DATE 20 August 2012 **PROJECT No.** 09-1373-1004 P9700

TO Dr. Rick Schryer
Fortune Minerals Limited

CC Lasha Young, Jen Range, Gary Ash

FROM John Faithful, Ken Bocking, Rein Jaagumagi

EA 0809-004 FORTUNE MINERALS LIMITED NICO PROJECT
RESPONSE TO REQUEST FOR CLOSURE SCENARIO ANALYSIS

1.0 INTRODUCTION

On 24 July 2012, Fortune Minerals Limited (Fortune) received a letter from Mackenzie Valley Environmental Impact Review Board (MVEIRB) requesting closure scenario analysis. Fortune has considered the concerns outlined by interested parties and has made several refinements to the closure plan. The intent of this memo is to provide detailed responses to MVEIRB's requests.

Fortune commissioned Golder to provide a written response to MVEIRB's 24 July 2012 letter. Fortune commissioned Lorax Environmental (Lorax) and of Contango Strategies Limited (CSL) to support the information supplied by Golder. Full reports by CSL and Lorax are provided as attachments to this memo and have been summarized by Golder for incorporation into this memo. Unless, otherwise indicated, all references to section numbers are to sections in this memo.

1.1 Response to MVEIRB Requests

For ease of review, requests made by MVEIRB are re-iterated below with corresponding text that directs the reader to the full response within the memo.

MVEIRB Request #1: "*The developer to provide "detailed costing for the changed closure plan, including for all treatment options that have been proposed and to clearly identify the difference in costs if the passive treatment options fails." (from Tłįchǫ Government recommendation #8, Technical Report June 19, 2012)"*:

> **Fortune Response #1:** Treatment options are summarized in Section 11.0. Costs are provided in Section 12.0. Fortune has committed to active flooding in the event it is required, and to not allowing the pit to passively re-fill. Long-term active treatment is no longer considered a required option and, consequently, costs have not been calculated for this scenario. Fortune will demonstrate that the Constructed Wetland Treatment System will provide a "walk-away" solution to water treatment at the NICO mine later in this document.

MVEIRB Request #2: "*The developer should demonstrate the effect of failure of the passive treatment option on the net present value, ie. to compute the present value of the costs incurred in the event of failure of the option, in order to illustrate that this mine is feasible if the water has to be treated forever." (from Tłįchǫ Government recommendation #9, Technical Report June 19, 2012)*"

Fortune Response #2: After consultation with Aboriginal Affairs and Northern Development Canada (AANDC) and consideration of concerns raised by various Parties, Fortune has chosen to actively fill the open pit. Fortune will demonstrate that active filling combined with passive constructed wetland treatment will produce a closure scenario that will result in minimal changes to water quality at closure, through water quality modelling and a health risk assessment.

MVEIRB Request #3: "*One of the biggest concerns raised by parties is the possible need for perpetual active water treatment after mine closure. Although active water treatment has been identified as a contingency measure for poor water quality after the pit overflows, Fortune has not provided an indication of the relative likelihood of needing to employ this contingency. Please provide the Review Board with an estimate of this likelihood, with rationale, that is as quantitative as possible (for example, as a percentage). What additional data or information would Fortune need to refine this estimate of likelihood, for example, to a high (90%) degree of confidence?*"

Fortune Response #3: Fortune will commit to actively filling the open pit should be it necessary to mitigate water quality issues at closure. As several technological advances are being made in the field of in-pit water treatment and water management so alternatives will be examined on an on-going basis through the life of mine. Should treatment be required, Fortune has engaged the services of Contango Strategies Limited (CSL) in conjunction with their partners at Native Plant Solutions (NPS/DUC; a division of Ducks Unlimited Canada) and Drs. John Rodgers and James Castle (of Clemson, South Carolina). This team has prepared a work plan (Attachment A) to design and undertake a series of feasibility studies to confirm the performance of a Constructed Wetland Treatment System (CWTS) for removal of chemicals of potential concern (CoPCs) from the water (Section 12). Every CWTS they design and implement is created on a case-by-case basis, tailored to the specific water needing renovation and site-specific requirements. The CSL team has reviewed the post-closure water quality predictions for both the Co-Disposal Facility (CDF) and the open pit and based on their experience in dealing with similar situations, they are highly confident that they can design and implement a CWTS for treatment of water post-closure at the NICO site. Therefore, Fortune is highly confident that perpetual active treatment at the NICO site will not be required.

MVEIRB Request #4: "*Some parties have recommended that the pit be actively filled within 10 years, consistent with the information provided in 9.4.3.4 of the DAR; however, supporting details for the accelerated filling scenario have not been provided. Please provide detailed information regarding the accelerated filling scenario (from the Marian River), including the timeline, prediction of final pit water quality, and an evaluation of potential impacts to the Marian River, if any*."

Fortune Response #4: Section 6.0 and 8.0 provides detailed information on water quantity and water quality under an active filling scenario, respectively. Fortune has included estimates of the time it would take to fill the pit and the amount it would overflow as well as the water quality in the Marian River after the pit has overflowed (Section 13). As with the CWTS, Fortune sought a second assessment of open pit flooding scenarios from Lorax to add certainty to these estimates (Attachment E). Lorax estimate a lower open pit flow than Golder. Attachment A details the CWTS developments plans. Section 6.0 and Attachment D outline the timelines for the accelerated filling scenario. To provide context to the requests from MVEIRB regarding water quality post-closure, Fortune has also provided a summary of site-specific water quality objectives (SSWQOs) (Section 2.0). Section 14 outlines the human health risks in the Marian River under an active flooding scenario.

MVEIRB Request #5: "*At closure, the contingency plan in the event of poor water quality is active water treatment. Please describe, in detail, the proposed plan for financing the closure contingency of long-term active water treatment. What are the assumptions of the plan (investment returns, inflation and economic business as usual")? What are the major sensitivities of the plan (for example, which might affect the amount or accessibility of funds on different timescales)? Can you provide examples of this type of financial arrangement from other jurisdictions?*"

> **Fortune Response #5:** Costs for passive water treatment are provided in Section 12.0. Fortune is committed to providing options that do not require maintenance into perpetuity. Therefore, Fortune is planning to design CWTS' that do no require maintenance one they are established and are confirmed to be functioning appropriately. In summary, Fortune will demonstrate that the CWTS have a very high probability of success and that the risk of failure is minimal. Details on the CWTS are provided in Section 10.0. To help facilitate an understanding how wetlands remove nutrients and metals, Fortune has provided a summary of the baseline water quality in the existing wetlands in the NICO Project area (i.e., Grid Pond, Little Grid Pond, and unnamed wetland) (Section 3.0). To provide context for post-closure health risks, baseline risks from the natural wetlands are provided in Section 4.0.

MVEIRB had asked Fortune to provide quantification of predictions. Fortune cannot provide quantification given the complexity of all of the inputs into predictions. However, Fortune has provided qualitative statements describing likelihood and confidence of predictions throughout this memo and summarized in Section 15.0.

1.2 Summary of Likelihood Statements

Likelihood estimates are based on a fundamental understanding of environmental conditions within the NICO Project area at baseline, through the life of mine, and post-closure. Quantitative estimates were not provided due to the complexity of the project elements being assessed for likelihood of performance. Where uncertainty exists, the most conservative approach was taken to provide confidence that the predictions take into account the worst possible case scenario. Therefore, while there is uncertainty inherent in the predictions and modelling, Fortune is confident the actual conditions at the NICO Project will be no worse than predicted. The final conditions may be better than predicted, but that cannot be quantified at this time. Table 1-1 summarizes likelihood statements.

Table 1-1: Summary of Likelihood Statements

Project Component	Likelihood Statement
Overflow from the open pit	Fortune is highly confident that the open pit will overflow regardless of how it is filled.
Volume of water from open pit overflow	Fortune is confident that open pit overflow will not be greater than 169,000 m^3 per year. An option exists to reduce this flow considerably.
Co-Disposal Facility (CDF) water requiring treatment	Fortune is highly confident that seepage/run-off water from the CDF will require treatment through a Constructed Wetland Treatment System (CWTS).
Open pit requiring treatment	Fortune is committing to actively filling the open pit which will take approximately 12 years to complete. In-pit treatment options will be implemented, if required. Treatment CWTS will be built for open pit overflow, if required.
Wetlands will perform as expected	Contango and Fortune are highly confident that the CWTS's will ensure that water quality meets site-specific water quality objectives (SSWQOs) based on past experience and a strong work plan that will prove this technology early in the project life.
CDF not performing to expectations	Fortune is confident in the seepage quality estimates provided. The cover infiltration estimate is a level of performance that can be readily attained in the climate at the NICO Project, based on both detailed designs and case histories of actual soil cover performance at other sites in similar climates.
Post-closure water quality	Fortune is committed to mitigation measures such as a CWTS, actively filling the open pit and in-pit treatment to meet SSWQOs. Fortune is confident that the modelled water quality projections for the Marian River will not affect traditional uses of the river when these mitigations measures are implemented.
Post-closure health risk	Fortune is highly confident that adverse effects on receptors are not likely to occur in Nico, Peanut, and Burke lakes and the Marian River. The inclusion of CWTS provides an added measure of assurance that adverse effects on surface waters from the open pit will not occur during closure and post-closure.

2.0 CLOSURE OBJECTIVES AND UPDATED SITE-SPECIFIC WATER QUALITY OBJECTIVES

Site-specific water quality objectives (SSQWOs) were derived to help guide the design of the water treatment system for the NICO Project and to provide a basis for assessing potential impacts on aquatic life. As well, the Terms of Reference (TOR) for the NICO Project notes that SSWQOs are to be proposed for all CoPCs identified for the NICO Project to protect downstream water quality (MVRB 2009).

The approach to the development of SSWQOs is adopted from the approaches developed by the Canadian Council of Minsters of the Environment (CCME) and provincial agencies in the development of the Canadian Water Quality Guidelines (CWQGs). The approach is based on the following: (i) the overall objective of the CWQGs for the protection of aquatic life: *to be protective of the most sensitive species, in the most sensitive life stage, over an indefinite period of exposure*; (ii) the policy objectives and guiding principles as described in the Mackenzie Valley Land and Water Board & Effluent Quality Management Policy, dated 29 April 2010; and (iii) the effluent discharge limits for mining projects in the NWT (INAC 2009).

The numerical CWQGs for the protection of aquatic life are considered generic, since they are intended for application in all regions of Canada and do not make allowance for regional differences. Guidelines based on bulk water concentrations of metals can be overly conservative in some situations, due to the influence of local factors. Recognizing this, the CCME (2003) has provided methods for calculating site-specific objectives.

Based on this understanding, the development of SSWQOs for the NICO Project was generally conducted through the following step-wise approach:

- available toxicity literature was reviewed to characterize biological effect levels that correspond to concentrations of toxicity modifying parameters specific to each metal of concern;
- existing water quality was characterized with respect to metals of concern in Nico Lake and Peanut Lake;
- baseline aquatic ecology data were reviewed to identify species of aquatic biota that are present within Nico Lake and Peanut Lake; and
- site-specific toxicity concentrations were developed for each metal of concern that are protective of the most sensitive receptor in Nico Lake and Peanut Lake.

The SSWQOs have been derived for the waterbodies receiving Project discharge (i.e., Nico and Peanut lakes). Potential impacts downstream on Burke Lake and the Marian River were assessed relative to appropriate toxicity benchmarks that were derived on a similar basis to the SSWQOs. Site-specific water quality objectives were developed where predicted concentrations exceeded CCME CWQGs and average baseline concentrations +10%. Baseline concentrations are based on measured baseline data as provided in the DAR for each of the waterbodies. Measured baseline water quality data (average measured baseline concentrations +10%) and predicted water quality data for post-closure are provided in Attachment B.

Identification of the CoPCs during closure and post-closure is based on a comparison of the predicted water quality in the receiving waterbodies (Nico, Peanut, and Burke lakes, and Marian River) from the CDF and open pit overflow. To be conservative, the comparison excludes wetland treatment. The predicted water concentrations in Table B-1 (attached) are based on seepage from the CDF flowing into Nico Lake, while overflow from the open pit would be directed to Peanut Lake.

To take a conservative approach, water quality in post-closure was assessed without wetland treatment. Where predicted water quality without wetland treatment exceeds the average measured baseline concentration +10% and the SSWQO, the parameter is identified as a CoPC and is carried forward for further assessment. These are highlighted in Table B-1, attached. No CoPCs were identified with implementation of wetland treatment. These CoPCs are also carried forward in the wildlife risk assessment to assess whether there are risks to terrestrial receptors from consuming surface waters. Concentrations of metals and major ions (provided in Table B-1) that are similar to baseline concentrations, or that do not exceed the SSWQOs, are considered to present no risk to aquatic life or to terrestrial receptors and are not assessed further.

The SSWQOs are values that would be protective of aquatic life under the specific conditions within each of the receiving water bodies. They are not to be considered as effluent criteria.

The specific approaches used to derive the SSWQOs for the identified CoPCs are detailed in Appendix B of the Developer's Assessment Report (DAR) (Fortune 2011).

Table 2-1 summarizes the SSWQOs for the identified CoPCs for Nico Lake and Peanut Lake. The SSWQOs include only those CoPCs that were identified during the post-closure phase of the NICO Project as exceeding the CWQGs and average measured baseline concentrations +10%. There are no predicted exceedances of the SSWQOs in Nico, Peanut, and Burke lakes and the Marian River in post-closure when passive wetland treatment is included.

Table 2-1: Proposed Site-Specific Water Quality Objectives for the NICO Project

Chemicals of Potential Concern	CCME CWQG for the Protection of Aquatic Life[a] (µg/L)	Site-Specific Water Quality Objective[b] (µg/L)
Arsenic	5	50
Cobalt	NV	10
Iron	300	1,500
Lead	1[c]	1
Selenium	1	3.5

[a] Canadian Council of Ministers of the Environment (CCME) Canadian Water Quality Guideline (CWQGs) for the Protection of Aquatic Life.

[b] Site-Specific Water Quality Objective applies to both Nico Lake and Peanut Lake.

[c] The minimum CCME CWQG, regardless of water hardness.

µg/L = microgram per litre; NV = No guideline value.

3.0 BASELINE WATER QUALITY AND WETLAND CHARACTERISTICS

The existing wetlands at the NICO Project site consist of Grid Pond, Little Grid Pond, and an unnamed wetland east of Little Grid Pond, which form the upper watershed system of the Burke Lake watershed (Photo 3-1). Grid Pond is primarily fed by an upwelling groundwater stream on the northwest side of the pond, and Little Grid Pond is fed by a stream flowing south of Grid Pond. Flow from Little Grid Pond to Nico Lake passes through a wetland that exists approximately 200 metres (m) downstream of Little Grid Pond, which has a large beaver dam on its downstream side. Both Grid Ponds have maximum depths of 2 m or less, suggesting that they freeze to the substrate in winter.

The shoreline of Grid Pond features primarily cobble/gravel substrate, with a small area of boulder/cobble substrate on the northeast shoreline. The main basin and a small area along the north shoreline are composed of organic/silt substrate. The entire basin of Little Grid Pond is dominated by organics/silt substrate, with a large proportion of the lake shoreline covered by emergent and inundated vegetation. A small unnamed wetland is present at the east end of the pond were the outflow is located, although no distinct surface flow towards Nico Lake is evident.

Fish have not been observed or collected during baseline surveys from Grid Pond, Little Grid Pond, and the unnamed wetland. It is considered that these waterbodies likely do not support fish communities due to the highly mineralized water chemistry (e.g., elevated metals, particularly arsenic and copper) in the ponds and wetlands, the lack of distinct passage to Nico Lake from Little Grid Pond, and shallow depths that suggest the ponds and wetlands freeze to the substrate in the winter.

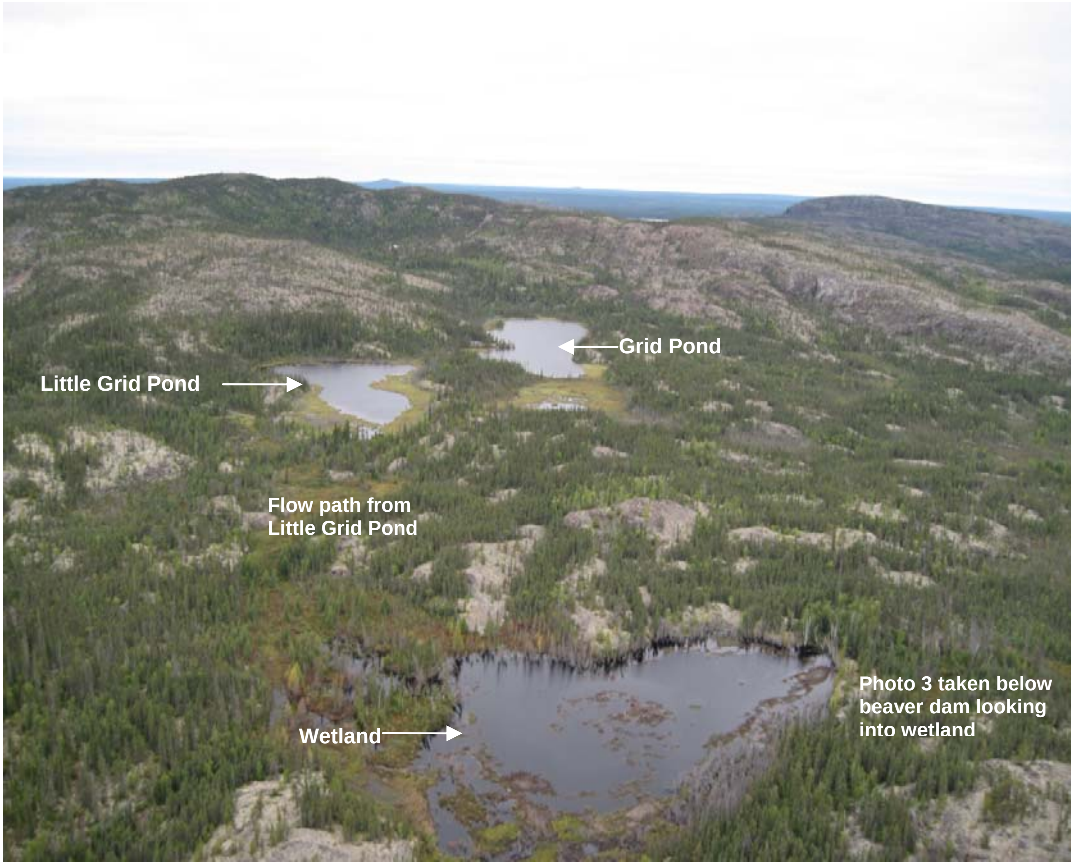

Photo 3-1: Aerial View of Wetland (foreground) Downstream of Little Grid Pond

Grid Pond System

Characterization of the water quality of the Grid Pond system is based on baseline water quality data collected from 2003 to 2010, for open water and under-ice conditions. This data are presented in Appendix IV, Table IV-2, of the Aquatics baseline report (Annex C of the DAR).

In general, the Grid Ponds can be described as clear, calcium bicarbonate-dominated ponds with water chemistry that is characteristically different compared to other local study area waterbodies. These ponds have moderately hard water and substantially higher total ion concentrations, as indicated by a higher specific conductance and total dissolved solid (TDS) values, compared to the downstream waterbodies of the Burke Lake watershed. Seasonal differences in major ions have also been measured, with hardness, alkalinity, specific conductance, and turbidity levels two to three - times higher during late under-ice conditions compared to open water periods. Winter (under-ice) concentration of major ions is commonly measured in northern lakes, particularly those that are shallow and isolated during the winter period.

The Grid Ponds have been shown to be well mixed in open water conditions, which is typical of shallow waterbodies that experience greater mixing due to wind exposure. During open-water, dissolved oxygen (DO) concentrations are typically below the CWQG for the protection of early stages of aquatic life (9.5 milligrams per litre [mg/L]), but above the CWQG for other life stages (6.5 mg/L). During under-ice conditions in late winter, DO concentrations have been measured as low as 0.3 mg/L, but this is not unusual for waterbodies with muskeg watersheds (e.g., McEachern and Noton 2002) or shallow ponds with organic substrates in the sub-arctic (e.g., Golder 2009).

Baseline nutrient concentrations in the Grid Ponds are higher than typically expected for sub-arctic waterbodies. Total phosphorus (TP) data (0.018 to 0.1 mg P/L) indicate that these ponds can be classified as mesotrophic to eutrophic (productive) waterbodies (EC 2004); however, based on the predominance of higher TP concentrations throughout the year, they can be characterized as eutrophic. Total nitrogen (TN) concentrations have been measured between 0.31 and 3.30 mg N/L, which represents a larger concentration range than is typical in northern sub-arctic waterbodies.

Metals and metalloids (metals) concentrations in the Grid Ponds are characterized primarily by elevated arsenic and iron concentrations (Tables 3-1 and 3-2), which is directly related to the upper watershed of the Grid Pond system being naturally rich in arsenopyrite (iron arsenic sulphide [FeAsS]). In general, measured metals concentrations are below available CWQGs for protection of aquatic life, with the exception of arsenic and copper, which consistently are above guidelines (i.e., 30 to 50 times in the case of arsenic), and cadmium and iron, which are only occasionally above CWQG. Arsenic and copper are mostly present in dissolved forms, which are considered to be potentially more bioavailable to aquatic life; iron was present in both particulate and dissolved forms. There is a strong attenuation of ore-influenced metals from the Grid Pond system through the Burke Lake watershed to the Marion River (e.g., arsenic, Figure 3-1). The strong attenuation gradient between the Grid Ponds and Burke Lake is not as notable for the remaining metals.

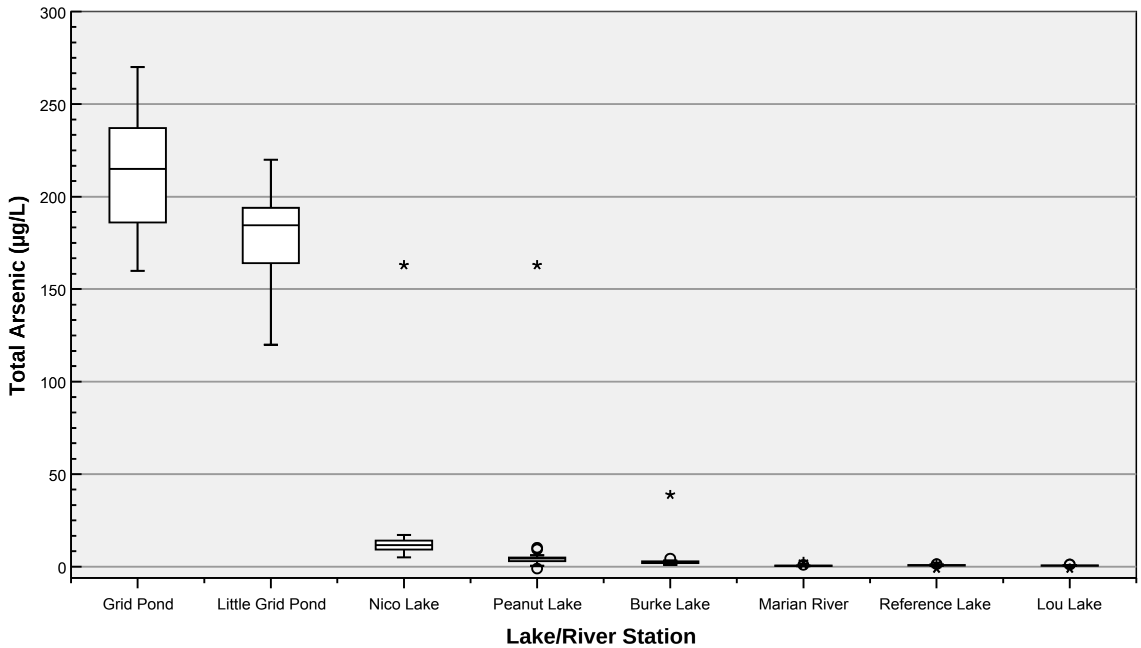

Figure 3-1: Attenuation of Baseline Total Arsenic Concentrations Measured Through the Burke Lake Watershed, Including Marian River, Reference Lake, and Lou Lake

Note: The length of the boxplot represents the inter-quartile range (25^{th} to 75^{th} inter-quartiles) with the median denoted by the dark horizontal line. The whiskers represent the minimum and maximum values of the dataset unless outliers are present, in which case the whiskers extend to a maximum of the 1.5 times the inter-quartiles range. Outliers (circles) are values that fall between 1.5 and 3 box lengths from the upper and lower edges of the box, and extreme cases (stars) are values that are more than 3 box lengths from the upper and lower edge of the box.

