Golder Associates Ltd.

500 - 4260 Still Creek Drive
Burnaby, British Columbia V5C 6C6
Telephone 604-296-4200
Fax 604-298-5253

REPORT ON

COST ESTIMATION MODEL FOR IMPLEMENTING GHG EMISSION REDUCTION PROJECTS AT LANDFILLS IN BRITISH COLUMBIA

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) was retained by the Ministry of Environment (MOE) under General Service Agreement Contract #EQB-08-148 dated February 18, 2008 (Contract) to develop cost estimation models for installing, operating and maintaining landfill gas (LFG) collection systems at landfills in British Columbia (BC). The objectives of this assessment were to:

- Obtain available cost information from six BC landfills with existing LFG collection systems;
- Carry out preliminary conceptual design of a LFG collection system for four landfills where no LFG management system presently exists for the purpose of estimating costs;
- Estimate potential greenhouse gas (GHG) emission reductions and environmental impacts due to a LFG management system at these landfills;
- Develop a relationship between LFG management system costs and landfill characteristics;
- Discuss current methane collection efficiency at landfills and potential measures to increase efficiency (as requested by the MOE on February 21, 2008); and
- Discuss potential beneficial usage options.

This report summarizes the information and methodology used in our assessment and presents the results.

Golder also prepared a report for the MOE on *Inventory of Greenhouse Gas Generation from Landfills in British Columbia*, project 07-1411-0243, dated February 14, 2008 (Inventory Report). This report identified 35 landfills in British Columbia that had a disposal rate greater than 10,000 tonnes in 2006. The present study references this Inventory Report.

Golder appreciates the input for this study provided by the Regional District of Nanaimo, the North Okanagan Regional District, the Capital Regional District, the Thompson-Nicola Regional District, the City of Prince Rupert, the Comox-Strathcona Regional District (solid waste now handled by Comox Regional District), the Regional District of Fraser-Fort George, the City of Kelowna, the Greater Vancouver Regional District (also known as Metro Vancouver), and the City of Vancouver.

2.0 DEGREES OF VERIFIABLE REDUCTIONS

There are many types of GHG emission reduction projects, each having various degrees of confidence regarding the ability to quantify and confirm that GHG emission reductions have occurred. For example, LFG projects with an enclosed flare can have a high degree of confidence regarding the GHG emission reductions that occur because the conversion of methane to carbon dioxide by combustion (thereby achieving a 21 to 25 times reduction in GHG emissions) can be measured and documented with a high degree of confidence. Other projects, such as a program for the general pubic to replace standard incandescent light bulbs with compact fluorescent bulbs, have a relatively low degree of confidence because there is significant uncertainty regarding what proportion of incandescent light bulbs will actually be replaced and whether the lower electrical consumption of compact fluorescent light bulbs will perhaps encourage consumption (e.g., lights could be left-on longer or more lights could be used).

For this report, Golder has classified LFG GHG emission reduction projects as follows:

Triple green – This would be a project with a high degree of confidence of the magnitude of GHG emission reductions that occur due to a project. The systems used in such projects can be regarded as "best-practice", and such projects could typically qualify for validation under the Clean Development Mechanism[1] (CDM) or Joint Implementation[2] (JI) programs, if such rules were to be applied to the projects. These projects are characterized by beneficial use of the LFG and/or the use of enclosed flares for flaring excess LFG, and by continuous (e.g., at 5- to 15-minute intervals) monitoring and recording of LFG flow rate and methane content of the LFG using high quality instruments;

Double green – This would be a project with a reasonable degree of confidence of the magnitude of GHG emission reductions that occur due to a project. The systems used in such projects can be regarded as "conventional practice", but such projects would likely not qualify for validation under the CDM or JI programs, if such rules were to be applied to the projects, nor would they have qualified for validation under the PERRL[3] Initiative. However, such projects qualify for validation under current Green Municipal Fund rules applicable to the current Nanaimo Landfill LFG flaring project in British Columbia.

[1] CDM is a program under the United Nations Framework Convention on Climate Change (UNFCCC) to assist developing countries in achieving sustainable development and contributing to the ultimate objective of the UNFCCC, and to assist developed countries in achieving compliance with their quantified emission limitation and reduction commitments. GHG emission reductions projects in Canada cannot be CDM projects.

[2] JI is a program under the UNFCCC to assist developed countries in achieving sustainable development, contributing to the ultimate objective of the UNFCCC, and to assist in achieving compliance with their quantified emission limitation and reduction commitments.

[3] The Pilot Emission Removals, Reductions and Learnings (PERRL) Initiative is a federal initiative developed as part of Canada's Action Plan 2000 to address climate change. It was designed to provide Canadian organizations and individuals with an economic incentive to take action to reduce greenhouse gas emissions. It was a pilot project intended to help both Canadian governments and private sector organizations learn about and better understand emissions trading. The PERRL program operated between 2002 and 2008.

In this class of project, LFG is not beneficially used in a manner that is quantified. These projects can typically be characterized by flaring of the collected LFG in a candlestick (open) flare and/or periodic monitoring of LFG flow rate and methane content of the LFG; and

Single green – This would be a project with a larger range of uncertainty of the magnitude of GHG emission reductions than the other classes of projects described above. The systems used in such projects can be regarded as “simple”. These projects would not qualify for validation under the CDM or JI programs, if such rules were to be applied to the projects, nor would they qualify for validation under past or present Canadian programs such as the PERRL Initiative or the Green Municipal Fund. Currently, such projects would not normally be considered as a valid GHG emission reduction project, mainly because protocols for validation and verification have not been developed. However, we mention these types of projects because they do have the potential to reduce GHG emissions for small landfills, although the state of practice for documenting such emission reductions, and for discounting measured reductions to account for uncertainty, is currently not developed. Such projects may or may not be economical for achieving GHG emission reductions, compared with double green and triple green projects. Such projects could include passive LFG flaring or enhanced methane-oxidation landfill covers.

The costing models of this report have been developed for triple green projects. Discount factors applied to the estimated costs of triple green projects have been developed for double green and single green projects.

3.0 ENVIRONMENTAL IMPACT OF ACTIVE LFG MANAGEMENT SYSTEMS

The overall environmental impact of the installation and operation of active LFG management systems is generally considered to be positive. The following summarizes the anticipated environmental effects:

GHG emissions – The system will reduce GHG emissions to the atmosphere, which is a positive environmental effect;

Power consumption – The system will utilize electricity to power blowers and other facilities associated with the system. This electricity generation can be considered to be sourced from fossil-fuel power plants. This is a very small environmental effect due to the relatively small power consumption of the equipment compared with the amount of GHG emissions reduced;

Construction – There will be dust, noise, and activity associated with construction of the system. The system will utilize materials that are derived from fossil fuels (plastics), although the quantities used will be insignificant compared with the factory capacity. There will be greenhouse gas emissions and other discharges to the atmosphere from construction equipment. This will be a temporary effect until the system is constructed;

Noise – The system will generate noise of perhaps 65 to 80 dB at the abstraction plant. Actual noise levels depend on equipment selection and other design parameters. This noise can be mitigated, if required, by enclosing the abstraction plant in a building; and

Water – Active LFG management systems generate condensate which is a liquid with a low pH of about 3 and contains traces of constituents such as certain hydrocarbons. This condensate is usually a relatively small quantity that is managed or disposed with landfill leachate, and thus, is anticipated to have a low environmental effect.

4.0 METHODOLOGY

4.1 Terminology

The following terminology is used herein:

- LFG abstraction plant – A powered plant with blowers to apply a vacuum to LFG collection piping, and a flare;

- LFG collection system – LFG extraction wells and piping up to, but not including, the LFG abstraction plant;

- Active LFG management system – A system that is powered and consists of LFG extraction wells, piping and LFG abstraction plant;

- Passive LFG management system – A system that is not powered and may consist of vents, LFG wells, vent flares, and/or LFG collection piping;

- O&M – Operations and maintenance;

- Medium and small-sized landfills – Landfills having total waste in-place of less than 3 million tonnes; and

- CO_2e – carbon dioxide equivalents. A measure that expresses the amount of GHGs in terms of the amount of carbon dioxide that would result in the same global warming potential.

4.2 Approach

This report is intended to provide a screening-level cost estimation model to be used by Regional Districts and municipalities (local government) for estimating the cost for installing triple green active LFG management systems at municipal solid waste landfills in British Columbia. This study is not intended to cover demolition, land clearing, and construction waste (DLC) landfills because such landfills have different LFG collection characteristics than household and commercial MSW landfills. Only one landfill (Ecowaste) was identified as meeting the threshold for inclusion in the Inventory Report, and this landfill has a LFG collection system.

Our approach to developing a cost model for triple green LFG projects was to:

- Obtain actual capital and O&M cost data from six landfills in British Columbia with active LFG collection systems, and adjust the costs to 2008 dollars. The quantities of various components at each landfill were also obtained. These data were then analyzed to estimate average unit costs for each component. These historical costs are relevant because they are actual costs as provided by these landfills;

- Carry out conceptual well layout design for an active LFG management system at four small to medium landfills in British Columbia where there is presently no such system. From these designs, the quantity of materials were totalled and, by applying the average unit costs, the total capital cost for each of these four landfills was then estimated. The following four landfills were selected to cover the range of annual tonnage, existing landfill area, and precipitation identified in the Inventory Report and where no LFG management system presently exists: Comox Valley Landfill, Vernon Landfill, Prince Rupert Landfill, and Lower Nicola Landfill; and

- Develop a simple relationship between capital costs and simple landfill parameters, and between O&M costs and simple landfill parameters.

To obtain costs for double green and single green projects, a discount factor for triple green project costing was developed.

5.0 COLLECTION EFFICIENCY AT EXISTING LANDFILLS

Based on the average 2006 methane collection rates provided to Golder by the various landfills and the modelled LFG generation rates in 2006 as described in the Inventory Report, CHART 1 summarizes the inferred methane collection efficiencies at the six landfills with active LFG collection systems. These calculated methane collection efficiencies must be considered to be approximate given the uncertainties associated with the modelling of methane generation.

CHART 1: Inferred Methane Collection Efficiencies at Existing Landfills

Landfill	Reported 2006 Methane Collection Rate (scfm)	Modelled 2006 Methane Generation Rate (scfm)	Inferred Methane Collection Efficiency (%)
Vancouver	1,473	4,200	35
Hartland	338	1,260	27
Cache Creek	280	775	36
Nanaimo	128	480	27
Glenmore	31	335	9
Foothills Boulevard	97	435	22

As a general statement, a methane collection efficiency of about 75%[4] from an active LFG management system is assumed to be achievable for large- to medium-sized landfills that have GHG emission reduction as a priority and have the resources to accomplish this. However, the actual methane collection efficiency at a landfill is unknown unless it is measured. Measurement of actual methane collection efficiency has only been conducted at a few landfills around the world due to the relatively complex work required.

Unless the landfill is completely enveloped in a geomembrane, it is usually not practical to achieve 100 % methane collection efficiency, for example, because efficient collection of methane from the toe area of a landfill is not practical. A recent presentation by J. O-Brien (2008) presented data indicating measured LFG collection efficiencies[5] at five landfills ranging from 82 % to 99 %. He further suggested that landfills having a good landfill cover system and a LFG collection system can have higher LFG collection efficiencies than 75 %. To determine the actual methane collection efficiencies at any of the six landfills listed in Chart 1, extensive field studies would need to be undertaken.

Each landfill has its own features that may result in lower or higher practically achievable methane collection efficiencies. For example, a lined landfill with a geomembrane final cover would be expected to be able to achieve at least 90% methane collection efficiency. In contrast, a small, unlined landfill situated on sand and gravel would be expected to have lower achievable methane collection efficiency of perhaps 50 % to 65 %. Operational skill also affects methane collection efficiency.

