June 13th, 2016 PRJ16021

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

Attention: **Dennis Labrie**
EHS Operations Supervisor

Dear Mr. Labrie,

Re: Lower Nicola Landfill 2015 Greenhouse Gas (GHG) Emissions Reduction Quantification

Sperling Hansen Associates (SHA) are pleased to submit this letter report on *2015 greenhouse gas (GHG) emissions reduction for the Lower Nicola Landfill.*

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 12,293 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 and 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.

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.

Landfill Gas (LFG) Generation Assessment

In 2014, SHA completed a LFG generation assessment for the Lower Nicola Landfill. The LFG generation estimates showed that the annual methane generation at this site was about 271 tonnes/year. Figure 1 shows the methane generation estimate at the Lower Nicola Landfill from 1984 to 2018.

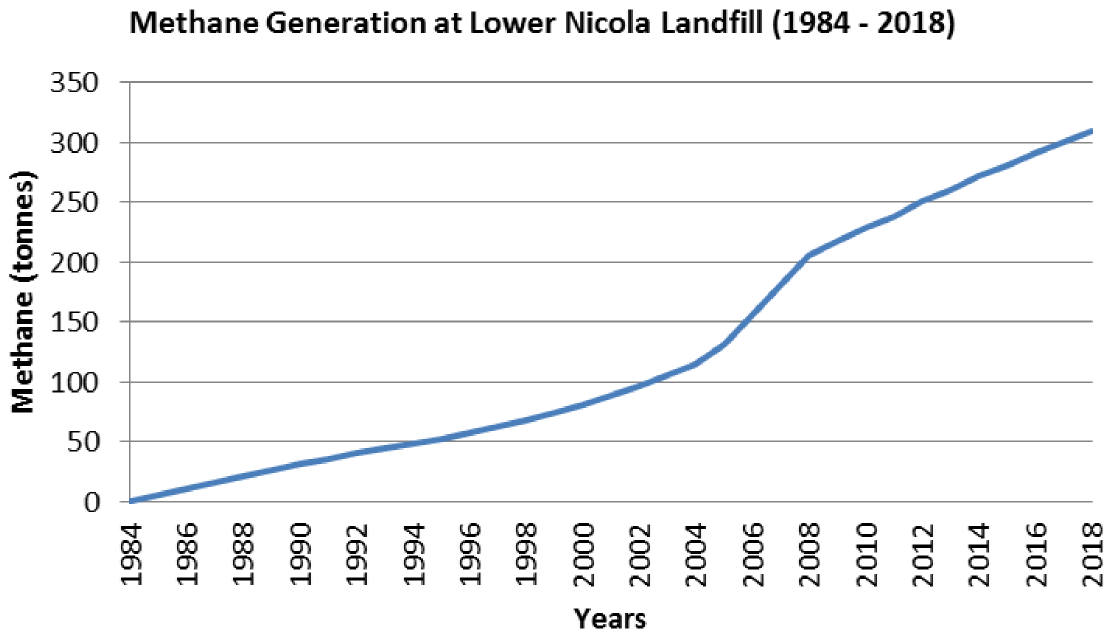

Figure 1 Methane Generation Estimate at Lower Nicola Landfill

Because the methane generation at the Lower Nicola Landfill is estimated to be far below the 1,000 tonnes per year threshold set by the BC Ministry of Environment (MOE) 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 take advantage of the carbon credits. We suggested that one of the most feasible options of generating carbon credits for small sites, such as Lower Nicola Landfill, is biological oxidization of the methane using a biocover system.

The TNRD has already 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. The implementation of the biocover system at the Lower Nicola Landfill started after a baseline GHG emission measurement was completed at this site by SHA in October 2014.

<u>Literature Review on Biological Oxidation of Methane</u>

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 (CH_4) oxidation fractions through operational soil cover at 22-55% (Whalen et al., 1990; Chanton et al., 2009; Chanton et al., 2011). 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 CH_4 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, the 10% baseline methane oxidation rate is ignored as it is already taken into account when the baseline methane emission measurement is completed.

For engineered fabricated biocovers, the methane oxidation rate is reported to be between 50-100%, depending on the methane loading rate on the biocover (Barlaz et al., 2004; Stern et al., 2007; Abichou et al., 2009). A number of researchers reported that in some cases biocover even reduces the existing atmospheric CH_4 concentration (Hilger and Barlaz, 2007; Abichou et al., 2009).

