Northwest Territories Environment and Natural Resources

July 16, 2010

Angela Plautz
Regulatory Officer
Mackenzie Valley Land and Water Board
7th Floor – 4910 50th Avenue
P.O. Box 2130
Yellowknife, NT
X1A 2P6

Dear Ms. Plautz,

Re: **Paramount Resources Ltd.**
Water Licence Application – MV2010L1-0001
Intervention Submission

Please find attached Environment and Natural Resources' (ENR) written submission to the Mackenzie Valley Land and Water Board (MVLWB) for the Public Hearing, concerning Paramount Resources Ltd. Type A Water Licence MV2010L1-0001, scheduled for July 27 and 28, 2010.

The Department of Environment and Natural Resources submits this intervention based on its mandated responsibilities under the *Environmental Protection Act,* the *Forest Management Act*, the *Forest Protection Act* and the *Wildlife Act.*

The GNWT represents the interests of the residents of the Northwest Territories, and submits that the intervention information and recommendations are made under the authority of the NWT *Environmental Protection Act* (EPA). ENR will formally present the contents of this intervention at the Public Hearing, and will answer questions as necessary.

Staff attending will include:

- Dr. Ray Case, PhD – Director, Environment Division, ENR
- Ms. Aileen Stevens, P.Eng. – Air Quality Programs Coordinator, ENR

- Mr. Todd Paget, P.Eng. – Industrial Specialist Oil and Gas, ENR
- Mr. Gerald Enns – Hazardous Waste Specialist, ENR
- Mr. Simon Toogood – Pipeline Environmental Officer, ENR

In support of ENR's intervention, the following technical specialists will also be presenting, in person and via telephone, at the Public Hearing:

- Mr. Jamie VanGulck, Ph.D, P.Eng.
- Ms. Susan Halla, C.E.T.
- Mr. David Picard, M. Eng., P.Eng.
- Dr. Allan Legge, PhD

CVs for these technical experts are attached for your reference.

ENR has focused its intervention on the same topics that were discussed at the Technical Hearing, including sump use and management, and air emissions management, both with the mandate of preventing the release of impacts to the environment. The information provided is intended to both address ENR's concerns and the specific requests made by the MVLWB throughout the regulatory review process. These requests are as follows:

- During the Technical Session, MVLWB staff requested that ENR "prepare in its intervention reasons for the Board to choose one (1) or the other [Guide 50 (1996) or Directive 50 (2007)]" [1]; and

- During the IR process, MVLWB requested that ENR clearly demonstrate identified pathways for any particular waste entering into water bodies as a result of incineration and flaring, so they can be addressed in a WL.[2]

In order for ENR to adequately present its intervention and appropriately fulfill its role in this process, ENR will require approximately 2 hours at the Public Hearing. ENR considers this to be a reasonable duration for an intervener to present their concerns for what is to be only the 2nd Type A Water License of an Upstream Oil and Gas development in this territory.

ENR wishes to reiterate its recommendation, as per ENR's letter to the MVLWB dated April 6, 2010, that a Board-led and organized Technical Advisory Committee (TAC) be formed to review, consider and manage the technical aspects of the proposed Type A Water Licence, going forward.

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[1] Page 9, lines 5-14. Mackenzie Valley Land and Water Board, Technical Session for Paramount Resources LTD. Type A Water Licence MV2010L1-0001. June 23, 2010.

[2] Page 16, MVLWB follow-up and information requests #63. Reviewer Comments – Paramount Resources Ltd. – MV2010L1-0001 Type A Water Licence Application.

If you have any questions or concerns relating to the intervention, please do not hesitate to contact Patrick Clancy, Environmental Regulatory Analyst at 920-6591 or email at patrick_clancy@gov.nt.ca.

Sincerely,

Ray Case
Director of Environment Division
Department of Environment and Natural Resources

Attached: 7

Environment and Natural Resources Written Intervention

For

Paramount Resources Ltd. Type A Water Licence, MV2010L1-001

Public Hearing July 27, 28

Contents

1. Introduction

ENR has provided this intervention for the Paramount Resources LTD. Type A Water Licence MV2010L1-0001 review for the purpose of providing technical advice to the Mackenzie Valley land and Water Board (MVLWB). This submission is based upon the following:

ENR understands that:

> "The mandate of the boards is to regulate the use of land and waters and the deposit of waste so as to provide for the conservation, development and utilization of land and water resources in a manner that will provide the optimum benefit to the residents of the settlement area and of the Mackenzie Valley and to all Canadians." [1]

ENR supports the mandate of Land and Water Boards in the Northwest Territories and the Mackenzie Valley Land and Water Board's vision as:

[1] http://www.mvlwb.com/html/mandate.htm

> "A forum for regional decision making, ensuring effective participation of residents in the use, protection, and benefits of the lands and waters of the Mackenzie Valley". [2]

In addition, ENR has drafted the following submission based on its understanding of the direction provided by the *Northwest Territories Waters Act* (S.C. 1992, c. 39. Current to June 16, 2010.). ENR would specifically like to reference the following sections of the Act:

DEPOSIT OF WASTE

9. (1) Except in accordance with the conditions of a licence or as authorized by regulations made under paragraph 33(1)(n), no person shall, subject to subsection (2), deposit or permit the deposit of waste

(*a*) in any waters in a water management area; or

(*b*) in any other place under conditions in which the waste, or any other waste that results from the deposit of that waste, may enter any waters in a water management area.

INTERPRETATION

2, In this Act,

"waste" means

(*a*) any substance that, if added to water, would degrade or alter or form part of a process of degradation or alteration of the quality of the water to an extent that is detrimental to its use by people or by any animal, fish or plant, or

(*b*) water that contains a substance in such a quantity or concentration, or that has been so treated, processed or changed, by heat or other means, that it would, if added to any other water, degrade or alter or form part of a process of degradation or alteration of the quality of that water to the extent described in paragraph (a),

and, without limiting the generality of the foregoing, includes

(*c*) any substance or water that, for the purposes of the Canada Water Act, is deemed to be waste,

(*d*) any substance or class of substances prescribed by regulations made under subparagraph 33(1)(b)(i),

(*e*) water that contains any substance or class of substances in a quantity or concentration that is equal to or greater than a quantity or concentration prescribed in

[2] http://www.mvlwb.com/html/introduction.htm

respect of that substance or class of substances by regulations made under subparagraph 33(1)(b)(ii), and

(*f*) water that has been subjected to a treatment, process or change prescribed by regulations made under subparagraph 33(1)(b)(iii);

OBJECTS AND POWERS OF BOARD

12. The objects of the Board are to provide for the conservation, development and utilization of waters in a manner that will provide the optimum benefit for all Canadians in general and, in particular, for the residents of any part of the Northwest Territories for which the Board is authorized to issue licences.

14. (1) Subject to this section, the Board may issue type A licences and type B licences, in accordance with the criteria set out in the regulations made under paragraph 33(1)(c), for a term not exceeding twenty-five years, permitting the applicant for the licence, on payment of the fees prescribed by regulations made under subparagraph 33(1)(k)(i)

(4) Where an application for a licence is made, the Board shall not issue a licence unless the applicant satisfies the Board that

(*a*) either

(i) the use of waters or the deposit of waste proposed by the applicant would not adversely affect, in a significant way, the use of waters, whether in or outside the water management area to which the application relates,

(A) by any existing licensee who holds a licence issued under this Act or the Nunavut Waters and Nunavut Surface Rights Tribunal Act, or

(B) by any other applicant whose proposed use of waters would take precedence over the applicant's proposed use by virtue of section 29, or

2. Drilling Waste Solids Management

2.1. Concern

The Department of Environment and Natural Resources (ENR) is concerned over potential adverse short and long-term impacts to land and water resulting from the inappropriate disposal of drill cuttings in sumps in the Cameron Hills Region. The potential toxicity and typical contaminants of drill wastes is well documented. Without proper mitigation, there is the potential for contamination of surface/and or ground water resources.

There exists a risk of contaminants from waste released into the environment, and possibly sump failure, if any or all the following are not done properly:

- Siting
- Design
- Construction
- Testing and monitoring
- Reclamation

The Proponent has provided little specific information with respect to the success and/or failure of previous sumps from the Proponents previous activities in the region, including monitoring information and the existing state of groundwater in and around existing sumps. And, the proponent has provided only general reference to guidance documents for the future disposal of drill waste cuttings for the life of the Cameron Hills project area. It has not provided specific details with respect to sump siting, investigation, drill waste testing, sump construction, operation, monitoring/reporting, and closure. This leads to significant uncertainty and provides little confidence that the risk of contaminants from waste released into the environment is appropriately mitigated.

2.2. Discussion

2.2.1. Drilling Waste Additives and Toxicity

Drill wastes are a complex and variable mixture, often site and hole specific (Piteau 1988). Concerns of drilling fluid toxicity have stimulated the development and addition of less toxic additives. However, there are a wide variety of drilling fluids and exotic mud additives that may be introduced to treat and/or improve drilling fluid properties throughout the drilling process that may potentially add toxicity of drilling waste. These additives may include, but are not limited to: biocides used to prevent reservoir contamination by sulphur reducing bacteria, coagulants, corrosion inhibitors, defoamers, emulsifiers, foaming agents, freeze suppressants, lubricating agents, pH adjusters, surfactants, tracer materials for studying reservoir characteristics, salts, shale control inhibitors, solvents for removing paraffins, stimulation fluids, and weighting agents (Fristoe,1991; Paget, 2003; PSAC, 2003; and others). These additives and drilling fluids can contaminate drill cuttings proposed for disposal, and toxic contamination can also occur from cuttings and fluids encountered during drilling, such as hydrocarbon formations.

2.2.2. Drilling Waste Disposal in Sumps

Various factors contribute either to the containment of waste and the potential for mobilization of contaminants leaving a waste disposal facility (e.g., sump). When contaminants leave a waste disposal facility, they can enter into groundwater and/or surface water and will alter water quality. Disposing drilling waste onto land, such as through sumps, may impact water. Water licence terms and conditions are required to manage industrial undertakings and limit impacts to water quality within acceptable limits.

A sump is a waste containment facility for the disposal of drilling waste. The sumps proposed by Proponent are the final storage location for drilling waste. An example of other waste containment facilities that are typically considered in water licences include:

- Landfills to contain municipal waste;
- Tailings containment area (TCA) to contain waste generated from the milling of rock;
- Landfarms to contain hydrocarbon contaminated soil; and,
- Lagoons to contain wastewater.

Regardless of the waste containment type (i.e., landfill, TCA, landfarm, lagoon), water licences include terms and conditions to regulate the attributes of the waste disposal facility (e.g., operations, management, monitoring, and closure) to limit impacts to water and land within acceptable levels. All the attributes of the waste disposal facility contribute to potential impacts to waters through waste deposition. As such, all attributes must be considered together, and not independently, to ensure that impacts to land and water are acceptable. For example, a municipal landfill may be required to have hazardous waste to be contained in a lined and bermed facility, whereas, inert waste (e.g., bulky metals) may not require a lined and bermed facility. Further, a municipal landfill may be required not to deposit hazardous waste in the inert waste containment facility. This example emphasizes a key point:

- Waste type/composition that is managed in a waste facility can have a direct influence on the construction and design of the waste facility.

The Proponent proposes to utilize a sump to contain drilling waste. It proposes to use Guide 50 (1996) for criteria related to waste disposal, and Draft Directive 50 (2007) for criteria related to sump construction. The process of selecting attributes from these two guideline documents may results in a separation of attributes that contribute to potential impacts to waters through waste deposition.

Hence, well defined terms and conditions are required for an A Water Licence to ensure proper storage of drill waste cuttings, and to ensure that future contamination of water resources does not occur, and that planning to facilitate future land reclamation requirements are in place.

2.2.3. Draft Directive 50 (2007) & Guide 50 (1996)

ENR is concerned that the Proponent has proposed to dispose of drilling waste cuttings in the Cameron Hills regions using the sump construction methods outlined in Draft Directive 50 (2007)[3] issued by the Energy Resources Conservation Board (ERCB), and dated waste disposal criteria outlined in Guide 50 (1996)[4] issued by the Alberta Energy and Utilities Board. Upon questioning at the Mackenzie Valley Land and Water Board (MVLWB) Technical Session for the A Water Licence Hearing, the proponent's representative stated that it is not adopting the Directive 50 (Draft 2007) requirements for toxicity and loading requirements determination because there "are issues with that draft" and that "It wouldn't be wise to do so". However, it was unable to provide evidence of these "issues". The text from the Transcript is provided as follows for reference[5]:

> "MS. KAREN HALWAS: Karen Halwas,
> 11 Paramount. No, the toxicity criteria referenced in 1996
> 12 are the criteria what -- that we use. Draft directive
> 13 2007 is draft because there are issues. There's a reason
> 14 why it isn't in force. So Paramount -- when the draft

[3] Energy Resources Conservation Board (2007). Directive 050: Drilling Waste Management.
[4] Alberta Energy and Utilities Board (1996). Guide 50: Drilling Waste Management.
[5] P 133, Transcript, *Mackenzie Valley land and Water Board, Technical Session for Paramount Resources LTD. Type A Water Licence MV2010L1-0001*, held at 2nd Floor Nunasi Building Yellowknife, NT, June 22nd, 2010.

15 directive first came out, Paramount decided to test some
16 of the potentially new criteria, and that -- that -- those
17 were in the area of sump selection.
18 So when we reference the -- the 2007 draft
19 directive, it's only for sump selection criteria. There
20 are issue -- Paramount follows that practice in -- in
21 Alberta, as well, and there are issues with that draft
22 2000 -- that 2007 draft.
23 I can't -- I can't give a lot of detail
24 because I don't have a lot of detail, but they're --
25 they're draft for a reason, and so, no, Paramount isn't
Page 134
1 adopting the 2007 version. It wouldn't be wise to do so."

Furthermore, during the Technical Session MVLWB staff requested to ENR, with respect to the use of Directive 50 and Guide 50 for drilling waste management,

> "would ENR be able to, like in your interventions, present that sort of information to the Board?... So it would be helpful if ENR could prepare in their interventions reasons for the Board to choose one (1) or the other [Guide 50 (1996) or Directive 50 (2007)]." [6]

This submission provides that technical advice as requested.

Draft Directive 50 (2007) provides a summary of the evidence that was collected to justify updating the Guide 50 (1996) document[7]. One of the reasons for the update from Guide 50 (1996) to Draft Directive 50 (2007) was the release of national guidelines regarding environmental quality assessment. Specifically, in the late 1990s, "national environmental quality assessment and management guidelines were developed using a

[6] Page 9, lines 5-14. Mackenzie Valley Land and Water Board, Technical Session for Paramount Resources LTD. Type A Water Licence MV2010L1-0001. June 23, 2010.
[7] Appendix 1, Draft Directive 50 (2007). Details of historical background are not repeated in this intervention; however, Draft Directive 50 (2007) is considered to be part of the evidence to be considered by the MVLWB during the water licencing process.

conservative, generic form of risk assessment designed to preserve a range of development, activities, and conditions with distinct land use categories or sensitivities"[8]. Alberta Environment applied this concept of risk assessment for the derivation of soil and remediation objectives in several provincial guidelines, which was then adopted for inclusion in the Draft Directive 50 (2007)."

It is important to note the timeline for Guide 50 (1996) to Draft Directive 50 (2007). Guide 50 (1996) was released in 1996, national environmental quality guidelines were released after 1996, and Draft Directive 50 issued in 2007. Draft Directive 50 incorporates more recent scientific evidence that was not available in 1996. Incorporation of most recent scientific evidence is critical to limit impacts to water and land resulting from waste disposal in sumps.

Another fundamental shift from Guide 50 (1996) to Draft Directive 50 (2007) is a stronger emphasis to ensure a successful reclamation. In summary, the Draft Directive 50 (2007) outlines soil endpoints as concentrations (instead of loading rates); these concentrations are based on land use compatibility. The approach for reclamation within the Draft Directive 50 (2007) is consistent with national and Government of the Northwest Territories guidelines for site reclamation (detailed below). Planning for closure is critical to successful reclamation and to limit long term liability associated with potential impacts to land and water.

2.2.4. Best Practice

ENR respectfully submits that it is reasonable to assume, given the evidence of potential contamination of waste resources that may occur as a result of drill waste storage in sumps in the Cameron Hills region, that preferred best practice for disposal of drilling waste cuttings would be the selection of options with no surface footprint, and no potential for transport of contaminants to water recourses, and no future concerns over future abandonment and reclamation liabilities. This could also be considered, for the sake of this discussion at least, zero discharge.

[8] Energy Resources Conservation Board (2007). Directive 050: Drilling Waste Management.