4 AP-42, Compilation of Air Emission Pollutant Factors, Volume I: Stationary Point and Area Sources, Section 2.4.4.2.

5 LFG collection efficiency, when corrected for air intrusion, is essentially equivalent to methane collection efficiency. Golder refers to it as methane collection efficiency in this report because the focus of this report is on GHG emission reductions.

We are confident that the 2006 methane collection efficiencies for the Vancouver, Cache Creek, and Foothills Boulevard Landfills were significantly less than 75 % because Golder has previously back-calculated methane generation model parameters for these landfills based on measured methane flow rates, and higher methane collection efficiencies than in 2006 have been achieved at these landfills in the past and/or in specific areas. Although there is greater uncertainty with the collection efficiency calculations for the Hartland, Nanaimo, and Glenmore Landfills because back-calculation of parameters has not been conducted for these landfills, it is our opinion that the methane collection efficiencies at these landfills are also significantly less than 75%. However, it is recognized that back-calculation of methane generation model parameters does have limitations and thus there is some uncertainty regarding the actual methane collection efficiency.

In Chart 1, the only parameter that has uncertainty and that was used to calculate the inferred methane collection efficiency is the modelled 2006 methane generation rate. If one were to significantly differ with the Chart 1 inferred methane collection efficiencies, then one would be differing with the modelled 2006 methane generation rate. However, the parameters on which the methane generation rate modelling was carried out (Golder, 2008) correlate favourably with data points contained in SWANA (2005), assuming 75% methane collection efficiency. Thus, if one were to significantly differ with the Chart 1 inferred methane collection efficiencies, the data point for the particular landfill would then likely be outside of the range of the data points used to develop the model parameters.

Measures to improve methane collection efficiency to 75% could include integration of LFG management systems with the overall landfill operations and design, design improvements, on-going training and coaching of LFG operations staff, involving the designers in the construction monitoring of capital works, and/or allocation of sufficient resources. For example, if the LFG management system was integrated with the overall landfill operations and design of the Foothills Boulevard Landfill, LFG could be collected from areas that presently do not have LFG extraction wells. Each landfill would need a detailed assessment to determine the scope of work needed to increase methane collection efficiency to about 75%.

6.0 INFORMATION ON LANDFILLS

The following information was provided to Golder for this study:

Regional District of Nanaimo – 2004 LFG collection capital cost and 2004 LFG control plant capital cost, and annual operations and maintenance costs;

North Okanagan Regional District – Autocad topographic plan of Vernon Landfill and a cross-section through the landfill. Three-phase power is available at the site;

Capital Regional District – Spreadsheet of asset inventory for LFG collection system showing replacement cost in November 2007 dollars;

Thompson-Nicola Regional District – Autocad topographic plan of Lower Nicola Landfill. The Regional District plans to install three-phase power at the site in 2008;

City of Prince Rupert – Autocad topographic plan of landfill. There is three-phase power available at the site;

Comox-Strathcona Regional District (solid waste now handled by Comox Regional District) – Autocad topographic plan of Comox Valley Landfill (formerly known as Pidgeon Lake Landfill). Three-phase power is presently not available at the site;

Regional District of Fraser-Fort George – Capital and O&M costs;

City of Kelowna – Breakdown of components and quantities, and capital cost and annual O&M cost estimate;

Greater Vancouver Regional District (also known as Metro Vancouver) – Capital cost for the Cache Creek Landfill for each year since 1999. However, only costs since 2004 have been considered since these are the most recent costs (there were virtually no capital expenditures on LFG in 2002 and 2003) and include the capital cost for a LFG abstraction plant; and

City of Vancouver – Capital cost for Phase 2 horizontal collectors and annual O&M cost estimate.

7.0 CONCEPTUAL DESIGN OF LFG WELL LAYOUT AT FOUR LANDFILLS

While the larger landfills in BC have actual cost information, the smaller landfills do not have active LFG management systems, and thus, actual cost information is not available from such landfills. While Golder has actual cost information for active LFG management systems at small landfills in other parts of North America, we were concerned that such cost information may not reflect the large increase in construction costs in British Columbia over the past three years or so. Thus, our approach was to carry out conceptual design of a LFG well layout for four landfills from which quantity estimates could be obtained and total costs could be estimated.

The purpose of the conceptual designs was only to obtain quantities. These landfills were selected to provide a range of methane generation rates, landfill areas and precipitation conditions. For consistency of costing, the conceptual design of these four landfills was to a similar standard as the six landfills with existing LFG collection systems (25% to 40% methane collection efficiency). The following four landfills were selected for the conceptual designs:

- Comox Valley Landfill – A medium-sized landfill, with a medium methane generation rate for a wet climate;
- Vernon Landfill – A medium-sized landfill, with a medium methane generation rate for a dry climate;
- Prince Rupert Landfill – A small landfill with a low methane generation rate for a wet climate; and
- Lower Nicola Landfill – A small landfill with a low methane generation rate for a dry climate.

The conceptual well layout design plans for the existing landfills are provided in Appendix I. An estimate of quantities for an active LFG management system was obtained from the conceptual design plans, and these quantity estimates do not include future expansion of the system.

8.0 COST ESTIMATION MODEL

8.1 Development of Models

8.1.1 Unit Price Model for Capital Cost of Triple Green Projects

A unit price model was developed to enable capital costing of triple green, active LFG management systems at each of the Comox Valley, Vernon, Prince Rupert, and Lower Nicola Landfills. The unit price model was developed using capital cost information from the Vancouver, Hartland, Cache Creek, Nanaimo, Glenmore and Foothills Boulevard Landfills that is provided in Table 1. Unit prices were assumed to be independent of methane collection efficiency. For most of these landfills, only total costs (not unit costs) were available. Only cost information between 2004 and 2007 was used for the Cache Creek Landfill. The cost for portions of the Cache Creek Landfill active LFG management system installed between 1996 and 2001 (i.e., a LFG abstraction plant and 32 wells) was not included in the development of the unit price model because extrapolation of these old costs to 2008 dollars has significant uncertainty.

The spreadsheet for the unit price model is shown in Table 2. The green font in Table 2 summarizes the capital cost and component quantity information received by Golder for each of the six landfills. The blue font is Golder's estimated quantities. The red font is Golder's estimated unit prices. The estimated unit prices include items not identified in the list of items, such as valves and fittings. These unit prices are intended for estimating a total cost for installation of an active LFG management system, and thus, they should not be used in isolation or outside this context. All extension costs are assumed to be proportional to unit costs and quantities, except the following where a fixed cost as indicated below was also applied:

- Blower capacity – $5,000;
- Variable frequency drive – $2,000;
- Utility flare – $15,000; and
- Enclosed flare – $60,000.

The "capital cost in 2008$" in Table 2 is the capital cost information adjusted to present value (PV in 2008 dollars) by applying the Statistics Canada Construction Price Index (apartment buildings) for Vancouver obtained from http://www40.statcan.ca/l01/cst01/econ144a.htm?sdi=construction%20price%20indexes and assuming a 12% price increase from 2007 to 2008. The 2008 value for costs incurred in previous years is shown on CHART 2. The Vancouver apartment building construction price index was used because it was the closest reflection of civil construction costs for British Columbia, even though it is recognized that apartment building construction is not the same as construction of LFG management systems. There is no price index available for the construction of LFG management systems.

CHART 2: Present Value for Vancouver Apartment Building Construction

Year of Construction	Present Value
1997	$1.82
2001	$1.82
2002	$1.82
2003	$1.66
2004	$1.52
2005	$1.42
2006	$1.27
2007	$1.12

The "model percent of capital cost in 2008$" in Table 2 is the percent the capital cost in 2008 dollars that the unit price model predicts. A value of less than 100 % indicates that the unit price model under-predicts the actual capital cost adjusted to 2008 dollars. A value of more than 100 % indicates that the model over-predicts the actual capital cost adjusted to 2008 dollars. The model percent of capital cost in 2008 for each of the six landfills is shown on Table 2 and indicates that the unit price model costs are within 7 % of capital cost adjusted to 2008 dollars for the Vancouver, Hartland, Cache Creek, and Glenmore Landfills.

The Foothills Boulevard Landfill had actual costs (adjusted to 2008 dollars) about 19 % higher than that predicted by the unit price model. However, this higher cost for the Foothills Boulevard Landfill is expected because LFG components needed to be designed for the cold winters (compared with the other five landfills), and this resulted in increased costs to excavate deeper pipe trenches and provide insulation.

The Nanaimo Landfill had actual costs (adjusted to 2008 dollars) that are almost 50 % higher than that predicted by the unit price model. The reason for this difference could not be determined.

Although the unit price model costs are within 7 % of the capital cost adjusted to 2008 dollars for four of the six landfills, and there is a reasonable explanation for the Foothills Boulevard Landfill costs being higher than that predicted by the model, this does not mean that the model can necessarily predict capital costs to within ±7% for the reasons explained in Section 8.3 of this report.

8.1.2 Capital Cost Estimation Model for Triple Green Projects

The calculated average unit prices were applied to the quantities estimated for each of the Comox Valley, Vernon, Prince Rupert and Lower Nicola Landfills to provide an estimate of the capital cost for each landfill. Table 3 summarizes these quantities and includes cost estimation for capital works for the Cache Creek Landfill undertaken between 1996 and 2001.

Table 4 summarizes relevant data for the 10 landfills used in the development of the capital cost model. The active LFG management systems were assumed to include an enclosed flare and continuous monitoring of data, but do not include beneficial use. In some cases, these capital costs are not comparable to the Capital Costs in 2008 dollars of Table 2 because an adjustment was required to provide for triple green projects (i.e., the cost of a enclosed flare to replace a utility flare was added).

Figure 1 shows a plot of total in-place landfill tonnage (1977 – 2007) versus capital cost in 2008 dollars. This plot excludes the following data points:

- Vancouver Landfill and Cache Creek Landfills – These landfills have certain economies of size that the small- and medium-sized landfills do not have, and thus, inclusion of these data points would skew the correlation for small- and medium-sized landfills. In addition, the main interest of this study is to estimate active LFG management system costs for landfills in BC that presently do not have a LFG management system, and these are all medium-and small-sized landfills; and

- Foothills Boulevard Landfill – The LFG collection system covers less than 50 % of the landfill, and therefore, inclusion of this point would indicate a model capital cost much higher than the actual capital cost. Thus, this landfill was excluded from the model.

As shown on Figure 1, the capital cost estimation model for triple green projects for small to medium-sized (i.e., less than 3 million tonnes of waste in-place) municipal solid waste landfills in BC in 2008 dollars with an expected methane collection efficiency of 25% to 40% is:

Capital Cost (in 2008 dollars) = ($1.12/tonne x W) + $167,000---------- (1)

where W = total tonnage of waste in landfill in tonnes. This model assumes that the LFG collection system covers the entire landfill, except at the toe area of the landfill where collection is normally inefficient. If the LFG collection system covers only a portion of the landfill, then this quantity should be pro-rated. Although the R^2 correlation value is excellent, it must be recognized that this was achieved by removing three data points from the plot as explained above.

This model is not intended for large landfills (i.e., landfills with an in-place capacity greater than 3 million tonnes, such as the Vancouver Landfill and the Cache Creek Landfill) and in fact may over-predict the cost for such large landfills by a considerable margin. Other possible relationships between capital cost and other parameters (such as methane generation) were assessed. In addition, separate correlations for dry landfills and wet landfills were examined. However, the added sophistication did not significantly improve the correlation. Thus, for simplicity, equation (1) is used.

