May 3rd, 2019 PRJ19001

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

Attention: **Kory Ryde**
EHS Technologist

Dear Mr. Ryde,

Re: Lower Nicola Landfill 2018 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 Lower Nicola Landfill.*

1 LANDFILL INFORMATION

The Lower Nicola Landfill is located 2 km west of Lower Nicola on Highway #8 in British Columbia (BC). The site serves approximately 13,000 people from the City of Merritt and surrounding rural areas and also accepts refuse from the Thompson Nicola Regional District (TNRD) transfer stations in Aspen Grove, Mamit Lake, Spences Bridge and surrounding First Nation communities. The landfill footprint, Lot B which encompasses approximately 16 Ha, is surrounded by the TNRD land titled District Lot 4553 of approximately 25 Ha.

Figure 1 shows location of the Lower Nicola Landfill.

Figure 1. Lower Nicola Landfill Location

The Lower Nicola Landfill was originally permitted as a waste management site in September, 1976 for the disposal of municipal refuse from Merritt, Lower Nicola and surrounding rural areas. Historically, waste filling activities at the Lower Nicola Landfill have been in the central and southern portions of the site and have been completed using a combination of the trench and ramp methods. The current active face of the landfill is located in the north east corner of the landfill footprint as shown in Figure 3 and the enclosed Figure 4.

2 LANDFILL GAS GENERATION ASSESSMENT

In 2014, SHA completed a landfill gas (LFG) generation assessment for the Lower Nicola Landfill. The LFG generation estimates showed that the annual methane generation at this site was approximately 271 tonnes/year. Methane generation rate in 2018 was estimated to be approximately 310 tonnes/year. Figure 2 below shows the methane generation estimate at the Lower Nicola Landfill from 1984 to 2018.

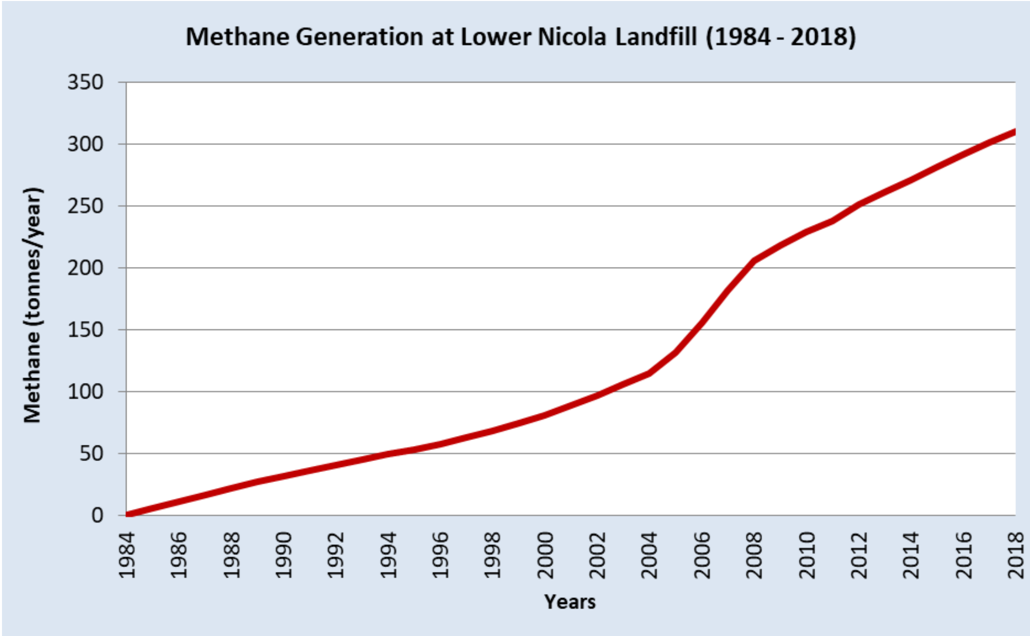

Figure 2. Methane Generation Estimate at Lower Nicola Landfill

The methane generation at the Lower Nicola Landfill is estimated to be well below the 1,000 tonnes/year threshold set by the BC Ministry of Environment (ENV) as per LFG Management Regulation (2008). Therefore, this site is not required to install an active LFG management system and the relatively small amount of the generated methane can be released to the atmosphere without any active LFG management system.