Any subsequent considered Best Practice option for onsite or remote treatment, storage or disposal, compared to removal and disposal at an appropriately designed and operated disposal facility, would be the treatment and/or disposal of drill waste and/or cuttings using methods that result in little potential for contamination of land and water, that would prevent the potential for future liabilities to government and the public that may result from contaminated soils or subsoil, and would ensure that future abandonment procedures ensure feasible reclamation to the local environment's natural state.

2.3. Recommendations

ENR provides the following recommendations for disposal of drilling waste that can be directly incorporated into Terms and Conditions for the A Water Licence. These Recommendations are provided through collaboration with ENR technical staff and ARKTIS Solutions Inc., and with the help of expert advice from the Energy Resource Conservation Board (ERCB) of Alberta.

Jamie VanGulck, Ph.D., P.Eng, and Chief Technical Officer of ARKTIS Solutions Inc., will present and be available for questions regarding these recommendations at the A Water Licence hearing in question on behalf of ENR. With respect to proper representation of the requirements of and intent of Directive 50, both 1996 and Draft 2007 respectively, Susan Halla, Section Leader for the Waste and Storage Group of the ERCB, responsible for administrative and operational aspects of oilfield waste management and material storage for the upstream petroleum industry, including auditing, providing technical evaluations or assistance, and developing and reviewing policy, will also be available for questions regarding Directive 50 at the A Water Licence Hearing on behalf of ENR.

1. It is recommended that the Draft Directive 50 (2007) be used as a basis for development of applicable water licence terms and conditions for sump construction, and waste disposal criteria.
2. It is recommended that Draft Directive 50 (2007) be applied as the fundamental guideline when developing water licence terms and conditions. It is

recommended that where Alberta Environment guidelines were applied in Draft Directive 50 (2007) that comparable NWT and/or Federal guidelines are employed, such as:

- Government of the Northwest Territories (2003). Environmental Guideline for Contaminated Site Remediation.
- CCME (2003). Canadian Environmental Quality Guidelines.
- CCME (2008). Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil.

3. It is recommended that the water licence include specific terms and conditions regarding sump investigation, construction, operation, monitoring/reporting, and closure. It is not recommended that the water licence only generally reference the use of a Guide 50 (1996) or Draft Directive 50 (2007). Generally referencing a guidance document has the potential to lead to uncertainty. Well defined terms and conditions, **based** on guidelines (not referencing guidelines), allow for a better understanding of expectations of the proponent and allow for stiffer boundaries with respect to enforcement and aid in planning for closure for successful reclamation and to limit long term liability associated with potential impacts to land and water.
4. It is recommended that the items listed in Table 1, related to sump attributes, are included in the water licence. The Table is attached for specific reference. The fundamental basis for these recommendations is to adhere to the principles of Draft Directive 50 (2007). Elements of Draft Directive 50 (2007) have been amended to partially account for northern conditions (e.g., permafrost) and allow the reference of remediation guidelines applicable in the NWT. The format of information presented in Table 1 will allow for direct integration into specific water licence terms and conditions.
5. If the Proponent cannot satisfy Recommendations 1 through 4, then ENR recommends that drill waste cuttings from the Cameron Hills Region are transported off site to a properly designed and operated waste management facility in Alberta or British Columbia.

Table 1: Summary of recommendations regarding drilling waste solids management in sumps, Paramount Cameron Hills.

Attribute	Recommendations	Comments
Site investigation and sump location	The following water licence terms and conditions: 1. A sump site investigation report, prepared by an engineer, licenced to practice in the Northwest Territories, that includes, but is not limited to, the following: a. Description of lithology of subsoils by completing a minimum of three boreholes, arranged in an approximate equilateral triangle. Boreholes are to extend to a depth ≥ 1 m below the anticipated base elevation of the sump. b. One sample of soil from an elevation below the anticipated base elevation of the sump is to be characterized as follows: i. If sump depth is between 1 and 1.5 m: electrical conductivity (EC) and sodium absorption ratio (SAR); and. ii. Clay content, plasticity index (PI), liquid limit (LL), and grain size. c. Digitized map with vector layers and GPS coordinates of sampling locations. 2. Sump location restricted by the following criteria: a. Non-permafrost soils; b. Minimum 50 m setback distance between sump and on-site well;	Proper sump location and soil characteristics are essential to contain drilling waste and minimizing the migration of contaminants into the groundwater and surface water away from the sump. Senes (2010)[9] acknowledged that groundwater is the initial receiver of waste around sumps and water migrating through the subsurface can reach surface water. Monitoring and reporting is required to demonstrate that proper sump location and site characteristics were achieved. The recommendations provided for sump investigation and location are independent of the details provided by PRL within the water licence application. It

[9] Senes Consultants Ltd. (2010). Technical Memo to MVLWB subject heading: Water Monitoring Program for the Cameron Hills Upstream Oil and Gas Field. Dated June 2010.

	c. 100 m setback distance from a water body; d. Restricted to lease area; e. Sump depth > 1 m; f. If sump depth is between 1 and 1.5 m: EC ≤ 5 dS/m, SAR ≤ 8; g. Minimum 1 m thickness of clayey soils (defined below) beyond the horizontal and vertical dimensions of the sump; and, h. Clayey soil characteristics, within 1 m below base elevation of sump, must achieve the following: i. Greater than 30% fines (grain size passing No. 200 sieve); ii. Greater than 20% clay (<0.002 mm in grain size); iii. LL ≥ 30; and, iv. PI ≥ 10.	is noted that PRL references the use of Draft Directive 50 (2007) for sump location, but does not provide all details regarding site investigation and location as identified in Draft Directive 50 (2007). For example, without limitation, the PRL water licence application does not reference the testing for EC or SAR.
Sump construction	The following water licence terms and conditions: 1. Sump construction characteristics restricted by the following criteria: a. Freeboard ≥ 0.5 m; b. Constructed to not collect natural surface waters; and, c. Constructed to not allow migration of contaminants beyond the walls and bottom of the sump. The following annual reporting requirements: 1. Sump capacity calculations that considers, but not limited to, volume of: drilling waste, subsoil to waste mixture ratio, and precipitation;	Proper sump construction is essential to ensure containment of waste solids and limit the migration of contaminants into groundwater and surface water. Reporting is required to demonstrate that sump construction criteria were achieved. The recommendations provided for sump construction are independent of details provided

	2. Dimensions of the sump, along with an as-built drawing signed/stamped by an engineer; 3. Photographic record of sump location prior to construction and after excavation of the sump; and, 4. Observations of the subsoil characteristics during construction.	by PRL within the water licence application. It is noted that PRL references the use of Draft Directive 50 (2007) for sump construction. Details of waste disposal facility construction/design are typical terms and conditions in a recent Type A water licence. For example, within the City of Yellowknife water licence (MV2008L3-0007): Item D.11 requires the proponent to submit a design report signed and stamped by an engineer for the new landfill cell (a waste disposal facility); and Item D.14 requires as-built plans and record drawings for the landfill is to signed and stamped by an engineer and submitted to the Board. These example water licence terms and conditions regarding waste disposal facility construction/design demonstrate that the recommendation regarding site sump construction are applicable for consideration in the PRL water licence.

<table>
<tr>
<td>Sump operations</td>
<td>
The following water licence terms and conditions:

1. Sump operations restricted by the following criteria:
a. Only accept drilling waste that may contain water-based drilling mud. Non-water-based drilling mud is not acceptable for disposal in sump;
b. Use of sump is limited to one season;
c. Subsoil to waste mixture ≥ 3 and < 7 on a volume basis;
d. Subsoil to waste mixture limited to a maximum increase of:
i. For a sump with depth 1 and 1.5 m: 2 units for EC and 4 units for SAR beyond background soil conditions; and,
ii. For a sump with depth greater than 1.5 m: 3 units for EC and 6 units for SAR.
e. Soil hydrocarbon endpoints for the subsoil/waste mixture must achieve limits identified in GNWT (2003)[10], as follows:
<table>
<tr><th>Soil Texture</th><th>Fraction 1</th><th>Fraction 2</th><th>Fraction 3</th><th>Fraction 4</th></tr>
<tr><td>Coarse-grained soil</td><td>130 mg/kg</td><td>450 mg/kg</td><td>400 mg/kg</td><td>2800 mg/kg</td></tr>
<tr><td>Fine-grained soil</td><td>260 mg/kg</td><td>900 mg/kg</td><td>800 mg/kg</td><td>5600 mg/kg</td></tr>
</table>
<table>
<tr><th>Benzene</th><th>Toluene</th><th>Ethylbenzene</th><th>Xylenes</th></tr>
<tr><td>0.05 mg/kg</td><td>0.1 mg/kg</td><td>0.1 mg/kg</td><td>0.1 mg/kg</td></tr>
</table>
f. If a hydrocarbon flag[11] was encountered, measurement of hydrocarbon concentrations (F1, F2, F3, F4, and BTEX) in
</td>
<td>
Proper operations are essential to ensure waste disposal will result in concentrations and toxicity of sump materials (i.e., drilling waste) such that there will be success in the reclamation and compatible with land use. This is critical to limit impacts to land and water.

According to the Northwest Territories Waters Regulation, Item 6.f. ii. the anticipated constituents of the deposited waste and the construction are to be provided in the water licence application. PRL did not provide chemical compositions of the drilling waste and mud properties within the water licence application; however, select information was provided at request after the MLVWB June 2010 Technical Session. The recommendations provided aim to partially fulfill this gap.

GNWT (2003) soil reclamation
</td>
</tr>
</table>

[10] GNWT (2003). Environmental Guideline for Contaminated Site Remediation.

the drilling waste. If any hydrocarbon component has concentrations 2x the hydrocarbon endpoint criteria (detailed above), measurement of hydrocarbon concentrations in the subsoil/waste mixture is required.

g. Trace element endpoints for the subsoil/waste mixture must achieve limits identified in GNWT (2003), as follows:

Parameter	Concentration (mg/kg)
Antimony	20
Arsenic (inorganic)	12
Barium	750
Beryliium	4
Boron (hot water soluble)	2
Cadmium	1.4
Chromium (total)	64
Chromium (hexavalent)	0.4
Cobalt	40
Copper	63
Lead	70
Mercury (inorganic)	6.6
Molybdenum	5
Nickel	50
Selenium	1
Silver	20
Thallium	1
Tin	5

criteria were applied as the waste disposal criteria. It is noted that GNWT (2003) were consistent with the CCME CEQG prior to the issuance of the Canadian Wide Standards for Petroleum Hydrocarbons (PHC) in Soil in 2008. Land use compatibility is required to establish reclamation criteria. None of the land uses defined by GNWT (2003), and also CCME CEQG, is directly applicable to wilderness setting, which is considered typical of the Cameron Hills area. The agricultural guidelines are recommended for application in natural areas in the absence of site specific guidelines (CCME 2006[12]) and therefore applied herein.

Monitoring and reporting is required to demonstrate that disposal criteria, and therefore reclamation objectives, have

[11] Hydrocarbon flag means any situation that could introduce hydrocarbons into a water-based drilling waste (e.g., the drilling waste contains visible hydrocarbons).
[12] CCME (2006). A Protocol for the Derivation of Environmental and Human Health Soil Quality Guidelines.

		been achieved. The recommendations provided for sump operations are independent of the details provided by PRL within the water licence application. It is noted that PRL references the use of Draft Directive 50 (2007) for sump operations. PRL reported during the MVLWB June/2010 Technical Session that Guide 50 (1996) applied for sump operations. Regardless of the use of Guide 50 (1996) or Draft Directive 50 (2007), both of which specify waste disposal criteria, it is noted that the PRL water licence application does not reference any waste disposal criteria. Further, it is noted that sampling testing, and reporting of results is also not addressed within the PRL water licence application.

Vanadium	130
Zinc	200

h. Measurement of trace element concentrations in the drilling waste is required if either of the following conditions occur:
   i. Calculated concentration of trace elements in the drilling waste exceeds soil trace element endpoints; or,
   ii. Mud additives/product trace element information is unavailable.
i. Measurement of the trace element concentration in the subsoil/waste mixture if measured trace element concentrations in the drilling waste exceed trace element endpoints.
j. Measurement for nitrogen (N) if more than 400 kg of N were added to the mud system.
k. Measurement of toxicity if either of the following conditions occur:
   i. Mud additive/products exceed the Petroleum Services Association of Canada (PSAC) toxicity threshold levels; or,
   ii. Hydrocarbon flag was encountered.
l. Luminescent bacteria toxicity testing is to be employed. A toxicity test pass threshold of 75% for an EC50(15) (i.e., the aqueous concentration for the drilling waste that halves the initial light output of the luminescent bacteria after 15 minutes must be 75% or greater).
m. If drilling waste fails toxicity testing, treatment of drilling waste with charcoal is to be completed in the laboratory, and the luminescent bacteria toxicity test completed on the treated drilling waste. If the treated drilling waste passes the EC50(15) threshold, the drilling waste is to be tested for

	hydrocarbons to ensure hydrocarbon endpoint limits are not exceeded. The following annual reporting requirements: 1. Volume of drilling waste deposited in the sump; 2. Volume of subsoil mixed with drilling waste and deposited in the sump; 3. Calculated subsoil to waste mixture ratio; 4. EC and SAR results for the subsoil/waste mixture; 5. Notification if a hydrocarbon flag was encountered, and results of hydrocarbon concentrations (i.e., F1, F2, F3, F4, and BTEX) measured in the drilling waste, and if applicable, subsoil/waste mixture; 6. List of mud additives/product; 7. Calculated concentration of trace elements in the subsoil/waste mixture and comparison to trace element endpoints; 8. Calculated concentration of nitrogen in the mud system; 9. Trace element results for the drilling waste and subsoil/waste mixture; 10. Comparison of the mud additives/products employed to the PSAC Mud List to examine toxicological information; 11. Toxicity testing results; 12. Date when waste was first deposited in the sump, and anticipated date of sump closure; 13. Results of all PRL and INAC inspection reports for each sump.	
Sump Closure	The following water licence terms and conditions: 1. Minimum of 1 m soil cover placed over the sump;	According to the Northwest Territories Waters Regulation, Item 6.h., plans for

	2. Monitoring plans for sumps post-closure until certification of reclamation is obtained; and, 3. Backfill/contour sump area to restore to equivalent pre-construction land capability. The following annual reporting requirements: 1. Date of sump closure; 2. Photographic record of sump area before and after closure; and, 3. Certification that sump is closed from qualified engineer and INAC inspector.	abandonment of the proposed undertaking is required with the water license application. Details of sump closure were limited in the water licence application and did not fully address inspection, monitoring, and certification of reclamation. The recommendations for sump closure are independent of details provided by PRL within the water licence application. It is noted that PRL references the use of Guide 50 (1996) for sump closure. Guide 50 (1996) was not developed to ensure the closure is compatible with land use. As such, PRL has not demonstrated that acceptable closure land use can be achieved. The use of Draft Directive 50 (2007) will close this information gap, and help ensure successful reclamation of the site in avoiding contamination of water and creating future liabilities to the proponent and government.

Total Waste Sampling	The following water licence terms and conditions: 1. A Quality Assurance and Quality Control plan. The plan shall be in accordance with Indian and Northern Affairs Canada's "Quality Assurance (QA) and Quality Control (QC) Guidelines for Use By Class "A" Licensees in Meeting SNP Requirements and for Submission of a QA/QC Plan, 1996". In addition to the items detailed within the INAC guidelines, the plan is to include details for soil, drilling waste, and subsoil/waste mixture sampling and testing. Specific reference to testing methodologies outlined in Draft Directive 50 (2007) is to be followed. 2. A total waste sample of a sump is to be representative of the entire depth of the sump, encompassing both the fluid and solid phase. A composite sample is to be obtained that is composed of equal amounts of five subsamples.	Proper sampling and testing is essential in ensuring that operations and management has occurred under approved plans. QA/QC plans for sampling and testing is a typical term and condition in recent Type A water licence. For example, the Town of Hay River (WL2009L3-0005), Schedule 4, Item p. Sampling and testing of waste is a typical requirement of recent Type A water licence Surveillance Network Programs (SNP). For example, North American Tungsten Corp. Ltd. (MV2002L2-0019), SNP Items C.4 and C.5 require chemical characteristics of waste rock and tailings to be measured prior to disposal in their respective waste disposal facilities. Waste rock is to be measured weekly and tailings are to be measured monthly.

3. Deposit to Waters – Air Emissions Management

ENR is concerned that releases of compounds to the atmosphere are occurring as a result of the current and proposed operations at the Cameron Hills facility, and that these releases can have adverse impacts to both the land and water as a result of atmospheric deposition.