As stated previously, each landfill requires a detailed assessment to determine the scope of work needed to increase methane collection efficiency to 75 %. For this report, we have assumed that additional capital expenditure of 50 % of the model capital cost, in addition to the additional O&M expenditure of 70 % of the O&M cost discussed later in section 8.1.3, could result in 75 % methane collection efficiency. The additional capital cost was assumed based on Golder's preliminary estimate of the cost to provide LFG collection wells at the Foothills Boulevard Landfill in areas that presently do not have wells. However, the actual expenditures may vary, perhaps substantially, from this assumption, depending on the site-specific conditions.

In summary, the steps to apply this model are:

1. Determine the percentage of the overall landfill that will have an active LFG management system installed. If the entire landfill is to have an active LFG management system (as many landfills do), then the proportion would be 100 %;

2. Determine the tonnage of waste within the above proportion;

3. Check that the tonnage of waste does not exceed 3 million tonnes. If it does, then this model is not applicable;

4. Apply the model (i.e., equation (1) above);

5. Apply any other costs or factors that could alter the capital cost. For example, if it is necessary to drain leachate from the landfill to enable the collection of LFG, then this cost should be added. If the site is in an area where costs could be higher due to a supercharged economy, such as in the Peace River Regional District at the present time, then an adjustment factor should be provided;

6. Add engineering and administrative costs;

7. Allow for future capital costs of expansion of the system when more waste is placed; and

8. Increase the capital cost by 50 % to achieve a target of about 75 % methane collection efficiency.

8.1.3 O&M Cost Estimation for Triple Green Projects

Table 5 summarizes the available O&M cost information for the six landfills. It is uncertain what these O&M costs include since a cost breakdown was not provided to Golder. These costs do not include an allowance for on-going vertical well replacement costs since the need for such replacement must be evaluated on a case-by-case basis. Such well replacement costs could be equivalent to an additional 25%, or so, increase in the annual O&M costs. Activities to lower leachate levels are not considered in this report to be an O&M cost. The Foothills Boulevard Landfills was classified as a “dry climate” landfill because it receives 644 mm of annual precipitation, which is less than the upper limit of 650 mm that we have used to define “dry” landfills.

Figure 2 shows a plot of O&M costs in 2008 dollars versus tonnage of waste in the landfill (1977 – 2007). The data are insufficient to carry out a regression analysis. However, we have provided two equations in CHART 3 which are Golder's opinion of the very approximate relationship between annual O&M costs and waste tonnage (excluding a cost for on-going LFG extraction well replacement), with an expected methane collection efficiency of 25% to 40%.

CHART 3: O&M Cost Model

Climate	O&M Cost (2008 dollars)
Wet	OMW = 0.009 * W + $35,000
Dry	OMD = 0.0069 * W + $30,000

where:

- "Wet" is a climate with more than about 650 mm of precipitation;
- "Dry" is a climate with less than about 650 mm of precipitation;
- OMW = Annual O&M cost for landfills in wet climates;
- OMD = Annual O&M cost for landfills in dry climates; and
- W = Total waste tonnage in tonnes.

O&M costs can vary widely depending on site-specific conditions, the effort and resources devoted to LFG management, the skill of the operators, the need for LFG extraction well replacement, the condition of equipment, and the quality of equipment, materials and construction of the active LFG management system.

As stated previously, each landfill would need a detailed assessment to determine the scope of work needed to increase methane collection efficiency to 75%. For this report, we have assumed that additional O&M expenditure of 70% of the O&M cost (over and above that indicated in CHART 3), in addition to the 50% capital cost increase, could result in 75% methane collection efficiency. However, the actual expenditures may vary, perhaps substantially, from this assumption, depending on the site-specific conditions.

8.1.4 Discount Factor for Double Green Projects

If it is assumed that double green projects are the same as triple green projects, except a utility flare is used instead of an enclosed flare, and continuous monitoring of methane and oxygen by a dedicated instrument is replaced by periodic manual monitoring with a portable instrument, then we estimate the capital cost of double green projects to be 75% to 90% of the capital cost of a triple green project. Operational costs are expected to be about the same or slightly less than triple green projects, but actual costs depend in part on the protocols for verification of GHG emission reductions.

8.1.5 Discount Factor for Single Green Projects

The cost for single green projects can vary widely depending on the scope and technology of the project. We guesstimate that the capital cost of a single green project could be 15% to 33% of the capital cost of a triple green project. Operational costs could vary widely depending on the technology and the protocols, if any, for verification of GHG emission reductions.

8.2 Application of Cost Estimation Model to Landfills in British Columbia

The cost estimation model was applied to the other 25 landfills that were part of the Inventory Report. Table 6 provides the estimated capital and O&M costs in 2008 dollars for active LFG management systems in British Columbia based on the model and assumed 25% to 40% methane collection efficiency. This does not include engineering costs or the cost of future expansions of the system when more waste is placed.

The estimated capital costs to install an active LFG management system in 2008 dollars, for landfills that do not already have an active LFG management system, range from a low of $258,000 for the Fort Nelson Landfill to a high of $1,600,000 for the Mission Flats Landfill in Kamloops. The total capital cost and total annual O&M cost in 2008 dollars for initial installation, operation and maintenance of active LFG management systems at all landfills in the inventory that presently do not have such systems (i.e., 28 landfills) is estimated to total $18 million and $1 million, respectively. This total excludes the cost of future expansions of the landfills beyond 2008.

It should be noted that the capital costs shown on Table 4 and the O&M costs shown in Table 5 have resulted in the inferred methane collection efficiencies summarized in Chart 1. Thus, it is expected that application of the capital and O&M expenditures estimated by the model and shown on Table 6 for other landfills would result in similar LFG collection efficiencies shown on Chart 1 (25% to 40% methane collection efficiency).

Table 7 and Figure 3 provide the estimated cost in 2008 dollars per tonne of CO_2e emission reductions for landfills with various waste tonnages in 2020. On Figure 3:

- "Wet" represents landfills that were assumed to have more than 1,000 mm of annual precipitation;
- "Medium" represents landfills that were assumed to have between 650 and 1,000 mm of annual precipitation; and
- "Dry" represents landfills that were assumed to have less than 650 mm of annual precipitation.

The cost figures on Table 6 were increased by 50% for capital cost and 70% for O&M cost, and these increased costs are shown on Table 7. The capital costs for the two largest landfills, the Vancouver Landfill and the Cache Creek Landfill, were not computed using equation (1) since this model is not applicable for large landfills. Instead, capital costs shown in Table 4 were increased proportionally with waste tonnage.

The assumed methane collection efficiencies shown on Table 7 are based on our opinion that methane collection efficiency decreases with decreasing landfill size for landfills that are less than 500,000 tonnes. A methane collection efficiency of 65% was assumed for landfills with a total quantity of waste landfilled between 1977 and 2007 of 250,000 to 500,000 tonnes. Landfills with less than 250,000 tonnes had an assumed methane collection efficiency of 50%. An assumption of 92% operational efficiency was also applied to the potential GHG emission reductions. Methane destruction efficiency in an enclosed flare was assumed, for simplicity, to be effectively 100%.

These costs of GHG emission reductions assume the following:

- The operational period of the active LFG management systems is 2011 to 2020, and all capital costs are assumed to be depreciated within this period. However, it is recognized that these systems would likely be operated beyond 2020;
- All costs are in 2008 dollars;
- Waste composition does not vary with time. A decrease of organic content would increase the cost of GHG emission reductions;
- Waste quantities are as assumed in the Inventory Report;
- The LFG generation modelling presented in the Inventory Report predicts LFG generation accurately. However, the discussion in the Inventory Report about the accuracy of the model should be referred to;
- Additional revenue due to selling of GHG emission reduction credits are excluded (the market and value for such credits in BC are presently uncertain due to pending GHG regulations);
- Additional revenue and costs of LFG utilization are excluded; and
- There are no issues (e.g., high leachate levels or aerobically affected waste) that prevent achieving the assumed collection efficiencies.

CHART 4 summarizes the costs of landfills that presently do not have active LFG management systems and the total potential GHG emission reductions over 10 years (2011 – 2020) if active LFG management systems are installed and operated at these landfills.

CHART 4: Summary of Costs and Total GHG Emission Reductions over 10 Years for Landfills that Do Not Presently Have an Active LFG Management System

Cost of GHG Emission Reductions ($/tonne CO_2e)	Number of Landfills	Landfills	Total Potential GHG Emission Reductions 2011 – 2020 (tonnes CO_2e)
<$10/tonne	5	Alberni Valley, Comox Valley, Campbell River, Bailey, Mini's Pit,	3,545,000
$10 – $15/tonne	7	Ootischenia, Salmon Arm, Vernon, Campbell Mountain, Ft. St. John, Sechelt, Prince Rupert	1,272,000
$15 – $20/tonne	5	Central (RDCK), Westside, Columbia Regional, McKelvey Creek, Mission Flats	656,000
>$20/tonne	11	Knockholt, Gibraltar, Central Subregion (RDEK), Thornhill, Terrace, Armstrong, Ft. Nelson, Bessborough, Squamish, Lower Nicola, Heffley Creek	577,000

8.3 Accuracy of Cost Estimation Model

The economic model is an attempt to provide a simple method of estimating capital and O&M costs for an active LFG management system in British Columbia. Actual costs may differ, perhaps significantly, from model costs due to the following factors:

Design details – Costs can vary significantly due to design details. For example, the cost for installation of header piping in the interior of Northern British Columbia is significantly higher than that in the Lower Mainland of British Columbia (southwest BC) since pipe trenches in the north need to be deeper for frost-protection. This simple costing model cannot account for all of these design details;

Equipment selection – Costs can vary significantly for different types of equipment. Some types of equipment may have a lower initial installation cost but have higher O&M costs. For example, variable frequency drives are optional for active LFG management systems, but their installation (at higher capital cost) in some situations can result in significant power savings;

Market forces – The state of the economy and market forces can significantly affect pricing. The factors used to adjust pre-2008 costs to present value in 2008 dollars were based on Vancouver, BC apartment construction costs from Statistics Canada, and the actual adjustment factors may be different for landfill gas projects. The factors may also vary depending on location. For example, the construction price index for apartment buildings in Toronto, Ontario indicates a price increase between 2002 and 2007 of 25% compared with 48% for Vancouver, BC. Thus, the capital cost for a project in Toronto, Ontario in 2007 may have been 85% of the cost that the model predicts for Vancouver, BC;

Site conditions – Site conditions can have a significant effect on the cost of LFG management. For example, if a landfill has high leachate levels, LFG collection can be problematic and significant additional capital and operational costs may be incurred;

Operating condition – Some landfills have more or higher capacity abstraction plant equipment than is required to collect LFG at the present time. This is likely done either to provide redundancy (back-up) or in anticipation of LFG collection increasing in the near future. Provision of a higher capacity abstraction plant than is required at present would increase abstraction plant capital costs. Similarly, some landfills have installed horizontal collectors in anticipation of future waste placement, although LFG may not be extracted for awhile. This would also increase the apparent capital cost;

Operational skill – The skill of personnel who operate the LFG management system can affect O&M costs; and

Inclusiveness of data provided to Golder – Most of the costs provided to Golder appear to be estimated costs, and a detailed breakdown with itemized costs was generally not available. There is some uncertainty regarding what the costs include.

The estimated cost of GHG emission reductions on a per tonne basis is based on the assumed LFG generation presented in the Inventory Report. However, costs could increase on a per tonne GHG emission reduction basis if there is a change in the waste composition to reduce the quantity of organic matter of the incoming waste.

9.0 BENEFICIAL USE OPTIONS

Rather than flaring, the methane in LFG can be used in a beneficial manner to displace the use of fossil fuels. High capital cost is the main barrier to more widespread utilization of LFG. This is especially true for small landfills.

The following lists various LFG utilization technologies, the number of projects in the United States that are currently operational (as of early March 2008), the range of installed capacity, and the median capacity. The data are from the United States Environmental Protection Agency's website (http://www.epa.gov/lmop/proj/index.htm).