Biocover Application and Monitoring

After the first round of emission measurement that was completed in October 2014, the TNRD placed fabricated biocover on the crest areas (Crest 1 and Crest 2 in Figure 2) as well as the side slope areas (Slopes 1 through 4 in Figure 2) of the central and southern parts of the Lower Nicola landfill. More biocover material was fabricated and applied subsequently throughout 2014 and 2015.

The following photos show the Slope 3 area before and after biocover application.

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

Photo 2 – Slope 3 (S3) Area after biocover application

Photo 3 – Areas Slope 2 (S2) and Crest 1 (C1) after biocover application

The areas of the landfill that have reached the final design elevation and/or will not receive more lifts of waste for the next two years were selected for the application of biocover. The central and southern part of the landfill was divided into 6 designated areas. Area Slope 1 (S1), Area Slope 2 (S2), Areas Slope 3 (S3), Area Slope 4 (S4), Area Crest 1 (C1), and Area Crest 2 (C2). The total area that was scanned for methane emission and evaluation of effectiveness of the biocover was approximately 4.4 hectares. Figure 2 shows the measurement areas.

Figure 2 - GHG emission measurement areas at the Lower Nicola Landfill

We conducted these two rounds of investigation using an advanced technique to measure the fugitive methane emissions and to quantify the GHG emission reductions achieved by application of biocover. The methodology and the results of these site investigations are fully explained in the next section.

LFG Emission Measurement Methodology

The fugitive methane emission measurements were conducted through an approach developed by Abedini and Atwater (2014). This methodology involves measurement of surface methane concentrations from the area of interest, as well as conducting flux chamber measurements in representative portions of the landfill.

The surface methane concentration (SMC) scan using a flame ionization detector (FID) is an approved methodology used across the US, when is required by the U.S. 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 the average methane concentrations at the surface of the regulated landfills to be kept below certain levels. If the FID field measurements register values above the threshold then the owner would have to implement control measures within a given period of time.

The flux chamber technique is also 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 relatively high detection limit of the technique, it would be difficult to achieve reliable data from flux chamber measurements on top of the biocover areas where methane is almost fully oxidized. However, the FID instruments can detect methane concentrations down to 0.1 ppm levels (i.e. 1×10^{-5} percent).

The methodology adopted to evaluate the Lower Nicola Landfill biocover performance is a combination of the two aforementioned techniques. This methodology was developed through the Ph.D. research of Dr. Ali Abedini, SHA's LFG specialist. Abedini's methodology was developed based on comprehensive field investigations including an FID surface scan of about 18 Ha and approximately 190 flux chamber measurements conducted at the Vancouver Landfill. In order to apply the same technique to evaluate the effectiveness of the biocover placed at the Lower Nicola Landfill, the measurements were completed in two rounds. The first round was completed in 2014 before placement of the biocover. This round showed the baseline methane emission levels from each area. Also, hot spots (areas with higher methane emission rates) were identified and communicated with the TNRD staff to be considered during biocover installation. The second round of field measurement was completed in May 2016. The results of the field measurements are discussed in the following sections.

Surface Methane Concentration Scan

A surface methane concentration (SMC) scan was conducted over approximately 4.4 Ha area at the Lower Nicola Landfill. The surface scan was conducted over the central and southern areas of landfill that were accessible, before and after application of biocover. A *Thermo Scientific TVA 1000* FID instrument was used to measure and log methane concentrations at the landfill's surface. The scanned area was walked on approximate 10 m spaced pathways while logging methane concentration every 5 seconds. The FID instrument was calibrated using calibration gas from a tank before and after conducting each set of measurements. Accordingly, the recorded methane concentrations were adjusted when a drift in the calibration gas reading was observed. Photo 4 shows SHA's staff Dr. Abedini conducting FID measurement on a similar project.


Photo 4 – SMC Scan Using a Portable FID Instrument

Flux Chamber Measurements

Application of flux chamber measurements at landfills to measure fugitive methane emissions from the soil surface through isolating and monitoring the emitting gas from soil is a well-established measurement method. The flux chamber technique includes placing a closed chamber (box) on the landfill's surface and monitoring the change of methane concentration inside 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.

During the course of the field investigations in 2014, a total of 10 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. Due to the very low emission rates observed at this site, no reliable chamber data were achieved. Similarly, for the second round of the field measurements, the flux chamber technique was utilized with no reliable data generated. Therefore, the index factor that was previously developed by Abedini, (2014) at Vancouver Landfill was used for the Lower Nicola Landfill.

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. The BP variations were monitored during the field work and the emissions measurement results were adjusted for the rate of change in BP values. The climate data, presented in Figures 3 and 4 below, were acquired from the Kamloops Airport Weather Station during the days of field investigation in 2014 and 2016.

