions Measurement

Fugitive methane emissions measurements from the biocover area were conducted through an approach developed by Abedini and Atwater (2014). This patent pending methodology involves measurement of surface methane concentrations (SMC) from the area of interest, as well as conducting complementary flux chamber measurements in representative areas to measure methane emission rates (MER). When emission rates are below detection limit of the flux chamber technique, the SMC results, measured down to 0.00001% percent methane, are translated to MER using a default correlation factor (Abedini, 2014). The SMC and MER measurement techniques are further described below.

5.1.1 Surface Methane Concentration Scan

The surface methane concentration (SMC) scan using a flame ionization detector (FID) is an approved methodology used across the united states (US), where it is required by the US Environmental Protection Agency's (EPA) new source performance standard (NSPS) regulation. Because quantification of methane emissions is not economically feasible for all landfills, the NSPS regulation requires that methane concentrations at the surface of the regulated landfills be kept below certain levels, indicating efficiency of the site's active LFG collection and control system. According to the NSPS, if the FID field measurements register values above the threshold then the owner would have to implement mitigation measures within a given period of time.

5.1.2 Flux Chamber Measurements

Application of flux chambers in landfills is a well-established measurement method. This technique is to measure fugitive methane emissions from the soil surface through isolating and monitoring the emitting gas from soil. The flux chamber technique includes placing a closed chamber (box) on the landfill's surface and monitoring the change of methane concentration in the box over time. Based on the rate of change of methane concentration in the chamber over time, chamber volume and area beneath the chamber, the methane flux emitted from landfill's surface can be calculated.

Flux chamber technique is an approved methodology by the US EPA and is used when quantification of methane emissions is required. However, because it is a very time-consuming methodology, it's been rarely implemented in MSW landfills at full scale. On the other hand, due to the technique detection limits, achieving reliable data from flux chamber measurements over top the biocover areas, where the methane is almost fully oxidized, is not practical and can be very difficult to detect. In contrast, the FID instrument can detect methane concentrations down to 0.1 parts per million by volume (ppmv) levels (i.e. 1 x 10^{-5} percent). Photo 5 shows SHA's staff Scott Garthwaite conducting flux chamber measurement at Kamloops Indian Band Landfill Site.

Photo 5. Methane Emission Measurement Using Flux Chamber

5.1.3 LFG Emission Measurement Technique at the Heffley Creek Landfill

The adopted methodology to evaluate biocover performance is a combination of the two above-mentioned techniques. This patent pending methodology was developed through the PhD research of Dr. Ali Abedini (Abedini, 2014). Abedini's methodology was developed based on comprehensive field investigations including FID surface scan of about 18 Ha and approximately 190 flux chamber measurements conducted at the Vancouver Landfill in BC. This technique, that involves quantification of fugitive methane emissions overtop of the biocover area based on the near-surface concentration of methane, was applied at the Heffley Creek landfill. The methane emission rates were then compared against the baseline methane emission rates (previously quantified using the same technique) to quantify the methane emissions reductions that were achieved by the biocover system.

For quantification of 2018 GHG emissions reductions at the Heffley Creek Landfill, series of SMC field measurements using the FID technique were completed in April 2019. The SMC scan was conducted over the entire biocover area, as well as two side slope areas with no biocover in place (i.e. S4 and S6) (approximately 1.6 Ha). A Thermo Scientific TVA 2020 FID instrument was used to measure and log methane concentrations, along with GPS coordinates, approximately 2 to 4 inches above ground on the biocover surface. The scanned area was walked on approximate 5 to 10 m pathways while logging methane concentration every 3 seconds. The FID instrument was calibrated using calibration gas tanks prior conducting each set of measurements. Photo 6 below shows SHA's LFG Specialist, Dr. Abedini, conducting FID scan in a similar project.

Photo 6. Surface Methane Concentration Scan Using a Portable FID Instrument

Results of these field investigations at the Heffley Creek Landfill are presented in Section 6.