ENR understands that the terms and conditions included in a Type A Water License by the MVLWB are in part meant to mitigate potential impacts to water, and ENR was directed by the MVLWB to provide interventions related strictly to this area of focus[13]. ENR was further notified by the MVLWB during this Type A Water License regulatory process that:

> "...it is within the Board's jurisdiction to evaluate any potential waste from a project that may enter waters....If there is an identified pathway for any particular waste entering into water bodies as a result of incineration practices, they have to be clearly demonstrated so that they can be addressed in a WL..."[14]

ENR further notes that the MVLWB stated the following:

> "If there is an identified pathway for any particular waste entering into water bodies as a result of flaring practices, they have to be clearly demonstrated so that they can be addressed in a WL..."[13]

As such, the following sections and appended documents have been compiled by ENR to provide the MVLWB with clear, scientifically defensible, and well-established evidence on:

- The types of compounds (i.e. wastes) that are released to the atmosphere as a result of a sour gas Upstream Oil and Gas (UOG) Facility;
- The mechanisms that cause deposition of these compounds;
- The effects of these deposited compounds on the land and aquatic environment; and,
- Potential mitigative measures at the source of their release.

Detailed reports on the above topics are attached, which were prepared by the following experts in their respective fields:

- David Picard, M.Eng., P.Eng. – Mr. Picard is a principal of Clearstone Engineering Ltd, an environmental consulting firm specializing in air emissions assessment and control. He has a Bachelor's degree in mechanical engineering, a Master's degree in chemical engineering plus 20 years of related experience. His work related to Oil and Gas facility emissions has included major studies for CAPP, CGA, Gas Technology Institute,

[13] Pre-Hearing Conference, July 13, 2010.
[14] Page 16, MVLWB follow-up and information requests #63. Reviewer Comments – Paramount Resources Ltd. – MV2010L1-0001 Type A Water Licence Application.

Environment Canada, US EPA, UNFCCC Secretariat, and numerous oil and gas companies.

- Dr. Allan Legge, PhD – Dr. Legge is President of Biosphere Solutions, an environmental consulting firm, and holds a Ph.D. in Plant Genetics/Ecology. His areas of specialization are environmental toxicology/atmospheric chemistry, and he focuses on the evaluation and assessment of the effects of the air pollutants SO_2,O_3, H_2S,NO_x, HF, PM and saline aerosols on forests and agricultural ecosystems. Throughout his career, Dr. Legge has been a Senior Research Scientist at the University of Calgary, a Senior Research Officer at the Alberta Research Council, a member of the US EPA Science Advisory Board, and a member of the U.S. National Research Council Committee.

3.1. Technical Summary

The basic sources of atmospheric emissions from sour natural gas facilities include fuel combustion (potentially by both mobile and stationary sources), fugitive equipment leaks, process venting and flaring, and storage losses. The types of pollutants that may be emitted include greenhouse gases (CO_2, CH_4 and N_2O), volatile organic compounds (VOCs), criteria air contaminants (i.e., CO, SO_2, NO_x, PM_{10}, $PM_{2.5}$), metals, dioxins and furans, polyaromatic hydrocarbons (PAHs), a number of complex organic products known to be carcinogenic, and other products of partial or incomplete combustion.

These compounds are released to the atmosphere and through various forms of atmospheric deposition, the compounds, or a chemical variation of them, fall directly to a surface water body, or first to the land where they can then mobilize further to a water body. What goes up ultimately comes down.

The sulphur dioxide and nitrogen oxides emitted into the atmosphere from a sour UOG facility can be dry deposited and taken up by local environmental receptors as well as subjected to medium and long-range transport and transformed to either acids (sulphuric and nitric acid) and/or salts (such as ammonium sulphate and ammonium nitrate) before being deposited (Finlayson-Pitts and Pitts, 2000). The sulphur and nitrogen oxides can also be incorporated into rain and be removed by washout or rain-out which is collectively referred to as wet deposition. When acid rain reaches Earth, it flows across the surface in runoff water, enters water systems, and sinks into the soil. The build-up of excess sulphur in the soils can result in the contamination of surface and ground waters, in reduced tree

growth, accelerated soil acidification and the disruption of plant nutrient cycling (Mayer et al. 1995; Legge et al., 1996; Krupa and Legge, 1998; Prietzel et al., 2004; De Kok et al. 2009). Excess nitrogen build-up in the soil can result in nitrogen saturation which can be seen as nitrate leaching below the rooting zone and into surface waters and/or soil eutrophication which can lead to changes in plant species composition (Bobbink and Lamers, 2002). Acidification of water bodies can causes the increased absorption of aluminum that makes its way from soil into lakes and streams. This combination can make waters toxic to fish, and other aquatic animals.

Toxic air contaminants (TAC or 'air toxics')"are characterized by their persistence in the environment, ability to bioaccumulate through food chains and/or ability to cause serious, short- or long-term health effects, even at low levels of exposure. The deposition of TACs to the land and water are therefore of concern to both terrestrial and aquatic species, but also to those consuming them. The primary TACs associated with oil and natural gas that have been identified include hydrogen sulphide (H_2S), BTEX (Benzene, Toluene, Ethylbenzene and Xylene) and n-Hexane (C_6H_{14}), and a variety of other toxic compounds demonstrated to cause adverse health effects.

There is abundant scientific evidence to support the conclusion that environmental receptors such as vegetation, soils, surface waters and other connected ecosystem components exposed to acute and/or long-term chronic deposition from emissions originating from a sour gas UOG facility will be adversely impacted, and should be reduced, controlled, or altogether prevented at their source.

3.2. Reference Guidelines

Similar to other forms of pollution mitigation, environmental impacts to water as a direct result of air emissions are best managed at the source. (For example, the acidification of a lake as a result of SO_2 emissions would be preferably managed by reducing SO_2 emissions rather than applying treatment technology to the lake water.) For a sour gas UOG facility, managing the source includes flaring and venting practices, incineration practices, fugitive leaks, and other emission sources. The document titled "ERCB Directive 60: Upstream Petroleum Industry Flaring, Incinerating and Venting", 2006, provides regulatory requirements, guidelines, and procedures for the Alberta upstream petroleum industry facilities for flaring, incinerating and venting, in addition to modelling, measuring and reporting of gases. The Environment Canada document titled "Technical

Document for Batch Waste Incineration", 2010, provides guidance for the operation of batch waste incinerators in order to achieve the intent of the Canada-Wide Standards for Dixons/furans and mercury, and reducing releases of other toxic substances. ENR suggests that these documents, or most updated version of them as they are developed, be used for reference when establishing emission management requirements for the Cameron Hills project, in conjunction with consultation with ENR and EC. Managing the release of pollutants to the atmosphere will manage the deposition of pollution to the land and water.

3.3. Recommendations

ENR believes that the evidence provided on the link between atmospheric emissions from a UOG facility and impacts to water is substantive and justifies the requirement to consider and include terms and conditions in the proposed Type A Water License that will manage and mitigate these sources of indirect impacts to the water. *ENR understands that the National Energy Board (NEB) is the agency responsible for permitting the point source operations at this field. Regardless of the regulatory body that ensures mitigative measures are in place to prevent environmental impacts to water, they should be inclusive and available to the public, as per MVLWB's vision statement.*

Specifically, ENR recommends the following Terms and Conditions:

- The Proponent shall develop and implement an Emissions Management Plan, in accordance with ERCB Guide 60 and in consultation with ENR and EC, that models the dispersion and deposition of atmospheric releases, provides detailed analysis of mitigative measures and best practices, fugitive emissions management, monitoring requirements, and a reporting framework to the MVLWB. This shall be completed within 4 months of License issuance.

- The Proponent shall develop and implement a Flare Management Plan for Well Evaluation, in accordance with ERCB Guide 60 and in consultation with ENR and EC, that provides modeling for dispersion and deposition of predicted atmospheric releases, provides contingency response planning, community advisories, detailed alternative options analysis, mitigative measures, monitoring requirements, and a reporting framework to the MVLWB. This shall be completed within 4 months of License issuance.

- The Proponent shall develop and implement an Incineration Management Plan, in accordance with EC's Technical Document on Batch Waste Incineration and in consultation with ENR and EC, that incorporates appropriate technology selection, waste auditing, operational and maintenance record keeping, operator training, emissions measurements, and incinerator ash disposal, and a reporting framework to the MVLWB. This shall be completed within 4 months of License issuance.

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5. Attachments

1. Legge, Allan. Resume
2. VanGulk, Jamie. Resume
3. Halla, Susan. Resume
4. Picard, David. Resume
5. Legge, Allan. Linking Air Emissions From Sour Gas Upstream Oil and Gas Operations to Environmental Impacts on Land and Water.
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CURRICULUM VITAE

SUSAN HALLA, C.E.T.

July 2010

Present Position

Section Leader, Waste & Storage Section
Environmental Monitoring and Regulation Group
Energy Resources Conservation Board (ERCB)

Technical Specialist-Advanced

Education

1978 - 1980 Northern Alberta Institute of Technology
Edmonton AB
Honors Diploma in Chemical Technology

Technical Courses:
Chem 515: Instrumental Analyses, Environmental Law, Environmental Site Assessment, Environmental Impact Assessment, Pre-acquisition Site Assessment / Environmental Site Assessment (U of C Continuing Ed), Environmental Auditing in the Petroleum Industry, Fundamentals of the Petroleum Industry, Drilling Waste Management (PITS), Groundwater Monitoring and Hydrology, Human Health and Ecological Risk Assessment, Update for Environmental Law, Managing Salt Contaminated Sites (ESAA), Management of Contaminated Sites, Treatment of Contaminated Soil and Groundwater (Air & Waste Management), Aboveground Storage Tanks, Monitored Natural Attenuation, Environmental Field Screening Technologies, TDG Carriers and Shippers (APSS), and numerous technical conferences and seminars.

Other Courses:
Numerous regulatory, communication, computer, and leadership courses

Professional Membership

The Association of Science and Engineering Technology Professionals of Alberta
Alberta Fitness Leadership Certification Association

Employment

Twenty six years with the ERCB; 1984 to present.

2001 to present

Leader of the Waste and Storage Section
Technical Specialist-Specialist/Advanced

- Leading a section responsible for:
  - the review, development, and maintenance of policy in the areas of oilfield waste management and material storage for the upstream petroleum industry;
  - the processing of applications for oilfield waste management facilities, one-time oilfield/drilling waste management, and alternative storage systems; and
  - conducting audits on oil and gas licensees and oilfield waste management facility approval holders to ensure their waste

management and material storage practices meet ERCB requirements.

- Responsible to oversee work conducted by the section and mentor staff, with decision making authority on application disposition.
- Provide expert technical advice to ERCB staff, industry, other government agencies, and the public in the areas of waste management and material storage.
- Chaired the multi-stakeholder committee reviewing ERCB *Directive 050: Drilling Waste Management*, resulting in the 2007 publication of the draft update to *Directive 050.*
- Chaired the multi-stakeholder technical committee, which resulted in the 2001 publication of *Directive 0 55: Storage Requirements for the Upstream Petroleum Industry* and drafted the *Report 2009-A: Updates on Storage Requirements for the Upstream Petroleum Industry – Discussion Document on Directive 055*.
- Made presentations at workshops, seminars, conferences on:
  - An Update on the Review of *Directive 050*, and
  - *Directive 058: Oilfield Waste Management Requirements for the Upstream Petroleum Industry*
  - *Directive 055*
- Helped organize and made presentations in four annual inter-government (EUB/AENV/SRD/NRCB) information sessions.
- Attended AENV workshops on the Petroleum Hydrocarbon Standards for Soil and Analytical Methods.
- Attended Environment Canada Workshops on the Export and Import of Hazardous Waste and Hazardous Recyclable Material Regulations.
- Attended the 2001 Canadian Council Ministers of the Environment (CCME) Workshop on Canada-Wide Standards for Petroleum Hydrocarbons (PHC) in Soil

1998 – 2000 Waste Operations Section, Operations Group (ERCB)

Technical Specialist I / Staff Specialist I

- Acted as an adviser to ERCB staff, industry, agencies, and the public in the broad areas of material storage and waste management within the upstream oil and gas industry.
- Areas of responsibilities include technical / scientific / regulatory review, committee work, and policy development and implementation to ensure ERCB requirements are harmonized with provincial and federal requirements while maintaining focus on ERCB culture and needs as well as that of the oil and gas industry.
- Worked closely with senior AENV staff to develop memorandums of understanding on:
  - Deposition of Oilfield Waste into Landfills (introduced by ERCB *ID 99-4*), and
  - Harmonization of Waste Management (introduced by ERCB *ID 2000-3).*
- Made presentations on *ID 99-4* and *ID 2000-3.*

- Instrumental in the development of ERCB *ID 2000-4: An Update to the Requirements for the Appropriate Management of Oilfield Wastes.*
- Led an ERCB team that conducted a major review and update of the Oil and Gas Conservation Regulations.
- Attended the 1997 CCME Workshop on the Development of Canada Wide Standards for Petroleum Hydrocarbons (PHC) in Soil.
- Participated in the multi-stakeholder Task Group that developed *ERCB IL 99-2: Use of Produced Sand in Road Construction*
  - Chaired the Environmental Sub-committee under the Task Group
- Participated in the ERCB-AENV role out of *IL 98-2: Suspension, Abandonment, Decontamination, and Surface Land Reclamation of Upstream Oil and Gas Facilities* and the attached memorandum of understanding between the ERCB and AENV on the subject

1994 – 1997 Waste Section, Environment, Safety & Technical Services Group (ERCB)

Senior Tech II/III

- Processed applications for oilfield waste management facilities and provided technical expertise for waste management operational problems, material storage issues, and site contamination and remediation issues.
- Participated in the multi-stakeholder development of *Directive 58: Oilfield Waste Management Requirements for the Upstream Petroleum Industry*
  - chaired sub-committees that developed the sections on application requirements and biodegradation, as well as the site assessment appendix.
- Participated in the internal and external role out of *Directive 58* and provided training on these requirements through meetings and formal/informal presentations.
- Chaired the multi-stakeholder committee that developed the 1995 ERCB *Directive 055: Storage Requirements for the Upstream Petroleum Industry*
- Participated in the AENV Land Treatment Task Force

1989 - 1993 Environment Protection Department (ERCB)

Technician I/III

- Provided technical support and processed applications for oilfield waste disposal, waste facilities, and site remediation.
- Participated in a government / industry committee process that developed the 1993 draft Recommended Oilfield Waste Management Requirements.
- Also processed information for the ERCB Environmental Information System, processed sour gas flaring applications, and reviewed air monitoring reports.

1984 – 1989 Chemical Research Laboratory, (ERCB)

Lab Technician

- Conducted gas chromatographic analyses of soils and waters to identify potential hydrocarbon contaminant sources; researched and developed sample separation and gas chromatographic techniques.
- Researched and developed a gas chromatographic technique to separate and quantify trace sulphur compounds in sour gases and condensates.
- Conducted routine soil, water, and drilling waste analyses.
- Work involved the preparation of samples and standards, operation of instruments, interpretation, and reporting of the results.

1983 – 1984 Chemistry Department, University of Calgary

Lab Technician

- Under the direction of a professor researched reactions and methods to synthesize organic compounds and then performed the reactions, including isolating and purifying the compounds of interest.

1981 – 1982 Soils Laboratory, Alberta Agriculture, Edmonton

Lab Technician

- Conducted routine analyses of soils, as well as specialty trace elemental analysis using an inductively coupled argon plasma spectroscopy.
- Work involved the preparation of samples and standards, operation of instruments, interpretation, and reporting of the results.

1980 – 1981 Chemistry Department, University of Alberta

Lab Technician

- Under the direction of a professor conducted reactions to complex anti-tumor antibiotics with transitional metals and then performed electrochemical analyses of the complexes.

Résumé

DR. ALLAN H. LEGGE
President
Biosphere Solutions
1601 - 11th Avenue N. W.
Calgary, Alberta, Canada T2N 1H1

EDUCATION:

- BA Biology and Dramatic Arts, Whitman College, Walla Walla, Washington, 1965.
- PhD Plant Genetics/Ecology, Interdisciplinary Genetics Institute, Oregon State University, Corvallis, Oregon, 1971.
- U.S. National Science Foundation Post Doctoral Fellow, Marine Invertebrate Environmental Physiology, Friday Harbour Marine Laboratory of the University of Washington, Friday Harbour, Washington, 1971.

EMPLOYMENT:

- Kananaskis Centre for Environmental Research, The University of Calgary, 1972-1990.
- Environmental Engineering and Research Department, Alberta Research Council, 1990-1993.
- Founded **Biosphere Solutions**, July 1993.

EXPERTISE:

- The evaluation and assessment of air quality and of the effects of air pollution on forest and agricultural ecosystems.
- The development, testing and application of ecologically based biomonitoring systems and techniques.
- Evaluation and assessment of ambient air quality objectives/ standards.
- The development, testing and operation of air quality monitoring trailers and air handling systems.
- Multidisciplinary environmental research, design, initiation, coordination, management and execution.
- Industry and government environmental research assessment, planning and coordination.
- Communication of environmental research results and issues to government, industry and the public.
- Expert witness on air quality and related environmental effects issues.
- International environmental research cooperation and coordination.