µg/L = micrograms per litre

Table 3-1: Summary of Baseline Surface Water Quality in Grid Pond (2003 to 2010)

Parameter Name	Unit	Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Field measured												
pH	pH units	3	**5.2**[c]	**6.33**[c]	6.9	7	**6.4**[c]	7.3	7.8	6.5 - 9[d]	67%	14%
Temperature	°C	4	0	0.76	2.4	7	10.1	15.1	18.9	-	-	-
Specific Conductance	µS/cm	3	62.6	349	372	7	122	197	316	-	-	-
Dissolved Oxygen	mg/L	4	**1.19**[c]	1.51[c]	**5.02**[c]	7	8.3	9.66	10.21	6.5 or 9.5[e]	100%/100%	0%/43%
Turbidity	NTU	3	4.6	29.9	46.7	5	1.12	1.89	49.2	-	-	-
Secchi depth	m	1	-	1.8	-	3	0.9	1.5	1.6	-	-	-
Conventional Parameters												
Specific Conductance	µS/cm	3	349	410	424	10	125	189	217	-	-	-
Dissolved Organic Carbon	mg/L	2	8.3	-	9.7	5	8.6	9.7	11.6	-	-	-
Hardness	mg/L	3	165	190	192	10	53.2	90.5	100	-	-	-
pH	pH units	3	7.6	7.7	7.8	10	7.6	7.9	8.1	6.5 - 9[d]	0%	0%
Total Alkalinity, as $CaCO_3$	mg/L	3	111	130	140	8	38	57.8	60	-	-	-
Total Dissolved Solids	mg/L	1	-	239	-	4	114	125	150	-	-	-
Total Organic Carbon	mg/L	2	8.6	-	10	7	8	10	12.4	-	-	-
Total Suspended Solids	mg/L	3	1.5	2	4	7	1.5	3	4	-	-	-
Turbidity	NTU	2	1.9	-	2.3	6	0.5	0.98	4.5	-	-	-
Major Ions												
Bicarbonate, as $CaCO_3$	mg/L	3	136	160	171	8	46	70.2	73	-	-	-
Calcium	mg/L	3	42.7	51	51.5	10	13.7	22.6	26.1	-	-	-
Carbonate, as $CaCO_3$	mg/L	3	<5	-	<1	8	<5	-	<0.5	-	-	-
Chloride	mg/L	3	0.25	1	1	9	0.3	1	3	230	0%	0%
Magnesium	mg/L	3	14.2	15.3	16	10	4.6	8.0	8.7	-	-	-
Potassium	mg/L	3	2.4	2.6	3	10	1.2	1.7	2	-	-	-
Sodium	mg/L	3	5.4	6	8.4	10	2.6	4	4.4	-	-	-
Sulphate	mg/L	3	66.4	72.7	78	8	20	34.8	37.2	-	-	-
Nutrients												
Nitrate	mg N/L	3	<0.2	-	<0.05	10	0.001	0.0115	0.3	2.93	0%	0%
Nitrite	mg N/L	3	<0.06	-	<0.05	10	<0.05	-	<0.002	0.06	0%	0%

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Table 3-1: Summary of Baseline Surface Water Quality in Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Nitrate + Nitrite	mg N/L	3	<0.2	-	<0.071	10	0.001	0.0115	0.3	2.93	0%	0%
Nitrogen - Ammonia	mg N/L	3	0.41	0.417	0.54	10	0.0025	0.0283	0.065	0.019[f]	0%	0%
Nitrogen - Kjeldahl	mg -N/L	3	0.84	1.2	1.23	10	0.3	0.445	0.705	-	-	-
Nitrogen (N), Total	mg/L	1	-	<1	-	3	0.43	0.48	0.57	-	-	-
Phosphorus, total	mg/L	3	0.0188	0.021	0.06	9	0.0271	0.068	0.1	50	0%	0%
Phosphorus, dissolved	mg/L	2	0.0147	-	0.05	4	0.0109	0.0135	0.05	-	-	-
Total Metals												
Aluminum	µg/L	3	26	37	40	11	44.3	69	**200**[c]	5-100[g]	0%	18%
Antimony	µg/L	3	0.68	0.7	0.8	11	0.8	1.1	2.4	-	-	-
Arsenic	µg/L	3	**186**[c]	**190**[c]	**270**[c]	11	**160**[c]	**217**[c]	**257**[c]	5	100%	100%
Barium	µg/L	3	13.4	17.3	20	11	5	7.2	16.2	-	-	-
Beryllium	µg/L	3	<1	-	<1	11	<2	-	0.05	-	-	-
Bismuth	µg/L	1	-	<0.1	-	9	<1000	-	0.1	-	-	-
Boron	µg/L	3	<50	-	<20	11	10	14.5	25	1500	0%	0%
Cadmium	µg/L	3	0.01	0.08	**0.1**[c]	11	<1	-	**0.074**[c]	0.017[h]	33%	9%
Cesium	µg/L	1	-	<50	-	8	<50	-	0.04	-	-	-
Chromium	µg/L	3	<1	-	<0.8	11	0.1	0.655	**2.6**[c]	1	0%	18%
Cobalt	µg/L	3	10.4	11.7	20	11	4.19	5.5	7.3	-	-	-
Copper	µg/L	3	**6**[c]	**8**[c]	**8.6**[c]	11	**8.35**[c]	**11**[c]	**19**[c]	2-4[i]	100%	100%
Iron	µg/L	3	**694**[c]	**1120**[c]	**1300**[c]	11	43	71	113	300	100%	0%
Lead	µg/L	3	0.1	0.11	0.5	11	0.025	0.165	**2.5**[c]	1-7[j]	0%	0%
Lithium	µg/L	3	<20	-	<6	11	1.8	2.55	5	-	-	-
Manganese	µg/L	3	50	73	84	11	2	2.62	6.82	-	-	-
Mercury	µg/L	3	<0.1	-	<0.02	11	<0.2	-	0.02	0.026	0%	0%
Molybdenum	µg/L	3	2.5	2.8	3.8	11	2.1	2.7	3.9	73	0%	0%
Nickel	µg/L	3	1	1.7	2.5	11	0.25	0.8	6.6	25-150[k]	0%	0%
Rubidium	µg/L	1	-	<50	-	8	2.4	2.5	25	-	-	-
Selenium	µg/L	3	0.2	0.5	0.5	11	<0.5	-	0.15	1	0%	0%
Silicon	µg/L	1	-	4700	-	3	1270	1730	2190	-	-	-

Table 3-1: Summary of Baseline Surface Water Quality in Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Silver	µg/L	3	<0.4	-	<0.1	11	<5	-	<0.005	0.1	0%	0%
Strontium	µg/L	2	117	-	120	9	38.6	58.7	65.4	-	-	-
Sulphur	µg/L	1	-	25000	-	1	-	14000	-	-	-	-
Thallium	µg/L	3	<0.2	-	<0.1	11	<50	-	0.004	0.8	0%	0%
Tin	µg/L	3	0.2	5	25	10	<50	-	0.07	-	-	-
Titanium	µg/L	3	0.5	3	3	11	0.25	1	32	-	-	-
Uranium	µg/L	3	4.9	6.9	7.8	11	1.4	2.9	25	-	-	-
Vanadium	µg/L	3	0.1	1	1	11	0.1	0.25	2.7	-	-	-
Zinc	µg/L	3	4.7	6	15	11	2	6	14	30	0%	0%
Zirconium	µg/L	0	-	-	-	2	<5	-	<5	-	-	-
Dissolved Metals												
Aluminum	µg/L	3	18.3	23	30	9	27.9	49.7	62.5	-	-	-
Antimony	µg/L	3	0.1	0.68	0.8	9	0.79	1.1	1.5	-	-	-
Arsenic	µg/L	3	146	159	220	9	150	208	254	-	-	-
Barium	µg/L	3	10	13.8	18.3	9	4.9	7	10	-	-	-
Beryllium	µg/L	3	<1	-	<0.5	9	<1	-	0.01	-	-	-
Bismuth	µg/L	1	-	<0.05	-	7	<1000	-	0.05	-	-	-
Boron	µg/L	3	10	18	25	9	6	10.5	25	-	-	-
Cadmium	µg/L	3	0.03	0.04	0.05	9	0.005	0.017	0.5	-	-	-
Cesium	µg/L	1	-	<0.1	-	6	<50	-	0.03	-	-	-
Chromium	µg/L	3	<1	-	<0.4	9	0.1	1.1	2.5	-	-	-
Cobalt	µg/L	3	9	9.5	11	9	3.24	4	6.8	-	-	-
Copper	µg/L	3	3.6	3.7	4.5	9	6.2	9.8	15.7	-	-	-
Iron	µg/L	3	441	873	1300	9	15	41	64	-	-	-
Lead	µg/L	3	0.05	0.2	0.2	9	0.04	0.05	2.5	-	-	-
Lithium	µg/L	3	3.4	3.4	10	9	1.5	2	5	-	-	-
Manganese	µg/L	3	48	76	78	9	0.5	1.8	3	-	-	-
Mercury	µg/L	3	<0.1	-	<0.02	8	<0.2	-	<0.01	-	-	-
Molybdenum	µg/L	3	2.4	2.5	2.7	9	1.8	2.5	2.82	-	-	-

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Table 3-1: Summary of Baseline Surface Water Quality in Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Nickel	µg/L	3	1	1.7	2.4	9	0.2	0.39	1	-	-	-
Rubidium	µg/L	1	-	<50	-	6	2.6	2.6	25	-	-	-
Selenium	µg/L	3	<1	-	<0.4	9	<0.5	-	0.8	-	-	-
Silicon	µg/L	1	-	5000	-	3	1360	1680	2460	-	-	-
Silver	µg/L	3	<0.2	-	<0.1	9	<5	-	<0.005	-	-	-
Strontium	µg/L	2	120	-	123	7	35.9	52.8	67	-	-	-
Thallium	µg/L	3	<0.2	-	<0.05	9	<50	-	0.004	-	-	-
Tin	µg/L	3	0.1	7	25	9	<50	-	0.15	-	-	-
Titanium	µg/L	3	0.5	1	1	9	<1	-	0.6	-	-	-
Uranium	µg/L	3	5.2	6.3	6.5	9	1.4	2.9	25	-	-	-
Vanadium	µg/L	3	0.05	2	2	9	0.2	0.26	0.5	-	-	-
Zinc	µg/L	3	4.5	8	12	9	1.4	5	13.5	-	-	-
Zirconium	µg/L	0	-	-	-	3	<5	-	<0.1	-	-	-

[a] Ice cover season defined as November through April.
[b] Open water season defined as May through October.
[c] Result exceeds Canadian Council of the Minister of the Environment Protection of Freshwater Aquatic Life Guideline (CCME 1999), is beyond the pH guideline range, or is below the minimum DO guideline.
[d] Guideline represents a range.
[e] 6.5 = Guideline for early life stages in cold water, 9.5 = Guideline is for other life stages in cold water; exceedance summary reflects percentage of observations below the respective guideline values.
[f] Guideline is for un-ionized ammonia; total ammonia guideline concentrations were calculated using sample specific pH and temperature values for comparison to analytical results.
[g] 5.0 for pH<6.5, 100 for pH≥6.5.
[h] Cadmium Guideline = $10^{(0.86(\log(\text{hardness}))-3.2)}$
[i] 2 µg/L at hardness of 0 to 120 mg/L, 3 µg/L at hardness of 120 to 180 mg/L, 4 µg/L at hardness of > 180 mg/L.
[j] 1 µg/L at hardness of 0 to 60 mg/L, 2 µg/L at hardness of 60 to 120 mg/L, 4 µg/L at hardness of 120 to 180 mg/L, 7 µg/L at hardness of > 180 mg/L.
[k] 25 µg/L at hardness of 0 to 60 mg/L, 65 µg/L at hardness of 60 to 120 mg/L, 110 µg/L at hardness of 120 to 180 mg/L, 150 µg/L at hardness of > 180 mg/L.
n = number of samples; mg/L = milligrams per litre; °C = degrees Celcius; µS/cm = microSiemens per centimeter; NTU = Nephelometric turbidity units; mg-N/L = milligram nitrogen per litre; µg/L = micrograms per litre; percent represents percent of results per season per water body that was above guidelines; CCME = Canadian Council of the Ministers of Environment; PFAL = Protection of Freshwater Aquatic Life.
Bold values indicate summary statistic exceeding a guideline.

Table 3-2: Summary of Baseline Surface Water Quality in Little Grid Pond (2003 to 2010)

Parameter Name	Unit	Little Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Field measured												
pH	pH units	3	**5.03**[c]	**6.17**[c]	6.8	5	**6.28**[c]	6.9	7.3	6.5 - 9[d]	67%	20%
Temperature	°C	4	0.72	1.1	2.1	6	6.9	14.8	18.2	-	-	-
Specific Conductance	µS/cm	3	72.7	335	368	6	115	182	784	-	-	-
Dissolved Oxygen	mg/L	4	**0.33**[c]	**0.83**[c]	**3.06**[c]	6	6.8	8.31	9.36	6.5 or 9.5[e]	100%/100%	0%/100%
Turbidity	NTU	3	36.4	42	69.2	4	1.7	3.2	7.3	-	-	-
Secchi depth	m	0	-	-	-	3	0.55	1.3	1.4	-	-	-
Conventional Parameters												
Specific Conductance	µS/cm	3	359	369	400	10	123	176	210	-	-	-
Dissolved Organic Carbon	mg/L	2	10.6	-	11.1	5	9	10.2	11.6	-	-	-
Hardness	mg/L	3	160	170	200	10	55	81.7	102	-	-	-
pH	pH units	3	7.56	7.6	7.8	10	7.5	7.75	7.96	6.5 - 9[d]	0%	0%
Total Alkalinity, as $CaCO_3$	mg/L	3	122	140	140	8	37	57.5	62.4	-	-	-
Total Dissolved Solids	mg/L	1	-	235	-	4	80	107	130	-	-	-
Total Organic Carbon	mg/L	2	10.5	-	13	7	9	10.7	12.7	-	-	-
Total Suspended Solids	mg/L	3	4	4	7	8	1.5	4	14	-	-	-
Turbidity	NTU	2	1.3	-	2.2	6	0.55	1.35	12	-	-	-
Major Ions												
Bicarbonate, as $CaCO_3$	mg/L	3	149	170	171	8	45	70.5	76.1	-	-	-
Calcium	mg/L	3	41.8	43.5	51	10	13.8	20.7	25.8	-	-	-
Carbonate, as $CaCO_3$	mg/L	3	<5	-	<1	8	<5	-	<0.5	-	-	-
Chloride	mg/L	3	0.5	0.77	2	10	0.3	1.5	6.2	230	0%	0%
Magnesium	mg/L	3	13.5	15	17	10	4.9	7.5	9.1	-	-	-
Potassium	mg/L	3	2.4	3.4	3.4	10	1.1	1.5	1.9	-	-	-
Sodium	mg/L	3	5.9	6	8.8	10	3	3.8	4.7	-	-	-
Sulphate	mg/L	3	51.8	52.8	68	8	19.2	25.3	31	-	-	-
Nutrients												
Nitrate	mg N/L	3	0.191	0.6	0.8	10	0.003	0.127	0.2	2.93	0%	0%
Nitrite	mg N/L	3	<0.06	-	<0.05	10	<0.05	-	0.003	0.06	0%	0%

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Table 3-2: Summary of Baseline Surface Water Quality in Little Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Little Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Nitrate + Nitrite	mg N/L	3	0.191	0.6	0.8	10	0.003	0.13	0.2	2.93	0%	0%
Nitrogen - Ammonia	mg N/L	3	0.58	0.68	0.697	10	0.0141	0.0295	0.204	0.019[f]	0%	0%
Nitrogen - Kjeldahl	mg N/L	3	1.74	1.9	2.7	10	0.4	0.55	0.812	-	-	-
Nitrogen (N), Total	mg/L	1	-	2	-	3	0.6	0.7	0.8	-	-	-
Phosphorus, total	mg/L	3	0.0193	0.026	0.07	9	0.0311	0.076	0.1	50	0%	0%
Phosphorus, dissolved	mg/L	2	0.014	-	0.05	4	0.0118	0.0131	0.05	-	-	-
Total Metals												
Aluminum	µg/L	3	23	26.9	40	11	30	42.2	**170**[c]	5-100[g]	0%	18%
Antimony	µg/L	3	0.52	1	1	11	0.53	0.78	3.2	-	-	-
Arsenic	µg/L	3	**120**[c]	**168**[c]	**220**[c]	11	**129**[c]	**191**[c]	**207**[c]	5	100%	100%
Barium	µg/L	3	14.8	16.4	20	11	5.4	8.22	11.4	-	-	-
Beryllium	µg/L	3	<1	-	<1	11	<2	-	0.01	-	-	-
Bismuth	µg/L	1	-	<0.1	-	9	<1000	-	0.008	-	-	-
Boron	µg/L	3	<50	-	<20	11	<50	-	16	1500	0%	0%
Cadmium	µg/L	3	0.03	0.06	**0.1**[c]	11	0.005	0.01	**0.5**[c]	0.017[h]	0%	0%
Cesium	µg/L	1	-	<50	-	8	<50	-	0.04	-	-	-
Chromium	µg/L	3	<1	-	<0.8	11	0.1	0.355	**2.5**[c]	1	0%	9%
Cobalt	µg/L	3	7.1	12.6	19	11	3.2	4	7.7	-	-	-
Copper	µg/L	3	**4**[c]	**8.5**[c]	**10**[c]	11	**4.2**[c]	**6**[c]	**14**[c]	2-4[i]	100%	100%
Iron	µg/L	3	**544**[c]	**920**[c]	**1300**[c]	11	11	92	**1020**[c]	300	100%	9%
Lead	µg/L	3	0.05	0.2	0.6	11	0.03	0.06	**2.5**[c]	1-7[j]	0%	0%
Lithium	µg/L	3	<20	-	<6	11	1.8	2.3	5	-	-	-
Manganese	µg/L	3	56	60.7	63	11	2.5	6.3	25	-	-	-
Mercury	µg/L	3	<0.1	-	<0.02	11	<0.2	-	<0.01	0.026	0%	0%
Molybdenum	µg/L	3	2.5	3.5	5.8	11	1	2.7	4.5	73	0%	0%
Nickel	µg/L	3	1	2.3	2.7	11	0.1	0.655	2.9	25-150[k]	0%	0%
Rubidium	µg/L	1	-	<50	-	8	2.5	2.7	25	-	-	-
Selenium	µg/L	3	<1	-	<0.4	11	<0.5	-	0.5	1	0%	0%
Silicon	µg/L	1	-	3900	-	3	270	1670	2150	-	-	-

Table 3-2: Summary of Baseline Surface Water Quality in Little Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Little Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Silver	µg/L	3	<0.4	-	<0.1	11	<5	-	<0.005	0.1	0%	0%
Strontium	µg/L	2	96.9	-	120	9	37.4	56.2	68.1	-	-	-
Sulphur	µg/L	1	-	22000	-	1	-	11000	-	-	-	-
Thallium	µg/L	3	<0.2	-	<0.1	11	<50	-	0.004	0.8	0%	0%
Tin	µg/L	3	0.2	9	25	10	<50	-	0.6	-	-	-
Titanium	µg/L	3	0.5	2	2.5	11	0.25	0.9	2.5	-	-	-
Uranium	µg/L	3	7.4	7.53	12	11	1.4	2.8	25	-	-	-
Vanadium	µg/L	3	0.1	1	1	10	0.1	0.3	1.5	-	-	-
Zinc	µg/L	3	2	10	19	11	2	3.3	13	30	0%	0%
Zirconium	µg/L	0	-	-	-	2	<5	-	<5	-	-	-
Dissolved Metals												
Aluminum	µg/L	3	12	19.6	30	9	20	30	40.5	-	-	-
Antimony	µg/L	3	0.1	0.54	1.2	9	0.54	0.82	1.1	-	-	-
Arsenic	µg/L	3	83.9	100	153	9	135	187	218	-	-	-
Barium	µg/L	3	10	16.9	17.4	9	5.1	7	11.9	-	-	-
Beryllium	µg/L	3	<1	-	<0.5	9	<1	-	0.01	-	-	-
Bismuth	µg/L	1	-	<0.05	-	7	<1000	-	0.008	-	-	-
Boron	µg/L	3	10	16	25	9	7	11.5	25	-	-	-
Cadmium	µg/L	3	0.03	0.11	0.2	9	0.005	0.016	0.5	-	-	-
Cesium	µg/L	1	-	<0.1	-	6	<50	-	<0.03	-	-	-
Chromium	µg/L	3	<1	-	<0.4	9	0.1	0.9	2.5	-	-	-
Cobalt	µg/L	3	6.3	13.3	16	9	2.9	4	10.3	-	-	-
Copper	µg/L	3	2.3	5.8	10.6	9	3.2	4.98	9.4	-	-	-
Iron	µg/L	3	409	410	1030	9	15	62	405	-	-	-
Lead	µg/L	3	0.05	0.4	0.4	9	0.04	0.04	2.5	-	-	-
Lithium	µg/L	3	2.7	2.7	10	9	1.5	2	5	-	-	-
Manganese	µg/L	3	60.2	61	62	9	2	4.6	27	-	-	-
Mercury	µg/L	3	<0.1	-	<0.02	8	<0.2	-	<0.01	-	-	-
Molybdenum	µg/L	3	2.5	3.8	4.4	9	0.8	2.7	3.1	-	-	-

Table 3-2: Summary of Baseline Surface Water Quality in Little Grid Pond (2003 to 2010) (continued)

Parameter Name	Unit	Little Grid Pond								Canadian Council of the Ministers of Environment		
		Ice Cover[a] (2006 - 2010)				Open Water[b] (2003 - 2009)				Protection of Freshwater Aquatic Life		
		n	Minimum	Median	Maximum	n	Minimum	Median	Maximum	Guideline	% Ice-covered Results Above or Outside Guideline	% Open Water Results Above or Outside Guideline
Nickel	µg/L	3	1	2.5	2.6	9	<2	-	0.8	-	-	-
Rubidium	µg/L	1	-	<50	-	6	2.52	2.6	25	-	-	-
Selenium	µg/L	3	<1	-	<0.4	9	<0.5	-	0.7	-	-	-
Silicon	µg/L	1	-	4300	-	3	240	1590	2430	-	-	-
Silver	µg/L	3	<0.2	-	<0.1	9	<5	-	<0.005	-	-	-
Strontium	µg/L	2	109	-	120	7	35.9	49.3	76.6	-	-	-
Thallium	µg/L	3	<0.2	-	<0.05	9	<50	-	0.003	-	-	-
Tin	µg/L	3	0.1	7	25	9	<50	-	0.18	-	-	-
Titanium	µg/L	3	0.5	0.9	1	9	<1	-	<0.3	-	-	-
Uranium	µg/L	3	7.3	8.2	9.9	9	0.8	2.8	25	-	-	-
Vanadium	µg/L	3	0.05	2	2	9	0.05	0.28	0.5	-	-	-
Zinc	µg/L	3	2	15	21	9	0.9	4	10	-	-	-
Zirconium	µg/L	0	-	-	-	3	<5	-	<0.1	-	-	-

[a] Ice cover season defined as November through April.