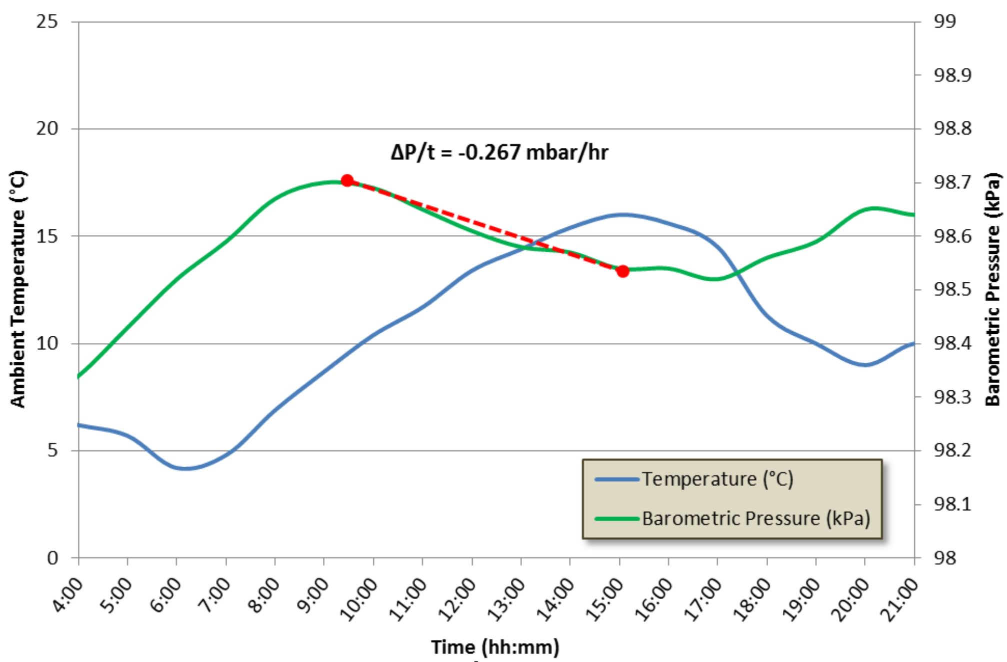

Figure 3 - Climate Data for October 2nd, 2014 (Source: Kamloops Airport Weather Station)

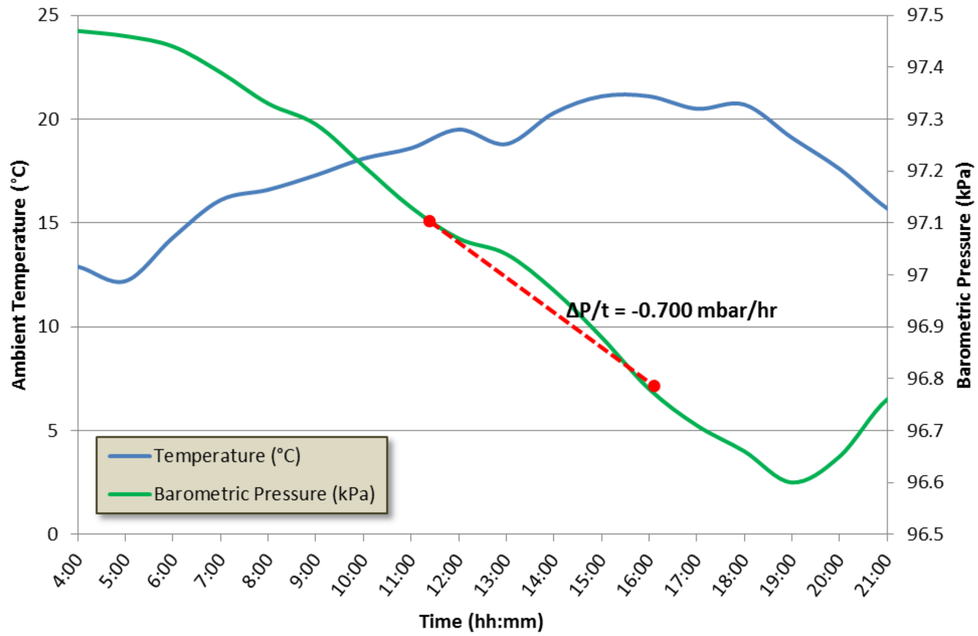

Figure 4 - Climate Data for October 18th, 2016 (Source: Kamloops Airport Weather Station)

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 the 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 (less than 4 $g/m^2/day$) 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 and using a conservative conversion index. The FID surface methane concentrations (SMC) scan showed an average methane concentration of 0.5 to 7 ppm in different areas before the placement of biocover. These values of SMC after the placement of biocover were reduced to 0.2 to 2.4 ppm. The overall methane emission reduction between the two rounds of sampling was found to be approximately 21%. This value is lower than what is expected from fabricated biocover system. The following are the main reasons, that we believe, why the overall emissions reduction was lower than the normally expected values:

- Biocover system was not installed over the entire area. For instance, most of the C2 area was similar during both rounds of sampling (no biocover).