Technologies that likely have the most potential for application to landfills in British Columbia that currently do not have LFG utilization systems are identified with an asterisk (*) in CHART 5. In this regard, the Median Capacity column is an indication of the typical size of technology applications that resulted in a viable project, although smaller projects can also be viable. Future advances in technology may also result in decreased costs for smaller projects.

CHART 5: LFG Utilization Options

Technology	Number of Facilities	Range of Installed Capacity	Median Capacity
ELECTRICITY GENERATION			
Reciprocating Engine*	313	0.2 to 14.9 MW	2.4 MW
Gas Turbine	27	0.7 to 12 MW	5.5 MW
Steam Turbine	21	0.5 to 50.0 MW	6.0 MW
Cogeneration*	20	0.1 to 7.0 MW	2.5 MW
Microturbine*	17	<0.1 to 2.5 MW	0.3 MW
Combined Cycle	8	6.6 to 17.4 MW	9.4 MW
Organic Rankine Cycle	2	0.2 MW	N/A
Sterling Engine	2	0.1 – 0.2 MW	N/A
DIRECT USE			
Boiler*	54	11 to 4,150 scfm of LFG	700 scfm of LFG
Direct Thermal*	39	3 to 3,200 scfm of LFG	545 scfm of LFG
Greenhouse*	4	15 to 210 scfm of LFG	140 scfm of LFG
Alternative Fuel	1	250 scfm of LFG	N/A
OTHER			
Liquefied Natural Gas	1	830 scfm of LFG	830 scfm of LFG
Medium BTU	4	2,850 scfm of LFG	N/A
High BTU	19	625 to 9,200 scfm of LFG	3,400 scfm of LFG
Leachate Evaporation	20	4 to 1,500 scfm of LFG	560 scfm of LFG

Note: "MW" stands for mega-watts. "scfm" is standard cubic feet per minute.

The following briefly describes each of the above technologies. Costs are only provided for the more popular technologies that have reasonable cost histories and a potential for application in British Columbia. The cost ranges for reciprocating engines and microturbines are provided in 2008 dollars for installation of the technology, but exclude the cost for the active LFG management system.

Reciprocating engine – This is by far the most common and established technology for utilizing landfill gas. LFG is the fuel for these engines to generate electricity. This technology is used at the Vancouver Landfill and the Hartland Landfill, and is proposed for the Nanaimo Landfill. Reciprocating engines can be sensitive to contaminants in the

LFG, such as siloxanes (organic silicones that form hard deposits in engines) and hydrogen sulphide, and either require pre-treatment to lower the concentration of such constituents or require greater maintenance. Electrical conversion efficiency typically ranges from 35 to 40% for modern engines. Typical installation costs are $1.25 million to $1.75 million per mega-watt (MW);

Gas turbine – Gas turbines are most popularly known as jet engines and turboprops of aircraft. LFG can be used as fuel in gas turbines to generate electricity. Gas turbines can be sensitive to siloxanes in the LFG, and pre-treatment to remove such contaminants is recommended. Electrical conversion efficiency typically ranges from 24 to 28%, but this decreases significantly at partial load. Gas turbines are the most popular for medium to large LFG projects with long-term flow rates in excess of 600 scfm;

Steam turbine – This is similar technology to many coal electrical generating plants. A fuel (LFG) is used to generate superheated steam, which turns a generator. This is a technology most suitable for large LFG projects, and is used at the CESM Landfill in Montréal, Québec and at the Keele Valley and Brock West Landfills near Toronto, Ontario;

Cogeneration – Both reciprocating engines and gas turbines generate substantial amounts of heat. The term “cogeneration” applies when much of this heat is captured and used as a heat source. For reciprocating engines, the overall fuel efficiency to generate electricity and heat can increase to as high as 80%;

Microturbine – This is a small version of a gas turbine and has all the same issues except that they are manufactured in units of 30 kilo-watts (kW) to about 300 kW. A 30 MW unit typically costs $40,000 plus the cost of compression and LFG treatment. Due to the need for relatively high compression of the LFG, parasitic loads can be high, and thus, the net output can be as low as 20 kW for each 30 MW unit;

Combined cycle – This is similar to cogeneration except that it applies to gas turbines that generate electricity, and the waste heat is used to produce steam for a steam turbine to generate more electricity. Electrical conversion efficiencies of about 40% are possible. However, due to the high capital cost, it is only economical for large LFG projects;

Organic Rankine cycle – A Rankine cycle engine is a heat engine that uses vaporization of a fluid, such as water, during the power cycle. An organic Rankine cycle engine uses an organic fluid that has a lower boiling pressure than steam. Although this technology is not new, it is considered to be an experimental technology when applied to landfill gas;

Sterling engine – A Sterling cycle engine is an engine that heats and cools a gas in a closed cycle to achieve power generation. The LFG would supply the heat for the engine. Although the theoretical efficiency can be relatively high, the technology has not yet developed to the point that it offers distinct advantages compared with other established technologies. Thus, there are few manufacturers of commercial units and it is considered to be an experimental technology when applied to landfill gas. Consideration needs to be given to the effect of relatively corrosive LFG on the metal surfaces of the engine;

Alternative fuel – LFG can be used as an alternative fuel in vehicles. There is one demonstration project in Los Angeles using this technology;

Boiler – LFG can be used as a fuel in boilers. Costs depend on the distance of the utilization facility from the landfill. This technology is used at a greenhouse in Delta, BC (using LFG from the Vancouver Landfill) and at the Georgia Pacific gypsum wallboard plant in Surrey, BC (using LFG from the closed Port Mann Landfill);

Direct thermal – LFG can be used for direct thermal heating. Costs depend on the distance of the utilization facility from the landfill. This technology is used at the Vancouver Landfill (radiant heaters and central air heating of the existing administration building);

Greenhouse – LFG can be used for direct heating of greenhouses. Costs depend on the distance of the utilization facility from the landfill;

Liquefied natural gas – There is one new project in the United States that purifies landfill gas into liquefied natural gas. This technology was piloted by Prometheus Energy at the Hartland Landfill in about 2000;

Medium BTU – This is normally defined as using LFG as a fuel without purification, and boiler, direct thermal, and greenhouse uses would fall under this category. However, in the categories in the United States Environmental Protection Agency (USEPA) database, it refers to alternative uses, such as direct injection into a natural gas reservoir;

High BTU – LFG can be purified to separate the combustible fraction (methane) from the remaining gases that comprise LFG. Technologies include pressure swing absorption technology, such as that developed by QuestAir of Burnaby, BC and piloted for use on LFG at the Vancouver Landfill in 2005; and

Leachate evaporation – Leachate from landfills can be disposed by evaporating it using heat from landfill gas. This technology is the most applicable at sites where leachate disposal costs are high.

Potential revenue, at the present time, from the generation of electricity in BC could range from $0.06 to $0.08 per kilowatt-hour (kW-hr), excluding potential revenue due to crediting of associated GHG emission reductions. As a broad rule of thumb at the present time, landfills having a methane flow rate of less than 350 scfm (600 m^3/hr) are unlikely to be able to utilize the methane from landfills to generate electricity in an economical manner. However, this threshold depends on the price paid to producers of electricity and the concentration of contaminants in the landfill gas. This approximate threshold could decrease if there is a price premium paid for “green energy” harnessed from LFG.

Potential revenue from the direct use of LFG is estimated to be about 75% of the price of natural gas (natural gas is presently about $8 per gigajoule). The lower price is due to the wet and corrosive nature of the LFG, compared with natural gas. The economic thresholds for direct use of LFG are strongly dependent on the proximity of the user, the LFG delivery pressure required, and topography and constraints along the utilization pipline alignment.

10.0 IMPLEMENTATION

To implement LFG management systems at landfills in BC that presently do not have such systems, the following outlines the steps and approximate duration. It should be noted that the duration provided is from a regulatory implementation perspective, to allow for differences in approaches by the different local governments. The actual durations are likely to be shorter for a specific project.

Step	Duration
Municipal or Regional government budgets for expenditures	12 months
Detailed assessment of potential methane collection – this would be a site-specific assessment of the potential for methane collection at the particular landfill. This would likely include a pump test to assess LFG extraction well radius of influence, and short-term LFG flow from a trial well. The cost would be on the order of $110,000 depending on location and duration of test.	6 months
Feasibility assessment of LFG utilization – cost is highly dependent on site conditions and availability of nearby potential users	3 months
Design of LFG collection system – cost is highly dependent on site conditions	6 months
Construction of LFG collection system	9 months

An allowance of about one year should be provided for new operators to gain sufficient experience and adequate skill to operate the systems in a reasonably efficient manner.

Another consideration regarding implementation is the capacity of local industry to design and construct LFG management systems. If many LFG management system are to be constructed at the same time, the local industry may not have the capacity to design and construct these systems all at the same time. This may result in some problematic projects with quality and performance issues.

11.0 CLOSING COMMENTS

Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the landfill gas engineering profession currently practicing under similar conditions in British Columbia, subject to the time limits and physical constraints of the scope of work for this project. No warranty, express or implied, is made. Actual capital costs and O&M costs for an active landfill gas management system may vary from the model predictions due to a number of factors as explained in section 8.3.

12.0 REFERENCES

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GOLDER ASSOCIATES LTD.

ORIGINAL SIGNED BY

Colin L. Y. Wong, P.Eng.
Principal

ORIGINAL SIGNED BY

Keith C. K. Lam, E.I.T.
Project Engineer

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TABLE 1: Capital Cost Information for Existing Active LFG Management Systems in BC

Year	PV	Vancouver Landfill	Hartland Landfill	Cache Creek Landfill	Nanaimo Landfill	Foothills Boulevard Landfill	Glenmore Landfill
1997	1.82						
2001	1.82	$2,800,000				$916,000	
2002	1.66						
2003	1.52	$805,000			$1,200,000		$133,000
2004	1.52			$121,574			$350,000
2005	1.42			$124,911			$405,000
2006	1.27	$350,000		$255,464			$482,000
2007	1.12			$210,587			$617,000
PV (2008)	1.00	$6,764,100	$5,568,000	$922,463	$1,824,000	$1,667,120	$2,612,440

Notes:
1. The cost for Hartland Landfill is a replacement cost as of November 2007, but was assumed to be a 2008 cost because it is within 6 months of this report.
2. PV is the present value based on Vancouver Construction Price Index (apartment buildings).