EXPERIENCE:

Dr. Legge has over 35 years' experience designing, conducting and evaluating research on air quality and the effects of air pollution on terrestrial ecosystems in Alberta as well as internationally. Before founding biosphere Solutions in 1993, Dr. Legge was a Senior Research Scientist with the Kananaskis Centre for Environmental Research, The University of Calgary, from 1972-1990 and a Senior Research Officer in the Environmental Research and Engineering Department of the Alberta Research Council from 1990-1993. He is Principal Investigator of the West Whitecourt Case Study which is a multidisciplinary research program designed to assess and evaluate the impacts on a forest ecosystem as a consequence of exposure to chronic long-term, low concentrations of sulphur gas emissions and sulphur dust originating from a sulphur recovery gas plant in west-central Alberta. This research program began in 1973 and is still ongoing on a biomonitoring basis and represents the longest continuous-running foliar sulphur monitoring program in the world. The biomonitoring research design using the concept of 'ecologically analogous' sampling locations developed for the West Whitecourt Case Study has received international recognition and is currently being applied in Finland, Germany, Poland, Canada and the United States. Dr. Legge was Principal Investigator of a five-year program (1981-1985) designed to determine the effects of nitrogen oxide emissions from compressor installations on vegetation in Alberta. This research program was carried out as a joint project with Alberta Environment and the Energy Resources Conservation Board. Dr. Legge was Principal Investigator of the Biophysics portion of the Alberta Government/Industry Acid Deposition Program (ADRP) from its start in 1985 to its completion in 1988. There were over 50 individual researchers on the $5.3 million Biophysics research team from both Canada and the U.S. The technical results of ADRP were published as a report in 1988 and as a scientific/technical book in 1990. Dr. Legge carried out an assessment and evaluation of environmental research in the Oil Sands region of Alberta for the Acidification Working Group of the Regional Air Quality Coordinating Committee in 1992. He has also carried out assessments and evaluations of the impact on vegetation of fluoride emissions from a brick manufacturing plant, SO_2 emissions from glycol dehydrators, SO_2 emissions from sour gas well production testing, sulphur gas emissions from elemental sulphur fires, emissions from sour gas well blowouts, SO_2 emissions from a cement plant, brine spills and sulphur dust. Dr. Legge has provided assessment of "greenhouse gas" emissions for the petroleum industry in Alberta/Canada. He proposed and developed a set of quantitative definitions for an environmentally-significant flare event from a sour-gas processing plant in 1995. The results of this work are currently being used in the permitting of sour gas well production testing by the B.C. Oil and Gas Commission in British Columbia. Dr. Legge was Principal Investigator of a research program funded by the Atmospheric Environment Service, Environment Canada, designed to assess the ambient air quality objective for ozone in Canada. This research program was initiated in 1992 and completed in 1996 and involved an evaluation and assessment of the ozone/crop response data from the U.S. National Crop Loss Assessment Program (NCLAN) and the European Open-Top Chamber Ozone/Crop Response Program (EOTCP). Dr. Legge carried out a scientific/technical review of the literature on the effects of ozone on forest trees for the Canadian Forestry Service, Natural Resources Canada. He has been involved in evaluating and assessing the effects of regional-scale ambient air pollutants (i.e. O_3, SO_2 and NO_2) along with other growth-regulating variables on Saskatoon serviceberry and alfalfa in the West Central Airshed of Alberta from 1997 to 2004.

In addition to his extensive experience in designing, conducting, managing and evaluating air quality related environmental research, Dr. Legge has served on provincial, national and international scientific peer review and advisory committees: Alberta Environment, Alberta Energy,

Clean Air Strategic Alliance, Atmospheric Environment Service, Canadian Forestry Service, Agriculture Canada, the Canadian Association of Petroleum Producers, TransAlta Utilities, Alberta Petroleum Industry/ Government Environment Committee, The Royal Society of Canada, Natural Sciences and Engineering Research Council, Tri-Council EcoResearch Program, B.C. Science Council, B.C. Oil and Gas Commission, Academy of Finland, Clean Air Science Advisory Committee (CASAC) and the Scientific and Technological Achievement Awards Subcommittee (STAA) of the Science Advisory Board of the U.S. Environmental Protection Agency (EPA), U.S. National Research Council and the United Nations Environment Program. Dr. Legge was Co-chair of the Forest Effects Review Panel, Science Advisory Board, U.S. EPA in 1985. He was chair of an international peer review team for the Academy of Finland (1990-1992) to evaluate the state of air quality/acidification effects research in Finland from 1985 to 1990. Dr. Legge has been a consultant member of the Clean Air Scientific Advisory Committee (CASAC) of the U.S. EPA Science Advisory Board since 1994 and has been directly involved in the assessment and evaluation of the air quality criteria documents on nitrogen oxides, ozone and related photochemical oxidants and particulate matter and associated staff papers of the Office of Air Quality Planning and Standards (OAQPS). He was science advisor to the Alberta Energy and Utilities Board in 1997-1999. Dr. Legge served as a member of the U.S. National Research Council Committee to Assess the North American Research Strategy on Tropospheric Ozone (NARSTO) from 1997-2000. He was appointed Chair of the Science Advisory Board (SAB) to the Terrestrial Environmental Effects Monitoring Committee (TEEM) of the Wood Buffalo Environmental Association (WBEA) in 1998 and continues to provide a lead science role to both TEEM and WBEA. Dr. Legge acted as Chairman of the 'Workshop on a Peer Review of the Health Science of Particulate Matter and Ozone in Air' held March 22, 2004 at the Palliser Hotel, Calgary, Alberta sponsored by Environment Canada and CETAC-WEST. He was a member of the U.S. EPA Science Advisory Board Review Panel in 2007 reviewing EPA's 2007 Report on the Environment: Science Report.

Dr. Legge has also served as an expert witness and has provided written reports and testimony, where required, at the following public hearings: Lodgepole Sour-Gas Blowout, 1983 (Energy Resources Conservation Board - ERCB); Syncrude Canada Expansion, 1993 (ERCB); Chem Security (Alberta) Ltd.'s Special Waste Treatment Centre Expansion Application, 1994 (Natural Resources Conservation Board - NRCB); Westcoast Energy Inc., Hasler, British Columbia, Liquid Elemental Sulphur Fire, 2001 (National Energy Board - NEB); EPCOR Genesee Generating Station Phase 3 Application, 2001 (Alberta Energy and Utilities Board - AEUB); and Lafarge Canada Inc., Industrial Approval Amendment Application, Exshaw Fuel Flexibility Project - Appeal (Alberta Environmental Appeals Board - EAB) . He also has actively worked with government, industry and the public to communicate environmental knowledge and understanding, not only in the form of the results/implications of environmental research but also in terms of issues and policies for the future. Dr. Legge has organized a number of major international air quality meetings in Alberta which include the following: International Conference on "Air Pollutants and Their Effects on the Terrestrial Ecosystem" (1980);16th International Air Pollution Workshop (1984); Second Symposium/Workshop on "Acid Forming Emissions in Alberta and Their Ecological Effects" (1986); "Acidic and Acidifying Air Pollutants in Alberta: Acid Deposition Research Program Results and Technical Amplification" Technical Meeting, Canadian Prairie and Northern Section (CPANS), Air and Waste Management Association (AWMA)(1989); Air and Waste Management Association (AWMA) International Specialty Conference entitled "Emerging Air Issues for the 21st Century: The Need for Multidisciplinary Management" (1997); and AWMA International Specialty Conference on "Recent Advances in the Science and Management of Air Toxics" (2000). He was the host

organizer for the 37th International Air Pollution Workshop/Symposium held at the Banff Park Lodge, in Banff, Alberta, on April 25-28, 2005.

Dr. Legge is active in a number of professional organizations such as the Air and Waste Management Association (AWMA), the International Air Pollution Workshop and the Alberta Society of Professional Biologists (ASPB). He was a Founding member of the Canadian Prairie and Northern Section (CPANS) of the Air and Waste Management Association (AWMA) and served as a Director (1999-2001). Dr. Legge has received the Peggy Thompson Publication Award for scientific excellence, given by the Alberta Society of Professional Biologists (ASPB), in 1987, 1991, 1995 and 2000. He was elected as a Fellow of the American Association for the Advancement of Science (AAAS) in 1992 and was elected as a Fellow of the Air & Waste Management Association (AWMA) in 2002).

Dr. Legge has published over 80 papers in the scientific/technical literature and has written over 100 reports and three books as well as preparing a documentary film on sulphur gas air pollution in Alberta. He serves on the Editorial Board of the international Journal Environmental Pollution and as a peer reviewer for many other journals and research funding organizations.

Dr. Legge is nationally and internationally recognized as an authority on air quality and the effects of air pollution on terrestrial ecosystems.

AWARDS:

- **U.S. National Defense Education Act (NDEA) Fellowship**
  Interdisciplinary Genetics Institute, Oregon State University, 1966-69
- **U.S. National Science Foundation Post Doctoral Fellowship**
  Friday Harbour Marine Laboratory, University of Washington, 1971
- **Board of Governors' Post Doctoral Fellowship**
  Environmental Sciences Centre (Kananaskis), The University of Calgary, 1972-73
- **Peggy Thompson Publication Award, Alberta Society of Professional Biologists**, 1987
- **Peggy Thompson Scientific Paper Award, Alberta Society of Professional Biologists**, 1991
- **Fellow, American Association for the Advancement of Science**, 1992
- **External Professional Award**, Alberta Research Council, 1992
- **Peggy Thompson Scientific Paper Award, Alberta Society of Professional Biologists**, 1995
- **Peggy Thompson Scientific Paper Award, Alberta Society of Professional Biologists**, 2000
  Fellow, Air & Waste Management Association, 2002

CLIENTS:

- "A Better Way to Go" Association, Calgary, Alberta
- Academy of Finland, Helsinki, Finland
- Ackroyd, Piasta, Roth and Day, Barristers and Solicitors, Edmonton, Alberta
- Alberta Energy and Utilities Board, Calgary, Alberta
- Alberta Environment, Edmonton, Alberta

$ Alberta Research Council, Edmonton, Alberta

- Alpine Environmental Consulting Ltd., Calgary, Alberta
- AMOCO Canada Petroleum Company Limited, Calgary, Alberta
- Atmospheric Environment Service, Environment Canada, Downsview, Ontario
  Anadarko Canada Corporation, Calgary, Alberta
- AXYS Environmental Consulting Limited, Calgary, Alberta

$ Barrington Petroleum Ltd., Calgary, Alberta

- B.C. Oil and Gas Commission, Fort St. John, British Columbia
- BP Canada Energy Company, Calgary, Alberta
- BOVAR Environmental, Calgary, Alberta
- Canadian Environmental Technology Advancement Corporation (CETAC) West, Calgary, Alberta
- Canadian Forest Service, Natural Resources Canada, Fredericton, New Brunswick
- Canadian Hunter Exploration Ltd., Calgary, Alberta
- Canadian Natural Resources Limited, Calgary, Alberta
- Clean Air Strategic Alliance (CASA), Edmonton, Alberta
- Clean Energy Coalition, Drayton Valley, Alberta
- Cumulative Environmental Effects Management Association, Fort McMurray, Alberta
- Duke Energy Gas Transmission, Fort St. John, British Columbia
- Ecosat Geobotanical Surveys Inc., North Vancouver, British Columbia
- ENERSUL Inc., Calgary, Alberta
- Environmental Research Centre, The University of Calgary, Calgary, Alberta
- Foothills Pipe Lines Limited, Calgary, Alberta
- Fort McKay Indian Band, Fort McKay, Alberta
- Golder Associates Limited, Calgary, Alberta
- Husky Oil Operations Limited, Calgary, Alberta
- Independent Environmental Monitoring Agency, Yellowknife, Northwest Territories
- IXL Industries Limited, Edmonton, Alberta
- Jacques Whitford Environment Ltd., Calgary, Alberta

$ Lafarge Canada Inc., Exshaw, Alberta

- Lesser Slave Lake Indian Band Regional Council, Slave Lake, Alberta
- Macleod Institute for Environmental Analysis, The University of Calgary, Calgary, Alberta
- Marie Lake Landowner's Association, Cold Lake, Alberta
- Matrix Solutions Inc., Calgary, Alberta

$ T.J. McCann and Associates Ltd., Calgary, Alberta

- McLennan, Ross, Barristers and Solicitors, Edmonton, Alberta
- Mobil Oil Canada Ltd., Calgary, Alberta
- Novacor Chemicals Limited, Calgary, Alberta
- Oil Sands Environmental Coalition (OSEC), Drayton Valley, Alberta
- Parlee McLaws, Barristers and Solicitors, Edmonton, Alberta

$ Petro Bank Energy and Resources Ltd., Calgary, Alberta
$ Petro-Canada Limited, Calgary, Alberta

- Poco Petroleum Ltd., Calgary, Alberta
- Suncor Energy Inc., Oil Sands, Fort McMurray, Alberta

$ The University of Calgary, Department of Physics and Astronomy, Calgary, Alberta
- TransCanada Pipeline Limited, Calgary, Alberta
- UMA Engineering Limited, Calgary, Alberta
- Union Carbide Chemicals and Plastics Canada Inc., Calgary, Alberta
- U.S. Environmental Protection Agency, Washington, D.C.
- U.S. National Research Council, Board on Environmental Studies and Toxicology, Washington, D.C.
- University of California, Department of Botany and Plant Science, Riverside, California
- University of Oulu, Department of Botany, Oulu, Finland.
- West Central Airshed Society, Drayton Valley, Alberta
- Westcoast Energy Inc., Vancouver, British Columbia
- Wood Buffalo Environmental Association, Fort McMurray, Alberta
- Wotherspoon Environmental Inc., Calgary, Alberta

PAPERS AND BOOKS:

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2. **LEGGE, A.H.** 1974. Design of a gas-exchange system for the study of effects of SO_2 upon vegetation. Proceedings Alberta Sulphur Gas Workshop I, November 1-2, 1973. Northern Forestry Research Centre, Edmonton, Alberta

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4. **LEGGE, A.H.**, D.R. Jaques, R.G. Amundson, and R.B. Walker. 1977. Field studies of pine, spruce and aspen periodically subjected to sulphur gas emissions. *Water, Air and Soil Pollution* **8**: 105-129.

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26. **LEGGE, A.H.** 1987. An overview of air quality monitoring in the Acid Deposition Research Program. *In*: Proceedings Canadian Prairie and Northern Section, Air Pollution Control Association, Technical Meeting, New Directions in Air Quality Standards, D.S. Chadder (Ed.), pp. 11-18, Calgary, Alberta.

27. Peake, E. and **A.H. LEGGE**. 1987. Evaluation of methods used to collect air quality data at remote and rural sites in Alberta, Canada. *In*: Proceedings of the 1987 EPA/ACCA Symposium on Measurement of Toxic and Related Air Pollutants, S. Hochheiser and R.K.M. Jayanty, Technical Program Committee Co-Chairmen, pp. 174-182, Research Triangle Park, North Carolina, May 3-6, 1987, Air Pollution Control Association, Pittsburgh, Pennsylvania. 755 pp.

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29. **LEGGE, A.H.** and R.A. Crowther. 1987. Acidic Deposition and the Environment: A Literature Overview. Phoenix Press, Calgary, Alberta, 235 pp. ISBN 0-921625-13-8 (Volume 11).

30. **LEGGE, A.H.**, J. Corbin, J. Bogner, M. Strosher, H.R. Krouse, E.J. Laishley, R.D. Bryant, M.J. Cavey, C.E. Prescott, M. Nosal, H.U. Schellhase, T.C. Weidensaul, and J. Mayo. 1988. Acidification in a Temperate Forest Ecosystem: The Role of Sulphur Gas Emissions and Sulphur Dust. Phoenix Press, Calgary, 399 pp.

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39. **LEGGE, A.H.** 1990. Sulphur and Nitrogen in the Atmosphere. *In*: Acidic Deposition: Sulphur and Nitrogen Oxides. **A.H. LEGGE** and S.V. Krupa (Eds.). pp. 3-128. Lewis Publishers, Chelsea, Michigan. 659 pp.