[b] Open water season defined as May through October.

[c] Result exceeds Canadian Council of the Minister of the Environment Protection of Freshwater Aquatic Life Guideline (CCME 1999), is beyond the pH guideline range, or is below the minimum DO guideline.

[d] Guideline represents a range.

[e] 6.5 = Guideline for early life stages in cold water, 9.5 = Guideline is for other life stages in cold water; exceedance summary reflects percentage of observations below the respective guideline values.

[f] Guideline is for un-ionized ammonia; total ammonia guideline concentrations were calculated using sample specific pH and temperature values for comparison to analytical results.

[g] 5.0 for pH<6.5, 100 for pH≥6.5.

[h] Cadmium Guideline = $10^{(0.86(\log(hardness))-3.2)}$

[i] 2 µg/L at hardness of 0 to 120 mg/L, 3 µg/L at hardness of 120 to 180 mg/L, 4 µg/L at hardness of > 180 mg/L.

[j] 1 µg/L at hardness of 0 to 60 mg/L, 2 µg/L at hardness of 60 to 120 mg/L, 4 µg/L at hardness of 120 to 180 mg/L, 7 µg/L at hardness of > 180 mg/L.

[k] 25 µg/L at hardness of 0 to 60 mg/L, 65 µg/L at hardness of 60 to 120 mg/L, 110 µg/L at hardness of 120 to 180 mg/L, 150 µg/L at hardness of > 180 mg/L.

n = number of samples; mg/L = milligrams per litre; °C = degrees Celcius; µS/cm = microSiemens per centimeter; NTU = Nephelometric turbidity units; mg-N/L = milligram nitrogen per litre; µg/L = micrograms per litre; percent represents percent of results per season per water body that was above guidelines; CCME = Canadian Council of the Ministers of Environment; PFAL = Protection of Freshwater Aquatic Life.

Bold values indicate summary statistic exceeding a guideline

Waterbodies close to the main ore body typically had metal concentrations in sediments that were elevated above CCME guideline concentrations (i.e., arsenic, copper, and zinc). Arsenic in the sediments of Grid Pond and Little Grid Pond consistently exceeded Interim Sediment Quality Guidelines (5.9 milligrams per kilograms [mg/kg]), Probable Effects Level (PEL) (17.0 mg/kg), and Government of the Northwest Territories Remediation Objective (150 mg/kg) guidelines, ranging from 341 to 2,370 mg/kg (note that the highest sediment arsenic concentrations were found in the deeper stations of these ponds). The PEL for copper (197 mg/kg) was exceeded in the sediments of Little Grid and Grid ponds, with concentrations ranging from 57 to 1,120 mg/kg. As noted in the water chemistry, sediment metals concentrations for those metals associated with the ore body, such as arsenic and copper, attenuated through the Burke Lake watershed (Figure 3-2). Sediment selenium concentrations showed a similar but lesser attenuation, with concentrations ranging from 2.6 to 4 mg/kg in the Grid Ponds, 0.6 to 3.6 mg/kg in Nico Lake, and <0.2 to 0.6 in Peanut, Burke, and Lou lakes (sediment selenium in Reference Lake ranged from 0.2 to 0.7mg/kg).

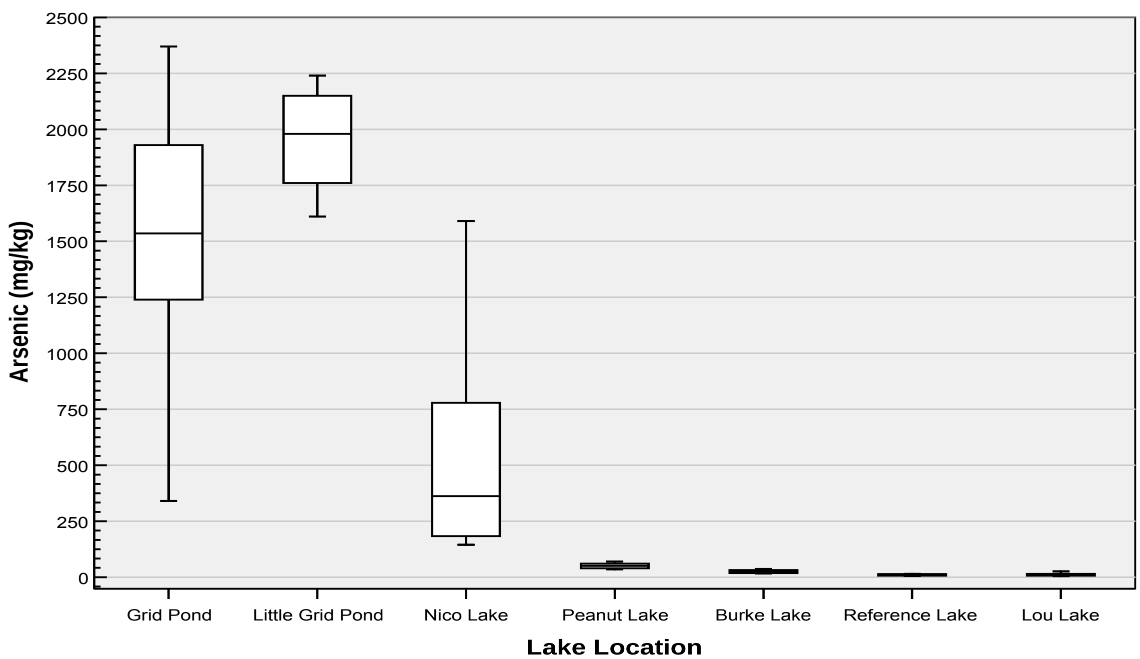

Figure 3-2: Attenuation of Baseline Sediment Arsenic Concentrations Measured Through the Burke Lake Watershed, Including Marian River, Reference Lake, and Lou Lake

Note: mg/kg = milligrams per kilogram as dry weight.

Wetland System Between Little Grid Pond and Nico Lake

The flow path of water exiting Little Grid Pond to Nico Lake was surveyed on two occasions, 25 August 2011 and 12 August 2012, to examine the potential connectivity for fish between the two waterbodies, and to collect water quality samples along the length of the watercourse.

Over most of its length, the watercourse from Little Grid Pond to Nico Lake meandered through sedge meadows and complexes of willows (Photo 3-2). This photo was taken approximately half way between Little Grid Pond and Nico Lake and shows the lack of a distinct channel that would allow for fish passage. A wetland located approximately 200 m downstream of Little Grid Pond, had a large beaver dam on its downstream side (Photo 3-3). The location of the wetland in relation to Little Grid Pond, and the lack of a distinct channel between this pond and the wetland, is shown in Photo 3-1. It was determined from the survey that fish passage was not possible between Little Grid Pond and Nico Lake due to the lack of a distinct channel in most locations and the presence of a large beaver dam on the downstream side of the wetland.

Total arsenic concentrations in samples collected through the water course between Little Grid Pond to Nico Lake indicated an attenuation of approximately 50% for both surveys. In 2011, total arsenic concentrations ranged from 163 micograms per litre (µg/L) at the outlet of Little Grid Pond to 129 µg/L at the upstream end of the wetland below Little Grid Pond. At the outlet of the wetland, total arsenic concentrations were 93 µg/L, but ranged from 75 to 100 µg/L in the lower portions of the watercourse. Water entering Nico Lake had a total arsenic concentration of 87 µg/L. In 2012, total arsenic concentrations ranged from 157 to 210 µg/L at the outlet of Little Grid Pond to 112 µg/L in water entering Nico Lake.

Photo 3-2: Upstream View of Little Grid Pond Outlet Flow, 25 August 2011

Photo 3-3: Upstream View of Wetland from the Base of the Beaver Dam, 25 August 2011

4.0 BASELINE RISK

To understand the potential risks presented to human receptors through exposure to water discharging from the CDF and open pit during post-closure, it is necessary to understand the current risks to people from potential sources of metals contamination at the site. Baseline data obtained prior to any site development for the two grid ponds (Grid Pond and Little Grid Pond) show that concentrations of some metals are elevated and may present risks to some receptors. These data were compared to screening guidelines that are protective of human health, i.e., the Health Canada Drinking Water Guidelines (DWGs). This comparison is provided in Attachment C.

The screening of Grid Pond water quality indicated that arsenic exceeded its DWG, with an overall average of 0.213 mg/L for Grid Pond and 0.177 mg/L at Little Grid Pond. Aside from arsenic, iron also exceeded its DWG at Little Grid Pond only, although its DWG is based upon aesthetic objectives, and it is anticipated that this metal would not pose a potential health concern.

For Marian River, the screening of chemical concentrations against DWGs indicated that there were no exceedances under baseline conditions.

For Nico Lake, most metals meet their respective DWGs under baseline conditions. For Peanut Lake and Burke Lake, most metals met their respective DWGs under baseline conditions, except for iron. The DWG for iron is based on aesthetic, and it is anticipated that iron would not pose a health concern.

Potential risks to receptors from all sources of exposure were assessed in the DAR, and risks were shown to be negligible. Therefore, in this assessment, only the risks from surface water are considered. While Nico, Peanut, and Burke lakes are not likely to be considered as culturally significant areas by people living in the nearby communities, the exposure scenarios considered in this assessment assumes a recreational user who may be using the surface water as a drinking water source for 30 days per year throughout their lifetime.

Baseline risks for the Grid Ponds are provided in Table 4-1 below.

Table 4-1: Human Health Risk Estimates for Arsenic at the Grid Ponds – Baseline

Location	Concentration (mg/L)	Hazard Quotient	Incremental Lifetime Cancer Risk
Grid Pond	0.21	**2**	**$7x10^{-4}$**
Little Grid Pond	0.18	**2**	**$6x10^{-4}$**

Notes:
Estimated risks greater than their target values are indicated by bold font and shading.
HQ = Hazard Quotient; target HQ = 0.2
ILCR = Incremental Lifetime Cancer Risk; target ILCR = $1x10^{-5}$

The results indicate a potential human health concern if a recreational user uses the surface water in the Grid Ponds as a drinking water source for 30 days/year during their lifetime.

Recent data indicated that the arsenic concentration in water entering Nico Lake from the Grid Pond system is at 112 µg/L. The results indicate a potential human health concern if a recreational user drinks this water prior to full mixing with Nico Lake (see Table 4-2).

Baseline risk associated with arsenic in Nico Lake is provided in Table 4-3.

Table 4-2: Human Health Risk Estimates for Grid Pond Discharge to Nico Lake – Baseline

Location	Concentration (mg/L)	Hazard Quotient	Incremental Lifetime Cancer Risk
Arsenic			
Nico Lake	0.112	**1**	**$4x10^{-4}$**

Table 4-3: Human Health Risk Estimates for Nico Lake – Baseline

Location	Concentration (mg/L)	Hazard Quotient	Incremental Lifetime Cancer Risk
Arsenic			
Nico Lake	0.021	0.2	**$7x10^{-5}$**

Notes:
Estimated risks greater than their target values are indicated by bold font and shading.
HQ = Hazard Quotient; target HQ = 0.2
ILCR = Incremental Lifetime Cancer Risk; target ILCR = $1x10^{-5}$

For arsenic in Nico Lake, the Baseline Case hazard quotient (HQ) meets the target HQ of 0.2, and Incremental Lifetime Cancer Risk (ILCR) is greater than the target ILCR of $1x10^{-5}$.

4.1 Terrestrial and Aquatic Baseline Risk

To understand the potential risks presented to terrestrial and aquatic receptors through exposure to water discharging from the CDF and open pit to the receiving environment and downstream waterbodies during post-closure, it is necessary to understand the current risks to wildlife and aquatic life from potential sources of metals contamination at the site. Baseline data obtained prior to any site development show that concentrations of some metals are elevated in waterbodies at the site, and may present risks to some receptors. As a result, for the CoPCs identified in Table 2-1, the risks to ecological receptors were assessed under baseline conditions to provide a suitable benchmark against which to assess any incremental change in risk during post-closure.

The baseline risk assessment for wildlife focuses on risks associated with the consumption of surface water. Potential risks to receptors from all sources of exposure (i.e., soil and food) were assessed in the DAR (Fortune 2011), and risks were shown to be negligible. Therefore, in this assessment, only the risks from surface water are considered in this assessment.

Baseline studies have shown that arsenic and cobalt are present in the Grid Ponds at concentrations above the SSWQOs, and these CoPCs were evaluated further in the aquatic risk assessment for these ponds. For Nico Lake, Peanut Lake, Burke Lake, and the Marian River, a baseline aquatic risk assessment was completed for only those CoPCs and for only those waterbodies for which potential risks were identified for the post-closure phase of the impact assessment. These were limited to arsenic, cobalt, iron, lead, and selenium. Those elements that exceeded CWQGs in baseline conditions (cadmium, silver, thallium) but did not increase in closure were not considered. These elements appear to be naturally elevated due to local geological conditions, and do not appear to be influenced by the NICO Project.

The predicted risks to aquatic life due to concentrations of CoPCs in surface water are provided in Table 4-4. Risks are assessed on the basis of risk quotients, which are simply a comparison of the exposure concentration in surface water to an effect threshold determined from toxicity studies. Where a risk quotient is greater than one, this indicates that the exposure concentration exceeds the effect threshold, and there is potential for adverse effect on some sensitive receptors.

Table 4-4: Predictions of Risk (as RQs) to Aquatic Life – Baseline Conditions

CoPC	Nico Lake	Peanut Lake	Burke Lake	Marian River	Little Grid Pond	Grid Pond
Baseline						
Arsenic	-	-	0.07	-	**3.4**	**4.2**
Cobalt	-	0.06	0.07	-	0.66	0.75
Iron	0.46	-	0.44	-	-	-
Lead	0.62	-	-	-	-	-
Selenium	0.07	-	-	-	-	-

Notes:
- = This parameter was not identified as a CoPC in this waterbody
Shaded + bold text = risk quotient > 1
CoPC = Chemical of potential concern
RQs for baseline conditions are based on average measured baseline concentrations

The results in Table 4-4 show that, under baseline conditions, there are potential risks to aquatic life in the Grid Ponds due to concentrations of arsenic. Negligible risks were present in the other waterbodies for cobalt, iron, lead, and selenium.

Potential risks to humans and wildlife are summarized in Tables 4-5 and 4-6. A similar approach was followed, where the potential for effects is assessed on the basis of a risk quotient. Baseline risks consider only exposure to surface water. The wildlife risk assessment described in the DAR considered all pathways of exposure, and concluded that there were no risks to wildlife as a result of the NICO Project. Therefore, only the risks due to consumption of surface water are considered, since this is the only exposure scenario that is affected by active filling of the open pit in post-closure and seepage from the CDF.

The risks to wildlife are based on conservative assumptions regarding exposure. Receptors are assumed to consume water only from the one source, and are assumed to consume water from this source for 12 months of the year. This represents the worst-case exposure condition for each waterbody.

The RQs calculated in Tables 4-5 and 4-6 show that under existing conditions, consumption of surface waters presents negligible risks to wildlife. Calculated RQs were well below the threshold of one, in most cases by orders of magnitude. The results show that there are no risks due to consumption of surface water from the Grid Ponds, lakes (Nico, Peanut, and Burke lakes), or the Marian River.

Table 4-5: Predictions of Risks (as RQs) to Birds Consuming Surface Waters – Baseline Conditions

COC	Common nighthawk	Loon	Mallard	Olive-sided flycatcher	Peregrine falcon	Ptarmigan	Rusty Blackbird	Short-eared owl
Little Grid Pond								
Arsenic	0.01	0.0006	0.0008	0.015	0.0056	0.001	0.01	0.007
Cobalt	0.0001	0.00004	0.00005	0.00016	0.00006	0.00006	0.0001	0.00007
Chromium	0.00000007	0.00000001	0.00000002	0.00000009	0.00000003	0.00000002	0.00000007	0.00000004
Copper	0.00000006	0.000000001	0.000000002	0.00000008	0.00000003	0.000000002	0.00000006	0.00000004
Lead	0.00004	0.000002	0.000003	0.00006	0.00002	0.000003	0.00004	0.00003
Molybdenum	0.00000006	0.000000002	0.000000003	0.00000008	0.00000003	0.000000003	0.00000006	0.00000004
Selenium	0.0001	0.00002	0.00002	0.0002	0.00007	0.00003	0.0001	0.00008
Vanadium	0.0000002	0.00000005	0.00000007	0.0000002	0.00000009	0.00000009	0.0000002	0.0000001
Zinc	0.000000006	0.000000001	0.000000001	0.000000007	0.000000003	0.000000001	0.000000006	0.000000003
Grid Pond								
Arsenic	0.01	0.0008	0.001	0.02	0.007	0.001	0.01	0.008
Cobalt	0.0001	0.00004	0.00006	0.0002	0.00007	0.00007	0.0001	0.00009
Chromium	0.00000007	0.00000001	0.00000002	0.00000009	0.00000003	0.00000002	0.00000007	0.00000004
Copper	0.00000006	0.000000001	0.000000002	0.00000008	0.00000003	0.000000002	0.00000006	0.00000004
Lead	0.00005	0.000002	0.000003	0.00006	0.00002	0.000003	0.00005	0.00003
Molybdenum	0.00000006	0.000000002	0.000000003	0.00000008	0.00000003	0.000000003	0.00000006	0.00000004
Selenium	0.0001	0.00002	0.00002	0.0002	0.00007	0.00003	0.0001	0.00008
Nico Lake								
Arsenic	0.001	0.00007	0.0001	0.002	0.0007	0.0001	0.001	0.0008
Cobalt	0.00002	0.000005	0.000007	0.00002	0.000008	0.000009	0.00002	0.00001
Lead	n/a	0.000002	0.000003	n/a	n/a	n/a	n/a	n/a
Selenium	0.0001	0.00001	0.00002	0.0001	0.00006	0.00002	0.0001	0.00007
Peanut Lake								
Arsenic	0.00001	0.0000007	0.000001	0.00002	0.000007	0.000001	0.00001	0.000008
Cobalt	0.00001	0.000004	0.000005	0.00001	0.000006	0.000006	0.00001	0.000007
Lead	0.00006	0.000003	0.000003	0.00007	0.00003	0.000004	0.00006	0.00004
Selenium	0.0001	0.00001	0.00002	0.0002	0.00006	0.00002	0.0001	0.00007

Table 4-5: Predictions of Risks (as RQs) to Birds Consuming Surface Waters – Baseline Conditions (continued)

COC	Common nighthawk	Loon	Mallard	Olive-sided flycatcher	Peregrine falcon	Ptarmigan	Rusty Blackbird	Short-eared owl
Burke Lake								
Arsenic	0.0002	0.00001	0.00002	0.0003	0.0001	0.00002	0.0002	0.0001
Cobalt	0.00001	0.000004	0.000006	0.00002	0.000007	0.000007	0.00001	0.000008
Lead	0.00007	0.000003	0.000004	0.00008	0.00003	0.000005	0.00007	0.00004
Selenium	0.0001	0.00001	0.00002	0.0002	0.00006	0.00002	0.0001	0.00007
Marian River								
Arsenic	0.00004	0.000002	0.000004	0.00005	0.00002	0.000003	0.00004	0.00002
Cobalt	0.00001	0.000004	0.000005	0.00001	0.000006	0.000006	0.00001	0.000007
Lead	0.00004	0.000002	0.000002	0.00005	0.00002	0.000003	0.00004	0.00002
Selenium	0.0001	0.00002	0.00002	0.0002	0.00007	0.00003	0.0001	0.00008

Notes:
Exceedances of the target hazard quotient of 1 are shown by shading.