TABLE 2: Available Cost Information and Estimated Average Unit Prices

			QUANTITY						ESTIMATED AVERAGE UNIT PRICE (2008$)	EXTENSION					
			2001 & 2003	1999 – 2005	2004 – 2007	2003	2002	2003							
No.	Item	Unit	Vancouver	Hartland	Cache Creek	Nanaimo	Foothills	Glenmore		Vancouver	Hartland	Cache Creek	Nanaimo	Foothills	Glenmore
1	Mobilizations	Each	2	2	4	1	1	5	$15,000	$30,000	$30,000	$60,000	$15,000	$15,000	$75,000
2	Vertical wells	m	2,696	1,012	693	386	264	392	$270	$727,920	$273,240	$187,110	$104,085	$71,280	$105,840
3	Horizontal collectors	m	4,525	5,660	0	450	0	5,635	$160	$724,000	$905,600	$0	$72,000	$0	$901,600
4	Wellheads	Each	192	89	41	30	16	66	$4,000	$768,000	$356,000	$164,000	$120,000	$64,000	$264,000
5	≤ 50 mm dia. pipe	m	0	2,794	0	0	925	125	$80	$0	$223,520	$0	$0	$74,000	$10,000
6	100 mm dia. HDPE pipe	m	4,250	1,855	0	1,500	990	395	$90	$382,500	$166,950	$0	$135,000	$89,100	$35,550
7	150 mm dia. HDPE pipe	m	2,100	4,991	0	205	0	635	$130	$273,000	$648,830	$0	$26,650	$0	$82,550
8	200 mm dia. HDPE pipe	m	1,475	417	890	1,350	976	700	$150	$221,250	$62,550	$133,500	$202,500	$146,400	$105,000
9	250 mm dia. HDPE pipe	m	1,750	222	0	0	0	0	$175	$306,250	$38,850	$0	$0	$0	$0
10	300 mm dia. HDPE pipe	m	600	182	0	0	0	0	$205	$123,000	$37,310	$0	$0	$0	$0
11	350 mm dia. HDPE pipe	m	0	99	0	0	0	0	$235	$0	$23,265	$0	$0	$0	$0
12	400 mm dia. HDPE pipe	m	1,375	1,727	0	0	0	460	$260	$357,500	$449,020	$0	$0	$0	$119,600
13	450 mm dia. HDPE pipe	m	1,500	0	0	0	0	0	$280	$420,000	$0	$0	$0	$0	$0
14	Gravity condensate traps	Each	36	4	3	3	0	3	$8,000	$288,000	$32,000	$24,000	$24,000	$0	$24,000
15	Pumped condensate traps	Each	0	0	0	1	2	0	$25,000	$0	$0	$0	$25,000	$50,000	$0
16	Blower capacity @ 40 in wc	scfm	4,000	4,500	750	800	1,700	1,200	$23	$97,000	$108,500	$22,250	$23,400	$44,100	$32,600
17	Instrumentation (CH_4/O_2)	Each	1	0	0	1	1	1	$50,000	$50,000	$0	$0	$50,000	$50,000	$50,000
18	Variable frequency drive	Each	0	2	1	1	2	0	$5		$24,500	$5,750	$6,000	$10,500	
19	Utility flare	scfm	0	600	640	855	0	350	$25		$30,000	$31,000	$36,375		$23,750
20	Enclosed flare	scfm	3,000	1,000	0	0	750	0	$85	$315,000	$145,000			$123,750	
21	Other abstraction plant	*Factor of blower $*	1	1	1	1	1	1	*10*	$970,000	$1,085,000	$222,500	$234,000	$441,000	$326,000

	Vancouver	Hartland	Cache Creek	Nanaimo	Foothills	Glenmore
Subtotal =	$6,053,420	$4,640,135	$850,110	$1,074,010	$1,179,130	$2,155,490
Model prediction of Total Capital Cost (including 15% for other costs) =	**$6,961,433**	**$5,336,155**	**$977,627**	**$1,235,112**	**$1,356,000**	**$2,478,814**
Capital Cost in 2008 dollars =	$6,764,100	$5,568,000	$922,500	$1,824,000	$1,667,120	$2,612,000
Model percent of capital cost in 2008$ (<100% means model underpredicts)	103%	96%	106%	68%	81%	95%

Notes:
1. Black font is calculation.
2. Green font is available data or is information supplied to Golder.
3. Blue font is assumed by Golder.

TABLE 3: Calculated Capital Costs for Four BC Landfills and Cache Creek Landfill

			QUANTITY					ESTIMATED	EXTENSION				
No.	**Item**	**Unit**	**Cache Creek Landfill (1996 – 2001)**	**Comox Landfill**	**Vernon Landfill**	**Prince Rupert Landfill**	**Lower Nicola Landfill**	**AVERAGE UNIT PRICE (2008$)**	**Cache Creek Landfill (1996 – 2001)**	**Comox Landfill**	**Vernon Landfill**	**Prince Rupert Landfill**	**Lower Nicola Landfill**
1	Mobilizations	each	4	1	1	1	1	$15,000	$60,000	$15,000	$15,000	$15,000	$15,000
2	Vertical wells	m	822	270	250	63	70	$270	$221,940	$72,900	$67,500	$17,010	$18,900
3	Horizontal collectors	m	0	190	690	110	220	$160	$0	$30,400	$110,400	$17,600	$35,200
4	Wellheads	each	35	15	25	7	10	$4,000	$140,000	$60,000	$100,000	$28,000	$40,000
5	≤ 50 mm dia. pipe	m	0	0	0	0	0	$80	$0	$0	$0	$0	$0
6	100 mm dia. HDPE pipe	m	120	0	0	0	0	$90	$10,800	$0	$0	$0	$0
7	150 mm dia. HDPE pipe	m	435	720	1,370	520	590	$130	$56,550	$93,600	$178,100	$67,600	$76,700
8	200 mm dia. HDPE pipe	m	1725	0	0	0	0	$150	$258,750	$0	$0	$0	$0
9	250 mm dia. HDPE pipe	m	0	0	0	0	0	$175	$0	$0	$0	$0	$0
10	300 mm dia. HDPE pipe	m	0	0	0	0	0	$205	$0	$0	$0	$0	$0
11	350 mm dia. HDPE pipe	m	0	0	0	0	0	$235	$0	$0	$0	$0	$0
12	400 mm dia. HDPE pipe	m	0	0	0	0	0	$260	$0	$0	$0	$0	$0
13	450 mm dia. HDPE pipe	m	0	0	0	0	0	$280	$0	$0	$0	$0	$0
	Sump connection	each	3	0	0	0	0		$45,000				
14	Gravity condensate traps	each	6	5	12	4	2	$8,000	$48,000	$40,000	$96,000	$32,000	$16,000
15	Pumped condensate traps	each	0	1	1	1		$25,000	$0	$25,000	$25,000	$25,000	$0
									$0				
16	Blower capacity @ 40 in wc	scfm	750	490	270	255	37	$23	$17,250	$16,270	$11,210	$10,865	$5,851
17	Instrumentation (CH_4/O_2)	each	1	1	1	1	1	$50,000	$50,000	$50,000	$50,000	$50,000	$50,000
18	Variable frequency drive	each	1	1	1	1	1	$5	$5,750	$4,450	$3,350	$3,275	$2,185
19	Utility flare	scfm						$25					
20	Enclosed flare	scfm	640	500	300	300	50	$85	$114,400	$102,500	$85,500	$85,500	$64,250
21	Other abstraction plant	*Factor of blower $*	*1*	1	1	1	1	*10*	$172,500	$162,700	$112,100	$108,650	$58,510
								Subtotal =	$1,200,940	$672,820	$854,160	$460,500	$382,596
								Model prediction of Total Capital Cost (including 15% for other costs) =	**$1,381,081**	**$773,743**	**$982,284**	**$529,575**	**$439,985**

TABLE 4: Input for Capital Cost Model for Triple Green Projects

Landfill	Tonnage (1977 – 2007)	Capital Cost (2008$)	Capital Cost (Not Used in Model Development)
Vancouver	14,884,626		$6,844,500
Hartland	4,793,000	$5,568,000	
Cache Creek	7,701,936		$2,456,910
Nanaimo	1,565,934	$1,934,745	
Foothills	2,328,000		$1,667,120
Glenmore	2,324,000	$2,705,900	
Comox Valley	744,000	$773,700	
Vernon	774,000	$982,000	
Prince Rupert	202,000	$530,000	
Lower Nicola	141,000	$440,000	

Notes:
1. Blue font is wet climate landfill.
2. Brown font is dry climate landfill.

TABLE 5: Operations and Maintenance Costs for Active LFG Management Systems in BC

Landfill	Waste Tonnage	O&M Cost	
	1977 – 2007	Wet Climate	Dry Climate
Vancouver	14,884,626	$175,000	
Hartland	4,793,000	$30,000	
Cache Creek	7,701,936		$75,000
Nanaimo	1,565,934	$75,000	
Foothills	2,328,000		$22,000
Glenmore	2,324,000		$60,000

Note: Cost Information was provided to Golder except for Cache Creek Landfill, which was obtained from the 2005 Operations and Closure Plan.

TABLE 6: Estimated Costs for Triple Green Active LFG Management Projects in BC

Regional District	Acronym	Landfill	No.	Total Quantity of Waste Landfilled between 1977 and 2007 (Tonnes)[3]	Estimated Capital Cost[2]	Estimated O&M Cost[2]
Alberni-Clayoquot	ACRD	Alberni Valley	L1	549,000	$781,880	$39,941
Bulkley-Nechako	RDBN	Knockholt	L2	119,000	$300,280	$30,821
Capital	CRD	Hartland	L3	4,793,000	$5,568,000	$30,000
Cariboo	CaribooRD	Gibraltar	L4	63,000	$237,560	$30,435
Central Kootenay	RDCK	Central	L5	387,000	$600,440	$38,483
		Ootischenia	L6	519,000	$748,280	$39,671
Central Okanagan	RDCO	Glenmore	L7	2,324,000	$2,630,000	$60,000
		Westside	L8	473,000	$696,760	$33,264
Columbia Shuswap	CSRD	Salmon Arm	L9	302,000	$505,240	$37,718
Comox-Strathcona	RDCS	Comox Valley	L10	744,000	$1,000,280	$41,696
		Campbell River	L11	661,000	$907,320	$40,949
East Kootenay	RDEK	Central Subregion	L12	231,216	$425,962	$31,595
		Columbia Regional	L13	336,000	$543,320	$32,318
Fraser-Fort George	RDFFG	Foothills	L14	2,328,000	$1,667,120	$22,000
Fraser Valley	FVRD	Bailey	L15	715,000	$967,800	$41,435
		Mini's Pit	L16	427,000	$645,240	$38,843
Greater Vancouver	GVRD[4]	Vancouver[1]	L17	14,884,626	$6,844,500	$175,000
		Cache Creek	L18	7,701,936	$2,399,410	$75,000
		Ecowaste	L19	4,408,000	N/A	N/A
Kitimat-Stikine	RDKS	Thornhill	L20	205,000	$396,600	$36,845
		Terrace	L21	290,000	$491,800	$37,610
Kootenay Boundary	RDKB	McKelvey Creek	L22	284,000	$485,080	$37,556
Nanaimo	RDN	Nanaimo	L23	1,565,934	$1,824,000	$75,000
North Okanagan	NORD	Vernon	L24	774,000	$1,033,880	$35,341
		Armstrong	L25	231,000	$425,720	$31,594
Northern Rockies	NRRD	Ft. Nelson	L26	81,000	$257,720	$30,559
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	1,251,000	$1,568,120	$38,632
Peace River	PRRD	Ft. St. John	L28	680,000	$928,600	$34,692
		Bessborough	L29	87,148	$264,606	$30,601
Sunshine Coast	SCRD	Sechelt	L30	358,000	$567,960	$38,222
Squamish-Lillooet	SLRD	Squamish	L31	284,000	$485,080	$37,556
Skeena-Queen	SQCRD	Prince Rupert	L32	202,000	$393,240	$36,818
Thompson-Nicola	TNRD	Mission Flats	L33	1,266,000	$1,584,920	$38,735
		Lower Nicola	L34	141,000	$324,920	$30,973
		Heffley Creek	L35	120,000	$301,400	$30,828

Notes: [1] Disposal includes DLC, but DLC was neglected in LFG generation modelling.
[2] Green font is from information provided to Golder or available information. Black font is model prediction.
[3] Quantities include MSW and DLC; tonnages with estimates have been rounded to the nearest thousand.
[4] Also known as Metro Vancouver.
[5] All costs in 2008 dollars for LFG management systems with methane collection efficiencies the same as existing landfills (i.e., about 25% to 40% collection efficiency).