- Some areas such as Area S2, has a steep slope (about 2H:1V). This has resulted in instability of the biocover system and formation of cracks and fissures in the biocover from which methane escape was observed.
- A small portion of the scanned area had received biocover just before the second round of FID scan was conducted. SHA believes that the methanotrophic activities were not fully established when the surface scan was conducted.

Photos 5 through 7 below show some of the hot spots identified during the second round of the FID scan.

Photo 5 – High methane emission zones in Area S3 with no biocover installed (Hot Spots)

Photo 6 & 7 – Cracks in biocover system resulted by steep slope in Area S2

Except for some steep slope areas, the biocover installation at the Lower Nicola Landfill was performed properly and most of the emission hot spots that were located during the first FID scan were fully covered. The hot spots that were identified during the second round of the FID scan are shown in Figure 5 included at the end of this report.

Table 1 below summarizes the finding and the results of the first and second round of the filed investigations at the Lower Nicola Landfill.

Table 1. Summary of Methane Emission Measurement Results at the Lower Nicola Landfill

	Grid Number	Footprint Area	Surface Methane Concentration			CH_4 Emission Rate ($g/m^2/d$)		Max. CH_4 Emission Rate	% Reduction from Baseline	GHG Emission
			MIN	MAX	AVG.	(Abedini, 2014)				
		m^2	ppm	ppm	ppm	MER	±ΔMER	kg/y	%	tonnes CO_2-e
Round 1 (Baseline)	S1	2,810	1.61	62.74	2.85	2.30	0.85	4,899	-	122.5
	S2	1,890	1.04	10.40	2.65	2.24	0.85	3,222	-	80.6
	S3	5,550	1.91	58.45	6.93	3.61	0.99	14,115	-	352.9
	S4	11,550	1.69	5.04	2.05	2.05	0.82	18,334	-	458.3
	C1	10,000	1.99	2.55	2.22	2.10	0.83	16,208	-	405.2
	C2	11,780	-	7.80	0.54	1.56	0.77	15,228	-	380.7
	TOTAL	**43,580**			**2.87**			**72,007**		**1800**
Round 1	S1	2,810	-	8.05	0.62	1.59	0.78	3,675	25%	91.9
	S2	1,890	-	17.82	1.29	1.80	0.80	2,718	16%	67.9
	S3	5,550	-	35.73	2.35	2.14	0.84	9,142	35%	228.6
	S4	11,550	-	1.96	0.21	1.46	0.76	14,173	23%	354.3
	C1	10,000	-	1.78	0.28	1.48	0.76	12,410	23%	310.2
	C2	11,780	-	4.57	0.32	1.49	0.77	14,708	3%	367.7
	TOTAL	**43,580**	**-**	**11.65**	**0.84**			**56,826**	**21%**	**1421**
						Annual Reduction (tonnes CO_2-e):				**379.5**

Taking into account the total footprint of the scanned area at the Lower Nicola landfill, SHA estimates that a total of 15.2 tonnes of methane, equivalent to 379.5 tonnes of CO_2-e, was oxidized at this site in 2015.

Conclusion

The current analyses showed that the implementation of biocover system at the Lower Nicola Landfill has resulted in GHG emissions reduction equivalent to 380 tonnes CO_2-e in 2015. SHA believes that performance of the newly installed biocover at this site will continue to improve in future. We recommend that the TNRD continues to expand the biocover system, specially, in the areas sown as emission hot spots in the attached Figure 5.

Quantification of the methane emission rates at the Lower Nicola Landfill was conducted through utilization of an advanced technique. These results show an average of 21% reduction in emission rates between the two measurements. This reduction includes the areas that did not receive biocover between the two sampling events, hence zero reduction in these areas (e.g. C2). The total methane emissions reduction from the Lower Nicola Landfill was approximately 15 tonnes of methane in 2015. This amount, based on the methane global warming potential of 25, is equivalent to 380 tonnes of CO2-e additional GHG emission reduction achieved in 2015.

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.