Table 4-6: Predicted Risks (as RQs) to Mammals Consuming Surface Water – Baseline Conditions

COC	Arctic Ground Squirrel	Black Bear	Caribou	Moose	Muskrat	Snowshoe Hare	Wolverine
Little Grid Pond							
Antimony	0.00000002	0.00000001	0.0000001	0.000000009	0.00000002	0.00000002	0.00000001
Arsenic	0.01	0.009	0.09	0.007	0.01	0.01	0.01
Cobalt	0.00009	0.00006	0.00006	0.00005	0.00009	0.00009	0.00007
Chromium	0.00000005	0.00000003	0.00000003	0.00000003	0.00000005	0.00000005	0.00000004
Copper	0.00000001	0.000000007	0.00000002	0.000000006	0.00000001	0.00000001	0.000000009
Lead	0.0000006	0.0000004	0.000006	0.0000003	0.0000006	0.0000006	0.0000005
Molybdenum	0.00000006	0.00000004	0.0000004	0.00000003	0.00000006	0.00000006	0.00000004
Selenium	0.00008	0.00005	0.0001	0.00004	0.00008	0.00008	0.00006
Vanadium	0.00000002	0.00000001	0.000000006	0.00000001	0.00000002	0.00000002	0.00000002
Zinc	0.000000001	0.000000001	0.000000002	0.000000000	0.000000001	0.000000001	0.000000001
Grid Pond							
Antimony	0.00000002	0.00000001	0.0000001	0.000000009	0.00000002	0.00000002	0.00000001
Arsenic	0.02	0.01	0.1	0.009	0.02	0.02	0.01
Cobalt	0.0001	0.00007	0.00006	0.00005	0.00001	0.00001	0.00008
Chromium	0.00000005	0.00000003	0.00000003	0.00000003	0.00000005	0.00000005	0.00000004
Copper	0.00000001	0.000000007	0.00000002	0.000000006	0.00000001	0.00000001	0.000000009
Lead	0.0000007	0.0000004	0.000007	0.0000003	0.0000006	0.0000006	0.0000005
Molybdenum	0.00000006	0.00000004	0.0000004	0.00000003	0.00000006	0.00000006	0.00000004
Selenium	0.00009	0.00006	0.0001	0.00004	0.00008	0.00008	0.00007
Nico Lake							
Arsenic	0.002	0.001	0.01	0.0009	0.002	0.002	0.001
Cobalt	0.00001	0.000008	0.000007	0.000006	0.00001	0.00001	0.000009
Lead	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Selenium	0.000070	0.00004	0.00001	0.00004	0.00007	0.00007	0.00005
Peanut Lake							
Arsenic	0.00002	0.02	0.0001	0.000009	0.00002	0.00002	0.00001
Cobalt	0.000009	0.000000000	0.000005	0.000004	0.000008	0.000008	0.000006

Table 4-6: Predicted Risks (as RQs) to Mammals Consuming Surface Water – Baseline Conditions (continued)

COC	Arctic Ground Squirrel	Black Bear	Caribou	Moose	Muskrat	Snowshoe Hare	Wolverine
Lead	0.0000009	0.005	0.000009	0.0000004	0.0000008	0.0000009	0.0000006
Selenium	0.00008	0.3	0.0001	0.00004	0.00007	0.00007	0.00006
Burke Lake							
Arsenic	0.0003	0.0002	0.002	0.0001	0.0003	0.0003	0.0002
Cobalt	0.00001	0.000006	0.000006	0.000005	0.000009	0.000009	0.000008
Lead	0.000001	0.0000006	0.00001	0.0000005	0.0000009	0.0000009	0.0000007
Selenium	0.00007	0.00005	0.0001	0.00004	0.00007	0.00007	0.00006
Marian River							
Arsenic	0.00005	0.00003	0.0003	0.00002	0.00005	0.00005	0.00004
Cobalt	0.000009	0.000005	0.000005	0.000004	0.000008	0.000008	0.000006
Lead	0.0000006	0.0000004	0.000006	0.0000003	0.0000006	0.0000005	0.0000004

5.0 CLOSURE ELEMENTS THAT REQUIRE ATTENTION

Both MVEIRB (26 July letter) and AANDC (e-mail correspondence between Robert Jenkins of AANDC and Rick Schryer of Fortune) have highlighted concerns surrounding Fortune's closure scenario. Fortune will commit to actively filling the open pit should be it necessary to mitigate water quality issues at closure. At this time, Fortune no longer considers passive filling as a closure option. Fortune has taken steps to address additional points highlighted by AANDC and MVEIRB as follows:

- the likelihood of the open pit overflowing and the volume of water expected to flow from the open pit after it is filled;
- the likelihood of the CDF and open pit requiring treatment;
- the likelihood of the CDF not performing to expectations (i.e., what is likelihood of the CDF water quality being accurate);
- open pit water quality post-closure under active flooding; and
- likelihood that the post-closure water quality from the open pit under active flooding is accurate.

These points are addressed in the subsequent sections of this memo.

6.0 OPEN PIT FLOWS

Section 11.3.2.2 of the DAR states that after the open pit fills, water will flow at approximately 0.0118 cubic metres per second (m^3/s) annually under average conditions to a maximum of 0.0182 m^3/s annually in a wet year. The increase in discharge from Peanut Lake will be approximately 7.7% of the annual average discharge and less than 2% of the peak. Similarly for Burke Lake, the annual average discharge will be approximately 5.7% higher and less than 1% higher during peak discharge. As such, the increase in discharge at and downstream of Peanut Lake from the NICO Project is expected to result in a minor change to the hydrology in the local study area relative to baseline conditions, which should have a negligible effect on Peanut Lake and downstream waterbodies, such as Pond 11, 12, and 13, Burke Lake, and the Marian River.

Golder assessed four active filling scenarios. Under a sustainable pumping scenario, Scenario 4, in which the pumping rate is variable and adapts to the ability of the Marian River to supply water, the Pit Lake would require between 8.9 and 13.6 years to fill (Attachment D). The overflow rate after active filling would be the same as the overflow rate after passive filling.

In August 2012, Fortune solicited a second opinion regarding flow rate from the open pit under various scenarios to determine likelihood of the pit over flowing as well as the likelihood of existing open pit filling rates being accurate. Golder estimated approximately 169,000 m^3 per year of overflow from the open pit over the open water period. Lorax estimated a flow rate of 161,200 m^3 annually with most of the water released in May (Attachment E). In addition, Lorax estimate the flow rate if the the water from the CDF was diverted into the receiving environment, rather than the open pit. Under this scenario, the annual flow rate would be 8,700 m^3, with the entire volume releasing in May.

Depending on the inputs into the model, the flow can change. However, regardless of the scenario considered, there is still water being released from the open pit to the receiving environment that may need to be treated. All water quality modelling is based on Golder's overflow estimates and is thus based on the largest potential overflows.

7.0 CO-DISPOSAL FACILITY FLOWS

As part of the closure measures, a soil cover will be constructed on the top surface and sideslopes of the CDF. The cover is estimated to limit the infiltration of rain water into the CDF to about 15% of the mean annual precipitation. This is equivalent to about 50 millimetres (mm) per year, or 69,000 cubic metres (m^3) per year (over the 138 hectare footprint of the CDF). After the cover is in place, the CDF will slowly develop a state of flow equilibrium, such that the seepage flow out of the toes of the CDF will balance the rate of infiltration.

The cover infiltration estimate is a level of performance that can be readily attained in the climate at NICO. The actual infiltration will likely be significantly less. This conclusion is based on both detailed designs and case histories of actual soil cover performance at other sites in similar climates. SRK (2010), provides a useful tabulation of sites where soil covers have been constructed in cold regions. For example, Schnabel et al. (2012) used lysimeters to document that a similar soil cover in Anchorage, Alaska, reduced infiltration to about 13% of mean annual precipitation.

The design details of the cover (i.e., layer thicknesses and material specifications) will be finalized as part of detailed design, and will be based on both cover modelling and field testing. It is noted that the lake evaporation at NICO exceeds the annual average precipitation, which will allow the cover to act as a “store and release” cover during the spring runoff and as an infiltration reduction cover during summer and fall rains. There is a high level of certainty that under average precipitation condition the volume of seepage from the CDF post- closure will not exceed the high end estimate of 69,000 m^3 per year.

8.0 OPEN PIT WATER QUALITY

Post-closure pit lake water quality predictions were developed for the DAR (Fortune 2011) based on the passive filling of the pit lake, with natural watershed runoff and direct precipitation, which is supplemented by runoff from the CDF through trenching from Seepage Collection Pond (SCP) No. 4. This filling scenario was estimated to take approximately 120 years for the pit water level to rise to an elevation of approximately 266 metres above sea level (masl), at which time the flooded open pit would be expected to begin overflowing through the former haul road ramp towards Peanut Lake, but could be altered if required.

Separate to the DAR scenario, an active pit filling scenario has also been evaluated for the NICO Project, which included water pumped from the Marian River to supplement passive filling. This filling scenario resulted in the pit lake being filled in a considerably shorter timeframe (i.e., approximately 10 years) and resulted in improved water quality conditions during the early periods of the filled lake; however, the far future water quality projections in both scenarios are expected to be similar regardless of filling scenario once steady state has been achieved.

The conceptual model used to estimate pit water quality at closure for the actively filled pit was similar to that presented for the filling scenario in the DAR, and included the same sources of flows to the pit that would contribute to the chemistry of the filled lake. These included direct precipitation, pit wall runoff (e.g., precipitation that contacts exposed mine rock in the pit walls prior to reporting to the lake), local catchment runoff, groundwater inflows, and runoff from the CDF that is routed through SCP No. 4. The only additional flow source compared to the DAR passive filling scenario was the water pumped from the Marian River. As for the DAR case, water quality inputs to each of these flow sources were assigned a chemical signature based on the source, which included data collected from the regional Environment Canada meteorological monitoring station (for precipitation inputs), baseline water quality data (for groundwater and local catchment runoff flows), site water quality predictions (for flows from SCP No. 4), and geochemical characterization of mine rock that will be exposed in the pit walls during filling and when the pit is filled.

Two principle differences between the passive filling scenario and the active filling scenario were the relative contribution of water from the Marian River to fill the lake in the shortened fill time (~90% of the water in the filled pit would be comprised of Marian River water), and the reduced exposure of pit wall rock in the reactive zone (i.e., outer, fractured shell) of the open pit to physical and chemical weathering over time. With faster filling, rock exposed in the reactive zone of the pit walls will become inundated with water at a faster rate, effectively reducing the rate of mineral reactions in reactive zone, and therefore contributing a smaller chemical mass to the pit lake.

A comparison of the predicted water quality for passive filling (as detailed in the DAR) and the active filling scenario is presented in Table 8-1. The table lists the maximum dissolved and total concentrations of modelled substances in the pit lake during three periods:

- **Maximum in-pit water quality:** the maximum predicted dissolved and total concentrations of each parameter during the period of pit lake formation (i.e., through filling until the pit lake reaches the spill-point elevation);
- **Maximum effluent water quality:** the maximum predicted dissolved and total concentrations of each parameter after the pit lake reaches the spill-point elevation of approximately 266 masl; and
- **Expected Steady State Effluent Water Quality:** the steady-state concentrations of each parameter predicted after the pit lake has reached the spill-point elevation.

The active pit filling scenario reported the lowest concentrations of modeled substances (e.g., metals) of all pit lake scenarios. The reduction in metal concentrations compared to the DAR scenario was considered to be a combined result of the effect of dilution of the post-closure pit lake with water from the Marian River during the early years of pit lake formation, and the reduction in the duration of exposure of reactive lithologies in the pit walls.

A hydrodynamic model for the filled pit under the DAR scenario suggested that a limited monolimnion (approximately 3% of the filled volume of 28,000,000 m^3) will form. This indicates that the majority of the filled pit lake will be fully mixed. The small size of the monolimnion appears to be attributable to the relatively small differences in TDS content of inflow sources to the post-closure pit lake, associated weak or absent chemo-/pycnocline at depth, and high evaporation rates (which tends to result in evapo-concentration in the warmer surface layers in summer relative to the cooler waters below, followed by density-driven turnover in fall). This may be further compounded by the long axis of the filled pit lake being generally aligned with the orientation of dominant winds.

The pit lake water quality projections once the pit has filled and into the long-term, based on the results of geochemical characterization of tailings and mine rock and the pit wall, the site water balance, and understanding of the existing site conditions, are considered to be a reasonable estimate of the expected conditions. The level of confidence in these predictions is high. However, within the context of the assumptions used in the model, they are still considered to represent conservative estimates (i.e., represent an over-prediction or upper bound conditions) due to four key reasons:

- Under the active filling scenario, where water quality is projected to comprise lower substance concentrations, a fully mixed assumption remains valid; it is unlikely that a monolimnion (which can segregate higher density waters that provide a sink for a large proportion of mass of nutrients and metals from the surface waters) will make a substantial difference to the composition of the lake at initial overflow or once steady state conditions are reached. It is noted, however, fewer total and dissolved substances occur at concentrations in excess of the SSWQOs after the pit lake has reached the spill-point elevation and, in the long-term, for fully mixed conditions under the active filling scenario, aluminum, arsenic, cadmium, cobalt, iron, and lead.
- The pit lake water quality predictions do not account for mass loss owing to processes that result in the precipitation of geochemically credible mineral phases, or attenuation due to sorption. For example, metal hydroxide mineral phases (i.e., iron hydroxides and aluminum hydroxides) are capable of precipitating from water in the pit lake; sorption of metals to metal hydroxide minerals could result in a reduction in predicted metal concentrations.
- Total metals concentrations in the pit lake modelled on the assumption that total suspended solids (TSS) concentrations were 30 mg/L. It is very likely that the filled pit lake will possess much lower concentrations of TSS; therefore, total metals concentrations will decrease accordingly with decreases in TSS concentrations.
- The pit lake water quality predictions were modelled under dry conditions, which tend to marginally concentrate substance concentrations.

The predicted water quality data for the pit lake and the approaches used to estimate water quality are currently believed to provide a reasonable approximation of the pit lake system as currently understood, within the context of the assumptions used in the model. As discussed in the DAR, it will be necessary to monitor the quality of the water in the pit lake for a period of time in advance of the lake overflowing. If it becomes clear that the water in the filled pit lake is not amenable for direct discharge, contingencies for treatment prior to overflow to Peanut Lake will be considered. In situ batch treatment by chemical addition or biological treatment methods to adjust the pH, TSS, and/or metal concentrations in the pit lake are options that could be considered to condition the water prior to overflow. Batch treatment of pit lakes to remove metals and nutrients through addition of fertilizer is a proven technology, which has been demonstrated in the north, as exemplified by Colomac Mine (Chapman et al. 2004) and Grum Pit Lake (Leberge 2010). Changes in NICO Project site conditions or assumptions regarding the site conditions will result in changes to water quality conditions. In the event that water quality in the filling pit lake indicates that water from the open pit at initial discharge requires treatment, the constructed wetland treatment system would be established. An operating model of a wetland will already have been in place at NICO for an extended period of time to treat seepage water from the CDF. It will be necessary to halt active pumping prior to open pit overflow to allow for wetland construction and testing, should be it be required.

Table 8-1: Comparison of Water Quality Predictions for the Filled Lake under the Developer's Assessment Report Scenario (Passive Filling) and Active Filling

Parameter	Units	Developer's Assessment Report Pit Filling Scenario			Active Filling from Marian River		
		Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration	Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration[b]
General Parameters							
pH	pH units	4.45	6.58	6.58	7.67	6.54	6.58
Alkalinity	mg/L as $CaCO_3$	18	14	14	64	62	14
Total Dissolved Solids	mg/L	123	87	83	101	95	83
Major Ions and Phosphorus							
Sodium	mg/L	9.4	7.4	6.9	4.9	3.7	6.9
Calcium	mg/L	9.6	8.1	8.0	19.3	19.1	8.0
Magnesium	mg/L	3.6	3.5	3.5	8.7	8.7	3.5
Potassium	mg/L	24.8	12.3	11.7	4.6	6.8	11.7
Chloride	mg/L	5.1	5.5	5.5	5.1	5.1	5.5
Sulphate	mg/L	81.1	43.4	40.8	22.8	20.1	40.8
Phosphorus	mg/L	0.048	0.037	0.033	0.112	0.084	0.033
Total Metals[a]							
Aluminum	mg/L	2.35	2.32	2.31	1.40	1.59	2.31
Antimony	mg/L	0.019	0.008	0.007	0.003	0.006	0.007
Arsenic	mg/L	0.642	0.338	0.308	0.131	0.173	0.308
Barium	mg/L	0.189	0.084	0.079	0.038	0.056	0.079
Beryllium	mg/L	0.0009	0.0007	0.0006	0.0009	0.0009	0.0006
Boron	mg/L	-	-	-	-	-	-
Cadmium	mg/L	0.00013	0.00009	0.00009	0.00027	0.00027	0.00009
Chromium	mg/L	0.004	0.005	0.005	0.006	0.006	0.005
Cobalt	mg/L	1.435	0.399	0.322	0.084	0.105	0.322
Copper	mg/L	0.074	0.034	0.031	0.010	0.013	0.031
Iron	mg/L	5.95	5.50	5.50	4.28	4.62	5.50
Lead	mg/L	0.007	0.004	0.003	0.004	0.003	0.003

Table 8-1: Comparison of Water Quality Predictions for the Filled Lake under the Developer's Assessment Report Scenario (Passive filling) and Active Filling (continued)

Parameter	Units	Developer's Assessment Report Pit Filling Scenario			Active Filling from Marian River		
		Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration	Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration[b]
Manganese	mg/L	0.144	0.076	0.072	0.049	0.044	0.072
Mercury	mg/L	-	-	-	-	-	-
Molybdenum	mg/L	0.032	0.015	0.014	0.005	0.007	0.014
Nickel	mg/L	0.040	0.020	0.019	0.004	0.004	0.019
Selenium	mg/L	0.025	0.007	0.006	0.002	0.003	0.006
Silver	mg/L	0.0001	0.0001	0.0001	0.0034	0.0026	0.0001
Strontium	mg/L	0.026	0.027	0.027	0.068	0.066	0.027
Thallium	mg/L	0.001	0.0008	0.0008	0.0001	0.0001	0.0008
Tin	mg/L	0.015	0.017	0.017	0.036	0.036	0.017
Uranium	mg/L	0.004	0.004	0.004	0.002	0.006	0.004
Vanadium	mg/L	0.004	0.003	0.003	0.002	0.002	0.003
Zinc	mg/L	0.165	0.056	0.049	0.012	0.018	0.049
Dissolved Metals							
Aluminum	mg/L	1.05	1.02	1.01	0.14	0.33	1.01
Antimony	mg/L	0.018	0.007	0.007	0.003	0.006	0.007
Arsenic	mg/L	0.522	0.218	0.188	0.044	0.086	0.188
Barium	mg/L	0.178	0.073	0.068	0.027	0.045	0.068
Beryllium	mg/L	0.0009	0.0006	0.0006	0.0008	0.0008	0.0006
Boron	mg/L	0.198	0.119	0.117	0.045	0.040	0.117
Cadmium	mg/L	0.00012	0.00008	0.00008	0.00027	0.00027	0.00008
Chromium	mg/L	0.003	0.003	0.003	0.004	0.004	0.003
Cobalt	mg/L	1.420	0.384	0.307	0.073	0.094	0.307
Copper	mg/L	0.068	0.028	0.025	0.005	0.008	0.025
Iron	mg/L	1.79	1.35	1.35	0.32	0.66	1.35
Lead	mg/L	0.007	0.003	0.003	0.004	0.003	0.003
Manganese	mg/L	0.113	0.046	0.042	0.024	0.019	0.042

Table 8-1: Comparison of Water Quality Predictions for the Filled Lake under the Developer's Assessment Report Scenario (Passive filling) and Active Filling (continued)

Parameter	Units	Developer's Assessment Report Pit Filling Scenario			Active Filling from Marian River		
		Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration	Maximum Simulated In-Pit Water Quality	Maximum Effluent Water Quality	Steady State Concentration[b]
Mercury	mg/L	0.000086	0.000094	0.000094	0.000162	0.000128	0.000094
Molybdenum	mg/L	0.032	0.015	0.014	0.005	0.007	0.014
Nickel	mg/L	0.040	0.020	0.019	0.003	0.003	0.019
Selenium	mg/L	0.025	0.007	0.006	0.002	0.003	0.006
Silver	mg/L	0.0001	0.0001	0.0001	0.0034	0.0026	0.0001
Strontium	mg/L	0.026	0.027	0.027	0.068	0.066	0.027
Thallium	mg/L	0.0007	0.0007	0.0007	0.0001	0.0001	0.0007
Tin	mg/L	0.015	0.017	0.017	0.036	0.035	0.017
Uranium	mg/L	0.004	0.004	0.004	0.002	0.006	0.004
Vanadium	mg/L	0.003	0.002	0.002	0.001	0.001	0.002
Zinc	mg/L	0.165	0.055	0.048	0.012	0.017	0.048

[a] The model assumes that the filled pit lake has a background total suspended solids (TSS) concentration of 30 mg/L

[b] The steady state concentration under the active filling scenario are expected to be similar to the passive filling case, regardless of the accelerated filling with water from the Marian River

Note: Shaded cells indicate value above SSWQO for that substance

9.0 CO-DISPOSAL FACILITY WATER QUALITY

The decision to co-dispose tailings and mine rock in a single facility (the CDF) was made in part because a CDF is expected to reduce impacts to downstream water quality, relative to separate facilities for tailings and mine rock. In a conventional mine rock dump, air circulates freely into the pile by convective flow. This supplies ample oxygen that enhances the rate of sulphide oxidation and acid generation. In the CDF design, the problematic mine rock will be placed within the interior of the CDF in the form of isolated layers interlayered with layers of tailings. The tailings layers will greatly interrupt the convective flow of air and will thus reduce acid generation. With reduced acid generation, the ability of metals to dissolve will be reduced and the water quality will be improved in contrast to a waste management scenario that utilizes separate mine rock and tailings storage facilities. It should be noted that geochemical testing has demonstrated that the tailings themselves have a low potential for acid generation; thus, the CDF concept uses the tailings to diminish the potential for acid generation in the mine rock.

Seepage collection ponds (SCPs) will be located around the perimeter of the co-disposed tailings facility (CDF) to capture seepage through the CDF and some runoff. Seepage collection ponds Nos. 1, 2, and 3 will be located in topographic lows adjacent to the east end of the CDF, and designed to intercept seepage from the CDF that would otherwise flow to Nico Lake. The key inflows to these SCPs will be contact seepage from the co-disposed tailings and mine rock, and infiltration through the Type 2 rock (i.e., rock with a low potential for acid generation, i.e., possessing <0.3% sulphide sulphur) used to construct the perimeter embankments of the CDF. Following closure, the annual combined volume of flow from these SCPs will be approximately 109,000 cubic metres per year (m^3/y) of which approximately 47,000 m^3/y is sourced from contact seepage through the CDF, which will be limited to open water conditions (April to September). For comparison, the estimated volume of Nico Lake is 1.57 million cubic metres.

Seepage collection pond No. 4 will be located on the southern perimeter of the CDF, and SCP No. 5 will be located to the south of the CDF. These SCPs will be designed to collect runoff from the CDF and surrounding watershed. Following closure, the annual volume of flow from SCP No. 4 and SCP No. 5 will be approximately 33,000 m^3/y and 4,000 m^3/y, respectively.

The model to determine the water chemistry of seepage from the CDF that enters the SCPs was presented in Appendix 7.II (Site Water Quality Predictions), Section 7 (KLOI: Water Quality) of the DAR (Fortune 2011). The model predicted seepage quality by assigning a chemical signature to flows to the SCPs provided by the site water balance, based on the material within the CDF that the flows come into contact with over a monthly time step. For the SCPs, inflows were proportioned between surface flows over the CDF (assigned a mine rock contact chemistry), infiltrate through the CDF (assigned a mine rock and co-disposed tailings contact chemistry), direct precipitation (assigned a regional baseline rainwater chemistry), and a local catchment runoff chemistry. Additionally, processes, such as losses through evaporation, were considered in the model.

Each source of water as defined in the site water balance was characterized as non-contact, or mine contact, water. Non-contact water, such as precipitation and local catchment runoff, were assigned a chemistry based on the local precipitation data sourced from the Environment Canada Snare Lake monitoring station, and natural runoff chemistry was assigned baseline water quality data for the pond or lake located within the local catchment (e.g., the chemistry of local catchment runoff to the SCPs was assigned baseline chemistry associated with the Grid Pond). Contact water flows were defined a chemistry using the range of results of the geochemical characterization of mine rock (Type 1 and 2 mine rock) and tailings (wet and dry tailings, and closure cover) depending on the type of material flows intercepted or contacted (based on the site water balance). The geochemistry data were determined from many sources of site specific mine rock and ore materials, which were comprehensively tested under lab-based short-term leach and longer term humidity cell tests, and field tests.