5.2 Climate Effect

A very important aspect of measurement of fugitive methane emissions from landfills is the effect of barometric pressure (BP) on the gas flux intensity. Fluctuation in BP is known to greatly impact LFG atmospheric emission (Abedini, 2014). When the BP is increasing, the heavier atmospheric pressure is applied on the ground, restricting natural LFG venting through the landfill surface, or migrating through the soil. Dropping BP reduces the pressure exerted on the ground, enabling LFG to move more freely from the landfill and increasing the potential for gas escape through surface or offsite lateral migration.

In order to account for the impact of BP on level if methane emissions during the field work, the BP variations were monitored, and the filed measurement results were adjusted for the rate of change in BP values. The data presented in Figure 5 below were acquired from the Kamloops Airport Weather Station during the days of field investigation in 2019.

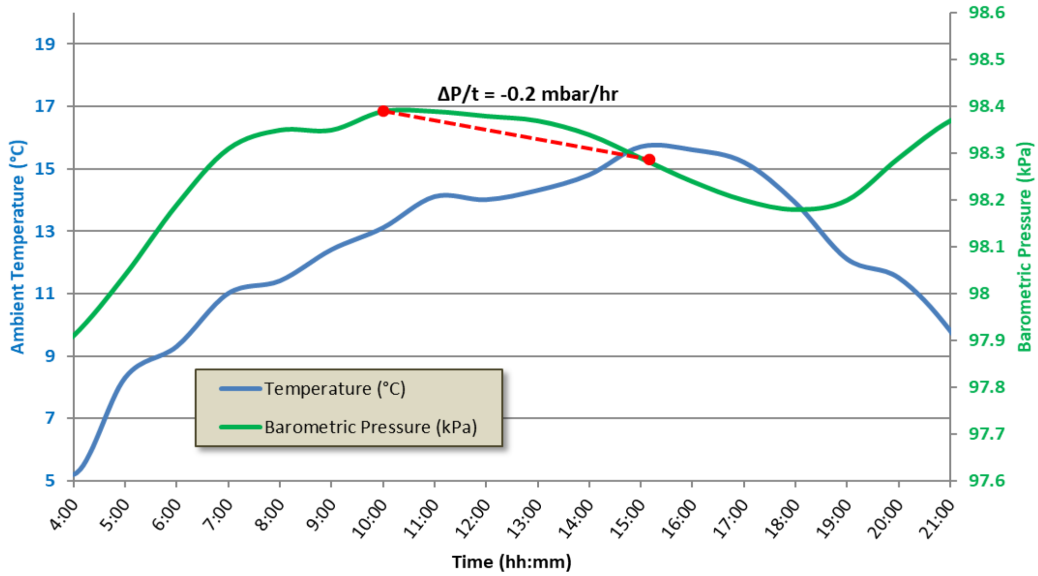

Figure 5. Climate Data for April 24th, 2019 (Source: Kamloops Airport Weather Station)

6 RESULTS

The total GHG emissions reduction achieved through biological oxidation of methane in biocover at the Heffley Creek Landfill includes "baseline" reductions and "additional" reductions. The average baseline reduction is normally the 10% methane oxidation that naturally occurs when methane travels through the cover soil placed at the top of completed phases. By quantifying the emission rates in two rounds, before and after placement of the biocover, the "additional" oxidation resulted from the application of biocover was estimated at the Heffley Creek Landfill.

During the course of the baseline field investigations, a total of 16 flux chamber measurements were conducted to generate a site-specific index factor similar to what Dr. Abedini developed for the Vancouver Landfill. During these tests, methane concentrations inside the chamber were continuously monitored using a Landtec GEM 2000+ gas analyzer. However, due to the low baseline methane emission rates at this site, flux chamber measurements did not produce meaningful results. Therefore, the surface methane concentrations were translated into the methane emission rates based on Abedini's methodology using the technique's default correlation factor.