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June 13th, 2016

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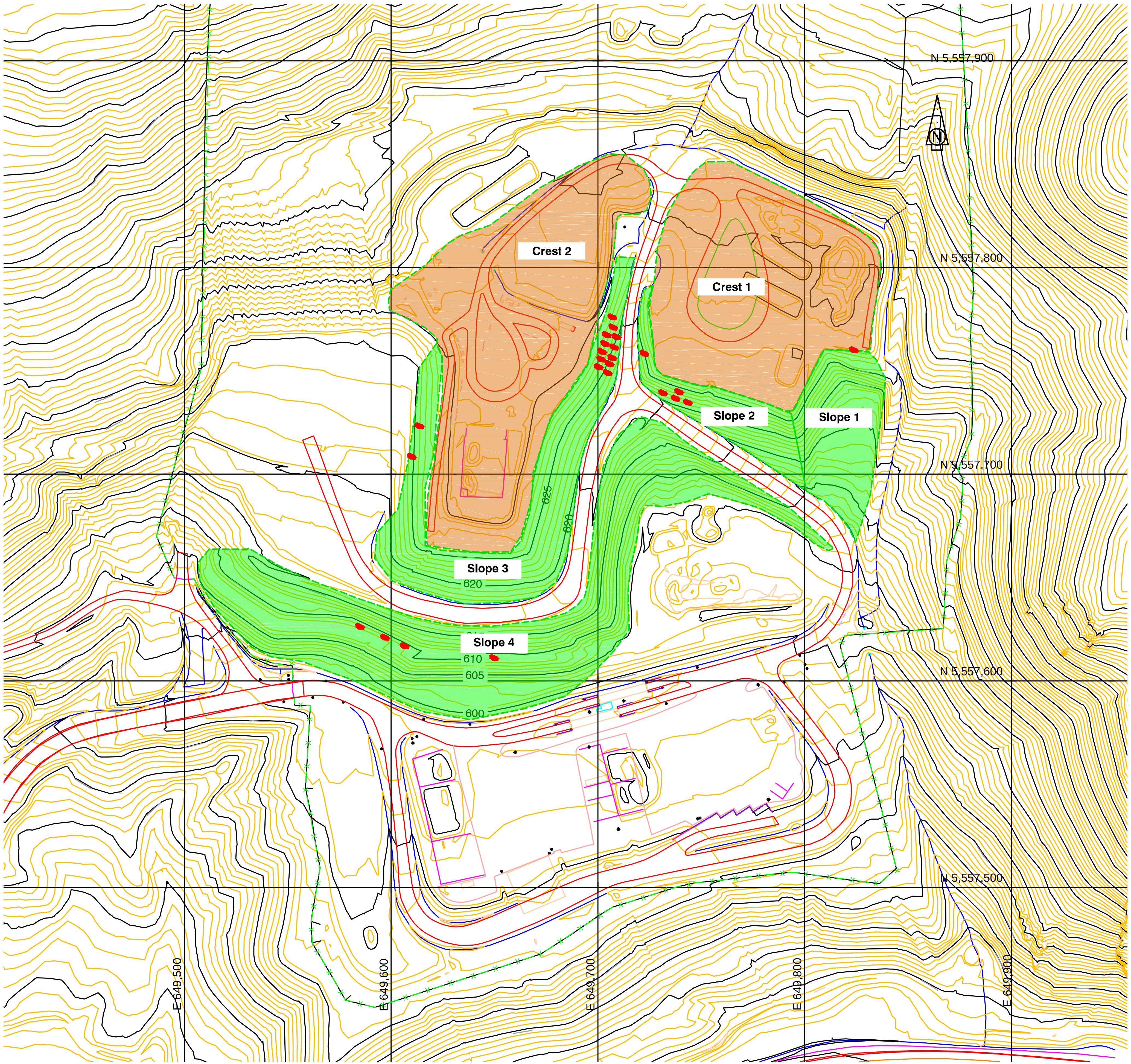

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LEGEND:

- 5m EXISTING CONTOUR
- 1m EXISTING CONTOUR
- FENCE
- DITCH LINE
- ROAD
- LFG EMISSION HOT SPOT
- SIDE SLOPE AREA
- CREST AREA

CLIENT: THOMPSON-NICOLA TNRD REGIONAL DISTRICT

PROJECT:

LOWER NICOLA LANDFILL BIOCOVER 2015 GHG OFFSET QUANTIFICATION

TITLE:

FID SURFACE SCAN AREAS

SCALE:	DATE:	PROJECT NO:
1:2,000	2016/06/01 yyyy/mm/dd	PRJ 16021

		DRAWING NO:
DESIGNED	AA	**FIGURE 5**
DRAWN	AA	
CHECKED	IB	