How reasonable are the SCP water quality predictions? There is a moderate to high level of conservatism in including these seepages in the predictive watershed water quality modelling, as a detailed seepage analysis has not yet been completed to verify the flow rates out of each of the SCPs. Other sources of positive bias or overestimation in the SCP water quality predictions include the following:

- geochemical source terms for mine contact sources were defined by maximum concentrations measured in geochemical testing of the source material;
- where any geochemical source term that was measured less than the detection limit during geochemical testing for the derivation of mass loading to the SCPs, it was assigned the analytical detection limit value for constituent concentrations;
- mineral precipitation, metal sorption, or other processes resulting in the reduction of chemical mass were not considered in the SCP; and
- maximum site water quality predictions were used directly in the GoldSim™ model for seepage to the SCPs.

The prediction of the quality of the seepage to the SCPs is based on several inputs to the site water quality model (i.e., surface flows, background water quality, and geochemical characterization), each of which have inherent variability and uncertainty. The site water quality model has attempted to incorporate natural processes and mineral weathering of mine materials, and combine them with mine site flows to develop seepage chemistry predictions. Seepage quality is based on our current understanding of the Project Description and site water balance, and the application of standard geochemical testing and modelling approaches, which have been utilized in other northern Project impact assessments. As a result, there is a high level of confidence that the seepage quality derived for the DAR is reasonable.

10.0 WETLAND STUDY PLAN AND BACKGROUND ON HOW THEY WILL WORK

A long-term method for treatment of waters that will originate from seepage and snow melt/rainwater run-off from the CDF containing mine rock and tailings (approximately 50,000 to 100,000 m^3/year) and treatment of overflow from a filled open pit mine (approximately 169,000 m^3/year) at the NICO Project will be developed. It is the intention of Fortune that the renovated waters be safely released to the surface water system. The target goal is to preserve the water quality in the ultimate receiving system of the Marian River, which is downstream of the NICO mine site, by treating the water in a passive manner, with no long-term operations or maintenance required after the wetland has become established.

Fortune has requested that CSL in conjunction with their partners at NPS/DUC, and Drs. John Rodgers and James Castle (of Clemson, South Carolina) submit a work plan to design and undertake a series of feasibility studies to confirm the performance of a CWTS for removal of CoPCs from the water. Every CWTS that CSL designs and implements is created on a case-by-case basis, tailored to the specific water needing renovation and site-specific requirements. Contango Strategies Limited have reviewed the post-closure water quality predictions for both the CDF and the open pit and, based on CSL's experience in dealing with similar situations, are highly confident that they can design and implement a CWTS for treatment of water post-closure at the NICO site; however, pilot studies and testing are needed to determine exact removal rates, optimal design factors, and overall footprint and cost of the potential full scale CWTS.

The four phases of CWTS design are as follows:

- Build an indoor pilot CWTS to test various methods of metals removal from water and associated sedimentation rates using influent water made to simulate the runoff expected at the NICO mine site after closure. The indoor pilot CWTS will be housed in a computer-controlled, year-round greenhouse on premises of CSL in Saskatoon, Saskatchewan
- Build an outdoor pilot CWTS to validate the designs optimized indoors. The outdoor pilot CWTS will be located adjacent to CSL's laboratory and greenhouse facilities in Saskatoon, Saskatchewan.
- Design, build, and monitor a demonstration-scale CWTS at the NICO mine site at the beginning of operations.
- Design, build and monitor the full-scale CWTS as early in the operations period as feasible to demonstrate the effectiveness of the CWTS at the NICO Project site.

The purpose of the pilot CWTS is to identify the ideal combination of conditions, using locally sourced plants in Northern climate conditions to create a water treatment system resulting in maximum removal of CoPCs and best outflow water quality.

A detailed work plan for this first-phase of the program, including feasibility and planning, experimental design, setup, sampling and analyses of the pilot CWTS and reporting of activities and findings is provided in the Attachment C. The study team is highly confident that implementation of this work plan will result in the development of a CWTS that can treat waters from the NICO Project at closure to safe levels.

11.0 CLOSURE PLAN

Fortune conducted extensive series of analyses to update and refine its closure plans. In relation to the open pit, Fortune considered the option of passively allowing the open pit to fill or, alternatively, actively filling it. Fortune chose to actively fill the open pit. The previous sections of this report outlined each project element of closure and gave quantified likelihood estimates concerning the certainty that they would perform as stated. This section outlines the base closure plan and options available for the NICO Project.

For the purposes of this section, the following will be assumed:

- Seepage/run-off from the CDF will require treatment prior to release into Nico Lake;
- A CWTS will be built to passively treat this water;
- The open pit will be actively flooded so that a final closure condition can be reached within 10 to 14 years after operations have ceased; and
- Overflow from the open pit will be approximately 169,000 m^3/year. For the purposes of this section, Fortune is using the more conservative Golder estimate over the one provided by Lorax.

These assumptions not only apply to the closure plan itself but to the closure financing (i.e. closure financing will be developed assuming these activities will occur). With these assumptions in place, the timeline for closure becomes more defined so the following discussion on closure plans will be presented in chronological order as they would occur over the closure period.

Construction and Operations

As detailed in Section 9.0, the seepage/run-off from the CDF will require a moderate amount of treatment to achieve SSWQO levels. Section 10.0 showed that this level of treatment can be achieved with a purposely built CWTS. This would be a passive treatment system that will function without maintenance once established. This CWTS is likely to be required.

Fortune will initiate the indoor and outdoor pilot scale CWTS during the construction phase. The demonstration CWTS would be built in the first or second year of operations and would use waters taken directly from the seepage collection ponds at the base of the CDF. Once performance of the demonstration scale CWTS has been verified over a number of years, plans would be made to build the full-scale version. This full–scale version will need to be in place and functioning (i.e., achieving SSWQO's) prior to closure. The exact timing for the construction of the full-scale CWTS will depend on the results of the first three phases of CWTS development.

The CWTS team is confident that the SSWQO's can be achieved in a passive wetland treatment system. It should be remembered that the SSWQO for arsenic (50 µg/L) proposed by Fortune is substantially lower than the current concentration of arsenic (112 µg/L) flowing into Nico Lake under baseline conditions. Fortune has a high level of confidence that the required level of treatment can be achieved based on the performance of other CWTS's and the performance of the natural wetlands (i.e., Grid Ponds and unnamed wetland).

Early Closure

Details on how site infrastructure would be dealt with at closure were provided in the DAR. Fortune would have to maintain a presence at site (e.g., small camp, fuel, vehicles) while the open pit is being actively filled. A water intake with approved screen, pumps, power supply, and pipeline will need to be constructed to pump water from the Marian River. The most logical place for the water pipeline from the river to the open pit is along the access road.

The assumptions and calculations for the time it would take to fill the open pit were provided in a technical memo from Golder (Attachment D). It is calculated that between 10 and 14 years of active pumping (during the summer) would be required to achieve overflow. Assuming a 12 year pumping period, pumping will occur for about 10 summers and then pause to allow time for the water to settle and to test the water quality profile in the open pit to determine if in-pit treatment should be undertaken. Experience has shown that snow melt waters are typically very low in total dissolved solids (e.g., low salinity and low density) and often does not mix with underlying pit lake waters. The result of this limited mixing is that freshet waters “ride” over the surface of the pit lake waters and are generally of good quality (Attachment E).

Late Closure

Should the water in the open pit require treatment after a settling period, in-pit treatment will be examined. Estimates of open pit overflow water quality are conservative, and it is likely this water may not require treatment to achieve SSWQO’s. Opportunities to improve water quality from the open pit prior to overflow will be examined over time. The objective would be to improve water quality to a point where it does not require treatment. In-pit treatment of flooded open pits has been undertaken at several sites in the north, including Colomac, Grum Pit (Faro Mine) (Laberge 2010), and Gunnar (northern Saskatchewan).

The in-pit treatment process that would be considered (if necessary) at NICO would involve a one-season, batch treatment with addition of fertilizer to the surface of the pit lake to enhance algae growth and promote biological removal of metals and nutrients. This would probably require multiple applications of a total of about 9 tonnes (dry weight basis) of fertilizer in dissolved form applied over the course of one summer using a boat. The treatment would take place several years before pit overflow is expected. This will allow the algae to die and settle to the bottom of the open pit so that algae and residual nutrients are not present in the overflow water when that occurs. It would also be feasible to add ferric sulphate to the pit water to precipitate arsenic and metals; however, this would only be considered in the future if measured water quality indicated that it was specifically required.

The open pit would be allowed to fill naturally during the last two years prior to predicted overflow to allow for settling and in-pit treatment options. The decision to build a second CWTS specifically to treat overflow water would be made during this time period. The CWTS would be put in place to treat localized exceedances of SSWQOs in both Nico and Peanut lakes. The CWTS will be built to open pit water quality and quantity conditions to maximize treatment efficiency. The chemistry and an approximation of the potential flows will need to be known before final design can proceed. This information will be gathered when pumping is halted prior to open pit overflow. From a practical standpoint, the CWTS cannot be put into operation until there is flow from the open pit. The amount of money required for the monitoring of the open pit, design of the wetland, wetland construction, and initial performance monitoring will be part of the security bond. The size of this CWTS would depend on two factors. The first is the quality of the water from the open pit and the second is the potential lack of run-off from the cover of the CDF. Treatment wetlands are scaled to treat influent waters. This CWTS, as with the first one built for the CDF, would be built with contingencies for freshet, freezing, and wet year scenarios. The years of data collected at the CDF CWTS will be instrumental in the proper design of the open pit CWTS, should it be required.

The worst case open pit water quality predictions (Section 8.0) show that predicted steady state total arsenic levels are comparable to naturally occurring levels. The CWTS can achieve a higher level of performance than the natural wetlands at removing arsenic and other metals because they are designed for that purpose. The CWTS in Alaska has been operating successfully for 10 years. The size and configuration of the CWTS will be tailor made to meet treatment levels required to meet SSWQO’s.

In its calculations for open pit overflow scenarios, Fortune requested that Lorax examine what would happen to open pit flows if surface run-off from the CDF were not directed into the open pit. This flow would be directed towards Peanut Lake along a natural drainage path. The DAR predicted that the run-off from the cover of the CDF would meet water quality standards because it would only be in contact with the glacial till cover. This water would improve water quality in the open pit and aid in filling the open pit in a shorter time frame. Directing the run-off from the cover of the CDF would still occur during the period of active filling. There would be a 10 to 12 year period to monitor water quality from the surface of the CDF to demonstrate its suitability for direct discharge. However, if this flow were diverted once the open pit was filled, Lorax calculated that the open pit overflow would be reduced dramatically to approximately 8,700 m^3/year, all of which would occur in May during freshet. This equates to a discharge flow rate of roughly 3 litres per second for the one month period of overflow. This freshet overflow would likely be clean meltwater that could be discharged without treatment. Monitoring of open pit water quality and stratification characteristics will be vital in determining the design of a CWTS. An equalization pond would likely be needed upstream of the CWTS to maintain a steady flow of water throughout the open water season.

The closure plan outlined above demonstrates a clear “walk-away” solution to potential water quality issues at the NICO Mine.

The CDF CWTS will be built according to a vigorous study plan that can only move forward based on the success of previous pilot-scale studies and the on-site demonstration-scale CWTS. This CWTS will have performed for years prior to closure and will provide the basis of design for the open pit CWTS.

The open pit will be actively filled if in-pit treatment solutions cannot be found that would ensure acceptable water quality under a passive filling scenario. However, the new calculations on open pit water quality and quantity show that the potential for changes to water quality in the Marian River, with or without CWTS treatment, are negligible.

12.0 CLOSURE COSTING

As stated in the introduction, active treatment of water from the NICO Mine in perpetuity at closure is not an acceptable option. Consequently, the only costs that need to be discussed are those associated with construction of the treatment wetlands, in-pit treatment options, and active pumping of water into the open pit.

Contango Strategies Ltd. estimated that the cost of building a CWTS would range between $15,000 and $75,000 per hectare, based on past experience. The exact size of the CWTS will depend on the results of the pilot-scale testing and the on-site demonstration scale CWTS. The size and cost of the CDF CWTS will be known in time to adjust the security bond as it will be early in operations.

The cost of actively filling the open pit was calculated to be in the order of $4 million dollars assuming a 12 year filling period. These costs will be re-examined every five years when the closure plan is updated.

In-pit treatment options are difficult to estimate since they vary considerably in their techniques and materials. Fortune will work with AANDC to better define these costs as the project moves closer to closure.

13.0 FINAL WATER QUALITY IN MARIAN RIVER WITH MOST LIKELY OPTION

13.1 Summary of Water Quality Modelling Efforts

Predicted changes to surface water quality in Nico Lake, Peanut Lake, Burke Lake, and the Marian River due to the NICO Project were presented in Section 7.6.3 of the DAR (Fortune 2011) submitted to the MVEIRB in May 2011. The DAR provided an assessment of potential effects to these waterbodies for operations and the active closure phase, i.e., the transitional period after the end of operations when Effluent Treatment Facility (ETF) discharge and dust deposition have ceased and treatment wetlands begin discharging to Nico Lake. The assessment did not project the potential effects of overflow from the pit lake, as the pit lake was timed to overflow following passive filling approximately 120 years after the closure of the mine.

Since the DAR was submitted, Fortune altered the effluent treatment technology from an ion exchange (IX) treatment system to a treatment system based on reverse osmosis (RO) with chemical and biological treatment of the brine. Although the IX treatment system originally selected and presented in the DAR had higher removal efficiencies for some metals relative to the RO based system, the IX system was sensitive to changes in influent water quality (i.e., influenced by increases in calcium, magnesium, and other background water quality parameters), but was not projected to meet the SSWQO for selenium. This resulted in a re-assessment of the water quality predictions during operations, which were presented in a technical memo and submitted to the Board in April 2012 (Golder 2012a). The most substantive changes to the water quality predictions in Peanut and Burke lakes were an increase in total dissolved solids (i.e., major ions), phosphorus, and several metals (i.e., aluminum, antimony, molybdenum, molybdenum, and silver) relative to that presented in the DAR and baseline conditions. In the Marian River, only antimony was assessed to increase beyond the DAR predictions and baseline conditions. These increases were consistent with the projected effluent quality for the modified ETF system.

Superimposed on these predictions, however, was a very conservative input loading of metals to the lakes associated with the deposition of fugitive dust emissions from the NICO Project site. The deposition of fugitive dust was noted in the DAR as the largest source of change in receiving water quality for the majority of metals during construction and operation. Although the predicted dust and metals inputs to the receiving waterbodies were substantially greater than has been measured at operating mines, particularly during winter conditions, a mechanism to address the potential natural mitigation afforded by winter was not available. As a result, air quality assessments did not apply a winter mitigation factor. The water quality assessment assumed that all dust emissions modelled during winter deposited in the watersheds around the proposed NICO Project, subsequently made their way in the surrounding waterbodies (i.e., no retention of deposited dust in the watershed, and indefinite suspension of dust particles greater than 10 microns [µm]). In July 2012, following discussions with AANDC, the receiving water quality modelling was updated to incorporate a winter dust mitigation of 50%, compared to the zero winter mitigation assumption presented in the DAR. This update showed that that the modelled water quality projections for Nico, Peanut, and Burke lakes and Marian River are reduced substantively depending on the substance (expected substances with the largest reduction based on reduced winter dust emissions are aluminum, arsenic, barium, beryllium, cadmium, chromium, copper, cobalt, iron, and lead), with the most notable changes occurring in the Burke Lake watershed (Golder 2012b). It is still considered that the 50% mitigation assumption is very conservative, as it is expected that natural winter dust mitigation would be considerably greater than 50%.

Golder (2012a) concluded that the overall changes in water quality throughout the operations phase in Peanut Lake, Burke Lake, and the Marian River remain consistent with those described in the DAR, particularly for the Marian River, and that the residual effects classification remained unchanged. Additionally, the evaluation of risk to aquatic life based on the revised water quality predictions (Golder 2012c) concluded that the projected changes are not expected to result in a significant adverse impact on the suitability of water in these waterbodies to support a viable and self-sustaining aquatic ecosystem.

For the operations phase, therefore, if the conservatism associated with the dust deposition inputs to the water quality projections are reduced based on the new information in Golder (2012b), it can be stated with a high degree of confidence that the water quality projections for Nico, Peanut, and Burke lakes during operations will be lower than presented in the memo (Golder 2012b).

13.2 Active Filling

Recently, Fortune was requested to consider the alternative of actively filling the pit lake following closure to shorten the timeline it would take to reach a final closure condition at the NICO mine. By supplementing the pit fill with water pumped from the Marian River, it is estimated that the pit lake will be filled approximately 10 years after the closure of the mine. As indicated in Section 8.0, use of water from the Marian River is expected to improve water quality conditions during the early periods of the filled lake compared to the modelled water quality projections for the passively filled pit lake (as presented in the DAR); however, the far future water quality projections are expected to be similar regardless of filling scenario once steady state has been achieved.

Modelled water quality for Nico Lake, Peanut Lake, Burke Lake, and then to the Marian River, in post-closure is provided in Tables 13-1 to 13-4. Modelled water quality projections are made for two time periods: once the pit lake overflows to Peanut Lake, and into the far future reflecting steady state conditions. Modelled concentrations with and without wetlands are also provided, with the wetlands scenario assuming SSWQOs or a 50% reduction in the influent concentration of metals is achieved (whichever is lower). Modelled average concentrations are provided.

The DAR presented and assessed the modelled 95th percentile concentration data in the effects analysis. This data case represents an upper bound water quality projection, which has led to some confusion by reviewers because it has been assumed that this case represents the most likely water quality projections for the receiving environment. The rationale for this use of the modelled 95th percentile concentration data is based on two key premises: the first, to provide with a high level of confidence that the modelled water quality will not underestimate the potential effects to water quality; the second, to give the aquatic risk assessment team an upper bound to evaluate potential risk to the receiving waterbodies. From a modelling perspective, the conservatism applied by this approach, built on top of the conservatism associated with many of the input source terms to the watershed water quality model (see Sections 8.0 and 9.0), provides the potential for an overestimate of expected average water quality conditions (this is the case for operations and closure assessment scenarios); i.e., the results would be equivalent to the maximum source terms (concentration and flows) flowing into the Burke Lake watershed under dry (low flow conditions) conditions. It could be argued, however, that under dry conditions, the inflows from the SCP and pit lake would be similarly affected (i.e., concentrations would still be high, but flows would be comparably low), which further adds to the conservatism.

The more reasonable approach, therefore, should be to evaluate the modelled average concentrations presented in Tables 13-1 to 13-4, which would represent average climate conditions. The majority of changes in water quality parameter concentration due to the NICO Project during operations and closure phases are large in terms of relative change compared to baseline conditions (compare the average versus 95th percentile baseline data), so natural variability would be a relatively small contributor to overall change. Additionally, using average conditions allows for a straightforward assessment of incremental changes due to the NICO Project.

Table 13-1: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Nico Lake)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Nico Lake		
				Baseline	Post-Closure	
Parameter	**Units**	**Guidelines**	**(June 2012)**	**(as presented in DAR)**	**Without Wetlands**	**With Wetlands**
Major Ions and TDS						
Calcium	mg/L	-	-	9.1	10.2	10.2
Chloride	mg/L	120	353	0.80	7.67	7.67
Magnesium	mg/L	-	-	4.21	4.96	4.96
Potassium	mg/L	-	-	1.13	22.16	22.16
Sodium	mg/L	-	-	2.68	4.50	4.50
Sulphate	mg/L	-	500	3.9	21.4	21.4
Total Dissolved Solids	mg/L	-	-	54.0	95.2	95.2
Nutrients						
Nitrate	mg N/L	2.93	6.09	0.07	0.14	0.14
Ammonia	mg N/L	1.1	-	0.025	0.115	0.115
Total Kjeldahl Nitrogen	mg N/L	-	-	0.72	0.62	0.62
Total Phosphorus	mg P/L	-	-	0.020	0.020	0.020
Total Metals						
Aluminum	mg/L	0.005-0.1	0.41	0.056	***0.743***	0.140
Antimony	mg/L	0.006	0.03	0.00032	0.00294	0.00157
Arsenic	mg/L	0.005	0.05	**<u>0.014</u>**	0.044	0.013
Barium	mg/L	-	1	0.0078	0.019	0.012
Beryllium	mg/L	-	-	0.000013	0.000115	0.000061
Boron	mg/L	1.5	-	0.0070	0.021	0.013
Cadmium	mg/L	0.000017	-	0.000011	**0.000071**	**0.000028**
Chromium	mg/L	0.001	-	0.00043	**0.00154**	0.00093
Cobalt	mg/L	-	0.01	0.00036	0.0049	0.0022
Copper	mg/L	0.002	0.022	0.0018	0.0034	0.0022
Iron	mg/L	0.3	1.5	**<u>0.38</u>**	***3.41***	0.70
Lead	mg/L	0.001	0.001	0.00007	***0.00144***	0.00029
Manganese	mg/L	-	0.7	0.022	0.072	0.045

Table 13-1: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Nico Lake) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Nico Lake		
				Baseline	Post-Closure	
Parameter	Units	Guidelines	(June 2012)	(as presented in DAR)	Without Wetlands	With Wetlands
Mercury	mg/L	0.000026	0.00026	0.0000084	0.000022	0.000014
Molybdenum	mg/L	0.073	-	0.00049	0.00457	0.00234
Nickel	mg/L	0.025	-	0.00052	0.00139	0.00089
Selenium	mg/L	0.001	0.0035	0.00014	***0.00462***	0.00092
Silver	mg/L	0.0001	-	0.000006	**0.000144**	0.000074
Thallium	mg/L	0.0008	-	0.0000017	**0.00130**	0.00065
Uranium	mg/L	0.015	-	0.00032	**0.0263**	0.0066
Vanadium	mg/L	-	0.006	0.00033	0.00083	0.00054
Zinc	mg/L	0.03	-	0.0044	0.0233	0.0132
Dissolved Metals						
Aluminum	mg/L	0.005-0.1	0.41	0.025	0.328	0.062
Antimony	mg/L	0.006	0.03	0.00023	0.00207	0.00110
Arsenic	mg/L	0.005	0.05	**0.011**	0.037	0.011
Barium	mg/L	-	1	0.0068	0.0162	0.0106
Beryllium	mg/L	-	-	0.000009	0.000082	0.000044
Boron	mg/L	1.5	-	0.0058	0.0174	0.0107
Cadmium	mg/L	0.000017	-	0.000005	**0.000028**	0.000011
Chromium	mg/L	0.001	-	0.00022	0.00077	0.00046
Cobalt	mg/L	-	0.01	0.00024	0.0033	0.0014
Copper	mg/L	0.002	0.022	0.0013	0.0024	0.0015
Iron	mg/L	0.3	1.5	0.21	***1.89***	0.39
Lead	mg/L	0.001	0.001	0.00004	0.00086	0.00017
Manganese	mg/L	-	0.7	0.013	0.042	0.026
Mercury	mg/L	0.000026	0.00026	0.0000018	0.0000047	0.0000030
Molybdenum	mg/L	0.073	-	0.00041	0.00381	0.00195
Nickel	mg/L	0.025	-	0.0004	0.0011	0.0007
Selenium	mg/L	0.001	0.0035	0.00012	***0.0039***	0.00079