TABLE 7: Potential Greenhouse Gas Emission Reductions and Costs

Regional District	Acronym	Landfill	No.	Assumed Collection Efficiency	Potential GHG Emission Reductions 2008	2012	2016	2020	Approximate Total (2011 – 2020)	Approximate Total Waste Tonnage in 2020	Approximate Total Cost PV	Approximate Cost per Tonne CO_2e
					CO_2e/year (tonnes)	CO_2e/year (tonnes)	CO_2e/year (tonnes)	CO_2e/year (tonnes)	CO_2e/year (tonnes)		(2008 $)	(2008 $)
Alberni-Clayoquot	ACRD	Alberni Valley	L1	75%	31,349	32,315	31,921	31,014	318,144	812,886	$2,295,145	$7.21
Bulkley-Nechako	RDBN	Knockholt	L2	50%	3,212	4,301	5,207	5,961	49,311	288,000	$1,258,299	$25.52
Capital	CRD	Hartland	L3	75%	186,563	198,363	212,422	228,464	2,095,490	7,240,489	$12,924,522	$6.17
Cariboo	CaribooRD	Gibraltar	L4	50%	2,032	3,808	5,278	6,495	48,280	277,732	$1,234,480	$25.57
Central Kootenay	RDCK	Central	L5	65%	12,073	11,893	11,762	11,666	118,067	530,400	$1,795,783	$15.21
		Ootischenia	L6	75%	15,261	14,692	14,278	13,976	144,189	661,541	$2,036,296	$14.12
Central Okanagan	RDCO	Glenmore	L7	75%	52,489	61,879	72,125	83,371	698,727	4,174,234	$8,283,214	$11.85
		Westside	L8	65%	9,631	11,542	10,935	9,678	107,877	612,518	$1,845,013	$17.10
Columbia Shuswap	CSRD	Salmon Arm	L9	65%	10,016	12,074	13,822	15,342	133,085	552,441	$1,819,807	$13.67
Comox-Strathcona	RDCS	Comox Valley	L10	75%	35,480	37,291	38,350	38,968	379,302	1,134,161	$2,864,722	$7.55
		Campbell River	L11	75%	33,093	34,190	34,746	17,620	298,648	860,778	$2,392,740	$8.01
East Kootenay	RDEK	Central Subregion	L12	50%	4,598	7,330	9,878	12,269	91,900	762,208	$2,068,132	$22.50
		Columbia Regional	L13	65%	7,371	8,828	10,185	11,460	98,189	593,044	$1,796,227	$18.29
Fraser-Fort George	RDFFG	Foothills	L14	75%	65,427	70,476	74,609	77,994	733,304	3,446,096	$6,413,942	$8.75
Fraser Valley	FVRD	Bailey	L15	75%	42,094	45,961	49,947	54,161	490,172	1,208,940	$2,985,914	$6.09
		Mini's Pit	L16	65%	21,473	25,897	29,175	32,073	281,966	743,725	$2,160,289	$7.66
Greater Vancouver	GVRD[1]	Vancouver	L17	75%	713,226	893,920	989,199	1,039,439	9,490,982	21,358,608	$9,821,476	$1.03
		Cache Creek	L18	75%	127,383	150,708	139,121	128,425	1,405,098	9,501,936	$2,960,170	$2.11
		Ecowaste	L19	75%	48,752	55,448	61,653	67,404	599,560	6,921,493	N/A	N/A
Kitimat-Stikine	RDKS	Thornhill	L20	50%	8,732	7,626	4,138	2,245	53,161	235,000	$1,271,665	$23.92
		Terrace	L21	50%	8,970	6,642	3,604	1,955	46,984	309,500	$1,409,830	$30.01
Kootenay Boundary	RDKB	McKelvey Creek	L22	65%	9,664	10,167	10,530	10,792	104,052	427,157	$1,606,576	$15.44
Nanaimo	RDN	Nanaimo	L23	75%	76,329	85,732	91,273	94,538	890,875	2,540,934	$5,794,269	$6.50
North Okanagan	NORD	Vernon	L24	75%	19,656	23,358	27,641	32,612	267,825	1,469,760	$3,320,487	$12.40
		Armstrong	L25	50%	4,620	5,523	6,415	7,310	61,923	408,587	$1,474,023	$23.80
Northern Rockies	NRRD	Ft. Nelson	L26	50%	2,064	3,161	4,213	5,235	39,397	265,363	$1,215,811	$30.86
Okanagan-Similkameen	RDOS	Campbell Mtn	L27	75%	23,235	26,339	29,590	33,009	288,293	2,011,442	$4,286,465	$14.87
Peace River	PRRD	Ft. St. John	L28	75%	18,915	18,994	16,084	13,619	167,810	753,182	$2,105,609	$12.55
		Bessborough	L29	50%	2,550	4,617	6,663	8,731	61,562	397,583	$1,438,662	$23.37
Sunshine Coast	SCRD	Sechelt	L30	65%	13,168	13,963	14,938	16,062	147,430	548,823	$1,822,297	$12.36
Squamish-Lillooet	SLRD	Squamish	L31	65%	20,673	9,341	2,943	927	59,580	302,196	$1,396,642	$23.44
Skeena-Queen	SQCRD	Prince Rupert	L32	50%	12,269	12,366	12,394	12,401	123,781	338,125	$1,444,456	$11.67
Thompson-Nicola	TNRD	Mission Flats	L33	75%	18,370	20,830	23,430	26,185	228,282	2,014,227	$4,292,904	$18.81
		Lower Nicola	L34	50%	1,799	2,510	3,213	2,932	27,747	256,604	$1,208,134	$43.54
		Heffley Creek	L35	50%	2,206	3,178	4,103	4,612	37,586	276,393	$1,238,916	$32.96

Note: [1] Also known as Metro Vancouver.

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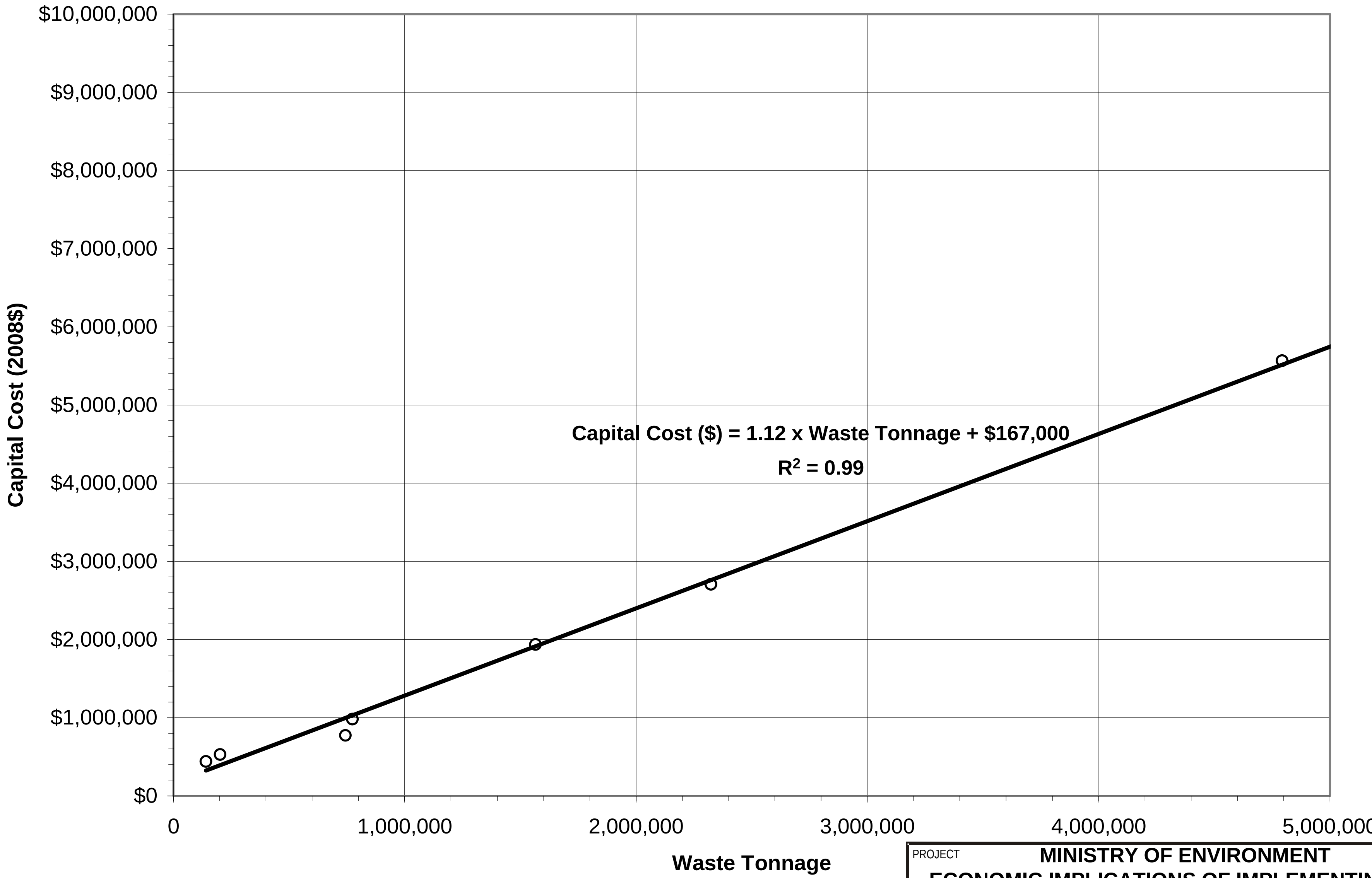
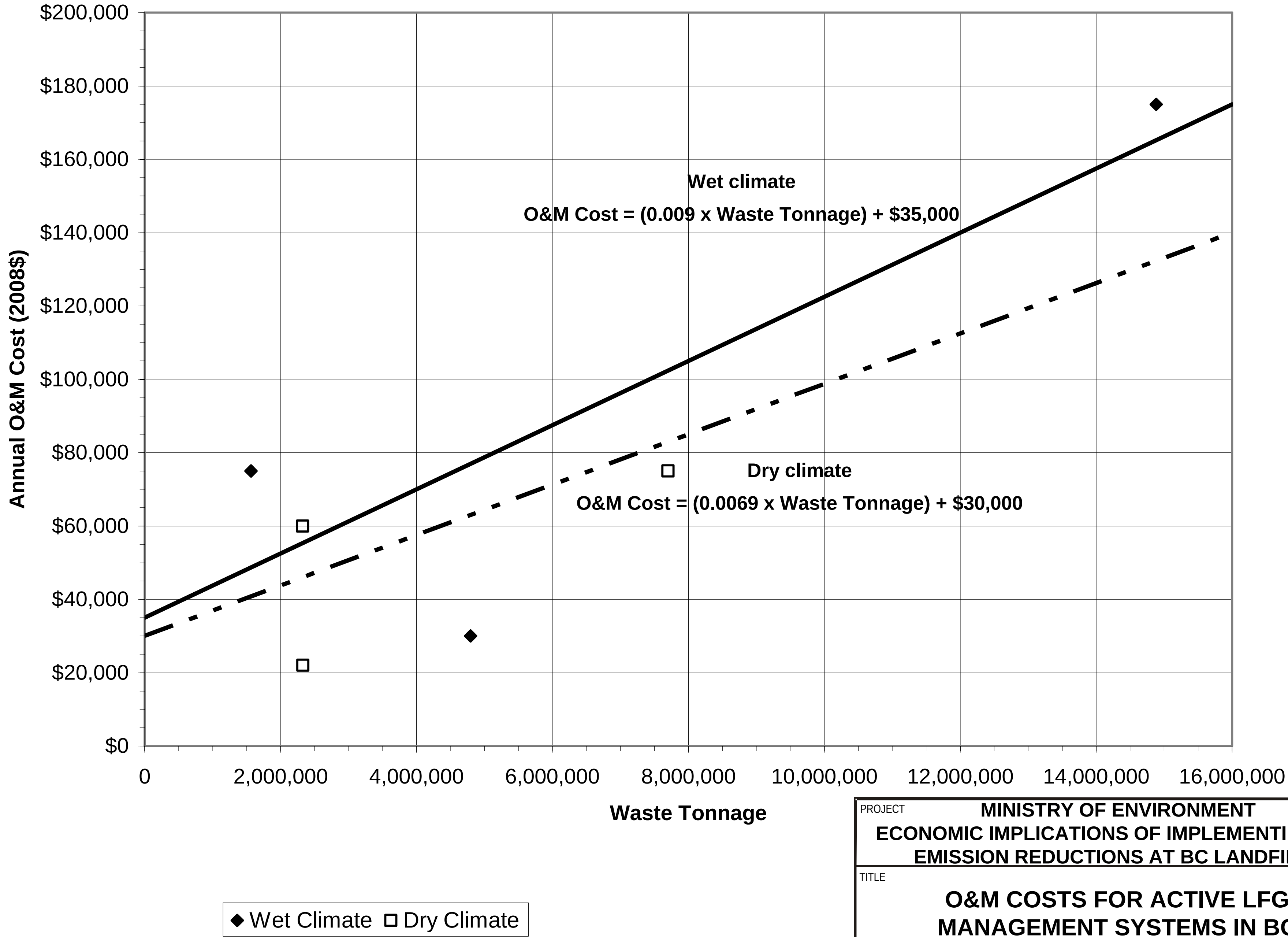