As reported in our previous report, (*Heffley Creek Landfill 2016 Greenhouse Gas (GHG) Emissions Reduction Quantification)*, the FID surface methane concentrations (SMC) scan showed an average methane concentration of 2 to 16 ppmv in areas of S1, S2, and C1 before placement of biocover. In the post construction monitoring events, these values were reduced to values ranging from 0.2 to 3.6 ppmv in 2016 and 0.2 to 1.0 ppmv in 2017. The range that we measured during the recent field work was 0.3 and 1.2 ppmv. To account for the decline in LFG generation, we applied a 5% per year reduction on the baseline emission values that were used for previous year calculations

As part of the recent 2018 sampling event, SHA also completed the surface methane scan over the new biocover areas, including S3, S5, and S7, as well as the slopes in the vicinity of these areas with no biocover systems in place (marked as S4 and S6 in enclosed Figure 4). These scans showed an average SMC values of 0.4, 0.5 and 1.3 ppmv in areas of S3, S5, and S7, respectively. The baseline SMC values for these areas ranged between 0.6 and 24.3 ppmv, measured in S4 and S6 areas, with an overall average value of 12.5 ppmv. Tables 3 below summarizes the finding and the results of the recent filed investigations at the Heffley Creek Landfill.

Table 3. Summary of Methane Emission Measurement Results at the Heffley Creek Landfill

Grid Number	Area	Surface Methane Concentration (SMC)			Methane Emission Rate (MER)
		MIN	MAX	AVG.	AVG.
	(m^2)	(ppmv)	(ppmv)	(ppmv)	$g/m^2/day$
S1-Biocover	770	1.00	1.60	1.18	2.56
S2-Biocover	1,520	0.60	2.40	0.78	2.42
C1-Biocover	6,580	0.17	3.01	0.36	2.27
S3-Biocover	1,600	0.25	4.76	0.41	2.29
S4-Soil	250	0.17	7.18	0.62	2.36
S5-Biocover	1,400	0.17	40.34	0.52	2.33
S6-Soil	600	1.25	3,350.0	24.32	10.76
S7-Biocover	3,000	0.93	5.09	1.26	2.59
Biocover Areas (avg.)	**14,870**	**0.52**	**9.53**	**0.75**	**2.41**
Soil Areas (avg.)	**850**	**0.71**	**1678.60**	**12.47**	**6.56**

The overall methane emissions reductions that were achieved by the older biocover systems placed in Areas S1, S2, and C1 in 2018 ranged between 21% and 70%. The newer biocover systems placed over Areas S3, S5, and S7 in early 2018 showed better efficiencies ranging between 70 and 77%.

Because C1 biocover with low efficiency of 21% has a relatively large footprint area in comparison with the other biocover areas, the weighted average efficiency of the Heffley Creek Landfill biocover system is concluded to be 49%. However, Considering the majority of the generate methane are emitted from side slopes, SHA concludes that the biocover system placed at this site reduces the fugitive methane at an approximate reduction rate of 70%. Our analyses showed that the biocover system at the Heffley Creek Landfill has resulted in 341 tonnes CO_2-e GHG emissions reduction equivalent in 2018. Table 4 summarizes the biocover methane reduction efficiencies and the 2018 GHG emissions reductions for the Heffley Creek Landfill.

Table 4. Summary of 2018 Results and GHG Emissions Reductions at the Heffley Creek Landfill