A summary of estimated methane generation rates for the Lower Nicola 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	261
Estimated Quantity of Methane Produced in the Year of Assessment	2014	271
Estimated Quantity of Methane Produced one Year after the Assessment	2015	281
Estimated Quantity of Methane Produced two Years after the Assessment	2016	291
Estimated Quantity of Methane Produced three Years after the Assessment	2017	301
Estimated Quantity of Methane Produced four Years after the Assessment	**2018**	**310**

3 GHG EMISSIONS REDUCTION INITIATIVE

Even though the Lower Nicola Landfill is not mandated to collect and destroy/oxidize the generated methane, the TNRD engaged SHA to explore options for implementation of a methane emissions reduction initiative at this site in 2014. SHA's recommendation was to apply an engineered biocover system in the areas of the landfill that would not receive additional waste in the near future. The use of engineered biocover systems to reduce fugitive methane emissions from landfills is an emerging GHG mitigation technology. Biocover systems, fabricated using organic residuals such as biosolids, compost and wood chips, can have ideal physicochemical properties that stimulate the growth of methanotrophic bacteria that consume methane and produce carbon dioxide, a less potent GHG.

The TNRD adopted this approach and implemented biocover system over top of the closed areas of the Lower Nicola Landfill in the central and southern portions of the site early 2015 and continued to expand the biocover system when an area of the landfill reached the final design elevations. The initial implementation of the biocover system at the Lower Nicola Landfill started after a baseline GHG emissions measurement was completed at this site by SHA in October 2014. Subsequently, SHA completed additional rounds of GHG emissions measurement once a year 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. SHA concluded biocover efficiency levels of 21%, 30% and 21% with total GHG emissions reduction of 370, 350 and 142 tonnes of carbon dioxide equivalent (CO_2-e) per year for 2015, 2016 and 2017, respectively.

The TNRD retained SHA to conduct another round of field measurement at the Lower Nicola 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 10-25% 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 biocover systems, the methane oxidation rate is reported to be between 50-100%, 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 fabricated biocover was placed by the TNRD on the crest area on the north east corner of the site. However, during 2018 the active face of the landfill was moved from north west corner to the north east corner and the crest biocover was buried with new lifts of disposed waste. Biocover system was also placed on the side slope areas of the central, west and southern parts of the Lower Nicola landfill (Slopes 1 through 6 in Figures 3 and 4). The biocover systems S1 to S4 were placed in early 2015, followed by additional biocover systems labeled as S5 and S6. Furthermore, additional biocover have been placed on Slopes 1, 2 and 3, on the areas that SHA identified as emissions "Hot Spots" in its previous GHG emissions measurement field works at the Lower Nicola Landfill. Figure 3 shows different Biocover areas at the Lower Nicola Landfill.