PROJECT	MINISTRY OF ENVIRONMENT ECONOMIC IMPLICATIONS OF IMPLEMENTING LFG EMISSION REDUCTIONS AT BC LANDFILLS
TITLE	IN-PLACE TONNAGE VERSUS TRIPLE GREEN PROJECT CAPITAL COST

Golder Associates

PROJECT No.	08-1411-0043		PHASE / TASK No.	1000
DESIGN	KCKL	12MAR08	SCALE NTS	REV.
CADD	KCKL	12MAR08	FIGURE 1	
CHECK	KCKL	12MAR08		
REVIEW	CLYW			

REVISION DATE: MARCH 12, 2008 BY: KCKL FILE: O:\FINAL\2008\1411\08-1411-0043\0312_08\Components\fig 1 to 3-0312_08 MOE.ppt



PROJECT
MINISTRY OF ENVIRONMENT
ECONOMIC IMPLICATIONS OF IMPLEMENTING LFG EMISSION REDUCTIONS AT BC LANDFILLS

TITLE
O&M COSTS FOR ACTIVE LFG MANAGEMENT SYSTEMS IN BC

Golder Associates

PROJECT No.	08-1411-0043		PHASE / TASK No.	1000
DESIGN	KCKL	12MAR08	SCALE NTS	REV.
CADD	KCKL	12MAR08	**FIGURE 2**	
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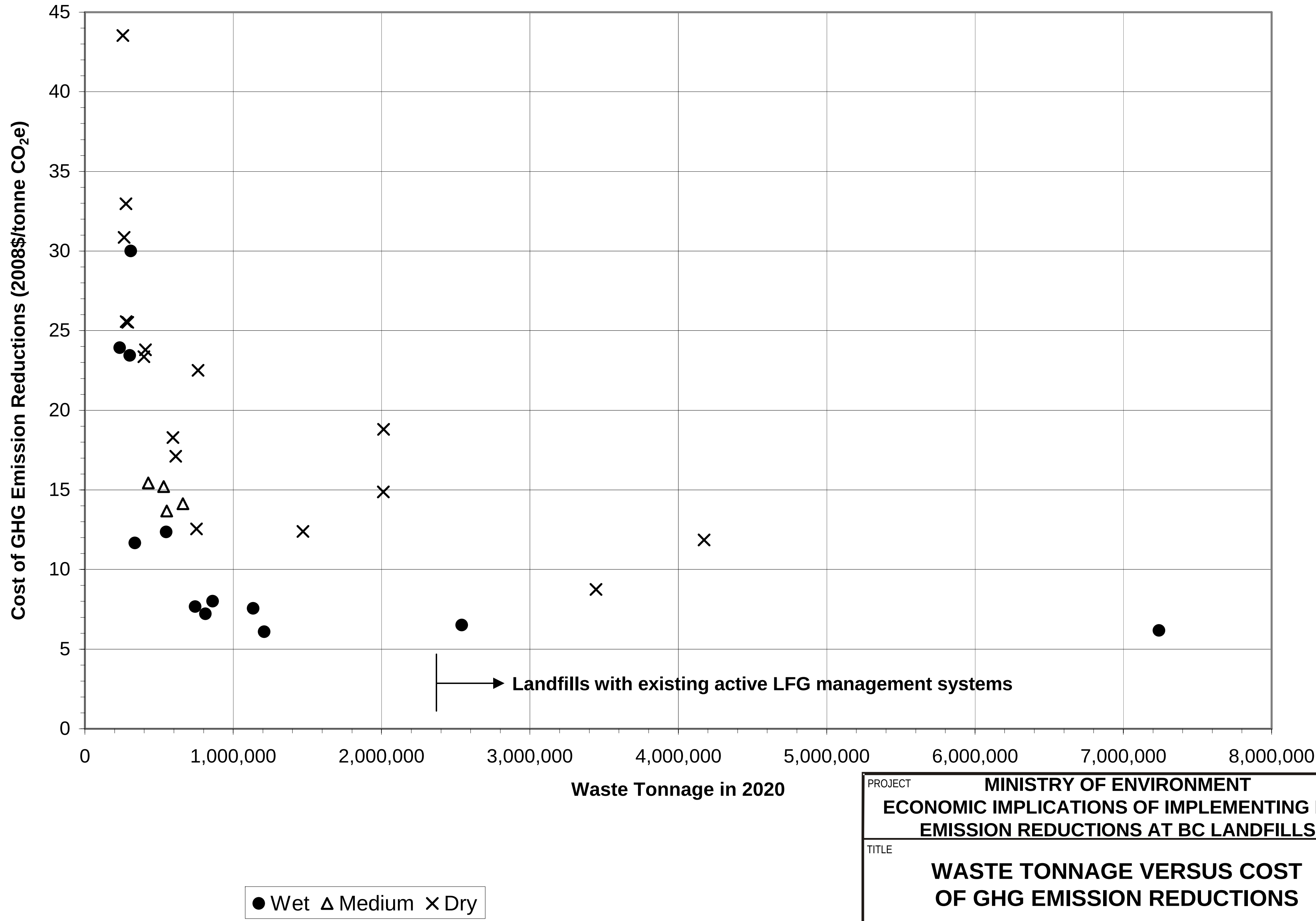
REVIEW	CLYW			

REVISION DATE: MARCH 12, 2008 BY: KCKL FILE: O:\FINAL\2008\1411\08-1411-0043\0312_08\Components\fig 1 to 3-0312_08 MOE.ppt



PROJECT
MINISTRY OF ENVIRONMENT
ECONOMIC IMPLICATIONS OF IMPLEMENTING LFG EMISSION REDUCTIONS AT BC LANDFILLS

TITLE
WASTE TONNAGE VERSUS COST OF GHG EMISSION REDUCTIONS

Golder Associates

PROJECT No.	08-1411-0043		PHASE / TASK No.	1000
DESIGN	KCKL	12MAR08	SCALE NTS	REV.
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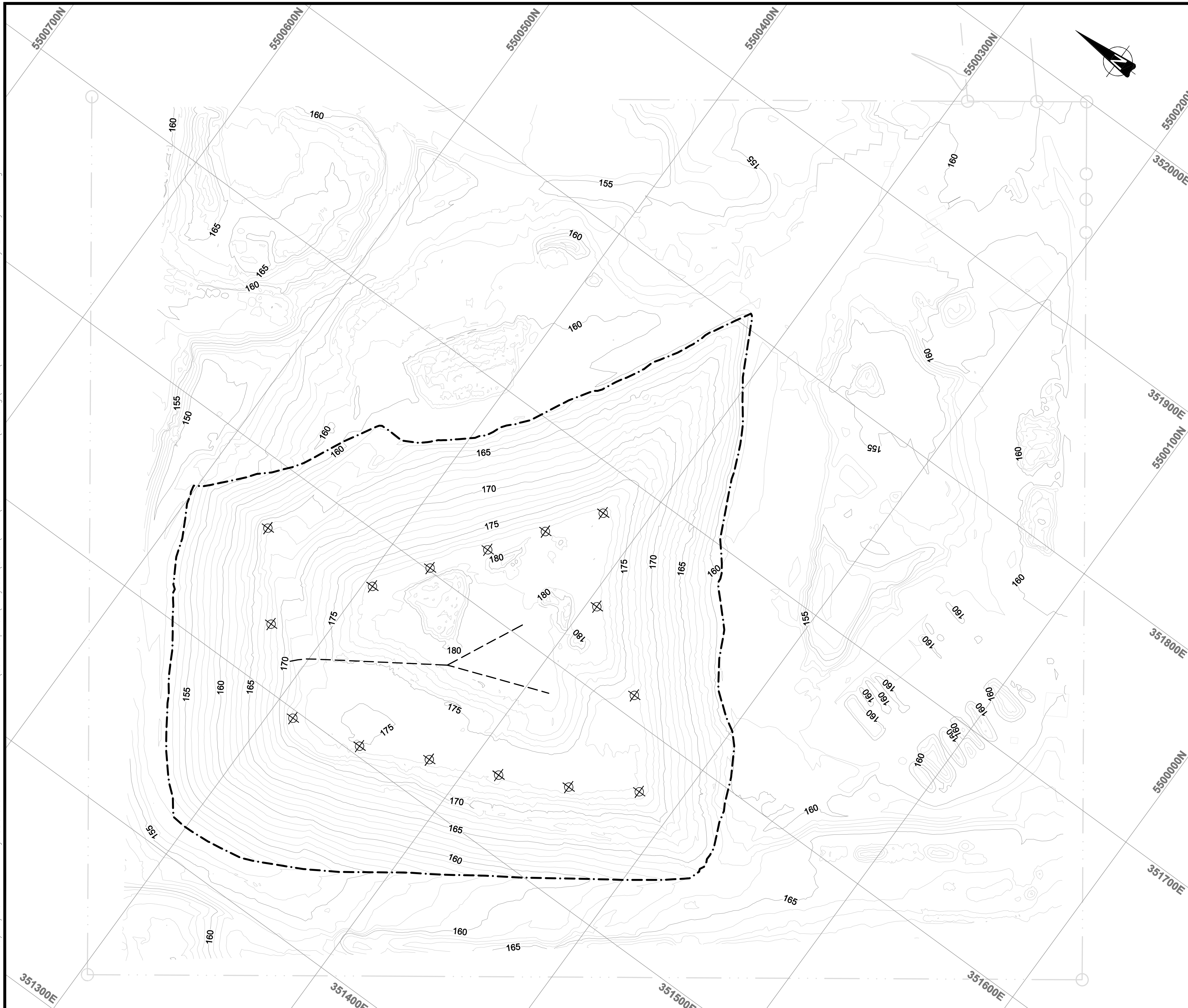
CHECK	KCKL	12MAR08		
REVIEW	CLYW			

APPENDIX I

CONCEPTUAL WELL LAYOUT DESIGN PLANS



CADD FILE: N:\Bur-Graphics\Projects\2008\1411\08-1411-0043\Drafting\1000\FIG-I-1 - Comox Valley LFG System.dwg

REVISION DATE: 08/04/03 10:46AM By: ODurcau

LEGENDS

- Inferred Extent of Waste
- Property Line of Landfill
- 160 Landfill Topography
- Vertical Landfill Gas Extraction Well
- Horizontal Landfill Gas Collector

NOTES

Site topography was provided by Comox Valley Regional District on February 26, 2008.