	Grid Number	Footprint Area	Surface Methane Concentration (SMC)			CH_4 Emission Rate ($g/m^2/d$) (Abedini, 2014)		% Reduction from Baseline	GHG Emissions Reduction
			MIN	MAX	AVG.				
		m^2	ppmv	ppmv	ppmv	MER	±ΔMER	%	tonnes CO_2-e/yr
Baseline Data	S1-Biocover	770	-	-	-	5.99*		-	-
	S2-Biocover	1,520	-	-	-	4.18*		-	-
	C1-Biocover	6,580	-	-	-	1.90*		-	-
	S3-Biocover	1,600	-	-	-	6.56**		-	-
	S5-Biocover	1,400	-	-	-	6.56**			
	S7-Biocover	3,000	-	-	-	5.99		-	-
	TOTAL	**14,870**	**-**	**-**	**-**	**5.20**			
2018 Data	S1-Biocover	770	1.00	1.60	1.18	1.77	0.80	70%	29.6
	S2-Biocover	1,520	0.60	2.40	0.78	1.64	0.78	61%	35.2
	C1-Biocover	6,580	0.17	3.01	0.36	1.51	0.77	21%	23.6
	S3-Biocover	1,600	0.25	4.76	0.41	1.52	0.77	77%	73.6
	S5-Biocover	1,400	0.17	40.34	0.52	1.56	0.77	76%	63.9
	S7-Biocover	3,000	0.93	5.09	1.26	1.79	0.80	70%	114.7
	TOTAL	**14,870**	**0.52**	**9.53**	**0.75**	**1.63**	0.78	**49%**	**341**
						Annual Reduction (tonnes CO_2-e):			**341**

* From 2017, reduced 5% to account for LFG Generation Decline

** Based on average MER measured at slopes with soil cover (i.e. S4 & S6)

Photos 7 and 8 show example of the methane emission hotspots that were identified during the surface scan in Areas S2, C1 and S5. Enclosed Figure 4 shows the major emissions hotspots in all areas.

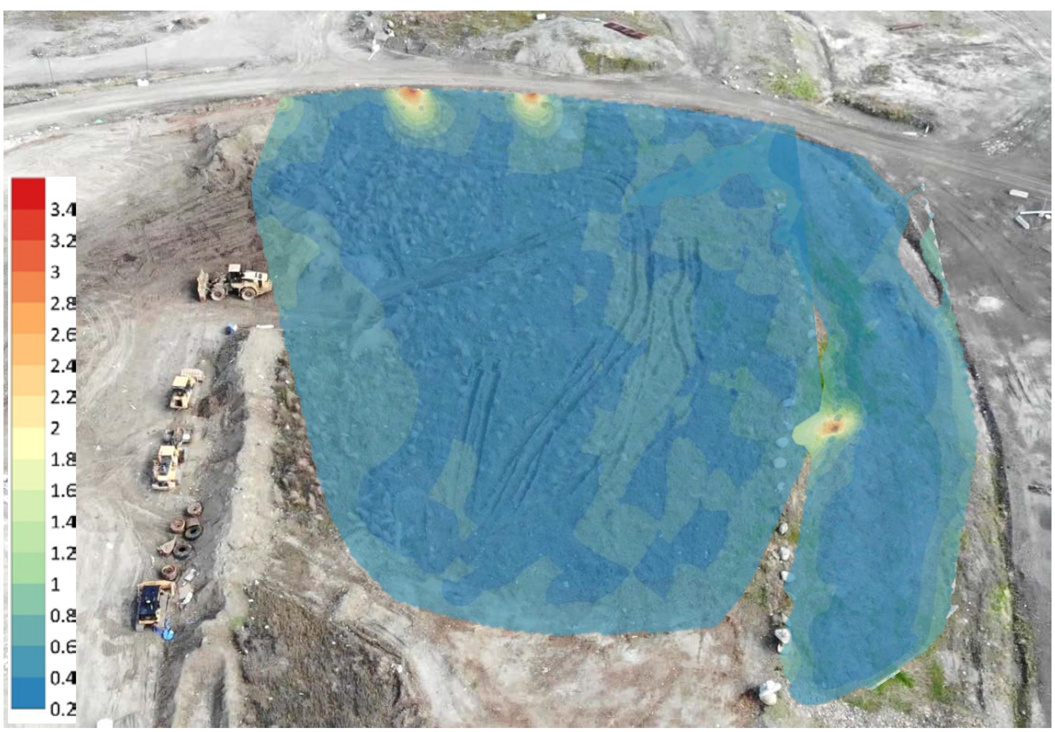

Photo 7. Surface Methane Concentration (ppmv) and Methane Emission Hot Spots in S2 and C1 Biocover Areas

Photo 8. Surface Methane Concentration (ppmv) and Methane Emission Hot Spot in S5 Area