Table 13-1: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Nico Lake) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Nico Lake		
				Baseline	Post-Closure	
Parameter	**Units**	**Guidelines**	**(June 2012)**	**(as presented in DAR)**	**Without Wetlands**	**With Wetlands**
Uranium	mg/L	0.015	-	0.0003	**0.0219**	0.0055
Vanadium	mg/L	-	0.006	0.00018	0.00044	0.00029
Zinc	mg/L	0.03	-	0.0026	0.0132	0.0075

Note: Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

Bold Underline	Baseline concentration exceeds CCME guideline
Bold	Projected concentration exceeds CCME guideline (no SSWQO)
Bold Italics	Projected concentration exceeds SSWQO value

Table 13-2: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Peanut Lake)

Parameter	Units	CCME Fresh Water Aquatic Life Guidelines	Site Specific Water Quality Objectives (June 2012)	Peanut Lake				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
				(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Major Ions and TDS								
Calcium	mg/L	-	-	8.1	9.4	9.4	8.3	8.3
Chloride	mg/L	120	353	0.91	2.93	2.93	2.97	2.97
Magnesium	mg/L	-	-	3.53	4.24	4.24	3.74	3.74
Potassium	mg/L	-	-	1.13	6.24	6.24	6.99	6.99
Sodium	mg/L	-	-	2.73	3.28	3.28	3.59	3.59
Sulphate	mg/L	-	500	1.6	7.6	7.6	9.6	9.6
Total Dissolved Solids	mg/L	-	-	42.6	58.5	58.5	56.7	56.7
Nutrients								
Nitrate	mg N/L	2.93	6.09	0.06	0.08	0.08	0.08	0.08
Ammonia	mg N/L	1.1	-	0.020	0.043	0.043	0.043	0.043
Total Kjeldahl Nitrogen	mg N/L	-	-	0.60	0.59	0.59	0.59	0.59
Total Phosphorus	mg P/L	-	-	0.015	0.021	0.021	0.015	0.015
Total Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.099	0.256	0.110	0.246	0.105
Antimony	mg/L	0.006	0.03	0.00025	0.00103	0.00061	0.00150	0.00085
Arsenic	mg/L	0.005	0.05	0.0040	0.0137	0.0050	0.0226	0.0085
Barium	mg/L	-	1	0.0092	0.013	0.010	0.017	0.013
Beryllium	mg/L	-	-	0.000011	0.000113	0.000061	0.000034	0.000022
Boron	mg/L	1.5	-	0.0073	0.014	0.0100	0.021	0.014
Cadmium	mg/L	0.000017	-	0.000010	**0.000050**	**0.000027**	**0.000032**	**0.000018**
Chromium	mg/L	0.001	-	0.00055	**0.00114**	0.00079	0.00074	0.00059
Cobalt	mg/L	-	0.01	0.00020	0.0050	0.0016	***0.031***	0.0016
Copper	mg/L	0.002	0.022	0.0011	0.0017	0.0013	0.0020	0.0014
Iron	mg/L	0.3	1.5	**0.37**	1.06	0.42	1.04	0.41
Lead	mg/L	0.001	0.001	0.00007	0.00068	0.00022	0.00042	0.00013
Manganese	mg/L	-	0.7	0.024	0.036	0.029	0.039	0.030

Table 13-2: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Peanut Lake) (continued)

Parameter	Units	CCME Fresh Water Aquatic Life Guidelines	Site Specific Water Quality Objectives (June 2012)	Peanut Lake				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
				(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Mercury	mg/L	0.000026	0.00026	0.0000088	0.000024	0.000016	0.000020	0.000014
Molybdenum	mg/L	0.073	-	0.00022	0.00154	0.00083	0.00251	0.00132
Nickel	mg/L	0.025	-	0.00079	0.00114	0.00091	0.00273	0.00171
Selenium	mg/L	0.001	0.0035	0.00014	0.00130	0.00038	0.00173	0.00059
Silver	mg/L	0.0001	-	0.000006	**0.000286**	**0.000146**	0.000051	0.000028
Thallium	mg/L	0.0008	-	0.0000016	0.00031	0.00016	0.00038	0.00019
Uranium	mg/L	0.015	-	0.00020	0.0065	0.0018	0.0067	0.0018
Vanadium	mg/L	-	0.006	0.00034	0.00053	0.00042	0.00065	0.00048
Zinc	mg/L	0.03	-	0.0044	0.0090	0.0063	0.0130	0.0083
Dissolved Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.044	0.113	0.048	0.109	0.046
Antimony	mg/L	0.006	0.03	0.00018	0.00072	0.00043	0.00106	0.00060
Arsenic	mg/L	0.005	0.05	0.0034	0.0114	0.0042	0.0188	0.0071
Barium	mg/L	-	1	0.0079	0.0111	0.0089	0.0150	0.0109
Beryllium	mg/L	-	-	0.000008	0.000080	0.000043	0.000024	0.000015
Boron	mg/L	1.5	-	0.0059	0.0113	0.0081	0.0174	0.0112
Cadmium	mg/L	0.000017	-	0.000004	**0.000020**	0.000011	0.000013	0.000007
Chromium	mg/L	0.001	-	0.00028	0.00057	0.00039	0.00037	0.00029
Cobalt	mg/L	-	0.01	0.00013	0.0033	0.0011	***0.0209***	0.0011
Copper	mg/L	0.002	0.022	0.0008	0.0012	0.0009	0.0014	0.0010
Iron	mg/L	0.3	1.5	0.21	0.59	0.23	0.58	0.23
Lead	mg/L	0.001	0.001	0.00004	0.00041	0.00013	0.00025	0.000079
Manganese	mg/L	-	0.7	0.014	0.021	0.017	0.023	0.018
Mercury	mg/L	0.000026	0.00026	0.0000019	0.0000050	0.0000033	0.0000043	0.0000030
Molybdenum	mg/L	0.073	-	0.00019	0.00129	0.00069	0.00210	0.00110
Nickel	mg/L	0.025	-	0.0006	0.0009	0.0007	0.0021	0.0013
Selenium	mg/L	0.001	0.0035	0.00012	0.0011	0.00032	0.0015	0.00051

Table 13-2: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Peanut Lake) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Peanut Lake				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
Parameter	**Units**	**Guidelines**	**(June 2012)**	**(as presented in DAR)**	**Without Wetlands**	**With Wetlands**	**Without Wetlands**	**With Wetlands**
Uranium	mg/L	0.015	-	0.0002	0.0054	0.0015	0.0055	0.0015
Vanadium	mg/L	-	0.006	0.00018	0.00028	0.00022	0.00034	0.00025
Zinc	mg/L	0.03	-	0.0025	0.0051	0.0036	0.0074	0.0047

Note: Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

Bold Underline	Baseline concentration exceeds CCME guideline
Bold	Projected concentration exceeds CCME guideline (no SSWQO)
Bold Italics	Projected concentration exceeds SSWQO value

Table 13-3: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Burke Lake)

Parameter	Units	CCME Fresh Water Aquatic Life Guidelines	Site Specific Water Quality Objectives (June 2012)	Burke Lake: Baseline (as presented in DAR)	Burke Lake: Post-Closure Initial Discharge – Without Wetlands	Burke Lake: Post-Closure Initial Discharge – With Wetlands	Burke Lake: Post-Closure Steady State – Without Wetlands	Burke Lake: Post-Closure Steady State – With Wetlands
Major Ions and TDS								
Calcium	mg/L	-	-	8.7	9.3	9.3	8.9	8.9
Chloride	mg/L	120	353	1.18	2.14	2.14	2.15	2.15
Magnesium	mg/L	-	-	3.52	3.82	3.82	3.62	3.62
Potassium	mg/L	-	-	1.28	3.82	3.82	4.12	4.12
Sodium	mg/L	-	-	2.80	3.07	3.07	3.19	3.19
Sulphate	mg/L	-	500	2.0	4.7	4.7	5.5	5.5
Total Dissolved Solids	mg/L	-	-	42.3	49.0	49.0	48.3	48.3
Nutrients								
Nitrate	mg N/L	2.93	6.09	0.05	0.06	0.06	0.06	0.06
Ammonia	mg N/L	1.1	-	0.020	0.032	0.032	0.032	0.032
Total Kjeldahl Nitrogen	mg N/L	-	-	0.60	0.59	0.59	0.59	0.59
Total Phosphorus	mg P/L	-	-	0.015	0.017	0.017	0.015	0.015
Total Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.090	**0.172**	0.099	**0.168**	0.097
Antimony	mg/L	0.006	0.03	0.00025	0.00062	0.00042	0.00081	0.00052
Arsenic	mg/L	0.005	0.05	0.0028	**0.0072**	0.0030	**0.011**	0.0044
Barium	mg/L	-	1	0.0090	0.011	0.0097	0.013	0.011
Beryllium	mg/L	-	-	0.000011	0.000054	0.000032	0.000023	0.000016
Boron	mg/L	1.5	-	0.0061	0.0091	0.0074	0.012	0.0089
Cadmium	mg/L	0.000017	-	0.0000097	**0.000027**	0.000017	**0.000020**	0.000013
Chromium	mg/L	0.001	-	0.00058	0.00084	0.00068	0.00068	0.00060
Cobalt	mg/L	-	0.01	0.00017	0.0022	0.00075	***0.013***	0.00075
Copper	mg/L	0.002	0.022	0.0012	0.0015	0.0013	0.0016	0.0013
Iron	mg/L	0.3	1.5	**0.38**	**0.73**	**0.41**	**0.72**	**0.40**
Lead	mg/L	0.001	0.001	0.00008	0.00036	0.00014	0.00025	0.00011
Manganese	mg/L	-	0.7	0.025	0.031	0.028	0.032	0.028

Table 13-3: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Burke Lake) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Burke Lake				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
Parameter	Units	Guidelines	(June 2012)	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Mercury	mg/L	0.000026	0.00026	0.0000087	0.000015	0.000012	0.000014	0.000011
Molybdenum	mg/L	0.073	-	0.00021	0.00082	0.00049	0.00121	0.00068
Nickel	mg/L	0.025	-	0.00073	0.00090	0.00079	0.00153	0.00111
Selenium	mg/L	0.001	0.0035	0.00013	0.00071	0.00025	0.00088	0.00033
Silver	mg/L	0.0001	-	0.000006	**0.000120**	0.000063	0.000027	0.000016
Thallium	mg/L	0.0008	-	0.0000015	0.00016	0.00008	0.00018	0.00009
Uranium	mg/L	0.015	-	0.00023	0.00337	0.00101	0.00345	0.00104
Vanadium	mg/L	-	0.006	0.00040	0.00048	0.00043	0.00053	0.00045
Zinc	mg/L	0.03	-	0.0045	0.0068	0.0055	0.0084	0.01
Dissolved Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.040	0.076	0.044	0.074	0.043
Antimony	mg/L	0.006	0.03	0.00018	0.00044	0.00030	0.00057	0.00036
Arsenic	mg/L	0.005	0.05	0.0023	**0.0060**	0.0025	**0.0089**	0.0036
Barium	mg/L	-	1	0.0077	0.0093	0.0083	0.0109	0.0091
Beryllium	mg/L	-	-	0.000008	0.000038	0.000023	0.000016	0.000012
Boron	mg/L	1.5	-	0.0050	0.0074	0.0060	0.0099	0.0072
Cadmium	mg/L	0.000017	-	0.000004	0.000011	0.000007	0.000008	0.000005
Chromium	mg/L	0.001	-	0.00029	0.00042	0.00034	0.00034	0.00030
Cobalt	mg/L	-	0.01	0.00011	0.0015	0.0005	0.0084	0.0005
Copper	mg/L	0.002	0.022	0.0009	0.0010	0.0009	0.0011	0.0009
Iron	mg/L	0.3	1.5	0.21	**0.40**	0.23	**0.40**	0.22
Lead	mg/L	0.001	0.001	0.00005	0.00021	0.00008	0.00015	0.00006
Manganese	mg/L	-	0.7	0.014	0.018	0.016	0.019	0.017
Mercury	mg/L	0.000026	0.00026	0.0000019	0.0000032	0.0000025	0.0000029	0.0000023
Molybdenum	mg/L	0.073	-	0.00017	0.00069	0.00041	0.0010	0.00057
Nickel	mg/L	0.025	-	0.0006	0.0007	0.0006	0.0012	0.0008
Selenium	mg/L	0.001	0.0035	0.00011	0.00061	0.00021	0.00075	0.00029

Table 13-3: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Burke Lake) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Burke Lake				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
Parameter	Units	Guidelines	(June 2012)	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Uranium	mg/L	0.015	-	0.00019	0.00281	0.00084	0.00287	0.00087
Vanadium	mg/L	-	0.006	0.00021	0.00025	0.00023	0.00028	0.00024
Zinc	mg/L	0.03	-	0.0025	0.0039	0.0031	0.0048	0.0036

Note: Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

Bold Underline	Baseline concentration exceeds CCME guideline
Bold	Projected concentration exceeds CCME guideline
Bold Italics	Projected concentration exceeds SSWQO value

Table 13-4: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Marian River)

Parameter	Units	CCME Fresh Water Aquatic Life Guidelines	Site Specific Water Quality Objectives (June 2012)	Marian River: Baseline (as presented in DAR)	Marian River: Post-Closure Initial Discharge – Without Wetlands	Marian River: Post-Closure Initial Discharge – With Wetlands	Marian River: Post-Closure Steady State – Without Wetlands	Marian River: Post-Closure Steady State – With Wetlands
Major Ions and TDS								
Calcium	mg/L	-	-	25.5	22.7	22.7	22.7	22.7
Chloride	mg/L	120	353	2.68	2.56	2.56	2.56	2.56
Magnesium	mg/L	-	-	11.0	9.8	9.8	9.8	9.8
Potassium	mg/L	-	-	1.94	1.83	1.83	1.84	1.84
Sodium	mg/L	-	-	3.79	3.41	3.41	3.42	3.42
Sulphate	mg/L	-	500	20.9	18.2	18.2	18.3	18.3
Total Dissolved Solids	mg/L	-	-	119	111	111	111	111
Nutrients								
Nitrate	mg N/L	2.93	6.09	0.06	0.06	0.06	0.06	0.06
Ammonia	mg N/L	1.1	-	0.028	0.027	0.027	0.027	0.027
Total Kjeldahl Nitrogen	mg N/L	-	-	0.76	0.72	0.72	0.72	0.72
Total Phosphorus	mg P/L	-	-	0.0088	0.010	0.010	0.010	0.010
Total Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.032	0.055	0.052	0.054	0.052
Antimony	mg/L	0.006	0.03	0.000025	0.000041	0.000034	0.000049	0.000038
Arsenic	mg/L	0.005	0.05	0.00041	0.00061	0.00046	0.00075	0.00051
Barium	mg/L	-	1	0.015	0.014	0.014	0.014	0.014
Beryllium	mg/L	-	-	0.000011	0.000012	0.000011	0.000011	0.000011
Boron	mg/L	1.5	-	0.017	0.016	0.016	0.016	0.016
Cadmium	mg/L	0.000017	-	0.000016	0.000016	0.000016	0.000016	0.000016
Chromium	mg/L	0.001	-	0.00038	0.00040	0.00039	0.00039	0.00039
Cobalt	mg/L	-	0.01	0.00010	0.00018	0.00012	0.00059	0.00012
Copper	mg/L	0.002	0.022	0.0006	0.0007	0.0007	0.0007	0.0007
Iron	mg/L	0.3	1.5	0.14	0.15	0.14	0.15	0.14
Lead	mg/L	0.001	0.001	0.00007	0.00008	0.00007	0.00007	0.00007
Manganese	mg/L	-	0.7	0.031	0.026	0.026	0.026	0.026

Table 13-4: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Marian River) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Marian River				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
Parameter	Units	Guidelines	(June 2012)	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Mercury	mg/L	0.000026	0.00026	0.000011	0.000012	0.000012	0.000012	0.000012
Molybdenum	mg/L	0.073	-	0.00021	0.00023	0.00021	0.00024	0.00022
Nickel	mg/L	0.025	-	0.00100	0.00072	0.00072	0.00074	0.00073
Selenium	mg/L	0.001	0.0035	0.00018	0.00020	0.00019	0.00021	0.00019
Silver	mg/L	0.0001	-	0.000003	0.000008	0.000005	0.000004	0.000004
Thallium	mg/L	0.0008	-	0.0000013	0.000007	0.000004	0.000008	0.000005
Uranium	mg/L	0.015	-	0.00086	0.00088	0.00079	0.00088	0.00080
Vanadium	mg/L	-	0.006	0.00042	0.00046	0.00046	0.00046	0.00046
Zinc	mg/L	0.03	-	0.01	0.01	0.01	0.01	0.01
Dissolved Metals								
Aluminum	mg/L	0.005-0.1	0.41	0.016	0.027	0.025	0.027	0.025
Antimony	mg/L	0.006	0.03	0.000018	0.000030	0.000025	0.000036	0.000028
Arsenic	mg/L	0.005	0.05	0.00035	0.00051	0.00039	0.00063	0.00043
Barium	mg/L	-	1	0.013	0.012	0.012	0.012	0.012
Beryllium	mg/L	-	-	0.000008	0.000009	0.000008	0.000008	0.000008
Boron	mg/L	1.5	-	0.014	0.014	0.013	0.014	0.014
Cadmium	mg/L	0.000017	-	0.000007	0.000008	0.000007	0.000007	0.000007
Chromium	mg/L	0.001	-	0.00021	0.00022	0.00021	0.00021	0.00021
Cobalt	mg/L	-	0.01	0.00007	0.00012	0.00009	0.00041	0.00009
Copper	mg/L	0.002	0.022	0.0005	0.0005	0.0005	0.0005	0.0005
Iron	mg/L	0.3	1.5	0.082	0.090	0.084	0.090	0.083
Lead	mg/L	0.001	0.001	0.00004	0.00005	0.00004	0.00005	0.00004
Manganese	mg/L	-	0.7	0.019	0.016	0.016	0.016	0.016
Mercury	mg/L	0.000026	0.00026	0.0000030	0.0000034	0.0000033	0.0000034	0.0000033
Molybdenum	mg/L	0.073	-	0.00017	0.00019	0.00018	0.00020	0.00019
Nickel	mg/L	0.025	-	0.00078	0.00056	0.00056	0.00058	0.00057
Selenium	mg/L	0.001	0.0035	0.00016	0.00018	0.00016	0.00018	0.00017

Table 13-4: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project (Marian River) (continued)

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Marian River				
				Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
Parameter	**Units**	**Guidelines**	**(June 2012)**	**(as presented in DAR)**	**Without Wetlands**	**With Wetlands**	**Without Wetlands**	**With Wetlands**
Uranium	mg/L	0.015	-	0.00073	0.00075	0.00068	0.00075	0.00068
Vanadium	mg/L	-	0.006	0.00025	0.00026	0.00026	0.00026	0.00026
Zinc	mg/L	0.03	-	0.0043	0.0044	0.0044	0.0044	0.0044

Note: Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

For the closure phase of the NICO Project with the revised pit filling scenario, the water quality projections for the Burke Lake watershed and at the confluence with the Marian River were modelled using the same modelling approach and assumptions as described in the DAR.

For Nico Lake, inflows from the SCP in post-closure without passive treatment contribute to a number of metals exceeding SSWQOs (i.e., aluminum, iron, lead, and selenium) and CCME guidelines (i.e., cadmium, chromium, silver, thallium, and uranium). Passive treatment will be required to reduce the mass loading of CDF seepage to Nico Lake; with wetlands, it is expected that the SCP flows will be treated to reduce the modelled average concentration of metals levels to below SSWQOs and CCME guidelines (with the exception of cadmium; however, the cadmium guideline is under revision and anticipated the new guideline substantively higher than the current interim Water Quality Guideline, to the point where cadmium would not be a CoPC.

Modelled water quality in Peanut Lake in post-closure indicates a substantial attenuation from Nico Lake. Inflows from Nico Lake and the filled pit lake initially after the pit overflows without passive treatment contribute to a number of metals exceeding CCME guidelines (i.e., cadmium, chromium, and silver), and in the far future (cadmium). In the steady state condition, modelled cobalt exceeds the SSWQO, which is sourced from the filled pit lake. With the inclusion of wetlands, the modelled average concentration of metals levels reduces substantially.

Modelled water quality in Burke Lake in post-closure indicates a further attenuation from Peanut Lake. As SSQWOs are not applied to Burke Lake, inflows from Peanut Lake result in modelled exceedances of CCME guidelines for a number of metals (i.e., aluminum, arsenic, cadmium chromium, iron, selenium, and silver) consistently between the initial overflow and far future periods. With the inclusion of wetlands, only iron is modelled to exceed CCME guidelines.

For the Marian River in post-closure, with or without wetlands, the modelled average water quality remains similar to baseline conditions and below CCME guidelines. As a consequence, the modelled water quality projections for the Marian River indicate that traditional uses of the river will not be affected (i.e., the river downstream of the NICO Project will remain safe for fishing and for drinking).

However, the development of wetlands systems downstream of the SCPs Nos. 1, 2, 3, and 5 and the pit lake to passively treat the SCP flows to Nico Lake and the pit overflows to Peanut Lake will be implemented to increase the confidence that post closure flows to these lakes will consistently meet SSWQOs and better. To support the potential for the use of passive wetlands in this manner, there is strong evidence, as presented in Section 3.0, that the existing wetlands in the Grid Ponds system act as a natural passive treatment system for the highly mineralized flows into Nico Lake, because metal concentrations decrease along the hydrologic pathway through the Burke Lake watershed to the Marian River.

14.0 FINAL RISK AND COMPARISON TO BASELINE

Risk was assessed for the baseline condition at the NICO site for comparison with post-closure conditions to understand the relative risks at the site for aquatic, wildlife, and human receptors. The risk assessments were done for both scenarios. Risks were predicted to human health based on the higher value of either the initial discharge or steady state conditions. The risk assessment considered only water quality predictions without wetland treatment. Since wetland treatment has been predicted to result in lower concentrations of the CoPCs (Attachment B), if there are no predicted risks without wetland treatment, then it can be assumed there will also be no risks with wetland treatment.

For Marian River, the screening of chemical concentrations against DWGs indicated that there were no exceedances under post-closure conditions. Therefore, post-closure conditions will not impact the Marian River surface water quality and will not pose a human health concern. It should be remembered that this risk assessment was completed using the high end open pit flow estimate of 169,000 m^3/year and with water quality estimates that assumed no stratification of waters in the open pit and no wetland treatment. Therefore, the level of certainty that risk will not be greater than stated is very high.

For Nico Lake, most metals met their respective DWGs under post-closure conditions, except for aluminum, arsenic, iron, manganese, and uranium. The DWGs for aluminum, iron, and manganese are based on aesthetics and it is anticipated that these metals would not pose a health concern. Therefore, the risks associated with post-closure conditions for arsenic and uranium in Nico Lake were estimated.

For Peanut Lake and Burke Lake, most metals met their respective DWGs under post-closure conditions, except for aluminum, arsenic and iron. The DWGs for aluminum and iron are based on aesthetics and it is anticipated that these metals would not pose a health concern. Therefore, the risks associated with post-closure conditions for arsenic in Peanut Lake and Burke Lake were estimated.

The results are presented in Table 14-1.