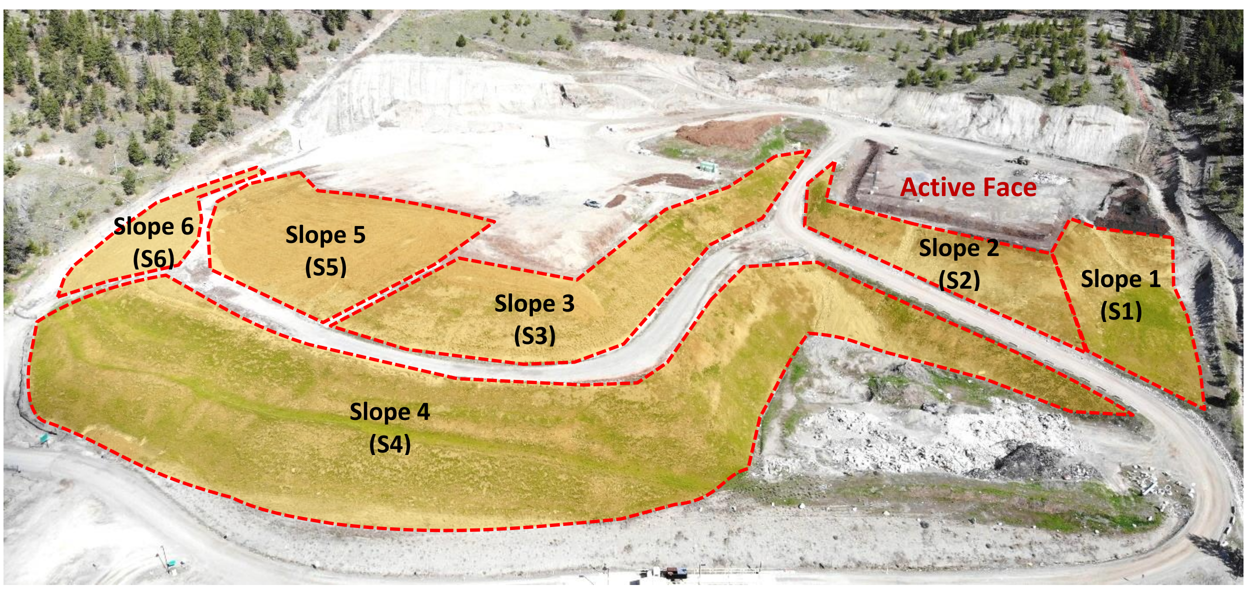

Figure 3. Lower Nicola Landfill Biocover System Areas

The following photos show the Slope 3 area before biocover application (2014), and after the latest round of surface scan (2018 and 2019).

Photo 1. Slope 3 (S3) Area before application of biocover (2014)

Photo 2. Slope 3 (S3) Area during 2017 GHG emission scan (2018)

Photo 3. Slope 3 (S3) Area during latest round of GHG emission scan (2019)

The following photos show the Slope 2 area after application of biocover in 2018 and 2019.

Photo 4. Slope 2 (S2) Area during 2017 GHG emission scan (2018)

Photo 5. Slope 2 (S2) Area during latest round of GHG emission scan (2019)

As part of the landfill operation and waste disposal activities in 2017 and 2018, a portion of the biocover in Slope 3 area (facing west), as well as the crest biocover at the north east corner were buried under next lifts of MSW. These areas were removed from the 2018 GHG emissions reduction calculations. However, 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 old active cell. These areas, shown as Slope 5 and Slope 6 in Figures 3 and 4, received biocover in early 2018. Therefore, the offset credits resulted from application of biocover in these areas are included in the current assessment for the 2018 GHG emissions reduction quantification.

Photos 4 and 5 show the new biocover material placed on slopes 6 and 7, respectively.

Photo 6. Slope 5 Area south of current active cell received biocover in early 2018

Photo 7. Biocover placed on Slope 6 Area, lower slopes south of the 2018 active cell

It is very important that the TNRD have been continuously expanding biocover system footprint. This will ensure that the GHG emissions reduction from this facility is maximized.

Field monitoring for quantification of the GHG emissions reductions achieved in 2018 by application of biocover were completed in April 23rd, 2019. Similar to previous years, SHA used an advanced pat-pending technique to measure the fugitive methane emissions and compared the results with the baseline emission rates before application of the biocover system. 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. 1×10^{-5} percent).

5.1.3 LFG Emission Measurement Technique at the Lower Nicola 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 Lower Nicola 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 Lower Nicola 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 (approximately 3.1 Ha). A Thermo Scientific TVA 2020 FID instrument was used to measure and log methane concentrations, along with GPS coordinates, approximately 1 inch 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 8 shows SHA's LFG Specialist, Dr. Abedini, conducting FID scan in a similar project.

Photo 8. Surface Methane Concentration Scan Using a Portable FID Instrument

Results of these field investigations at the Lower Nicola 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 2018.