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LINKING AIR EMISSIONS FROM SOUR GAS UPSTREAM OIL AND GAS OPERATIONS TO ENVIRONMENTAL IMPACTS ON LAND AND WATER

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It has long been recognized that emissions from industrial sources can have adverse effects on human health and the environment (Evelyn,1661). While governments and societies over the centuries have progressively regulated and reduced emissions from industrial sources, adverse effects on the environment and human health from inorganic and organic air pollutants emitted by industrial emission sources are still being documented (Legge and Krupa,1990 ; Lippmann, 1992; Lipfert,1994; Legge,1995; Henrikson and Brodin,1995; Legge et al.,1998; Langan,1999: Legge and Krupa, 2002; Visgilio and Whitelaw, 2009; Kozlov et al., 2009; Legge, 2009). The inorganic air pollutants include sulphur dioxide, nitrogen oxides, hydrogen sulphide, carbon monoxide, ozone, ammonia and trace metals to name a few. The organic air pollutants can include an extremely wide range of compounds such as dioxins, furans, polyaromatic hydrocarbons (PAHs), volatile and semi-volatile hydrocarbons and benzene. One of the main sources of many of these air pollutants results from the exploration, upgrading, refining and combustion of fossil fuels such as petroleum products (gas and oil) as well as coal.

A sour gas upstream oil and gas (UOG) facility falls into the fossil fuel petroleum category. Sour gas and/or sour oil is gas or oil containing hydrogen sulphide. Before the sour gas and/or sour oil can be upgraded and marketed, the hydrogen sulphide must be separated. Depending on the economics, the majority of the separated hydrogen sulphide can be recovered as elemental sulphur via a number of different catalytic processes and the residual hydrogen sulphide oxidized to sulphur dioxide in an incinerator stack and/or the hydrogen sulphide can be oxidized to sulphur dioxide using a flare stack. It is not uncommon for the sulphur recovery efficiency for sulphur recovery

sour gas plant facilities in Alberta to be 98.5% or higher. The combustion efficiency by flaring hydrogen sulphide in order to convert it to sulphur dioxide can be highly variable, however. While it has been commonly assumed that flaring achieves almost complete combustion, Strosher (2000) and Leahey et al. (2001) showed that flaring with weak to strong cross winds and/or entrained liquids in the gas stream can result in combustion efficiencies commonly in the range of 62 to 82%. A significant number of complex organic compounds are formed as a result of the incomplete combustion of the waste gas being flared. Many of these organic compounds are known carcinogens. An array of sulphur compounds will also be formed when hydrogen sulphide is in the waste gas being flared. It is highly probable that there will be fugitive releases and inadequately controlled venting of hydrogen sulphide from a sour gas UOG facility. Nitrogen oxides are also emitted by the large compressors at such a facility.

The sulphur dioxide and nitrogen oxides emitted into the atmosphere from a sour UOG facility can be dry deposited and taken up by local environmental receptors as well as subjected to medium and long-range transport and transformed to either acids (sulphuric and nitric acid) and/or salts (such as ammonium sulphate and ammonium nitrate) before being deposited (Finlayson-Pitts and Pitts, 2000). The sulphur and nitrogen oxides can also be incorporated into rain and be removed by washout or rain-out which is collectively referred to as wet deposition.

The exposure of environmental receptors such as vegetation, soils and water to pollutants are commonly characterized as being either acute or chronic [Legge et al.,1998] An acute exposure is characterized as being a high concentration for a short time duration which is usually minutes to hours while a chronic exposure is characterized as a low concentration for a long time duration which is usually days to weeks to months but can be years. It is not uncommon for the exposure of environmental receptors to given air pollutants to be a mixture of both acute and chronic exposures. The concentration range for acute exposures of an environmental receptor approaches and/or exceeds what is considered the 1-hour average ambient air quality objective and/or standard for that pollutant. The concentration range for chronic

exposures of an environmental receptor is above what is considered the global background concentration for the given pollutant but much less than the 1-hour, 24-hour and annual average ambient air quality objective and/or standard for that pollutant. Examples of characteristic symptoms of foliar injury to both acute as well as chronic exposures to sulphur dioxide have been documented in detail by Legge et al.,1998.

While both sulphur and nitrogen are essential elements for plant growth and development, the uptake of too much sulphur and/or nitrogen by plants and soils can results in adverse effects on plant growth and development. The build-up of excess sulphur in the soils can result in the contamination of surface and ground waters, in reduced tree growth, accelerated soil acidification and the disruption of plant nutrient cycling (Mayer et al. 1995; Legge et al., 1996; Krupa and Legge, 1998; Prietzel et al., 2004; De Kok et al. 2009). Excess nitrogen build-up in the soil can result in nitrogen saturation which can be seen as nitrate leaching below the rooting zone and into surface waters and/or soil eutrophication which can lead to changes in plant species composition (Bobbink and Lamers, 2002).

The key take-home message here is that there is abundant scientific evidence to support the conclusion that environmental receptors such as vegetation, soils, surface waters and other connected ecosystem components exposed to acute and/or long-term chronic emissions of sulphur and nitrogen oxides originating from a sour gas UOG facility will be adversely impacted.

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Sources and Types of Emissions from Sour Gas Facilities

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Sour natural gas facilities tend to have the same basic sources of atmospheric emissions as sweet facilities, namely: fuel combustion (potentially by both mobile and stationary sources), fugitive equipment leaks, process venting and flaring, and storage losses. The types of pollutants that may be emitted include greenhouse gases (CO_2, CH_4 and N_2O), volatile organic compounds, criteria air contaminants (i.e., CO, SO_2, NO_x, PM_{10}, $PM_{2.5}$), metals, and products of partial or incomplete combustion.

The key issues related to these emissions include the following:

- *Toxic air contaminants (TAC or 'air toxics')*" (or hazardous air pollutants [HAP]). These are air pollutants that are characterized by their persistence in the environment, ability to bioaccumulate through food chains and/or ability to cause serious, short- or long-term health effects, even at low levels of exposure. The primary TACs associated with oil and natural gas that have been identified include hydrogen sulphide (H_2S), BTEX (Benzene, Toluene, Ethylbenzene and Xylene) and n-Hexane (C_6H_{14}). Exposure to these chemicals has been demonstrated to cause adverse health effects. In general, these findings have only been shown with concentrations higher than those typically found in the ambient air, with the exception of benzene, which is a non-threshold carcinogen. The potential key sources of BTEX in the oil and gas industry are dehydrator and storage tank vents; although, in sour applications these vents would normally connected to control device, BTEX emissions would be primarly due to fugitive equipment leaks and fuel combustion. H_2S emissions would be primarily due to fugitive equipment leaks and flaring inefficiencies.
- *Climate Change caused by greenhouse gas (GHG)* emissions. These emissions absorb infrared radiation and, in turn, emit it in the atmosphere. The net effect is a local trapping of energy and a tendency to warm the Earth's surface. Water vapour, carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. The principal greenhouse gas emissions emitted by the oil and gas industry are CO_2, CH_4 and N_2O. The atmospheric oxidation of gaseous non-CO_2 and non-CH_4 carbon emissions (e.g., CO, and non-methane VOCs) are also contributors to climate change. While there is not agreement on the amount and location of climate change, it is estimated the average global surface temperature could increase one to five degrees Celsius, and that there could be substantial change in precipitation patterns. It is believed northern latitudes (including Canada) would be affected more than equatorial regions; however, the effects of higher temperatures, accompanied by rising sea levels and changes in precipitation would be global. Food production could be affected by both coastal flooding and more frequent and severe droughts. Fresh water supplies, forests and land use could also be affected.

- Tropospheric (i.e., g*round level) Ozone (O_3)"formation. This* is a highly reactive gas; termed a secondary pollutant since it is not directly emitted but formed due to the chemical reaction of *precursor pollutants, namely NO_x and VOCs,* in the presence of heat and sunlight; a component of photochemical smog and associated with human health concerns, environmental impacts and property damage. At ground level, ozone is a major component of photochemical smog which has a noticeable light brown colour and results in reduced visibility and health concerns. Fuel and waste gas combustion activities are the primary sources of NO_x. VOC emissions may be contributed by all primary source categories, including fuel and waste gas combustion, fugitive equipment leaks, and process venting..
- "*Nuisance odours*" are the presence of malodorous air at such intensity, concentration, frequency, duration and time of occurrence as to "materially interfere" with the normal use and enjoyment of property. Offsite odors are often attributed to emissions of reduced sulphur compounds, including H_2S, due to their low odour detection thresholds. Hydrocarbon emissions can be the dominant smell in the nearfield. Uncontrolled process vents (especially for dehydrator and storage tank vents), combustion sources and fugitive equipment leaks are the potential sources of VOC emissions. The main sources of H_2S emissions and other reduced sulphur compoumnds are flaring inefficiencies and fugitive equipment leaks in sour gas applications.
- Acid rain is caused by emissions of sulphur oxides (SO_x) and nitrogen oxides (NO_x) which in the atmosphere are converted chemically to sulphuric acid (H_2SO_4) and nitric acid (HNO_3), among other products. Diluted forms of these acids, and other substances, can fall to earth as rain, snow, sleet, hail, or fog. When it is not raining, the oxides interact directly with soil, vegetation and water in a variety of ways referred to as dry deposition. Dry deposition, mostly invisible, occurs through gravitational settling of large particles and uptake of gases and small particles at the Earth's surface. Rain and other precipitation may be defined as acidic or alkaline (basic) depending on chemical composition. The acid rain precursors can be transported thousands of kilometres through the atmosphere, returning to earth as dry deposition or in wet acid form. The primary receptors of acid rain are soil and aquatic systems (Alberta Environment, 2008). Systems lying on the Precambrian Shield and are highly sensitive to acid deposition. Systems lying to the south are influenced by a very complex network of buffering agents and are relatively insensitive (Shewchuk, 1981).

The key differences between sour and sweet facilities is the tendency for sour facilities to use closed control systems to help preclude the release of hydrogen sulphide (H_2S) and other malodorous or toxic constituents of the produced gas, the application of more stringent design, operating, maintenance and monitoring standards, and greater emissions of sulphur containing compounds. Notwithstanding this, the amount of emissions is generally related to other factors such as:

- Age and maintenance history of the facility.
- Capital constraints, energy efficiency standards and emission control standards at the time the facility was designed.
- Level of regulatory enforcement.

- Reliability and effectiveness of installed emission controls.
- Reservoir specific properties of the produced hydrocarbons such as the types and levels of impurities in the produced hydrocarbons, gas-to-hydrocarbon-liquid ratios, gas-to-water ratios, and the rate of pressure decline.
- Disincentives such as contractual agreements, administrative structure and corporate policies that prevent those responsible for the costs of emissions control from sharing in the benefits achieved.
- Lack of practicable on-site opportunities to utilize waste energy and uneconomic access to nearby markets for the energy.
- Remoteness of the facility and the available access to sweet fuel gas, electric power, nearby gathering systems and produced water disposal system.

Sour natural gas facilities generally offer a greater level of control in managing atmospheric emissions from sources such as fugitive equipment leaks, process venting, storage losses and flaring, than do similar sweet natural gas facilities. However, they may result in increased emissions from combustion sources due to the greater energy intensity of sour operations compared to similar sweet facilities and will have SO_2 emissions due to flaring, incinerators and possibly some use of sour fuel gas.

Some of the key factors and practices that have a positive impact in reducing atmospheric emissions at sour facilities include the following:

- Use of more stringent design, operating, maintenance and monitoring standards due to the greater safety hazard posed by components in sour service.
- Easy detection of sour gas emissions by operator olfactory responses resulting in early detection and correction of problems.
- Greater concern by operations personnel in managing sour gas releases.
- Limitations by equipment suppliers on the amount of H2S that may be tolerated in the fuel.
- Stringent emission source standards and ambient air quality objectives aimed at limiting SO_2 emissions and odours.

Factors that tend to cause increased emissions include the following:

- At larger facilities, sweetening of the produced gas occurs at an early stage in the process so that most of the facility is in sweet service and will tend to have increased emissions.
- The need to either deliver sweet fuel to the site or install sweetening facilities onsite.

Fuel Combustion

At most facilities, natural gas, or sometimes even hydrocarbon liquid, is taken from the process and used as fuel. On an industry-wide basis, most of this fuel is used by compressor engines, pump engines, heaters and boilers. At larger sour gas facilities the fuel would be sweetened onsite before being used. At upstream sour gas production facilities the tendency is to build pipelines to deliver sweet fuel gas to the facilities. The potential for sour fuel gas to be used is

most likely to occur at minor field installations and the gas is limited to applications where the level of sulphur compounds in the gas can be tolerated. This may include process heaters, flare purge gas, and turbine engines.

Other fuel uses include make-up gas to flare gas streams to satisfy minimum heating value requirements for stable combustion, supplemental fuel for incinerators to achieve good destruction efficiencies and/or to maintain the minimum stack temperatures needed to achieve good atmospheric dispersion of the emitted substances, flare and incinerator pilot gas, flare and vent header purge gas, blanket gas for storage tanks, and the supply medium for gas operated devices (e.g., instrument control loops, chemical injection pumps and compressor starters).

Acid Gas

Acid gas is a bi-product of the sweetening process at sour gas processing plants, and may contain large amounts of raw CO_2 extracted from the process gas (typically, from 20 to 95 mol percent CO_2). The rest of the acid gas tends to be mostly H_2S. The amount of acid gas production is usually metered and the CO_2 content, although not normally tracked by regulatory agencies, is known by the facility operators. The allowable options for disposal of the acid gas depend on the sulphur inlet rate.

Storage Losses

Production and processing facilities are often equipped with one or more atmospheric tanks for temporary storage of the produced hydrocarbon liquids (i.e., oil or condensate) and water. In sour applications these would normally be equipped with a vapour collection and control system.

If the tanks are vented to the atmosphere, they are sources of storage losses (i.e., product is lost to the atmosphere due to evaporation effects). The amount and type of emissions normally depends on the composition of the stored product, its vapour pressure, storage conditions and the amount of liquid level movement in the tank.

Storage tanks can be a source of a wide range of reduced sulphur compound, volatile organic compound and methane emissions.

Fugitive Equipment Leaks

A leak is the unintentional loss of process fluid past a seal, mechanical connection or minor flaw at a rate that is in excess of normal tolerances allowed by the manufacturer or applicable health, safety and environmental standards. Those in the first category should be fixed wherever this is economical to do (i.e., based on direct repair or replacement costs and the value of the process fluid being lost), while those in the latter category should be fixed regardless of the cost.

Fugitive equipment leaks may arise due to normal wear and tear, improper or incomplete assembly of components, inadequate material specification, manufacturing defects, damage during installation or use, corrosion, fouling and other operational effects (e.g., vibrations and thermal cycling). Some components, like mechanical seals, are designed to leak a small amount

to provide lubrication and remove heat and debris from the contact surfaces, but can leak excessively as the seal wears out.

The potential for equipment leaks depends on a variety of factors including the type, style and quality of components, type of service (gas/vapour, light liquid or heavy liquid), age of component, frequency of use, maintenance history, process demands, process fluid characteristics (highly toxic or malodorous) and operating practices. Most equipment components leak to some extent; however, only a few percent of the potential sources at a site actually leak sufficiently at any time to be in need of repair or replacement. If the number of excessive leakers is less than 2 percent of the total number of potential leakers, the facility is typically considered to be well maintained and fugitive equipment leaks properly controlled.

The following are some noteworthy characteristics of fugitive equipment leaks:

- There is a strong correlation between the rate of leakage and the type of service (e.g., gas/vapour and light liquid/two-phase streams) (Wetherold and Provost, 1979); however, there is no clear relationship between the size of a component and the rate of leakage (U.S. EPA, 1983).

- The potential for leakage increases with operating pressure and ambient temperature, but is generally independent of operating temperature or elevation above grade (Langley et al., 1981).

- Control valves have a greater potential for leakage than block valves. For block valves, the gate design has the most potential for leakage, while plug and ball designs have the least potential.

- Off-line compressor units that have been depressurized and are left open to the atmosphere through the vent line leak more than ones that have not been depressurized or that are online (especially for reciprocating compressors) (Hummel et al., 1996). In the first case, the leakage is past the seats of upstream and downstream block valve. In the latter case, it is past the seat of the blowdown valve.

- Components in gas transmission service tend to leak more, on average, than components in gas distribution service. This may be due, in part, to the large disparity in typical operating pressures; however, it is likely that odourization of the distribution gas also is an important factor.

- Repaired components usually achieve a normal leak potential if the leaks do not recur during the first few weeks after repair (Eaton et al., 1980).

Pneumatic Devices

The use of gas-operated devices is a direct source of emissions where the supply medium is natural gas. In the upstream petroleum industry, it is common practice to use natural gas as the operating medium for pneumatic instrumentation systems and gas operated devices (e.g.,

chemical injection pumps and compressor starters) where compressed air is unavailable or deemed uneconomical to provide. This is usually the case at single-well oil batteries, single-unit compressor stations, well-site facilities, minor field installations, and at some small (design capacity below 0.7 Mm^3/d) and medium sized (design capacity of 0.7 to 7 Mm^3/d) gas processing plants. Natural gas may also be used in specific applications where the available air pressure is too low to operate a given device (e.g., large valves).

Normally, where the supply gas is natural gas, only sweet fuel gas would be used. However, at smaller remote facilities, sour fuel gas has sometimes been used if the levels of H_2S are not too high.