Table 14-1: Human Health Risk Estimates at the Lakes – Post-Closure

Location	Concentration (mg/L)	Hazard Quotient	Incremental Lifetime Cancer Risk
Arsenic			
Nico Lake	0.044	**0.4**	**1×10^{-4}**
Peanut Lake	0.023	0.2	**7×10^{-5}**
Burke Lake	0.011	0.1	**4×10^{-5}**
Uranium			
Nico Lake	**0.026**	**0.1**	**NC**

Notes:
Estimated risks greater than their target values are indicated by bold font and shading.
NC = Not Calculable
HQ = Hazard Quotient; target HQ = 0.2
ILCR = Incremental Lifetime Cancer Risk; target ILCR = 1×10^{-5}

For arsenic in Nico Lake, the Post-Closure Case HQ and ILCR is greater than the target HQ and ILCR of 0.2 and 1×10^{-5}, respectively, and greater than the Baseline HQ and ILCR. Additionally, the arsenic Post-Closure Case HQs for Peanut Lake and Burke Lake meet the target HQ values, whereas the ILCRs for these lakes are above the target ILCR.

For uranium in Nico Lake, the Post-Closure Case HQ meets the target HQ of 0.2.

The results show that risks to human health were present under baseline conditions due to arsenic in surface water in the Grid Ponds for both cancer and non-cancer effects, and that under baseline conditions and in post-closure risks were also present due to arsenic in Nico Lake. Risks due to exposure to arsenic at the modeled ingestion rate, expressed as HQs, increased slightly from 0.2, the target level, under baseline conditions to 0.4 in post-closure, while cancer risk increased slightly from 7×10^{-5} to 1×10^{-4}.

The estimated risk levels above indicate that there may be health concerns associated with exposure to arsenic for recreational users consuming surface water from Nico Lake, Peanut Lake, and Burke Lake for 30 days per year throughout their life. However, these lakes are not likely high traffic areas that are used for recreational purposes by people living in the nearby communities. Based on traditional knowledge information collected, the nearby locations of Hislop Lake, Marian River, and Bea Lake are known to be used for recreational purposes including fishing and camping. As a result, the exposure scenario assessed is considered to be hypothetical.

No risks were predicted to human health from consumption of surface water from Marian River either under baseline conditions or in post-closure, and indicate that local communities can continue to use the resources of the Marian River as they have in the past.

14.1 Terrestrial and Aquatic Post-Closure Risk

Risks were predicted to aquatic life based on the predicted water quality in Nico Lake, Peanut Lake, Burke Lake, and the Marian River following the initial pit overflow, and also in the long-term steady state condition due to pit overflow and seepage from the CDF. The aquatic risk assessment considered only water quality predictions without wetland treatment. Since wetland treatment has been predicted to result in lower concentrations of the CoPCs (Attachment 1, Table A-1), if there are no predicted risks without wetland treatment, then it can be assumed there will also be no risks with wetland treatment. The results are presented in Table 14-2.

Table 14-2: Predictions of Risk (as RQs) for Aquatic Life – Post-Closure

CoPC	Nico Lake	Peanut Lake	Burke Lake	Marian River
Initial Discharge				
Arsenic	-	-	0.14	-
Cobalt	-	-	0.22	-
Iron	**2.3**	-	0.49	-
Lead	**1.4**	-	-	-
Selenium	**1.3**	-	-	-
Steady State				
Arsenic	-	-	0.21	-
Cobalt	-	**3.1**	**1.3**	-
Iron	**2.3**	-	-	-
Lead	**1.4**	-	-	-
Selenium	**1.3**	-	-	-

Notes:
- = This parameter was not identified as a CoPC in this water body.
Shaded + bold text = risk quotient > 1
CoPC = Chemical of potential concern.
RQs for initial discharge and steady state conditions are based on predicted average concentrations without wetlands.

As shown in Table 14-2, low risks were predicted in Nico Lake due to iron, while marginal risks were predicted due to concentrations of lead and selenium due to seepage from the CDF, assuming no wetland treatment (no risks are predicted from any of these elements with wetland treatment). Given the conservative nature of the water quality predictions, and the conservatism inherent in the aquatic risk assessment, the concentrations of lead and selenium are considered to not present risks to aquatic life. Iron is unlikely to result in risks to aquatic life, since it is an essential element. The prediction of risks is a consequence of the conservative benchmark for iron.

The predicted risk due to cobalt in Peanut Lake and Burke Lake is also considered to be due to conservative assumptions. The toxicity benchmark for cobalt is based on a single study in which a 21-day EC16 of 10 µg/L was derived for reproduction in *Daphnia magna*. Aquatic invertebrates are the most sensitive group of organisms to cobalt exposure followed by fish and plants. For fish, no observed effect concentrations (NOECs) range from 132 to 10,000 µg/L. Lowest observed effect concentrations (LOECs) range from 225 to 1,610 µg/L. For plants, NOECs range from 500 to 550 µg/L. A LOEC for plants of 550 µg/L is reported in the literature. Concentrations of cobalt in the NICO Project Area therefore are well below the concentrations reported to have adverse effects on fish and plants (no risks are predicted in these waterbodies with wetland treatment).

No risks are predicted for aquatic life in the Marian River. Water quality predictions have not resulted in changes to water quality in the Marian River that could affect aquatic life. Concentrations of the CoPCs are below the CWQGs in post-closure.

Risks to wildlife due to consumption of water are provided in Tables 14-3 and 14-4. Risks are assessed based on the predicted concentrations in the waterbodies without wetland treatment. With the exception of the pit lake, where both the initial concentration and steady state conditions are assessed, the risk assessment has considered the highest predicted concentrations of the CoPCs during either the initial discharge or the steady state condition. The conservative assumptions used in assessing baseline conditions, namely that the receptor is consuming water exclusively from the one source for 12 months of the year, were also used in this assessment.

Table 14-3: Predicted Risks (as RQs) to Birds Consuming Surface Water – Post Closure

COC	Common Nighthawk	Loon	Mallard	Olive-sided Flycatcher	Peregrine Falcon	Ptarmigan	Rusty Blackbird	Short-eared Owl
Nico Lake								
Arsenic	0.003	0.0002	0.0002	0.004	0.001	0.0003	0.003	0.002
Cobalt	0.00009	0.00003	0.00004	0.0001	0.00005	0.00005	0.00009	0.00006
Lead	n/a	0.000006	0.000008	n/a	n/a	n/a	n/a	n/a
Selenium	0.002	0.0003	0.0003	0.003	0.001	0.0004	0.002	0.001
Peanut Lake								
Arsenic	0.001	0.00008	0.0001	0.002	0.0007	0.0001	0.001	0.0009
Cobalt	0.0006	0.0002	0.0002	0.0007	0.0003	0.0003	0.0006	0.0004
Lead	0.00006	0.000003	0.000004	0.00008	0.00003	0.000004	0.00006	0.00004
Selenium	0.0009	0.0001	0.0001	0.001	0.0004	0.0002	0.0009	0.0005
Pit Lake Post Closure Initial Discharge (10 Years)								
Arsenic	0.002	0.0001	0.0001	0.002	0.0009	0.0002	0.002	0.001
Cobalt	0.0007	0.0002	0.0003	0.0009	0.0004	0.0004	0.0007	0.0004
Lead	0.0003	0.00001	0.00002	0.0003	0.0001	0.00002	0.0003	0.0002
Selenium	0.0007	0.00007	0.0001	0.0008	0.0003	0.0001	0.0007	0.0004
Pit Lake Post Closure Maximum Predicted Water Quality (200 Years)								
Arsenic	0.003	0.0002	0.0002	0.004	0.001	0.0003	0.003	0.002
Cobalt	0.001	0.0004	0.0006	0.002	0.0007	0.0007	0.001	0.0008
Lead	0.0003	0.00001	0.00002	0.0004	0.0002	0.00002	0.0003	0.0002
Selenium	0.001	0.0001	0.0001	0.001	0.0005	0.0002	0.001	0.0006
Burke Lake								
Arsenic	0.0007	0.00004	0.00005	0.0009	0.0003	0.00006	0.0007	0.0004
Cobalt	0.0002	0.00008	0.0001	0.0003	0.0001	0.0001	0.0002	0.0001
Lead	0.00003	0.000001	0.000002	0.00004	0.00002	0.000002	0.00003	0.00002
Selenium	0.0004	0.00005	0.00006	0.0006	0.0002	0.00008	0.0004	0.0003
Marian River								
Arsenic	0.00005	0.000003	0.000003	0.00006	0.00002	0.000004	0.00005	0.00003
Cobalt	0.00001	0.000004	0.000005	0.00001	0.000006	0.000006	0.00001	0.000007
Lead	0.000007	0.0000003	0.0000004	0.000009	0.000003	0.0000005	0.000007	0.000004
Selenium	0.0001	0.00001	0.00002	0.0001	0.00005	0.00002	0.0001	0.00006

Table 14-4: Predicted Risks (as RQs) to Mammals Consuming Surface Water – Post-Closure

COC	Arctic Ground Squirrel	Black bear	Caribou	Moose	Muskrat	Snowshoe hare	Wolverine
Nico Lake							
Arsenic	0.004	0.002	0.02	0.002	0.003	0.003	0.003
Cobalt	0.00007	0.00004	0.00004	0.00003	0.00006	0.00006	0.00005
Lead	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Selenium	0.001	0.0009	0.002	0.0007	0.001	0.001	0.001
Peanut Lake							
Arsenic	0.002	0.02	0.01	0.0009	0.002	0.002	0.001
Cobalt	0.0004	0.000000000	0.0003	0.0002	0.0004	0.0004	0.0003
Lead	0.0000009	0.005	0.000009	0.0000004	0.0000008	0.0000008	0.0000007
Selenium	0.0005	0.3	0.0008	0.0003	0.0005	0.0005	0.0004
Pit Lake Post Closure Initial Discharge (10 Years)							
Arsenic	0.002	0.001	0.01	0.001	0.002	0.002	0.002
Cobalt	0.0005	0.0003	0.0003	0.0003	0.0005	0.0005	0.0004
Lead	0.000004	0.000002	0.00004	0.000002	0.000004	0.000004	0.000003
Selenium	0.0004	0.0003	0.0006	0.0002	0.0004	0.0004	0.0003
Pit Lake Post Closure Maximum Predicted Water Quality (200 Years)							
Arsenic	0.004	0.002	0.02	0.002	0.003	0.003	0.003
Cobalt	0.001	0.0006	0.0006	0.0005	0.001	0.0009	0.0008
Lead	0.000005	0.000003	0.00005	0.000002	0.000004	0.000004	0.000003
Selenium	0.0006	0.0004	0.0008	0.0003	0.0006	0.0006	0.0004
Burke Lake							
Arsenic	0.0009	0.0006	0.005	0.0005	0.000841905	0.0008	0.0007
Cobalt	0.0002	0.0001	0.0001	0.00009	0.0002	0.0002	0.0001
Lead	0.0000005	0.0000003	0.000005	0.0000002	0.0000004	0.0000004	0.0000003
Selenium	0.0003	0.0002	0.0004	0.0001	0.0003	0.0003	0.0002
Marian River							
Arsenic	0.00006	0.00004	0.0004	0.00003	0.00006	0.00006	0.00005
Cobalt	0.000008	0.000005	0.000005	0.000004	0.000008	0.000008	0.000006
Lead	0.0000001	0.00000006	0.000001	0.00000005	0.0000001	0.0000001	0.00000008
Selenium	0.00007	0.00004	0.00009	0.00003	0.00006	0.00006	0.00005

Exceedances of the target risk quotient of 1 are shown by shading

Tables 14-3 and 14-4 show that risks due to consumption of surface water are well below the RQ of 1, and that risks due to consumption of surface water in post-closure are negligible. The risk assessment has shown that there are no risks to wildlife either during existing baseline conditions, or in post closure due to consumption of surface waters from Nico, Peanut, and Burke lakes and the Marian River. As a result, wildlife can continue to use these areas as sources of drinking water with no risk of adverse effects. The risk assessment has also shown that there are no predicted risks to wildlife consuming water from the open pit. Since overflow water from the open pit would drain to the wetland treatment system, the results indicate that there would be no risk to wildlife consuming water from these areas as well. Risk predictions show that risks to receptors due to consumption of water from the open pit and wetland treatment system would be lower than currently predicted for exposure to water in the Grid Ponds.

Water quality data also show that conditions in the Marian River during baseline and in post-closure are virtually unchanged. As a result, there are also no predicted risks to terrestrial receptors that may consume water from the Marian River. Since the terrestrial risk assessment for the post-closure scenario assessed above assume that the receptor consumes water only from the designated waterbody, and is present at the site for 12 months of the year, the actual risks are would be lower than predicted, since most bird and large mammal species would not be consuming water from a single source year-round.

Based on the predictions of risk in the waterbodies potentially affected by seepage from the CDF and overflow of the open pit in post-closure, there are no increases in risks to any receptors in the Marian River. The risk assessment provided in the DAR noted that there were no risks to receptors at the Marian River when all pathways of exposure were considered. The active filling of the pit in post-closure has not changed the predictions of risk for wildlife and as a result, the Nico Project will not affect future uses of the Marion River, and local communities can continue to make use of the resources of the Marian River as they have in the past.

The risk assessment has also shown that adverse effects on receptors are not likely to occur in Nico, Peanut, and Burke lakes and the Marian River without wetland treatment, and confirms that inclusion of wetland treatment provide an added measure of assurance that adverse effects on surface waters will not occur during closure and post-closure. With wetland treatment, no risks are predicted to aquatic life or human receptors in the receiving waterbodies or downstream since concentrations of the CoPCs are predicted to be below the SSWQOs and DWOs.

15.0 CLOSURE

This memo has addressed each project element related to closure and assigned it a likelihood estimate. It is provided to the Review Board to support the overall conclusion that there is virtually no risk to aquatic, wildlife, and human receptors with the closure of the NICO mine.

In summary the long-term solutions to water quality at the NICO mine are as follows:

1) Build the CWTS for the CDF early in operations to confirm performance.

2) Actively fill the open pit to reduce the uncertainty associated with a lengthy open pit filling period.

3) Monitor water quality results prior to the pit reaching capacity to determine the need for the CWTS.

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c:\users\jgibson\documents\sharepoint drafts\closure memo to the review board.docx

Attachment A

Contango Strategies Ltd. Work Plan

Contango Strategies Ltd.

Forward looking. Lateral thinking.

NICO Constructed Wetland Treatment System, Phase 1

Prepared for

Fortune Minerals Limited

Submitted by

Contango Strategies Limited

(on behalf of CSL, NPS/DUC, and Drs. Rodgers and Castle)

August 17, 2012

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1. Introduction

Fortune Minerals Ltd (Fortune) has indicated that they will need a long-term method for treatment of waters that will originate from seepage and snow melt/rainwater run-off from the co-disposal facility (CDF) containing mine rock and tailings (approximately 50,000-100,000 m^3/year) and treatment of overflow from a filled open pit mine (approximately 170,000 m^3/year) at Fortune's NICO operation in the Northwest Territories. It is the intention of Fortune that the renovated waters be safely released to the surface water system. The target goal is to preserve the water quality in the ultimate receiving system of the Marian River, which is downstream of the NICO mine site, by treating the water in a passive manner, with no long-term operations or maintenance required after the wetland has become established.

Fortune has requested that Contango Strategies Limited (CSL) in conjunction with our partners at Native Plant Solutions (NPS/DUC; a division of Ducks Unlimited Canada) and Drs. John Rodgers and James Castle (of Clemson, South Carolina) submit a work plan to design and undertake a series of feasibility studies to confirm the performance of a Constructed Wetland Treatment System (CWTS) for removal of constituents of concern (COCs) from the water. Every CWTS we design and implement is created on a case-by-case basis, tailored to the specific water needing renovation and site-specific requirements. We have reviewed the post-closure water quality predictions for both the CDF and the open pit and based on our experience in dealing with similar situations, are highly confident that we can design and implement a CWTS for treatment of water post-closure at the NICO site; however, pilot studies and testing are needed to determine exact removal rates, optimal design factors, and overall footprint and cost of the potential full scale CWTS. The design and evaluation of indoor and outdoor pilot-scale CWTS are presented here as the first two phases of a four-phase process intended to develop a method for long-term passive water treatment at Fortune's NICO site. The purpose of the pilot CWTS is to identify the ideal combination of conditions, using locally sourced plants in Northern climate conditions to create a water treatment system resulting in maximum removal of COCs and best outflow water quality. Following the successful demonstration of the outdoor pilot scale CWTS, the third phase would be to design, build, and monitor a demonstration-scale CWTS at the NICO mine site at the beginning of operations. The fourth and final phase would be to design, build and monitor the full-scale CWTS as early in the operations period as feasible to demonstrate the effectiveness of the CWTS.

A detailed work plan for this first-phase of the program, including feasibility and planning, experimental design, setup, sampling and analyses of the pilot CWTS, and reporting of activities and findings is provided within this work plan.

2. Scope of Work

The scope of this work plan includes the following:

- Detailed consultation with client and design team members to determine and identify specific project objectives, timelines, requirements, site/scientific restrictions, information gaps, development of initial plans, etc;
- Determine if the water sources (CDF run-off, seepage, and open pit overflow) can be dealt with in same type of CWTS model, or combined into one water source for more effective treatment;
- Development of the workplan and project initiation;

- Preliminary likelihood analysis based on literature and background experience;
- Evaluation of pathways for sequestering COCs from the water;
- Development of a methodology for the pilot CWTS testing; including design, construction, experimental implementation, sampling, and analytical testing.
- Collaboration with Fortune to source and transport appropriate plant materials from sources near the NICO mine site;
- Baseline quantification of water samples in the context of CWTS remediation;
- Preparation of simulated water for renovation;
- Baseline quantification of hydrosoils (the soil used in the wetlands) and plants;
- Construction of indoor and outdoor pilot-scale CWTS;
- Sampling of water, sediments, and plants from each CWTS cell for multiple parameters according to sampling regimen (Appendix A);
- Provide analyses to Fortune after each sampling period;
- Evaluation of the performance of these pilot-scale CWTS for removing COCs, and calculation of possible necessary design modifications and footprint;
- Characterization of degradation, transport, and sequestration mechanisms used in the CWTS;
- End of project likelihood analysis for demonstration-scale and full-scale CWTS based on experimental results and pilot scale data;
- Attend progress meetings with selected Fortune personnel (frequency to be determined in consultation with Fortune); and,
- Provide Fortune with annual reports.

3. Background

This section provides background about the project team, constructed wetland treatment systems, our approach to design, and examples of our experience with cold weather treatment and treatment of metals and other pollutants.

3.1.Team

Over several decades, our partners (Dr. John Rodgers and Dr. James Castle) at Clemson University have been highly successful in developing constructed wetlands for targeted removal of priority pollutants, including metals and organics from a variety of waters. CSL has joined forces with Drs. Rodgers and Castle to develop their approach for CWTS applications in the Canadian climate and for a wider array of contaminated waters. CSL operates indoor and outdoor CWTS pilot testing facilities and laboratories in Saskatoon, Saskatchewan. Our team also includes Native Plant Solutions (NPS/DUC, a division of Ducks Unlimited Canada), bringing over 75 years of experience in wetlands research, management, design and construction. A primary goal of the partnership is to promote appropriate use of specifically designed CWTS for enhancing water quality and increasing reuse options using this environmentally sound, economically viable and socially acceptable technology. Biographies of companies and key personnel are provided in Sections 5.1 and 5.2 of this work plan, and CV's are provided as Appendix C.

3.2. Constructed Wetlands Background

Regardless of geographic location or climate, wetlands naturally have the ability to remove various COCs from a range of different types of water, including mining drainage, runoff and effluents. Exploration geologists have known for many years that metals frequently naturally accumulate in swamps and bogs located in mineralized areas (Brake et al. 2001). Since wetlands are self-sustaining ecosystems, they possess the potential to remediate contaminated mine drainage for as long as it is generated. Thus, constructed wetland treatment systems (CWTSs) represent a long-term solution for treatment of mine drainage, especially so in remote areas and northern climates where both access and power supplies may be limited.

CWTSs have been used for a variety of contaminated waters (Knight et al. 1999; Gillespie et al. 2000; Johnson et al. 2008). Potential benefits of CWTSs can include: effective treatment, solar energy driven, increased effectiveness over time, and tolerance of deviations in flow rate and contaminant load. CWTSs can often provide treatment of multiple constituents simultaneously and more effectively than chemical or physical treatment processes (Bhamidimarri et al. 1991; Sundaravadivel and Vigneswaran 2001; Rodgers and Castle 2008; Dorman et al. 2009). CWTSs can provide effective water treatment, provided that constituents for treatment are successfully targeted through operative pathways (Murray Gulde et al. 2005; Johnson et al. 2008; Murray Gulde et al. 2008). This report outlines a feasibility and pilot study to provide data regarding the efficacy of CWTSs for waters that would be occurring post-closure from seepage and snow melt/rainwater run-off from the CDF and the open pit at Fortune's NICO operation in the Northwest Territories.

Costs of building a full-scale CWTS are determined by the design used and based on the cumulative cost of land, earthwork, flow control structures, planting and monitoring. While numbers will need to be adjusted to reflect modern day costs, a survey reported in 1996 (Kadlec and Knight) suggests that surface flow CWTS in the United States may cost between $10,000 and $50,000 per hectare (2.47 acres), depending on the system size and complexity. Additional costs may be incurred depending on the accessibility and constructability of the site, including importing of topsoil, loss of economy of scale, or requirement for specialized architectural/aesthetic features.

3.2.1. Approach

Our approach to CWTS design and construction is directed and objective oriented. We establish design goals and performance criteria prior to proceeding with the design to construct systems in order to achieve those goals. The design that we propose is comprehensive and based on sound science (biogeochemistry, pilot studies, etc.). The Partnership between researchers at Clemson University, NPS/DUC, and CSL can provide assistance with development of CWTS from concept to sustained performance using the following approach:

1) Characterization of water for renovation
2) Evaluation of reuse options
3) Identify targeted constituents and performance goals
4) Design of pilot scale CWTS study
5) Assembly of indoor pilot scale CWTS at CSL
6) Performance monitoring and stress testing of the indoor pilot scale CWTS at CSL
7) Assembly of outdoor pilot scale CWTS at CSL
8) Performance and seasonal monitoring of the outdoor pilot scale CWTS at CSL
9) Design of demonstration scale CWTS
10) Construction of demonstration scale CWTS at NICO mine

11) Performance monitoring of demonstration scale CWTS at NICO mine
12) Design of full scale CWTS and regulatory and community consultation
13) Construction bids, permit and initiation
14) Construction and post-construction monitoring
15) Planting and maturation
16) Acclimation and initial monitoring
17) Owner assumption of CWTS

The content of this phase covers Steps 1 through 8. Our proven approach for CWTS was developed over decades of research and applications. With a strong basis in fundamental biogeochemistry, this approach differs substantively from alternative approaches that rely upon phytoconcentration, volatilization and other non-sustainable pathways for treatment of COCs that simply transfer the elements to other components of the environment (i.e. plant tissue or air). A key component to our successful approach is a complete wastewater characterization followed by the design, construction and monitoring of a pilot scale system. The pilot scale CWTS allows for testing different treatment approaches using a variety of wetland soils and plants to verify their efficacy in removing COCs. These pilot scale results are then scaled up for application in the field, thus improving the efficacy and efficiency of the wetland treatment system.