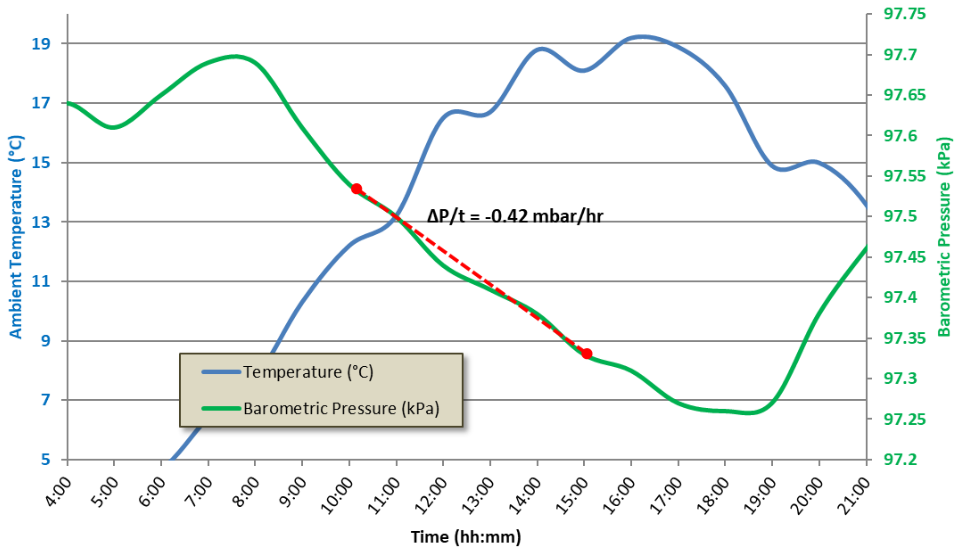

Figure 5. Climate Data for April 23rd, 2019 (Source: Kamloops Airport Weather Station)

6 RESULTS

The total GHG emissions reduction achieved through biological oxidation of methane in biocover at the Lower Nicola 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 Lower Nicola Landfill.

Due to the low baseline methane emission rates at this site (~ 3 $g/m^2/day$) 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 reports, (*Lower Nicola Landfill 2016 and 2017 GHG Emissions Reduction Quantification)*, the FID surface methane concentrations (SMC) scan showed an average methane concentration of 0.5 to 7 ppmv in different areas before the placement of biocover. In 2015, 2016 and 2017 post construction monitoring events, these values were reduced to values ranging from 0.2 to 2.4 ppmv, 0.07 to 2 ppmv, and 0.8 to 3.9 ppmv, respectively. The range that we measured during the recent field work was 1.1 to 2.1 ppmv showing lower level of emissions and higher average effectiveness of the biocover system in comparison to the previous year.

The overall methane emissions reductions that were concluded for 2015, 2016 and 2017 were approximately 21%, 30% and 21%, respectively. The slight improvement between 2015 and

2016 was a result of additional biocover material that was placed in late 2015 on northern areas of Slope 3, however; steep side slopes and formation of cracks in the biocover system in these areas reduced the overall efficiency of the biocover system in 2017. The methane emissions reduction for 2018 was increased to an average of 26%. Effectiveness of the biocover system in different areas was different and ranged between 11% and 48%. Notably, the biocover system in side slope areas that have a steeper slope (i.e. Slopes 1, 2, and 4 with approximately 2H:1V slope) showed much lower efficiency in comparison with the biocover system placed on shallower slopes (i.e. Slopes 3, 5, and 6). As mentioned in our previous reports, steep side slopes result in instability of the biocover system, high erosion and washout of the biocover, and formation of cracks and fissures in the biocover from which methane escape was observed during the surface scan. The TNRD, however, has followed our recommendations in this regard and the more recently completed phases have notable shallower side slopes (approximately 3:1) and much better biocover system performance (i.e. 40 to 48%).

Similar to previous years, we identified emission hot spots where more significant methane emission was detected during the field work. These hot spots are shown in the enclosed Figure 4. Figure 6 below shows a 2D illustration example of the SMC levels at S1 and S2 Biocover areas.