7 CONCLUSION AND RECOMMENDATIONS

The current analyses showed that the implementation of biocover system at the Heffley Creek Landfill has resulted in GHG emissions reduction equivalent to 341 tonnes CO_2-e in 2018. The biocover placed on the side slopes of Phase A area appear to be very effective and ranging between 61% and 77%. The biocover system on the rest (C1) had an efficacy of 21%, reducing the weighted average biocover efficacy of the site to 49%. Nevertheless, SHA's assessment showed that the performance of the biocover system at the Heffley Creek Landfill was greatly improved in comparison to pervious years.

We recommend that the TNRD continues to maintain the recommended minimum thickness of 300 mm of biocover media over the finished slopes. We also recommend that the side slopes not to be steeper than 3H:1 in order to have the optimum condition for the biocover system maintenance. Furthermore, in preparation of the new biocover media, we recommend an optimum blend be fabricated and applied. Important parameters affecting the efficiency of the system includes; (i) temperature, (ii) moisture content, (iii) organic matter, (iv) carbon to nitrogen ratio (C:N), (v) pH, and (vi) porosity and structure of the media. Some of the general recommendation for an optimum biocover media includes:

1. Moisture content of 10 to 30%,
2. Organic matter content of up to 35%,
3. Optimum C:N ration of 25 to 97. C:N ration of less than 12 is not recommended,
4. Optimal pH range of 6.5 to 8.0,
5. High porosity to allow oxygen to enter and move through the media.

8 LIMITATIONS

This report has been prepared by Sperling Hansen Associates (SHA) for the Thompson Nicola Regional District (TNRD) in accordance with generally accepted engineering practices to a level of care and skill normally exercised by other members of the engineering and gas science professions currently practicing under similar conditions in British Columbia, subject to the time limits and financial and physical constraints applicable to the services.

The report, which specifically includes all tables and figures, is based on engineering analysis by SHA staff on data compiled during the course of the project. Except where specifically stated to the contrary, the information on which this study is based has been obtained from external sources. This external information has not been independently verified or otherwise examined by SHA to determine its accuracy and completeness. SHA has relied in good faith on this information and does not accept responsibility for any deficiency, misstatements or inaccuracies contained in the reports as a result of omissions, misinterpretation and/or fraudulent acts of the persons interviewed or contacted, or errors or omissions in the reviewed documentation.

The report is intended solely for the use of the TNRD. Any use which a third party makes of this report, or any reliance on, or decisions to be made based on it, are the responsibilities of such third parties. SHA does not accept any responsibility for other uses of the material contained herein nor for damages, if any, suffered by any third party because of decisions made or actions based on this report. Copying of this intellectual property for other purposes is not permitted.

The findings and conclusions of this report are valid only as of the date of this report. The interpretations presented in this report and the conclusions and recommendations that are drawn are based on information that was made available to SHA during the course of this project. Should additional new data become available in the future, SHA should be requested to re-evaluate the findings of this report and modify the conclusions and recommendations drawn, as required.