Flare and Vent Systems

Flare and vent systems exist in essentially all segments of the oil and gas industry and are used for two basic types of waste gas disposal: intermittent and continuous. Intermittent applications may include the disposal of waste volumes from emergency pressure relief episodes, operator initiated or instrumented depressurization events (e.g., depressurization of process equipment for inspection or maintenance purposes, or depressurization of piping for tie-ins), plant or system upsets, well servicing and testing, pigging events, and routine blowdown of instruments, drip pots and scrubbers. Continuous applications may include disposal of associated gas and/or tank vapors at oil production facilities where gas conservation is uneconomical or until such economics can be evaluated, casing gas at heavy oil wells, process waste or byproduct streams that either have little or no value or are uneconomical to recover (e.g., vent gas from glycol dehydrators, acid gas from gas sweetening units, and sometimes stabilizer overheads), and vent gas from gas-operated devices where natural gas is used as the supply medium (e.g., instrument control loops, chemical injection pumps, samplers, etc.). Typically, waste gas volumes are flared if they pose an odour, health or safety concern, and otherwise are vented.

If a flare is not operating efficiently it can be a noteworthy source of products of partial or incomplete combustion and of soot or particulate emissions (especially $PM_{2.5}$). To help ensure good flaring destruction efficiencies, ERCB (2006) Directive 060 requires the combined net heating value (i.e. lower heating value) of flared gases and make-up fuel to meet or exceed 20 MJ/m^3 except for existing flares with a history of stable operation and emergency flare systems in sour gas plants where the heating value may be as low as 12 MJ/m^3.

Dehydrator Vents

Glycol dehydrators are widely used in the natural gas production and processing industry to remove water vapour from process gas. Typically, the still column vent on glycol dehydrators is vented to the atmosphere and is a source of steam, methane and potentially BTEX. If the gas is sour, the effluent from the still column vent will also contain noteworthy amounts of reduced sulphur compounds. In these cases, or if the BTEX emissions are excessive, the still column vent is routed to a control device such as flare or incinerator. Alternatively, in sour applications mole sieve units may be used instead of glycol dehydrators.

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U.S. Environmental Protection Agency. 1983. Equipment Leaks of Natural Gas Production Industry - Background Information for Proposed Standards. Office of Air Quality, Planning and Standards. Research Triangle Park, NC. Report No. EPA-450/3-82-024a.

DAVID J. PICARD, M.Eng., B.Sc., P.Eng.
Senior Project Engineer
Process and Environmental Services

EDUCATION

University of Calgary. 1985.
M.Eng., Chemical Engineering.

University of Alberta. 1981.
B.Sc., Mechanical Engineering.

PROFESSIONAL MEMBERSHIP

Association of Professional Engineers, Geologists and Geophysicists of Alberta

The Association of Professional Engineers and Geoscientists of the Province of British Columbia

American Institute of Chemical Engineers

The American Society of Mechanical Engineers

Air & Waste Management Association

National Fire Protection Association

CAREER SUMMARY

Clearstone Engineering Ltd
Principal (1989 to Present)

Responsible for the general management of Clearstone's engineering consulting services, and for the provision of specialized expertise in the areas of process design, air pollution control, odour control, emission measurement and information systems.

Western Research
Senior Project Engineer (1985 to 1989)

Environmental and process engineering specialist in the areas of air emissions assessments, emissions source testing, air pollution control, combustion technologies and process modelling.

O'Rourke Engineering Ltd.
Project Engineer (1981 to 1983)
Summer Student (1980)

Responsible for the design, construction and commissioning of natural gas production and processing facilities.

Canadian Superior Oil Ltd.
Summer Student/Relief Field Operator (1978 and 1979)

Relief field-operator and member of the maintenance team at a sour gas processing plant.

EXPERIENCE

Process/Facilities Engineering

- Design, safeguarding, construction management and commissioning of well-site facilities, compressor stations, flow lines, gas and water pipeline systems, solution gas conservation schemes, oil batteries and sour gas plants.

Air Pollution Control Systems

General

- Author of a comprehensive reference document for Canadian Association of Petroleum Producers (CAPP) on options for reducing CH_4 and VOC emissions from upstream oil and gas facilities.

- Development, for national oil and natural gas companies in China and Mexico, and for numerous oil and natural gas companies in Canada, site-specific and company-wide control options documents for managing Greenhouse Gas (GHG) emissions and improving energy efficiencies.

Storage Tanks

- Current performance, in collaboration with Carleton University, of a multi-year study sponsored by the Canadian government and upstream oil and gas industry to develop improved methods for assessing average and instantaneous emissions from crude oil storage tanks at production and downstream facilities.

- Preparation of Shell Canada's engineering guidelines for designing safe vapour control systems for tanks, process sewers, API separators, dissolved air floatation separators, atmospheric and low-pressure vessels, as well as product transfer and loading systems.

- Development of guidelines for Kinder Morgan to manage atmospheric emissions from storage tanks at crude oil terminals in Canada.

- Managed projects to de-gas and clean large petroleum storage tanks, select and install improved sealing systems on floating roofs, and design and install vapour control systems on both fixed-roof and floating-roof storage tanks.

- Developed a unique odour abatement system with Shell Canada and Amoco Canada for use on API 650 tanks equipped with internal floating decks.

- Corresponding member of the national task force that developed the Canadian Council of Ministers of the Environment (CCME) Environmental Guideline For Controlling Emissions of Volatile Organic Compounds From Aboveground Storage Tanks.

Fugitive Equipment Leaks

- Author of a number of key reference documents published by government and industry in Canada and internationally on controlling fugitive equipment leaks.

- Principal author of CAPP's best management practice for controlling fugitive emissions at upstream oil and gas facilities.

- Principal author of the Canadian Gas Association's (CGA's) best management practice for controlling fugitive emissions at natural gas transmission, storage and distribution facilities.

- Preparation of the CGA's protocol for measuring fugitive emissions at natural gas transmission and distribution facilities.

- Evaluated and designed leak detection and repair programs for facilities ranging from natural gas processing plants to hazardous waste treatment centres.

- Corresponding member of the national task force that developed the CCME Environmental Code of Practice for the Measurement and Control of Fugitive VOC Emissions From Equipment Leaks.

Combustion Equipment

- Preparation of the Global Gas Flare Reduction Partnership's (GGFR's) guidelines for measuring flaring and venting rates.

- Developed and implemented a comprehensive performance evaluation protocol for the waste-incineration system at the Alberta Special Waste Treatment Centre, and developed software to simulate the combustion process. Also, evaluated the use of SF_6 as a surrogate

compound for determining the destruction and removal efficiency (DRE) of the incineration process.

- Designed and commissioned thermal oxidizers for treatment of waste gas streams.

- Principal author of CAPP's best management practice for flaring solution and associated gas at oil production facilities.

Emissions Assessment and GHG Management

- Current development of guidelines for national oil and natural gas companies in China and Mexico for managing GHG emissions and improving energy efficiencies.

- Development of CGA's recommended practice for evaluation of emissions from pipeline ruptures and third-party damages.

- Developed detailed reference manuals for CGA for assessing methane and combustion emissions from natural gas transmission, storage and distribution facilities.

- Author of an emissions audit manual for use by operators of oil and gas facilities (sponsored by Environment Canada and B.C. Ministry of Energy, Mines and Petroleum Resources), and developed the air monitoring protocol for Peru's petroleum industry.

- Design and implementation of specialized measurement programs and tracer studies to assess trace air toxics and odorous emissions from a variety of industrial facilities and sources (e.g., reduced sulphur compounds [RSCs] and BTEX emissions from petroleum facilities; fugitive emissions of VOCs and RSCs at a major oil sands mining and upgrading facility; and fugitive dioxin and furan emissions from an integrated hazardous waste treatment, handling and disposal facility).

- Developed emission-source inventories and forecasts of greenhouse gases, ozone depleting compounds, acid forming emissions and air toxics. This has included the evaluation of sources as diverse as agricultural soils, domestic livestock, rail traffic, on- and off-road traffic, air traffic, stationary combustion sources, storage tanks, tanker loading and unloading operations, process vents, fugitive equipment leaks, accidental releases and spills, well testing, well servicing operations, land farms, urban centres, military operations, and hazardous waste facilities.

- Lead Reviewer of several proposed methodologies for the Clean Development Mechanism (CDM) Methodology Panel and performance of background research in support of decisions by the CDM Methodology Panel.

- A Lead Author for Volume 2 of the 2006 Intergovernmental Panel on Climate Change (IPCC) National GHG Inventories Guidelines, and Break out Group (BOG) Facilitator for the Natural Gas/Oil Fugitives section of the Energy Volume. BOG facilitators were responsible for writing background papers as well as steering the direction and focus of the discussions in each group.

- Preparation of a technical report for the United Nations Framework Convention on Climate Change (UNFCC) Secretariat on the impact of methodological choices on the estimated fugitive emissions from fuels.

- Preparation of the Fugitive Emissions and Energy e-learning modules and on-line instructor for these modules during training of the UNFCCC Secretariat's expert review teams on the review of national GHG inventories (2004).

- Prepared, under contract to the UNFCCC Secretariat, a background paper on preliminary options for methodologies to apply adjustments under Article 5.2 of the Kyoto Protocol for fugitive emissions from fuels, elaborated guidelines for the auditing of national estimates of fugitive GHG emissions by the energy sector, and a training module and exam on fugitive emissions for use by the United Nations reviewers of national GHG emission inventories.

- Principal author of Canada's guidelines for estimating GHG emissions from oil and natural gas systems (Sec. 7.3 of the Canadian methods manual), co-author of the same section of the IPCC guidelines for national GHG inventories, Chair of the session on fugitive GHG emissions from oil and gas activities at the IPCC/Organization for Economic Co-operation and Development (OECD)/International Energy Agency (IEA) Expert Group Meeting on Good Practice in Inventory Preparation, preparation of the background paper and final framework document for this session, and principal author of the IPCC guidelines for Good Practice in Inventory Preparation for the oil and gas sector.

- Co-author of CAPP's detailed inventory of CH_4 and VOC emissions from the upstream oil and gas industry in Canada, and from oil sands mining, extraction and upgrading. Also, principal author of the NO_x and SO_2 emissions inventory developed for the Alberta Government/Industry Acid Deposition Research Program.

Fuel Inventory Management and Reconciliation

- Principal developer of GreenScan, a software package, and the underlying algorithms for detecting leaks in underground storage tanks by statistical inventory reconciliation. This system was developed in joint venture with Shell Canada Products Limited and has been used since 1998 to provide monthly tightness monitoring of all underground tank systems in Shell Canada's retail network and in 2003 was adopted by Shell International as their global standard.

- Provision of on-going technical support to Shell Canada, Shell International and other clients on matters relating to fuel inventory management and reconciliation.

Software Development

- Project manager for the development of an interactive web-based flow-sheet model and relational database tool to support e-learning and dissemination of both GHG management and life-cycle analysis information on the oil and natural gas industry. The work was sponsored by Environment Canada, Natural Resources Canada and US Environmental Protection Agency (EPA). The current version of the application is hosted by the US EPA at http://www.gastool.methanetomarkets.org/m2mtool/index.html.

- Developed information systems for various engineering and environmental applications using a variety of data management packages including Access, dBase III, dBase IV, Paradox and COBOL, and has programmed extensively using C/C++ and FORTRAN.

- Retained by the Canadian Council of Ministers of the Environment to provide recommendations for a National Data Storage and Exchange System to manage Canada's air-pollution data and information used in related backcasting, forecasting and inventory efforts.

- Principal developer of *EnviroPro*, a commercial emission-source simulator and environmental-data management application used by five of the top ten oil and gas producers in Canada to manage their air, water and solid waste emissions, analyze their energy usage, and monitor their overall environmental performance.

- Architect of a software package to simulate the transient depressurization process associated with various blowdown events and rupture scenarios on high-pressure natural-gas pipeline systems. The developed model is able to account for real-fluid behaviour, including condensation, and non-isentropic effects (i.e., viscous dissipation and heat transfer). Additionally, it calculates decompression wave velocities for application in ductile fracture propagation analyses.

Applied Research

- Lead researcher for the development of a non-intrusive flow meter to simultaneously measure the mass flow of pulverized coal and the mass flow of air in the fuel lines of large utility boilers at thermal power plants.

Expert Witness

- Provided expert testimony on atmospheric emissions, odour control and computational fluid dynamics at various hearings by the National Energy Board and Alberta Energy Resources Conservation Board.

- Expert advisor on odour control during mediation between energy companies and interveners.

- Expert advisor to US Department of Justice (DOJ) in Regions 5 and 8 in legal cases relating to the control of atmospheric emissions at oil and natural gas facilities.

Awards

- Formally acknowledged by the World Meteorological Organization (WMO), United Nations Environmental Programme (UNEP) and the Intergovernmental Panel on Climate Change (IPCC) for having contributed significantly to the IPCC's receipt of the 2007 Nobel Peace Prize.

PAPERS AND PUBLICATIONS

Picard, D.J. 2008. Guidelines on Flare and Vent Measurement. Prepared by for the World Bank's Global Gas Flare Reduction (GGFR) Partnership. 33pp. (www.docstoc.com/docs/43780275/Guidelines-Flare-Vent-Measurement)

Picard, D.J. 2008. Protocol for the Identification and Evaluation of GHG Reduction & Energy Efficiency Improvement Opportunities at Oil and Gas Facilities. Prepared for PTAC. Calgary, AB. 35 pp.

Schwartz, D. and D.J. Picard. 2008. Best Management Practice: Reducing Fuel Gas Consumption in Flaring Operations. Prepared for CAPP. Calgary, AB. 18 pp. (www.capp.ca/GetDoc.aspx?DocId=137306)

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CURRICULUM VITAE

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EDUCATION

- Ph.D., Geotechnical and Geoenvironmental Engineering, Department of Civil Engineering, Queen's University
- B.E.Sc., Civil and Environmental Engineering University of Western Ontario

EMPLOYMENT HISTORY

- ARKTIS Solutions Inc., Chief Technical Officer
- VGQ Consulting Inc., Director
- University of Manitoba, Department of Civil Engineering, Adjunct Professor
- University of Manitoba, Department of Civil Engineering, Assistant Professor
- Geotechnical Research Centre, University of Western Ontario, Research Contractor

PROFESSIONAL SOCIETIES

- Association of Professional Engineers, Geologist & Geophysicists of NWT & Nunavut (NAPEGG)
- Association of Professional Engineers of Yukon (APEY)

SUMMARY OF EXPERIENCE

Prior to being a co-founder for Arktis Solutions Inc., Jamie worked for several years as an Assistant Professor in the Department of Civil Engineering at the University of Manitoba. He maintains a role of Adjunct Professor at the University of Manitoba. Jamie left academia to become a private consultant to link business and research opportunity to the science and engineering sectors and resulted in the development of VGQ Consulting Inc.

Jamie is the Chief Technical Officer with Arktis Solutions Inc. and lead engineer within the organization. Jamie's roles include contributing to the strategic, business and financial operations of the organizations, as well as, lead technical resource and project management.

Jamie has more twelve years of experience in the following areas: geotechnical, environmental, and geoenvironmental engineering; mining; hydrogeology; northern infrastructure development; policy and regulatory review and development; and research and development. He has authored and co-authored numerous technical papers in refereed journals and conferences in the mining, geotechnical, environmental, hydrogeology, hydraulics, and agricultural fields. Additionally, he has contributed to the development of regulations and guidance documents for Government and Aboriginal organizations in the sectors of mining and municipal infrastructure.

Jamie specializes in cross-disciplinary design and analysis which has led to fluid collaborations with multi-disciplinary and multi-sector teams. He has acted as an expert technical reviewer of: northern mining and site remediation projects; contaminated site clean up projects; and municipal infrastructure design and construction projects. Additionally, Jamie has been: a lead designer and project manager for municipal infrastructure projects; and, instructor for drinking water treatment, waste water treatment and solid waste management courses for community operators.

Jamie maintains ties to practical mine research and is a Canadian Environmental Network ENGO reviewer for Mine Environmental Neutral Drainage (MEND) Steering Committee reports and research. Also, Jamie is an international research reviewer for the Georgian Technical University (Tblilisi, Georgia) studying methods to neutralize arsenic containing mine waste.