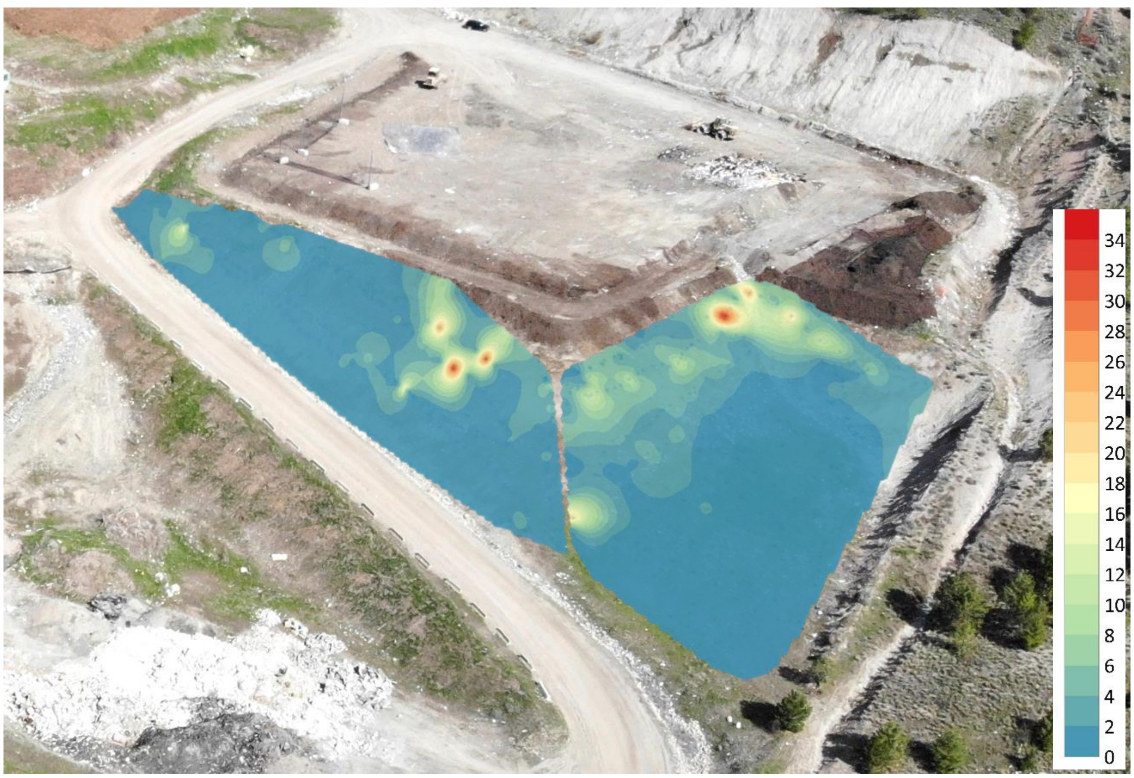

Figure 6. 2D Illustration of Surface Methane Concentration (ppmv) and Methane Emissions Hotspots in S1 & S2 Areas

Figure 7 shows a 2D illustration example of the SMC levels at S3 Biocover area.

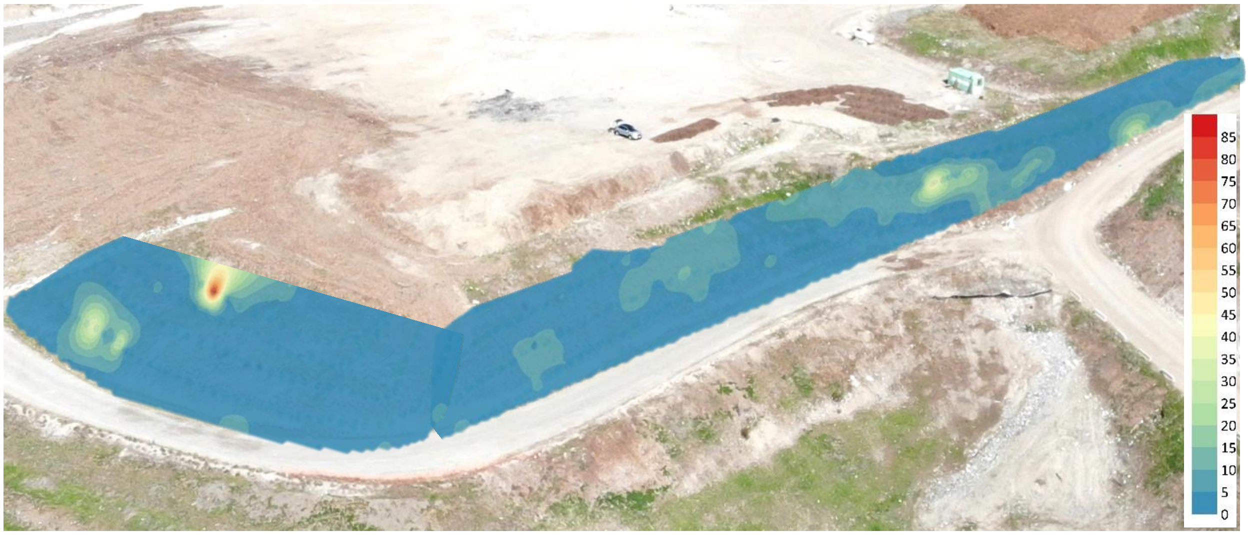

Figure 7. 2D Illustration of Surface Methane Concentration and Emissions Hotspot in S3 Area

Due to the emission hot spots and high intensity of the methane flux from these locations the overall effectiveness of the biocover system at the Lower Nicola Landfill has declined. Table 2 below summarizes the finding and the results of the baseline and follow-up round of the filed investigations at the Lower Nicola Landfill.