Yours truly,
SPERLING HANSEN ASSOCIATES

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Vice President

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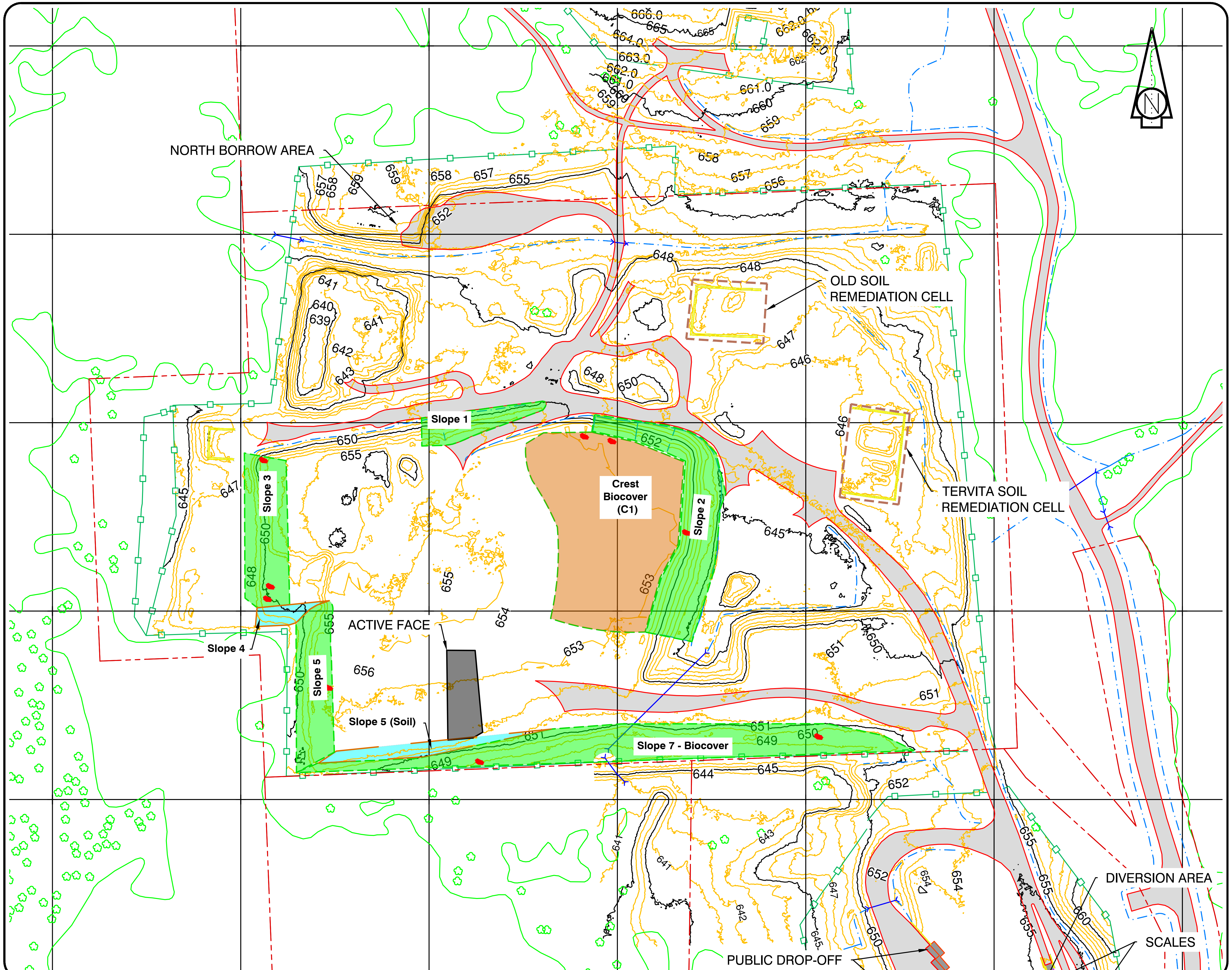

SPERLING
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- Landfill Siting
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LEGEND:

- 5m EXISTING CONTOUR
- 1m EXISTING CONTOUR
- FENCE
- DITCH LINE
- ROAD
- CULVERT
- PROPERTY LINE
- METHANE EMISSION HOT SPOT
- SIDE SLOPE - BIOCOVER
- SIDE SLOPE - NO BIOCOVER
- CREST AREA - WITH BIOCOVER
- 2018 WASTE DISPOSAL AREA

CLIENT: THOMPSON-NICOLA REGIONAL DISTRICT (TNRD)

PROJECT:
HEFFLEY CREEK LANDFILL
2018 GHG CREDIT QUANTIFICATION

TITLE:
BIOCOVER AREAS 2018

SCALE:	DATE:	PROJECT NO:
1:2,000	2019/05/01 (yyyy/mm/dd)	PRJ 19002

DESIGNED	AA	DRAWING NO:
DRAWN	HA	FIGURE 4
CHECKED	MC	