PROJECTS BY SECTOR

RESOURCE DEVELOPMENT

- **Qikiqtani Inuit Association (NU)** – Technical reviewer of the proponents A&R plan and security estimate for Baffinland Iron Mine's Marry River Bulk Sampling Program. Development of security estimate for the land owner. Participant in an environmental audit of the site.
- **Parks Canada Agency (NT)** – Technical reviewer of the Canadian Zinc Corporation, Prairie Creek environmental impact assessment. Review focused on winter road construction and geotechnical stability, spill contingency and risk, geochemistry of tailings predictions, and mine water management and treatment. Assisted in the development of information requests for consideration by Parks Canada Agency for submission to Mackenzie Valley Environmental Impact Review Board.
- **DeBeers Canada (NU)** – Engineering oversight in the development of a closure and reclamation plan and security estimate for the Snap Lake mine in Northwest Territories.
- **Mackenzie Valley Land and Water Board (NT)** – Expert technical reviewer for the Phase II Remedial Action Plan for the Tundra Mine Site that included reclamation and closure of: tailing containment area for ARD/ML tailings and waste rock, site water management and treatment, petroleum hydrocarbon contaminated soil and rock. Lead engineer in technical/regulator meetings with proponent and participant in the public hearing.
- **Mackenzie Valley Land and Water Board (NT)** – Technical reviewer for the Miramar Northern Mining Ltd. Con Mine backfill and cover plans for the tailings containment ponds and hazardous waste areas.
- **Mackenzie Valley Land and Water Board (NT)** – Project manager for a team of scientist and engineers in the water licence review of the North American Tungsten Corporation mine in the NWT. Technical lead in the review of surface infrastructure, hydrologic, hydrogeologic, and geochemistry components. Lead engineer in technical/regulator meetings with proponent and participant in the public hearing.
- **Mackenzie Valley Land and Water Board (NT)** – Technical reviewer of the following De Beer's Snap Lake mine engineering documents.
    - Waste Rock, Ore Storage, and Tailings Management Plan
    - East Waste Rock Cell – Embankment Design
    - East Waste Rock Cell – Water Control Structure Design
- **Lutsel K'e Dene First Nation (NT)** – Expert technical reviewer for following BHP Billiton Diamonds Inc. – EKATI diamond mine engineering documents.
    - Watershed Adaptive Management Plan
    - Water Licence
    - Interim Closure and Reclamation Plan
    - Waste Rock and Seepage Report
    - Tailings Containment Facility Water Management Plan and Geochemical Modelling
- **Lutsel K'e Dene First Nation (NT)** – Technical reviewer for the following Diavik Diamond Mine Inc. – management documents.

- Hazardous Materials Management Plan
- Spill Contingency Plan

- **Tlicho Government (NT)** – Technical resource development consultant and contributed to the regulatory and technical review of Proponent information in their advancement towards entering into an environmental assessment.
- **Yellowknives Dene First Nation (NT)** – Technical reviewer for the Tundra Mine, NWT Remedial Action Plan.
- **Yellowknives Dene First Nation (NT)** – Technical reviewer for the Hidden Lake Mine, NWT Remedial Action Plan.
- **Nunavut Water Board (NU) –**Technical reviewer of the following Tahara Diamond Corporation- Jericho Diamond Mine application documents for water licence consideration.
  - West dam design report and construction specifications
  - Waste rock management plan
  - Waste rock seepage monitoring
  - Processed kimberlite (tailings) management plan
  - Landfarm and contaminated snow containment facility design and construction specifications
  - Landfill design and construction specifications
  - Long Lake dewatering plan, divider dyke design and construction specifications
  - Tank farm design
- **Nunavut Water Board (NU) -** Technical reviewer of the following Miramar Hope Bay Limited- Doris North Gold Mine application documents for water licence consideration.
  - Geochemical characterization of portal development rock and quarry materials
  - Interim waste rock pile design and management plan
  - Landfarm design, management plan, and construction specifications
  - Landfill design, management plan, and construction specifications
  - Hazardous materials management plan
  - Environmental protection plan
  - Site monitoring and follow-up plan
  - Surface infrastructure components design
  - Tailings containment facility water quality model and management plan
  - North and south dam design
- **Nunavut Water Board (NU) -** Technical reviewer and licence compliance assessor for the Miramar Hope Bay Limited Windy Lake and Boston Exploration Camps, specifically, the water monitoring program, QA/QC plan, annual reporting, and abandonment and restoration plan.
- **Yukon Energy, Mines and Resources (YU)** – Technical engineer to provide advisory services related to Mineral and Environmental Projects within the Yukon Territory.
- **UMA Engineering Ltd. (MB)**- Chemical treatment of mine water effluent at Fox Lake, Manitoba.
- Submitted to third party contractor to **INCO LTD. (MB)** - Contributed to the characterization and trial revegetation of mine tailings at INCO Ltd., Thompson, Manitoba.

- **INCO LTD., Manitoba Sustainable Development Innovation Fund, and University of Manitoba (MB)** - Field and laboratory measurement of unconsolidated and cemented (hard-pan) tailings hydraulic properties and implications on metal leachate and acid mine drainage.
- **Manitoba Mines Branch, Manitoba Sustainable Development Innovation Fund, and University of Manitoba (MB)** - Assessment of attenuation and potential mobility of arsenic at New Britannia Mine, MB, Canada.
- **Federal University of Rio Grande do Sul, Brazil and University of Manitoba (MB and Brazil)** – Project manager and engineering advisor in the assessment of contaminant transport properties through compacted soil liners subjected to acid mine drainage percolation.
- **Federal University of Rio Grande do Sul, Brazil and University of Manitoba (MB and Brazil)** - Project manager and engineering advisor in the measurement of geotechnical strength characteristics of residual soils, with and without cement additives, subjected to acid mine drainage percolation.
- **Government of Northwest Territories – Environment and Natural Resources (NT)** – Expert technical reviewer of Oil & Gas Drilling Waste Disposal Practices for the Proposed Type A Water Licence in the Cameron Hills, NWT Region. Expert technical witness during the water licence public hearing.
- **Mackenzie Valley Land and Water Board (NT)** – Technical reviewer for Paramount Resources Ltd. Water licence application materials to support their Cameron Hills extension project.
- **Department of Indian Affairs and Northern Development (NT)** – Technical and regulatory reviewer for the Paramount Resources Ltd. Cameron Hills Type 'B' Water Licence Application that included aspect to evaluate impacts on surface water quality and quantity.
- **Northwest Territories Water Board (NT)** - Preliminary technical review of Shell Canada Ltd. Camp Farewell, NT Environmental Site Assessment.
- **Northwest Territories Water Board (NT)** - Preliminary technical review of MGM Energy Corporation 2D, 3D, and seismic drilling operations and review of draft water licence conditions.

MUNICIPAL INFRASTRUCTURE

- **Government of Nunavut (NU)** – Project manager and technical lead in the completion of best management practices for waste management in Nunavut. Analysis includes strategic planning, options analysis, and cost-benefit analysis.
- **Government of Nunavut, Hamlet of Resolute Bay (NU)** – Lead designer and engineer in the development of a new solid waste facility and decommission of the existing solid waste site (municipal landfill, recycling area, and bulky metals site) in Resolute Bay, Nunavut. Core activities included: siting and design of a new solid waste disposal facility; waste audit and development of waste management plan for the new disposal facility; and, provision of tendering services upon acceptance of design including tender documents, construction specifications and QA/QC plan, drawings, and contract administration during construction.
- **Government of Nunavut, Hamlet of Grise Fiord (NU)** – Lead designer and engineer in the development of a new solid waste facility and decommission of the existing solid waste site (municipal landfill, recycling area, and bulky metals site) in Grise Fiord, Nunavut. Core activities included: siting and design of a new solid waste disposal facility; and, provision of tendering services upon acceptance of design including tender documents, construction specifications and QA/QC plan, drawings, and contract administration during construction.

- **Government of Nunavut, Hamlet of Pangnirtung (NU)** – Lead environmental and geotechnical designer and engineer in the optimization of the hamlet's water supply facility and completion of a Comprehensive Performance Evaluation report. Activities include: watershed modelling and hydraulic monitoring of water source; assessment and repair of water retention structure and associated infrastructure; geotechnical and geothermal modelling of the water reservoir slopes; and, design of an improved water supply facility to meet current and future community needs.
- **Environment Canada (YK, NT, NU)** – Project lead in the review of the state of waste management practices for community solid waste within the three territories. The focus of the study was on regulatory requirements, territory wide solid waste profiles and challenges, as well as, community scale operations and challenges.
- **Mackenzie Valley Land and Water Board (NT)** – Project manager for a technical team to technically review the City of Yellowknife's water licence application and supporting documents. Topics covered included review of the proponent's landfilling and wastewater treatment practices and future expansion plans. Participant in technical /regulatory meetings with the proponent.
- **Mackenzie Valley Land and Water Board (NT)** – Technical reviewer of the Town of Hay River's water licence application and supporting documents. Topics covered included review of the proponent's landfilling and wastewater treatment practices and future expansion plans. Participant in technical /regulatory meetings with the proponent.
- **Department of Indian Affairs and Northern Development (NT)** – Lead geotechnical engineer in the completion of a desktop study for a leased land in Ft. Simpson, NT that is proposed for two storage facilities.
- **Department of Indian Affairs and Northern Development (NT)** – Project manager and geotechnical engineer in the completion of a geotechnical field investigation for a leased land in Ft. Simpson, NT that is proposed for two storage facilities.
- **Wekweeti Community Government – Tlicho (NT)** – Project manager for a community energy audit.
- **Gameti Community Government – Tlicho (NT)** – Project manager for a community energy audit.
- **Infrastructure Canada- Knowledge-building, Outreach, and Awareness Program (Canada) -** Assessment of national incidence of water well infrastructure deterioration in Canada, life-cycle cost analysis of groundwater extraction wells with consideration given to operations and maintenance, and characterization of water quality, hydrogeology, and well design and operation impacts on water well deterioration.
- **Grudfos Management A/S (Denmark)** – Grundfos is the world leader in the manufacturing of pumps. Acted as an expert participant in a workshop in Denmark to review mechanisms and process leading to biological, chemical, and physical clogging mechanisms and process for groundwater wells and pumps.
- **Agriculture and Agri-Foods Canada Water Supply and Expansion Program and City of North Battleford (SK)** – Project lead and engineer to obtain funds to support a $1.1 million capture zone study. The capture zone objectives were to: Design of a research program, budget and preparation of a grant application to support achievement of the following objectives:
    - Establish the causes of well and water quality deterioration and formulate methods of predicting long term well performance and service life.
    - Develop diagnostic tools and methods that will improve preventative maintenance techniques, improve best management practices, well design, and well restoration techniques.

- Perform evaluation of the performance of a new technology (impressed current system) to prevent well deterioration.
- Develop best management practices for well capture zone management.
- Transfer knowledge to water well users through a workshop or demonstration project.
- Prepare technical bulletins and peer reviewed journal reports describing project results.

- **Nunavut Water Board (NU) –** Technical reviewer of the geotechnical, construction specifications, containment function, and water quality impact, for the following:
  - Hamlet of Qikiqtarjuaq- lagoon, landfill, landfarm hazardous waste storage area, and water reservoir
  - Hamlet of Kugluktuk- lagoon, landfill, and landfarm
  - Hamlet of Kugaaruk- lagoon
  - Hamlet of Taloyoak- landfarm
- **Deline Land Corporation (NT)-** Lead geotechnical engineer in the investigation of the Grey Goose Lodge foundation evaluation and repair.
- **UMA Engineering Ltd. (MB) –** Field engineer to completed aquifer pump tests at Keewatin and PTH 59 North locations.
- **City of Winnipeg, Manitoba Waste Reduction and Pollution Prevention, University of Manitoba (MB)** – Project manager and engineering advisor for the field measurement of refuse hydraulic properties and efficiency of leachate extraction wells to reduce leachate levels in municipal solid waste landfills.
- **City of Winnipeg, Manitoba Waste Reduction and Pollution Prevention, University of Manitoba (MB)** – Engineering advisor for the bench top assessment of submerged membrane bioreactor to aerobically treat landfill leachate.

ENVIRONMENTAL ASSESSMENTS

- **Wekweeti Community Government – Tlicho (NT)** – Environmental engineer responsible to complete a fuel spill investigation that occurred adjacent to a community building in Wekweeti, NT. In addition to an assessment of the physical site characteristics, soil samples were collected and analyzed for total petroleum hydrocarbon levels. General recommendations for site restoration were provided.
- **Smiths Landing First Nation (AB) –** Lead engineer to compete a Phase 1 Environmental Site Assessment of a transfer land from the Crown to the Band through the provisions set in the Treaty Lands Entitlement framework.
- **Smith Landing First Nation (AB) –** Lead engineer to review the findings of Hay Camp, Wood Buffalo Park Phase 1, 2, and 3 Environmental Site Assessment to understand environmental and human health risk for the First Nation. Participant in technical meetings with consultant and government organizations regarding clean up strategies and proposed remedial action.
- **Smith Landing First Nation (AB) –** Lead technical participant in technical discussions on behalf of First Nation with various government organization with regards to radiation contamination on Reserve lands.

REGULATORY

- **Qikiqtani Inuit Association (NU)** – Contributed to the development of a lands resource security policy in conjunction with this land owner.
- **Plan Review Process & Guideline Working Group – Mackenzie Valley Land and Water Boards (NT)** – Lead engineer and technical resource consultant in the completion of a guideline for waste management practices that proponents seeking a water licence can use to ensure that their plans and designs capture elements necessary to understand waste management and the expectations that the Water Boards within the Mackenzie Valley. The guideline is applicable to the mining, oil and gas, exploration, industrial, and municipal sectors, and includes all sources of waste ranging from tailings, construction & demolition waste, hazardous waste, contaminated soil, and municipal refuse.
- **Environment Canada (YK, NT, NU)** – Project manager and lead engineer to evaluate the legal obligations (e.g., permitting, compliance promotion, and enforcement) and authorities of governments and Boards within the Canadian North responsible for environmental legislation and protection. Also, evaluated the potential implementation issues for the new CEPA Storage Tank regulation in the North and the proposed federal Clean Air Regulatory Agenda for the Northern Oil and Gas Sector.
- **South Australia Environmental Protection Authority (Australia)** - Contributed to the development of the landfill standards, specifically, barrier system design and contaminant transport, test methods for organic mater and calcium content for leachate collection drainage materials, leachate collection system design and service life predictions, and expert review of draft standards.
- **Nunavut Water Board (NU)** – Lead engineer responsible for the development of draft guidance document for northern waste and water containment facilities, specifically, landfills, landfarms, lagoons, and water retention structures. Document provides proponents involved in these facilities of the hydrology, hydrogeologic, geotechnical, design, operation, monitoring, and maintenance issues that may be considered and detailed in an application for the purposes of obtaining a water licence.
- **Nunavut Water Board (NU)** - Contributed to the development of application guidelines for Miramar Hope Bay Ltd.- Doris North Gold Mine and Cumberland Resources Ltd.- Meadowbank Gold Mine.
- **Nunavut Water Board (NU) -** Technical review and licence compliance assessment for monitoring program, QA/QC plan, annual reporting, and abandonment and restoration plan for the following Distant Early Warning (DEW) line sites:
    - DYE-M- Cape Dyer
    - CAM-2- Gladman Point
    - FOX-2- Longstaff Bluff
    - FOX-5- Qikiqtarjuaq
    - BAF-5- Resolution Island
    - CAM-1- Jenny Lind Island
- Submitted to third party consultant for the **Saskatchewan Environment Resource Management (SK)** - Technical reviewer of groundwater and brine migration model predictions below the Cory, Mosaic, Mosaic K1, Mosaic K2, and Patience Lake, Saskatchewan potash mines.
- Submitted to third party consultant for the **Ontario Ministry of Environment (ON)** - Contributed to the review of state-of-the-art of landfill design, specifically pertaining to leachate characteristics for municipal solid waste landfills, leachate collection system design, and geosynethics use in leachate collection system and cover applications.

AGRICULTURAL

- **Prairie Farm Rehabilitation Association- Agriculture and Agri-Foods Canada (Canada)** - Clogging of agricultural tile drains, impacts on performance, and field crop revenue loss.
- **Prairie Farm Rehabilitation Association- Agriculture and Agri-Foods Canada (Canada) -** Review of impressed current systems to mitigate biofouling clogging effects in groundwater extraction wells.
- **Manitoba Conservation and University of Manitoba (MB)** - Measurement of contaminant and nutrient migration below earthen manure storage lagoons in southern Manitoba. Evaluation of contaminant transport parameters for inorganic and nutrient constituents in various aquitards below manure lagoons.