0 20 40 60 80 100

Scale in Metres

PROJECT

MINISTRY OF ENVIRONMENT
CONCEPTUAL LANDFILL GAS SYSTEM DESIGN
BRITISH COLUMBIA

TITLE

CONCEPTUAL WELL LAYOUT DESIGN
COMOX VALLEY LANDFILL

Golder Associates

PROJECT No. 08-1411-0043			FILE No.	0814110043-1
DESIGN	KCKL	27FEB08	SCALE AS SHOWN	REV. –
CADD	KCKL	27FEB08	**FIGURE I-1**	
CHECK	KCKL	27FEB08		
REVIEW	CLYW			

LEGENDS

— · — Extent of Waste

665 Landfill Topography (August 23, 2007)

⌖ Vertical Landfill Gas Extraction Well

– – – – Horizontal Landfill Gas Collector

NOTES

Site topography and extent of waste were provided by Thompson-Nicola Regional District on February 11, 2008.

REFERENCE

Aero Geometrics Ltd.'s site plan surveyed on August 23, 2007, CAD file "2007 LN landfilling ext.dwg".

0 20 40 60 80 100

Scale in Metres

PROJECT

MINISTRY OF ENVIRONMENT
CONCEPTUAL LANDFILL GAS SYSTEM DESIGN
BRITISH COLUMBIA

TITLE

CONCEPTUAL WELL LAYOUT DESIGN
LOWER NICOLA LANDFILL

Golder Associates

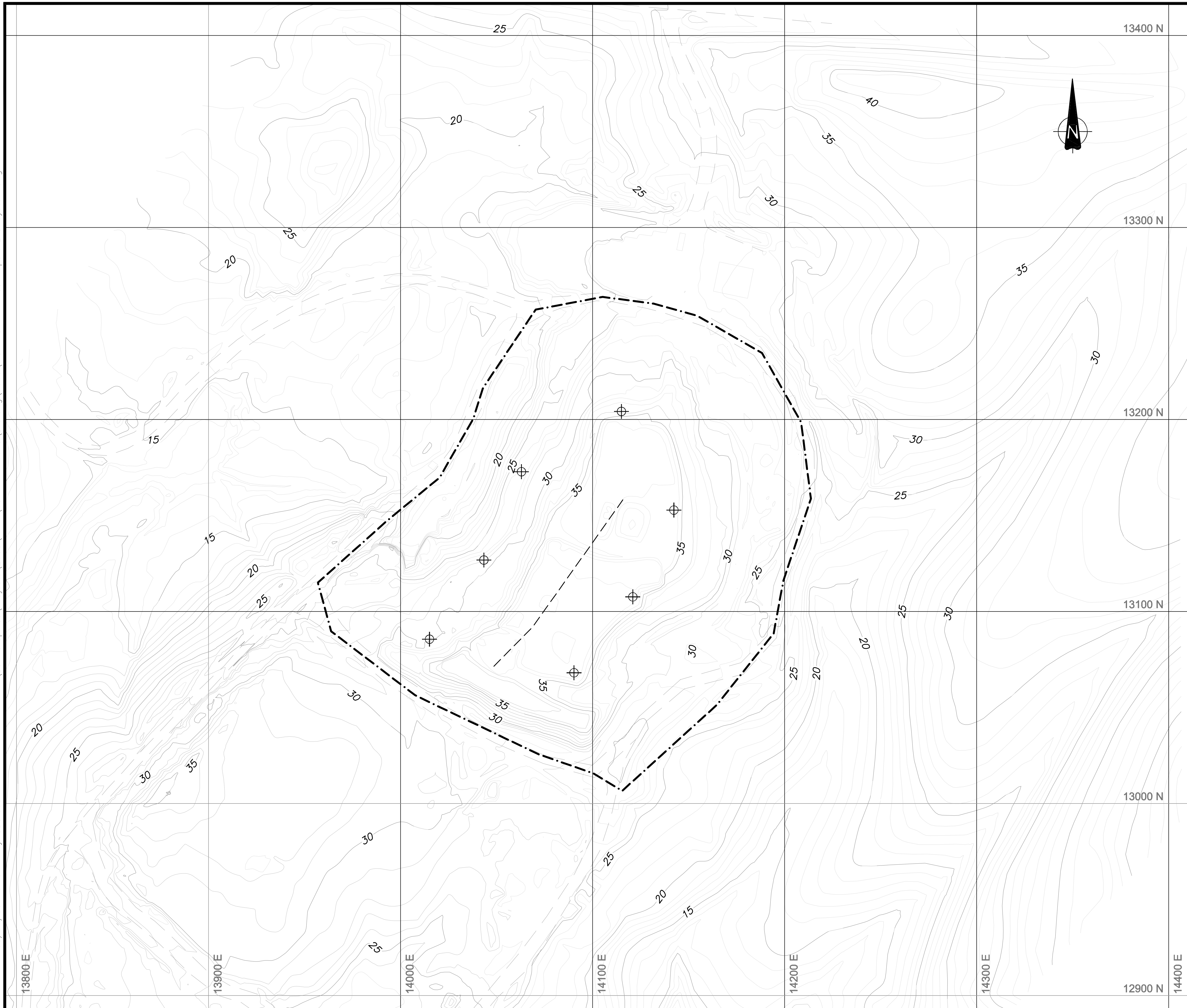
PROJECT No. 08-1411-0043		
DESIGN	KCKL	25FEB08
CADD	KCKL	22FEB08
CHECK	KCKL	25FEB08
REVIEW	CLYW	

FILE No. 0814110043-2

SCALE AS SHOWN REV. –

FIGURE I-2

REVISION DATE: 08/04/03 10:48AM By: ODurcau CADD FILE: N:\Bur-Graphics\Projects\2008\1411\08-1411-0043\Drafting\1000\FIG-I-2 - Lower Nicola LFG System.dwg



LEGENDS

Extent of Waste

665 Landfill Topography (2005)

Vertical Landfill Gas Extraction Well

Horizontal Landfill Gas Collector

NOTES

Site topography and limit of landfill were provided by the City of Prince Rupert on February 11, 2008.

REFERENCE

City of Prince Rupert's "Leachate Collection and Landfill Extension Site Plan", Drawing No. L02-21-D0091, Dated January 18, 2006.

0 20 40 60 80 100

Scale in Metres

PROJECT

MINISTRY OF ENVIRONMENT
CONCEPTUAL LANDFILL GAS SYSTEM DESIGN
BRITISH COLUMBIA

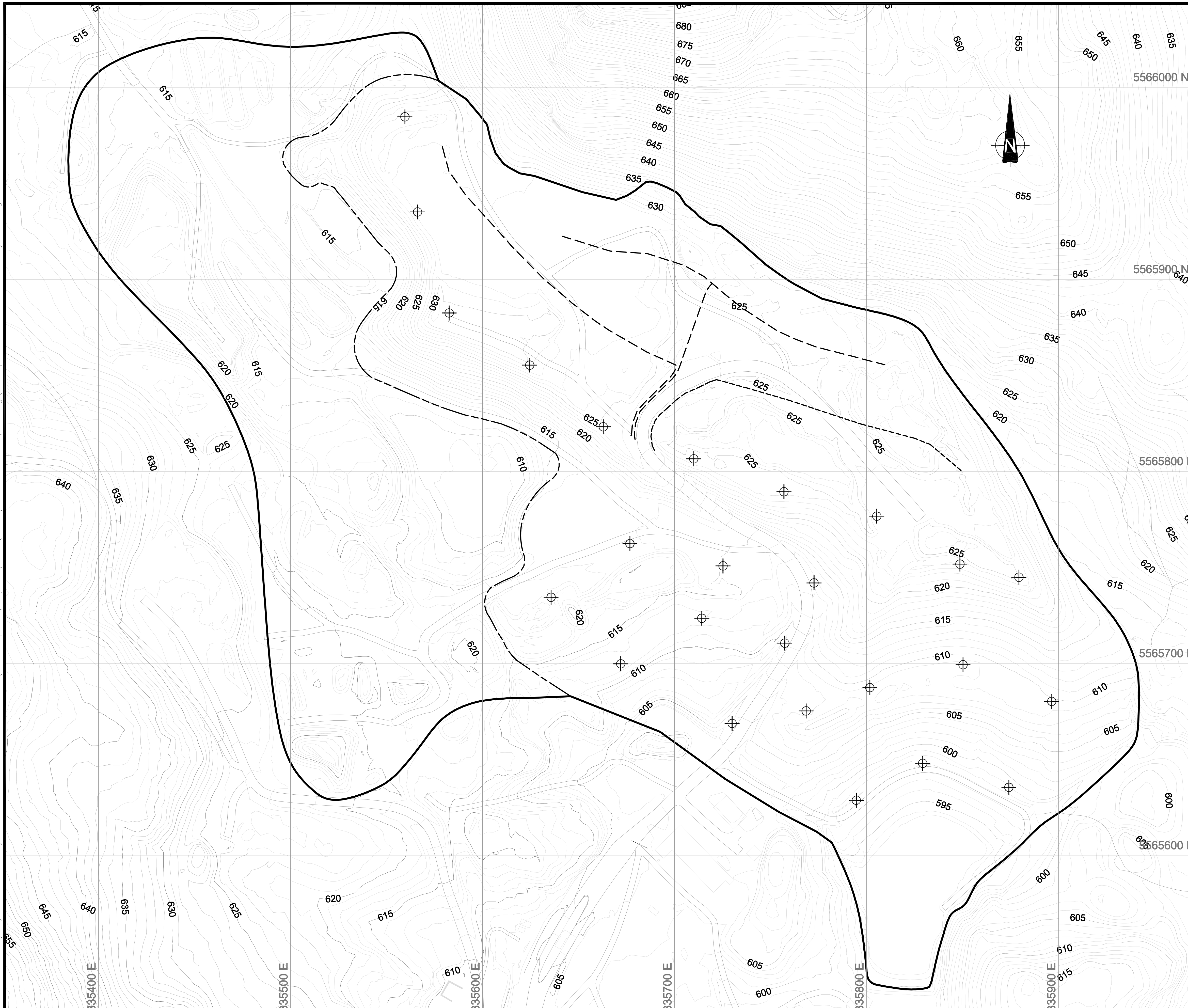
TITLE

CONCEPTUAL WELL LAYOUT DESIGN
PRINCE RUPERT LANDFILL

Golder Associates

PROJECT No. 08-1411-0043		FILE No.	0814110043-3
DESIGN	KCKL	29FEB08	SCALE AS SHOWN REV. –
CADD	KCKL	29FEB08	
CHECK	KCKL	29FEB08	**FIGURE I-3**
REVIEW	CLYW		

REVISION DATE: 08/04/03 10:49AM By: ODurcau CADD FILE: N:\Bur-Graphics\Projects\2008\1411\08-1411-0043\Drafting\1000\FIG-I-3 - Prince Rupert LFG System.dwg



LEGENDS

- Extent of Waste
- Extent of Current Landfilling
- 665 Landfill Topography (2005)
- Vertical Landfill Gas Extraction Well
- Horizontal Landfill Gas Collector

NOTES

1. Site topography and limit of landfill were provided by North Okanagan Regional District on February 12, 2008.
2. Extent of current landfilling was provided by North Okanagan Regional District on March 5, 2008.

PROJECT

MINISTRY OF ENVIRONMENT
CONCEPTUAL LANDFILL GAS SYSTEM DESIGN
BRITISH COLUMBIA

TITLE

CONCEPTUAL WELL LAYOUT DESIGN VERNON LANDFILL

Golder Associates

PROJECT No. 08–1411–0043			FILE No. 0814110043–4	
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CADD	KCKL	29FEB08	FIGURE I-4	
CHECK	KCKL	29FEB08		
REVIEW	CLYW			

REVISION DATE: 08/04/03 10:49AM By: ODurcau CADD FILE: N:\Bur-Graphics\Projects\2008\1411\08-1411-0043\Drafting\1000\FIG-I-4 - Vernon LFG System.dwg