Table 2. Summary of Methane Emission Measurement Results at the Lower Nicola Landfill

	Grid Number	Footprint Area	Surface Methane Concentration			CH_4 Emission Rate ($g/m^2/d$)		% Reduction from Baseline	GHG Emissions Reduction
			MIN	MAX	AVG.	(Abedini, 2014)			
		m^2	ppm	ppm	ppm	MER	±ΔMER	%	tonnes CO_2-e/yr
Baseline Data	S1	2,810	1.61	62.74	2.85	2.30	0.85	-	-
	S2	4,540	1.04	10.40	2.65	2.24	0.85	-	-
	S3	5,550	1.91	58.45	6.93	3.61	0.99	-	-
	S4	11,550	1.69	5.04	2.05	2.05	0.82	-	-
	S5	3,690	--	--	6.93*	3.61	0.99	-	-
	S6	2,860	--	--	6.93*	3.61	0.99	-	-
	TOTAL	**31,000**	**1.56**	**34.16**	**4.72**	**2.90**	0.92		
2018 Data	S1	2,810	0.39	26.99	2.08	2.06	0.83	11%	6.3
	S2	4,540	0.18	16.16	1.14	1.75	0.79	22%	20.1
	S3	5,550	0.19	57.92	2.47	2.18	0.84	40%	72.3
	S4	11,550	0.00	19.73	1.13	1.75	0.79	14%	30.8
	S5	3,690	0.06	28.39	1.55	1.89	0.81	48%	58.0
	S6	2,860	0.00	31.13	1.88	1.99	0.82	45%	42.2
	TOTAL	**31,000**	**0.14**	**30.05**	**1.71**	**1.94**	0.81	**26%**	**230**
						Annual Reduction (tonnes CO_2-e):			**230**

* No baseline data available, therefore, as a conservative approach assumed to be similar to S3 area baseline.

Taking into account the total footprint of the scanned area at the Lower Nicola Landfill, SHA estimated that a total of 9.2 tonnes of methane, equivalent to 230 tonnes of CO_2-e, was reduced through biological oxidization in the biocover system at this site in 2018.

7 CONCLUSION AND RECOMMENDATIONS

The current analyses showed that the implementation of biocover system at the Lower Nicola Landfill has resulted in GHG emissions reduction equivalent to 230 tonnes CO_2-e in 2018. The TNRD has placed additional biocover on the side slopes of the 2017 filling area where it has reached the final design elevations. Having a proper slope and better biocover blend resulted in better performance of these new biocover systems. Therefore, the overall effectiveness of the biocover system at the Lower Nicola Landfill was increased from last year's 21% to 26% in 2018.

We applaud TNRD's efforts in continuously expanding the biocover system at the Lower Nicola Landfill and recommend continuing to maintain the existing biocover area by placing additional layers of material, specially in the areas shown as emission hot spots in the attached Figure 4. We recommend minimum thickness of 300 mm of the biocover system to be maintained in order to maximize methane oxidation efficiency. Furthermore, in preparation of the 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

To assess the suitability of the biocover material that was recently placed at the Lower Nicola Landfill, SHA recommends the following tests to be completed on at least three samples from the media;

a) C:N Ratio
b) Total Carbon Content
c) Total Organic Carbon
d) Total Nitrogen
e) Total Organic Matter
f) Moisture Content
g) Density
h) pH

Having these information, SHA will be able to assist the TNRD and provide further recommendations to optimize the biocover media and maximize the methane oxidation levels at this site.

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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9 REFERENCES