EDUCATION AND TRAINING

- **Tlicho Government (NT)** – Developed and delivered a workshop to the Tlicho Assembly on the proposed NICO mine development.
- **Nunavut Municipal Training Organization (NU)** – Developed and instructed a translation workshop to assist translators in communicating scientific and construction terms, common in municipal infrastructure activities, from English to Inuktitut.
- **Nunavut Municipal Training Organization (NU)** – Developed and instructed a five day course for municipal operators and foremen in the areas of drinking water treatment, wastewater treatment, and solid waste management. The course was held in Iqaluit, NU and Rankin Inlet, NU in May, 2009, and in Iqaluit, NU in October, 2009.
- **Building Environmental Aboriginal Human Resources –BEAHR (Canada)** – Developed student manual, instructor manual, and instructor presentation materials for a solid waste coordinator course. Curriculum materials are to be licenced by BEAHR to instructors to train Aboriginals in topics relevant to operate and manage a solid waste facility.
- **Environmental Monitoring Advisory Board –EMAB (NT)** – Developed and facilitated a mining closure and reclamation workshop in Yellowknife, NT. EMAB is a consensus board of ensuring the protection of Lac De Gras environment where the Diavik Diamond Mines is located. Workshop participants included members of Aboriginal communities and regulators who ensure compliance with licences and leases, and Diavik personnel.
- **Government of Northwest Territories – Municipal and Community Affairs** – Managed, developed, and instructed an eight day Introduction to Environmental Management course in Inuvik, NT in 2008 and 2011. Course topics included: general environmental awareness; roles and responsibilities of regulators and legislation that helps protect the environment; Mackenzie Valley Resource Management Act and associated Boards; Inuvialuit Land Administration; challenges of waste disposal and community infrastructure such as sanitary landfills and wastewater lagoons; contaminants in the North and their effects; site inspection; remediation technologies; and understanding of Government of Northwest Territories and Indian and Northern Affairs Canada programs.
- **Government of Northwest Territories – Municipal and Community Affairs (NT) –** Managed, developed, and instructed a five day Class 1 Drinking Water Treatment Plant Operator course in Inuvik, NT in 2008. Hay River, NT in 2010, and Inuvik, NT in 2011.

- **Government of Northwest Territories – Municipal and Community Affairs (NT) –** Managed, developed, and instructed a five day Class 2 Drinking Water Treatment Plant Operator course in Norman Wells, NT in 2010 and Fort Smith, NT in 2010.
- **University of Manitoba – Department of Civil Engineering (MB)** – Developed curriculum and instructed the following undergraduate and graduate student courses:
    - Groundwater hydrology (2004, 2005)
    - Hazardous waste management (2005)
    - Fluid mechanics (2006)
    - Groundwater contamination (2006)
    - Solid waste engineering (2003, 2005)
    - Physical and chemical hydrogeology (2005)
    - Geoenvironmental engineering (2005)
- **University of Manitoba – Department of Civil Engineering (MB)** – Managed, trained, and operated an independently funded research program to support the completion of 2 Ph.D, 6 M.Sc., and 2 B.Sc. student theses.

RESEARCH AND DEVELOPMENT

- Evaluation of biological, chemical, and physical clogging mechanisms, and rates of clogging, in drainage stone used in landfill leachate collection systems and leachate transmission pipes used in landfills and bioreactors.
- Geochemical and hydrologic interactions in mine tailings exposed to atmospheric conditions.
- Validation of finite element model that links biogeochemical reactions to groundwater flow and solute transport to predict clogging in granular media permeated with leachate.
- Development of design tables for the design and operation of liquid injection systems in bioreactor landfills.
- Prediction of the interactions of pipe hydraulics and unsaturated/saturated refuse hydraulic properties on liquid injection system design and operation.
- Review of geotechnical strength parameters and saturated/unsaturated hydraulic properties of municipal solid waste.

PUBLICATIONS

ARTICLES IN REFEREED PUBLICATIONS

1. Lozecznik, S., Sparling, R., Oleszkiewicz, J.A., Clark, S., and VanGulck, J.F. 2009. Leachate treatment before injection into a bioreactor landfill: clogging potential reduction and benefits of using methanogenesis. Submitted for publication.
2. Lozecznik, S. and VanGulck, J.F. 2009. Full-scale laboratory study into clogging of pipes permeated with landfill leachate. ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, **13**(4): 261-269.
3. VanGulck, J., Lozecznik, S., and Murdock, J. 2009. Hydraulic design tables for horizontal liquid injection systems in bioreactor landfills. Accepted for publication in ASCE Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management (special edition), **13**(3): 147-155.
4. Sherriff, B.L., Ferguson, I., Gupton, M.W., VanGulck, J.F., Sidenko, N., Priscu, C. 2009. A Geophysical and geotechnical study to determine the hydrological regime of the Central Manitoba gold mine tailings deposit. Canadian Geotechnical Journal, **46**: 1-12.
5. Knop, A., VanGulck, J., Heineck, K.S., and Consoli, N. 2008. Transport of contaminants through a compacted soil liner subjected to acid mine drainage (AMD) percolation. Journal of Hazardous Materials, **155**(1): 269-276.
6. VanGulck, J.F. and Rowe, R.K. 2008. Parameter estimation for modeling clogging of granular medium permeated with leachate. Canadian Geotechnical Journal, **45**(6): 812-823.
7. Sadri, S., Cicek, N., and VanGulck, J. 2008. Aerobic treatment of landfill leachate using a submerged membrane bioreactor – prospects for on-site use. Environmental Technology, **29**: 889-907.
8. Sherriff, B., Salzsauler, K.A., Simpson, S., Sidenko, N.V., and VanGulck, J. 2008. Arsenic mobility from arsenopyrite-rich gold mine waste in Snow Lake, Manitoba, Canada. Chinese Journal of Geochemistry, **25**(1): 29-30.
9. Cooke, A.J., Rowe, R.K., VanGulck, J.F. and Rittmann, B.E. 2005. Application of the BioClog model for landfill leachate clogging of gravel-packed columns, Canadian Geotechnical Journal, **42**: 1600-1614.
10. VanGulck, J.F., Rowe, R.K. 2004. Influence of landfill leachate suspended solids on clog (biorock) formation. Waste Management, **24:** 723-738.
11. VanGulck, J.F. and Rowe, R.K. 2004. Evolution of clog formation with time in columns permeated with synthetic landfill leachate. Journal of Contaminant Hydrology, **75**: 115-139.
12. VanGulck, J.F., Rowe, R.K., Rittmann, B.E., and Cooke, A.J. 2003. Biogeochemical calcium precipitation in landfill leachate collection systems. Biodegradation, **14**: 331-346.
13. Rowe, R.K., VanGulck, J.F. and Millward, S.C. 2002. Biologically induced clogging of a granular medium permeated with synthetic leachate. Canadian Journal of Environmental Engineering and Science, **1**(2): 135-156.
14. Cooke, A.J., Rowe, R.K., Rittmann, B.E., VanGulck, J.F. and Millward, S.C. 2001. Biofilm growth and mineral precipitation in synthetic leachate columns. ASCE Journal of Geotechnical and Geoenvironmental Engineering, **127**(10): 949-856.

REFEREED FULL LENGTH CONFERENCE PAPERS

15. Sidenko, N., Sherriff, B., and VanGulck, J. 2006. Mineralogical and geochemical characterization of Ni-Cu Sulfide Tailings, Thompson, Manitoba. Proceedings 7th International Conference on Acid Rock Drainage (ICARD), St. Louis, USA.

NON-REFEREED CONTRIBUTIONS – FULL LENGTH CONFERENCE PAPERS

16. Lozecznik, S., Oleszkiewicz, J., Clark, S., VanGulck, J.F and Sparling, R. 2010. Clogging of leachate transmission pipes under in situ conditions. Global Waste Management Symposium, October 3-6, San Antonio, TX, US.

17. Lozecznik, S., Oleszkiewicz, J., Clark, S., Sparling, R., VanGulck, J.F. 2010. Clogging of leachate transmission pipes at field scale. 11th International Environmental Specialty Conference, June 9-12, Winnipeg, Canada (CD-ROM).
18. Simpson, S., Sherriff, B.L., Sidenko, N. and VanGulck J. 2010. Source, Attenuation and Potential Mobility of Arsenic at New Britannia Mine, Snow Lake, Manitoba. Submitted to 24th International Applied Geochemistry Symposium, Fredericton, NB.
19. Etcheverry, D.J. Sherriff, B.L., Sidenko, N., and VanGulck, J. 2010. Spatial and Temporal Evolution of Cu-Zn Mine Tailings while Dewatering. Submitted to 24th International Applied Geochemistry Symposium, Fredericton, NB.
20. Lozecznik, S., Oleszkiewicz, J., Sparling, R., Clark, S., and VanGulck, J. 2009. Methanogenic degradation of leachate from Brady Road Landfill. Proceedings of the Western Canada Water Conference & Trade Show, Winnipeg, MB, September.
21. Lozecznik, S., Oleszkiewicz, J., Clark, S., Sparling, R., and VanGulck, J.F. 2009. Treatment of Leachate Before Injection into a Bioreactor Landfill: Reduction of the Pipe Clogging Potential. Proceedings of the Air & Waste Management Association General Conference, Detroit, Michigan.
22. Sadri, S., Cicek, N., and VanGulck, J.F. 2005. Aerobic treatment of landfill leachate using submerged membrane bioreactor- prospects for on-site use. Proceedings of the Water Environment Federation's 78th Annual Conference & Exposition (WEFTEC05), Washington, DC, October.
23. Graham, J., Man, A., Alfaro, M., Blatz, J.A., and VanGulck, J.F. 2005. Gypsum cementation and yielding in plastic clay. Proceedings, 16th International Conference on Soil Mechanics and Geotechnical Engineering,, Japan, September,
24. Novy, L., VanGulck, J.F., and Ferguson, G. 2005. Role of refuse hydraulic properties on liquid injection system design. Proceedings, 58th Canadian Geotechnical Conference, Saskatoon, Saskatchewan, Canada, September.
25. Rowe, R.K. and VanGulck, J.F. 2004. Filtering and drainage of contaminated water. Keynote lecture. Proceedings, 4th International Conference on Filters and Drainage in Geotechnical and Environmental Engineering, Geofilters 2004, September (CD-Rom).
26. Gupton, M.W., Sherriff, B.L., Priscu, C., VanGulck, J.F. 2004. Hydrology of the Central Manitoba mine tailings. Proceedings, 57th Canadian Geotechnical Conference, Quebec City, Quebec, Canada, October (CD-Rom).
27. Ferguson, R.J., VanGulck J.F., Betcher, R.N. and Woodbury, A. 2004. Examining seepage from earthen manure storage facilities located in southern Manitoba. Proceedings, 57th Canadian Geotechnical Conference, Quebec City, Quebec, Canada, October (CD-Rom).
28. VanGulck, J.F. and Lozecznik, S. 2004. Hydraulic considerations of landfill leachate injection systems. Proceedings, 1st Canadian Young Geotechnical Engineers and Geoscientist Conference, Quebec City, Quebec, Canada (CD-Rom).
29. VanGulck, J.F. and Lozecznik, S. 2004. Predicting clog development in leachate transmission pipes-theoretical considerations. Proceedings, 32nd Annual General Conference of the Canadian Society for Civil Engineering, Saskatoon, Saskatchewan, Canada, June (CD-Rom).
30. VanGulck, J.F., Rowe, R.K., and Cooke, A.J. 2003. Predicting and modelling biogeochemical precipitation of calcium in leachate collection systems. 56th Canadian Geotechnical Conference, Winnipeg, Canada, September (CD-Rom).
31. Rowe, R.K. and VanGulck, J.F. 2003. Experimental and modeling study into clogging of leachate collection systems. Proceedings Sardinia 2003, 9th International Landfill Symposium, Cagliari, October (CD-Rom).
32. VanGulck, J.F. and Rowe, R.K. 2002. Observations of clog material within granular size medium permeated with leachate. 55th Canadian Geotechnical Conference, Niagara Falls, Canada, September, pp 551-556.
33. VanGulck, J.F. and Rowe, R.K. 2002. Experimental results and parameters obtained from leachate column clogging studies. 4th International Congress on Environmental Geotechnics, Brazil, August, pp 33-38.

34. Rowe, R.K. and VanGulck, J.F. 2001. Clogging of leachate collections systems: From laboratory and field study to modeling and prediction. Keynote lecture, 2nd Australian-New Zealand Conference on Environmental Geotechnic, Newcastle, November, pp. 1-22.
35. Rowe, R.K., Fleming, I.R., Rittmann, B.E. Longstaffe, F.J., Cullimore, D.R. McIsassc, R.S., Bennet, P., Cooke, A.J., Armstrong, M.D. and VanGulck, J.F. 2000. Multidisciplinary study of clogging of leachate drains. CSCE 6th Canadian Environmental Engineering Conference, London, Canada, 57-65.
36. Rowe, R.K., Fleming. I.R., Armstrong, M.D., Millward, S.C., VanGulck, J.F. and Cullimore, R.D 1997. Clogging of leachate collection systems: some preliminary experimental findings. 50th Canadian Geotechnical Conference, Ottawa, Canada, pp. 153-160.

NON-REFEREED CONTRIBUTIONS – CONFERENCE POSTER SESSION

37. Simpson, S.,, Sherriff, B., Sidenko, N., VanGulck, J., and Londry, K. 2006. Source, Attenuation, and Potential Mobility of Arsenic at New Britannia Mine, Snow Lake, Manitoba, Canada. Proceedings 7th International Conference on Acid Rock Drainage (ICARD), St. Louise, USA.
38. Etcheverry, D.J., Sidenko, N.V., Sherriff, B.L, Londry, K., and VanGulck, J. 2004. Spatial and Temporal variations in the Ruttan Mine tailings, Leaf Rapids, Manitoba, Canada. Manitoba Mining and Minerals Convention, Winnipeg, Canada.

CONTRIBUTIONS TO INDUSTRIAL RESEARCH AND DEVELOPMENT

39. Sherriff, B., Hozhina, E., Sidenko, N., and VanGulck, J.F. 2006. The characterization and trial revegetation of mine tailings at Inco Ltd., Thompson, Manitoba. Report submitted to Inco Ltd. 107 pages.
40. Clark, R., Koda, E., Lipinski, M., Wolski. W., Rowe, R.K., and VanGulck, J. 2005. Environmental Geotechnics- Chapter 1: Design Basics and Performance Criteria. Report for International Technical Committee No. 5 (ITC5) on Environmental Geotechnics of the International Society of Soil Mechanics and Geotechnical Engineering (ISSMGE).
41. VanGulck, J.F. 2005. Landfill barrier system contaminant fate and transport modeling. Report submitted to South Australia Environmental Protection Authority. 27 pages.
42. VanGulck, J.F. 2005. Review of test methods for organic mater and calcium carbonate content in soil. Report submitted to South Australia Environmental Protection Authority. 11 pages.
43. VanGulck, J.F. 2005. Sensitivity analysis of leachate collection system design and service life. Report submitted to South Australia Environmental Protection Authority. 16 pages.
44. VanGulck, J.F. 2005. Implications of leachate collection system clogging to the South Australia draft landfill standards. Report submitted to South Australia Environmental Protection Authority. 18 pages.
45. VanGulck, J.F. 2005. Review of impressed current systems to mitigate the clogging effects of biofouling in water wells. Report submitted to Agriculture and Agri-Food Canada-PFRA. 28 pages.
46. VanGulck, J.F. and Novy, L. 2005. Clogging of agricultural tile drains due to iron ochre. Report submitted to Agriculture and Agri-Food Canada-PRFA. 68 pages.
47. Hettiaratchi, J.P.A., Perera, M.D.N., Richards, N., and VanGulck, J.F. 2004. Methane emissions from landfills: opportunities and challenges. CSCE Magazine, Summer 21.3.
48. Rowe, R.K., Southen, J., VanGulck, J.F., Moore, I.D., Sangam, H.P. and Krol, M. 2001. Review of the state-of-the-art of landfill design. Report submitted to Ontario Ministry of the Environment, Waste Management Policy Branch. 533 pages.

BOOK CHAPTER

49. Rowe, R.K. and VanGulck, J. 2010. Landfilling: Geotechnology. Chapter 10, Solid Waste Technology and Management, eds. Christensen, Wiley-Blackwell.

North by Northwest is a 1959 American thriller film directed by Alfred Hitchcock, starring Cary Grant, Eva Marie Saint and James Mason. The screenplay was by Ernest Lehman, who wanted to write "the Hitchcock picture to end all Hitchcock pictures". North by Northwest is a tale of mistaken identity, with an innocent man pursued across the United States by agents of a mysterious organization trying to prevent him from blocking their plan to smuggle out microfilm which contains government secrets. This is Welcome to Spokane Washington's largest Casino. Featuring 24/7 Vegas-style casino gaming with world-class hotel rooms & suites, a luxury spa, 14 restaurants and lounges, 1,600 slot machines and 47 live table games. Learn more about everything Northern Quest Resort & Casino has to offer. North By Northwest is not an artistic masterpiece like Rear Window and Vertigo, but it is probably the most purely entertaining picture Hitchcock ever made. It's essentially a rehash of many of his earlier films, with a plot partially derived from The Thirty Nine Steps and the very similar Saboteur, while there are borrowings from Foreign Correspondent and Notorious, among others.