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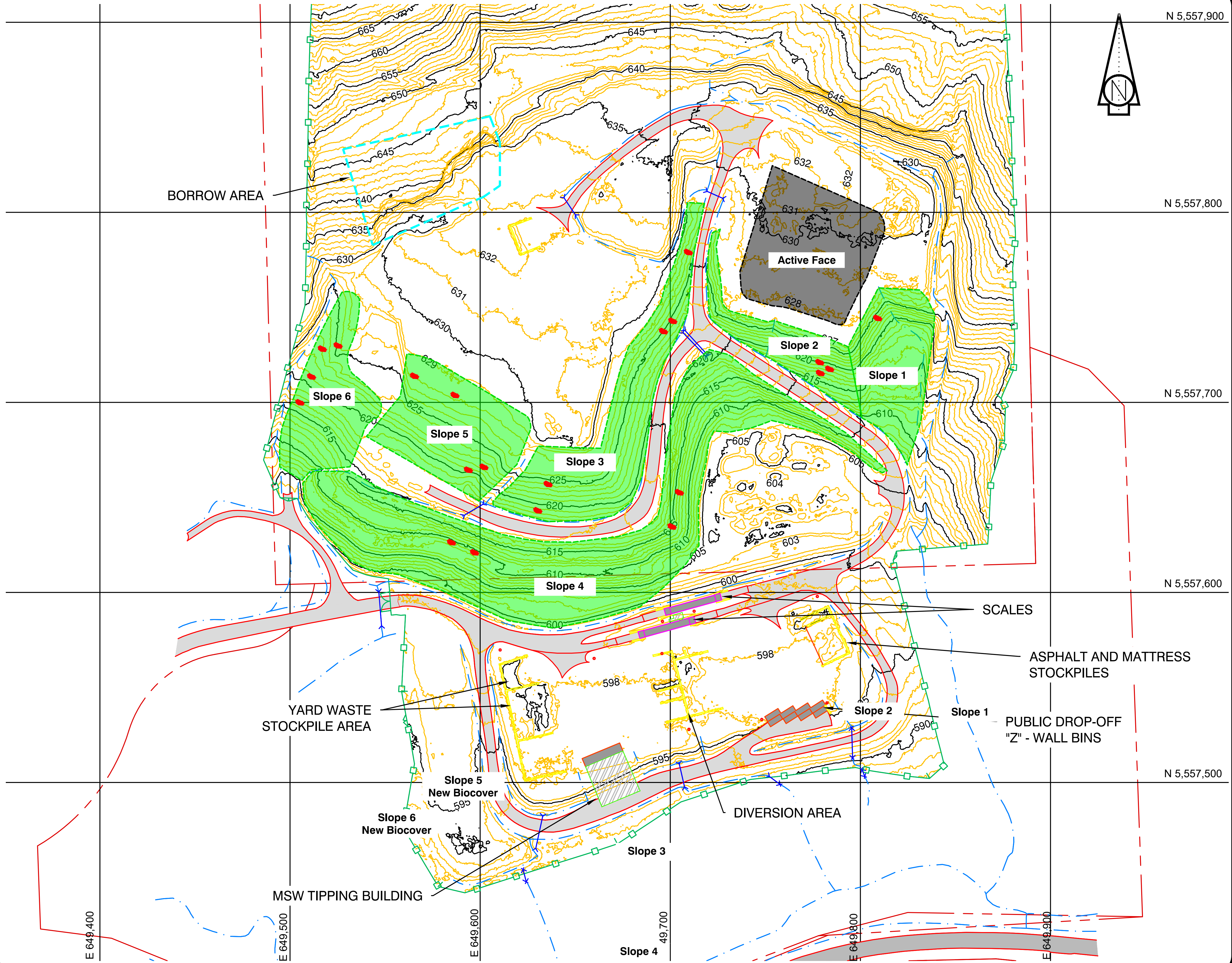

Sperling
Hansen
Associates

Landfill Services Group
- Landfill Siting
- Design & Operations Plans
- Landfill Siting
- Environmental Monitoring

#8 - 1225 East Keith Road
North Vancouver, B.C. V7J 1J3

Phone: (604) 986-7723
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LEGEND:

- 5m EXISTING CONTOUR
- 1m EXISTING CONTOUR
- FENCE
- DITCH LINE
- ROAD
- PROPERTY LINE
- CH4 EMISSION HOT SPOT
- SIDE SLOPE BIOCOVER AREAS
- 2018 WASTE DISPOSAL

CLIENT: TNRD (Thompson-Nicola Regional District)

PROJECT:

LOWER NICOLA LANDFILL BIOCOVER 2018 GHG CREDIT QUANTIFICATION

TITLE:

FID SURFACE SCAN AREAS

SCALE:	DATE:	PROJECT NO:
1:2,000	2019/05/01 yyyy/mm/dd	PRJ 19001

		DRAWING NO:
DESIGNED	AA	**FIGURE 4**
DRAWN	HA	
CHECKED	MC	