3.2.2. Experience with Constructed Wetland Treatment Systems in Cold Environments

Our team's experience with cold climate wetlands includes the design and implementation of a CWTS for treatment of munitions contaminated water in Anchorage Alaska and research operations in Saskatoon, Saskatchewan. In Saskatoon, winter conditions generally last from November through March, in the coldest months of January and February, temperatures are often below -40°C and average low temperatures are around -20°C with high temperatures rarely rising above -10°C. CSL operates greenhouse space to model and optimized processes year-round, and outdoor facilities to test pilot-scale CWTS in a cold-climate environment.

Based on our experience in dealing with widely fluctuating ambient temperatures and successfully achieving treatment goals at extreme altitudes or latitudes (with emphasis on extreme cold), two approaches have been used and could be evaluated for this situation involve: 1) Ambient Temperature Approaches and 2) Managed Temperature Approaches. It has been indicated by Fortune that the CWTS will need to function independently at post-closure. Consequently, only the ambient temperature designs would be appropriate for this site. The following discussion outlines some fundamental options in ambient temperature approaches. Ambient Temperature Approaches include those approaches for design and operation that do not attempt to alter existing temperatures at a site, even if the water to be treated is solid (frozen) for several months of each year.

3.2.2.1. Ambient Temperature Approaches

Based on the requirements of this project, we will only use seasonal approaches involving treatment during the warmer months of the year when water is liquid and treatment performance can be sustained at a high level. Water to be treated will be stored temporarily in equalization basins during the early spring months until thaw is completed, promoting treatment performance in the CWTS. The use of equalization basins would also allow for snow melt water to mix over time with rain water, resulting in an even water flow and more consistency in the concentration of COCs through the year. As noted above, the CWTSs must be designed with the temperature co-varying parameters in mind. Performance during freeze-thaw cycles will be evaluated at the outdoor pilot CWTS facilities CSL operates in Saskatoon, Saskatchewan.

3.2.3. How do you prevent development of a hazardous waste site?

We propose to build accreting CWTS for the treatment portions of this project as a key element for avoiding development of a hazardous waste site. Accreting wetlands are common in the boreal forest area and, in basic terms, simply require that the half-life of detritus produced in the CWTS be sufficient to carry over mass into subsequent seasons in the sediments. Typical half-lives for plants capable of achieving this goal are 150-200 days. In accreting wetlands, sediments are actually "growing" (increasing in mass over time) due to production of residual detritus by plants. If organics (e.g. naphthenic acids, PAHs, solvents) are treated in a CWTS, we determine the sorption and degradation rates vs. the rate of accrual of detritus in the sediments. For elements, such as aluminum, arsenic, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, nickel, selenium, vanadium and zinc, our approach is to use biogeochemical pathways that sequester them in the sediments. As for the organics, we determine metal loading, sediment accretion rate and other factors such as production of acid volatile sulfides in the sediments to ensure that we never achieve concentrations that exceed hazardous waste site limits. Further, we use toxicity testing to confirm the bioavailability (or lack of bioavailability) of the constituents in sediments.

3.2.4. How much space is required?

The space required for the eventual implementation of the full-scale CWTS is dependent on several factors: 1) the volume of the water to be treated, 2) the periodicity of the flow of the water to be treated, 3) the constituents and concentrations in the water, 4) site-specific rates of removal, and 5) extents of removal required (outflow concentrations or limits). The space requirement is largely dependent on site- and project-specific restraints and the option selected from pilot-scale results. The CWTS designed for Fortune's NICO site will treat water primarily during the summer months and store both treated and untreated water when the system is iced over (as we have done in the full-scale system built in Alaska).

As an example of footprint needed for construction of a CWTS, more than ten years ago, we designed and built a CWTS for a process wastestream and runoff from an industrial area at a Department of Energy facility in South Carolina (Savannah River Site). The wastestream was on average 1 million gallons per day with concentrations of targeted constituents (copper, mercury and organics) an order of magnitude in excess of allowable discharge limits. This wastestream has been treated for discharge for more than 10 years with an 8 acre system. Based on the knowledge and experience we have gained from that point to today, we could achieve the same goals with 4 acres (3.24 hectares).

The size for the full-scale CWTS at Fortune's NICO site will be first be approximated by the results and findings of the pilot scale CWTS at CSL and refined and finalized using the data gained through the demonstration scale CWTS on site at the NICO mine. Factors influencing the overall size of the CWTS will include the numbers of different types of treatment cells required to achieve desired water quality and varieties of different types of water to be treated (vs. a single CWTS using mixed equalized water). Contingency is also factored into all CWTS designs.

3.2.5. Treating impaired waters for discharge and other beneficial uses

We are confident that most impaired waters can be reliably treated by CWTS to comply with water quality criteria for surface water discharge. The treated water can be used for other beneficial purposes such as development of wildlife habitat as well as boreal wetland restoration. At present, we envision CWTSs located at appropriate elevations and locations in the landscape to take advantage of water flow by gravity. One of the considerations that must be made in treating water for beneficial use is to deter animals and birds from the CWTS until the water has attained a quality that can be discharged. Several measures are taken to deter wildlife, including planting the CWTS as a monoculture at a density where there is no open water for waterfowl to land, and plant species are used that are not eaten by many animals. Additionally, the embankments of the CWTS serve a dual purpose. The embankments are built at a steep angle and formidable height, both containing the slow accretion of the wetland over time, and deterring wildlife from approaching its edges. Moreover, the density of plants and lack of a shoreline due to the embankments removes potential nesting sites.

Downstream wetlands could be designated for habitat and designed as wildlife "refuges". DUC/NPS will be working to identify or develop habitat wetlands downstream of CWTS. The water could then be used to augment flows in receiving systems.

4. Methodology

This section includes information specific to this project, including detailed descriptions of the proposed CWTS design, experimental piloting procedure, sampling schedule, and analytical methods. Timelines are outlined in Appendix B.

4.1. Characterization of water for renovation and evaluation of reuse options

Fortune has indicated that they have previously conducted studies to determine the probable long-term characteristics and COCs for the water to be renovated. It is expected that this information will be used at this step. Additionally, it has already been decided by Fortune that the end reuse option will be for the water to enter the surface water system. When freshwater systems are used as receiving bodies for treated waters, it is also important to consider the ecology and conservation considerations of specific receiving locations. Local habitats will be assessed by NPS/DUC members on their ability to act as a potential receiving site with the goal of maintaining the ecological integrity of the receiving system.

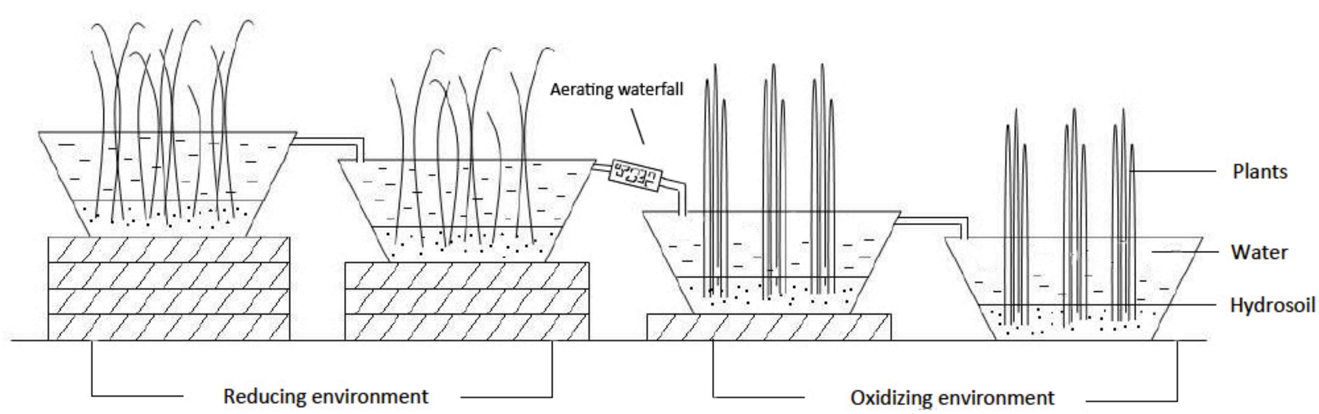
4.2. Determination of targeted constituents and performance goals

Targeted constituents will be determined based on a comparison of the predicted concentrations in the water and the Site Specific Water Quality Objectives (SSWQO's) developed by Fortune during the course of the environmental assessment review process. Considerations will be made for eventual increase in stringency of regulatory guidelines. The differences between the concentration of the constituent and the predicted future guideline will form the basis of our performance goals. Performance goals will also include volumes of water to be renovated, retention times, and duration of functional period in the year. Equalization basins will be used to reduce fluctuations in the loading of COCs over time.

4.3. Pilot CWTS design

4.3.1. Indoor pilot CWTS for design testing and optimization

The indoor pilot CWTS will be used to test various methods of metals removal from water and associated sedimentation rates using influent water made to simulate the runoff expected at the NICO mine site after closure. Effects of hydrosoil amendments, flow rates, water depths and sedimentation rates will be evaluated. Conditions will be created in sequential cells of the CWTS to create aerobic and reducing conditions in the sediments as needed for effective removal of the COCs. The indoor pilot CWTS will consist of three series composed of four containers each with approximately a 60cm diameter. Each of the three series will test a different combination of hydrosoil amendments, microbial feed additives, and water depths and flow rates to achieve maximum removal of metals. Extreme situations will be tested on the indoor wetlands, for example, a one in a one-hundred year drought or flooding conditions. Also included are worst-case scenarios for spikes in concentrations of COCs. Water flow will be initiated using a metering pump, and containers within a series will be connected by PVC pipe to allow gravity water flow. The PVC pipes connecting the CWTS cells each contain sampling ports to allow for testing of inflow and outflow waters of each individual cell to determine the efficacy of each cell's design. The indoor pilot CWTS will be housed in a computer-controlled, year-round greenhouse on premises of CSL in Saskatoon, Saskatchewan. Figure 1 shows an example of the layout of a pilot-scale CWTS and Figure 2 shows a pilot CWTS currently being tested at the indoor greenhouse facilities at CSL.

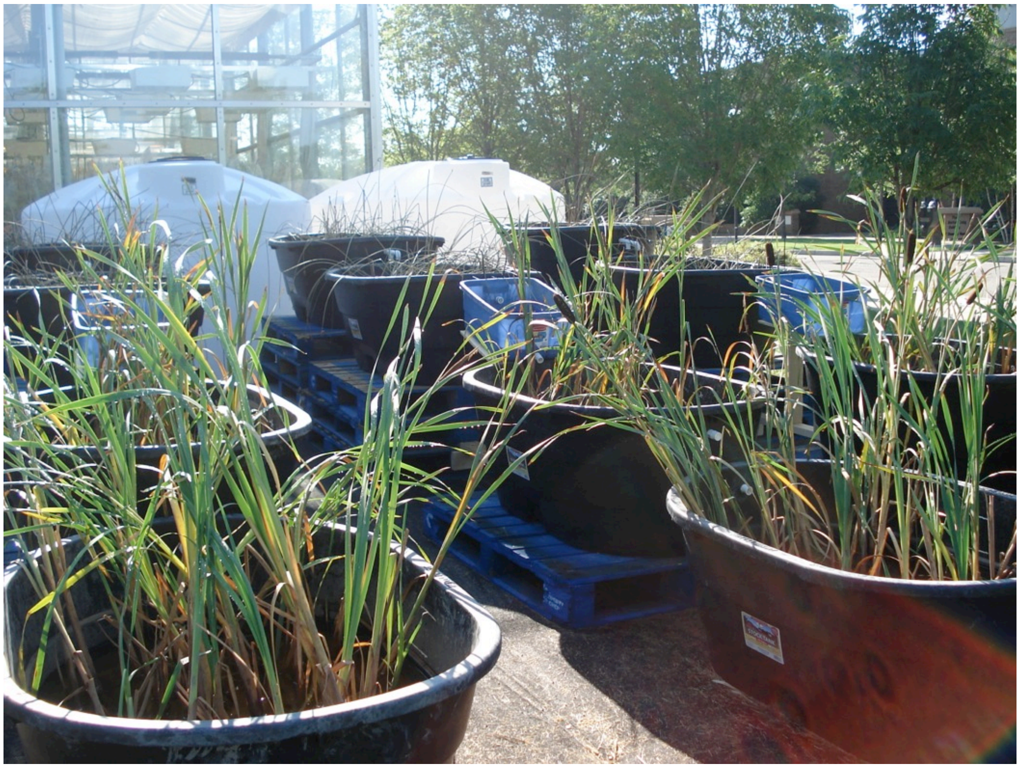


4.3.2. Figure 1. Example layout of a pilot-scale CWTS, side view

4.3.3. Figure 2. Indoor pilot scale CWTS at CSL in Saskatoon, Saskatchewan.

4.3.4. Outdoor pilot CWTS design for cold climate validation and data for scale-up to demonstration scale and full-size

The outdoor pilot CWTS will be used to validate the designs optimized indoors. The best combinations of hydrosoil, amendments and plants, as determined indoors, will be tested outdoors to validate function in our northern climate. Conditions will be created in sequential cells of the CWTS to create aerobic and reducing conditions in the sediments as needed for effective removal of the COCs. Function in spring thaw and cooling fall temperatures will be monitored and methods will be tested to attempt to further improve function at cold temperatures and reduce the spring lag period between thaw and function. Only methods which may have a permanent effect (e.g., CWTS water depth, retention time) will be tested for use in this CWTS. It is expected that outdoor cells will be built using three series of four rectangular bins, but these numbers may change based on the data gained from the indoor pilot CWTS data. The outdoor cells will be rectangular, approximately 120cm long and 90cm wide. In the same manner as the indoor pilot CWTS, water flow will be initiated using a metering pump, and containers within a series will be connected by PVC pipe to allow gravity water flow. The PVC pipes connecting the CWTS cells each contain sampling ports to allow for testing of inflow and outflow waters of each individual cell to determine the efficacy of each cell's design. The outdoor pilot CWTS will be located adjacent to CSL's laboratory and greenhouse facilities in Saskatoon, Saskatchewan. An example of a pilot scale CWTS currently being tested for a different project is shown in Figure 3.



4.3.5. Figure 3. Newly planted outdoor pilot CWTS at CSL in Saskatoon, Saskatchewan.

4.4. Experimental Setup

4.4.1. Hydrosoil

Approximately ten cubic meters of hydrosoil will be needed for the pilot scale CWTS. Ideally, hydrosoil will be composed of materials sourced from the NICO mine site. In particular, a sand grain size will be sought. First, small samples will be obtained and the samples will be tested to determine the natural concentrations of minerals, elements, and nutritional properties. Based on these analyses, it will be determined whether the materials are suitable for use as hydrosoil (e.g., if there is already high arsenic levels, the material should not be used). If the material is suitable, the necessary amendments (e.g., sulphate, iron, organic carbon, NPK) and their concentrations will be identified and determined. If suitable hydrosoil cannot be obtained at the NICO site, sand local to Saskatoon will be used, or blended with the hydrosoil available at the NICO site to reduce costs of future full-scale construction.

4.4.2. Water

Because the water needing renovation will not be present for this pilot-scale CWTS study, water will be simulated to mimic the water needing renovation. It has been explained by Fortune to CSL that this information has already been determined and will be available. It is expected that the actual water needing renovation will be available for future on-site demonstration scale CWTS testing and evaluation once the mine is in operation, which will be addressed in a future proposal, once pilot-scale design and evaluation is near completion.

4.5. Experiment Maintenance

The indoor and outdoor pilot CWTS will be conducted at CSL's facilities in Saskatoon. Trained laboratory technologists and scientists will maintain consistent observation over the individual pilot CWTS cells to ensure that any potential problems can be immediately addressed. A monitoring program will be instituted to inspect each cell on a regular basis (daily during regular workdays, and more frequently if needed). Fortune personnel will have access to the CSL greenhouse and outdoor space to observe and/or participate in scheduled sampling events and construction of the pilot CWTS.

4.6. Sampling Schedule

Duplicate samples will be collected and analyzed for every five samples collected for each cell or series (depending on type of analysis). For example, if 30 pH tests are to be performed over the two year duration, five of these will be duplicate samples. Routine sampling will be conducted on a scheduled basis as per Appendix A. This will include water pH, DO, evaporation, depth, temperature, flow rate, conductivity, hydraulic retention time and sediment redox potential on every cell. Every 2 weeks, the water will be tested for chemical oxygen demand, total organic carbon, phosphorous, ammonia, total kjeldahl nitrogen, nitrate, sulphate and total suspended solids. Every month, plants will be assessed for stem density and plant height, soil will be tested for cation exchange capacity, sodium absorption ratio, and most probable numbers of various metal-reducing bacteria, bacterial community profile will be established by DNA sequencing, and water will be tested for alkalinity, hardness, major/minor elements by ICP (and/or AA as applicable), biological oxygen demand, and microtox testing. Additionally, at the beginning and end of growing seasons, plant matter will be tested for elemental contents and detritus accumulation will be tested, and the soils will be tested for major and minor elements by ICP, nutrients (NPK), and electrical conductivity. Furthermore, at the start and end of the project, total plant mass (above and below ground) will be tested, and sediment particle sizes and total organic content will be tested.

4.7. Analytical

Analyses for pH, Eh and DO will be tested by CSL using a handheld probe and meter. Microbiological testing will be performed in CSL's laboratory. Conductivity, salinity, total dissolved solids, alkalinity, hardness, ammonia, nitrate, sulfate, conductivity, and chemical oxygen demand will be conducted in CSL's laboratory, with duplicate samples periodically sent to an external laboratory for confirmatory testing. All other analyses will be conducted by an external laboratory.

4.8. Information Gathering for Demonstration-Scale CWTS

Activities related to the information gathering for field implementation of the pilot site include:

1) Review, gather, analyze and interpret data or site-specific information leading to specialized conclusions regarding short and long-term water availability, on- and off-site specific conditions, specific considerations for design and construction.

2) Identification of data gaps related to site implementation.

3) Preliminary review, assessment for an implementation strategy based on site plan, regional location, water availability, provincial/federal guidelines and regulations, project timelines, and scientific findings.

4) Review and assessment of drainage, water needs and water storage requirements post development.

5) Investigation of a long-term management strategy for wetland function, sustainability and productivity.

6) An assessment of local water re-use options for the project based on sound science and the ecology of the region, including considerations for both the protection and enhancement of wildlife in the area.

7) Review all schedules and activities with recommendations to the client and design team prior to developing an on-site demonstration scale CWTS implementation.

8) Considerations for, and preparation of, a preliminary construction schedule associated with all CWTS related components.

5. Proponent Details

5.1. Corporate Profiles

Contango Strategies Ltd (CSL) is a Canadian owned and operated company that specializes in microbiological processes as applied to environmental and industrial processes. Operating a laboratory and indoor and outdoor CWTS pilot facilities in Saskatoon, Saskatchewan, Contango Strategies offers fee-for-service procedures in addition to contract scientific research, development, and value-added services the natural resources and energy sectors. Staff expertise includes microbiology, biochemistry, biology and biogeochemistry. Their combination of indoor year round facilities, laboratory, and outdoor cold-climate pilot CWTS area uniquely positions CSL to develop and test CWTS for the Canadian climate. CSL is actively involved in research aimed at developing new technologies, providing us with an advantage that allows us to be involved in major projects in the mining, oil & gas, and biofuels sectors. We believe that science should make financial sense, using scientific research and development to assist businesses in generating profits and increasing wealth through reducing their environmental impacts. We pride ourselves in developing intelligent scientific strategies for our clients through integration of industrial and environmental microbiology, bioinformatics, environmental sciences, and applied financial analysis. Contango Strategies provides clients with a wide range of scientific services including: scientific laboratory based research and development, technology assessment and feasibility, independent peer review and technical writing.

The **Native Plant Solutions** (NPS) product is the accumulation of Ducks Unlimited Canada's 75 years of wetland, waterfowl and riparian conservation activities and research in Canada. NPS was established by Ducks Unlimited Canada (DUC) in 2001 to provide science-based solutions using wetland and upland processes across Canada. The key to their success lies in their 75 years of experience in conserving, researching, managing and constructing upland and wetland habitats in both southern and northern Canada. The ability to do deliver all four products in-house puts NPS in the unique position to service the needs of a wide array of clients. Native Plant Solutions (NPS), a for-profit division of Ducks Unlimited Canada (DUC), has been working for the past decade with a number of partners on wetland, waterfowl and associated upland projects. In many situations we combine the skill sets of professionals within both NPS and DUC to provide the best service to our clients.

Over the last number of years Ducks Unlimited Canada's Native Plant Solutions has been working directly with forestry, mining and energy companies to advance sustainable development and to promote ecological practices. Our goal is to help advance sustainable development that is good for both the environment and industry. The native plant and wetland specialists at NPS possess over 30 years of direct experience in applying natural solutions that are scientifically proven, on-the-ground examples of restoration, reclamation and creation projects using wetland and native grass species and processes.

5.2.Key Personnel

CV's for each of the key personnel highlighted below can be found in Appendix C.

Dr. Monique Haakensen (Ph.D., P.Biol.) is the President and Principal Scientist at Contango Strategies Ltd. She also serves as an Adjunct Professor for the University of Saskatchewan School of Environment and Sustainability and as an Academic Lead for the University of the Arctic. Dr. Haakensen has expertise in microbiology, biogeochemistry, the long-term impacts of microbes on the stability of mine tailings and interactions of microbes with constituents from effluents and environments downstream of mining operations. Dr. Haakensen is experienced in both field and laboratory-based testing of mining wastes, including sampling, instrumentation installation and monitoring, field and laboratory experimental design and implementation. Dr. Haakensen will act as the project manager and will coordinate all aspects of the project, acting as a liaison between all members of the project team and will be responsible for ensuring the timelines for the project are maintained.

Dr. John Rodgers is a professor of environmental toxicology at Clemson University in the School of Agriculture, Forest and Environmental Sciences. In his career of over 30 years, Dr. Rodgers had published more than 100 peer-reviewed papers and several books on topics related to wetlands, aquatic toxicology and water quality. Dr. Rodgers manages an active research program that involves characterization and mitigation of ecological risks from potential pollutants in aquatic ecosystems. He has worked on mitigating risks using constructed wetland treatment systems throughout the world. Targeted constituents have included pesticides, organics as well as inorganics in complex mixtures. Dr. Rodgers will serve as a technical advisor and active participant in this project.

Dr. James Castle is a Professional Geologist and a professor in the Department of Environmental Engineering and Earth Sciences at Clemson University. Dr. Castle worked in the oil and gas industry for 17 years, achieving the position of Senior Staff Geologist before pursuing a career in academia. Dr. Castle has since spent 17 years as a professor at Clemson University and published a multitude of peer-reviewed papers and scholarly reports related to constructed wetlands and sedimentary geology. Dr. Castle will serve as a technical advisor and active participant in this project.

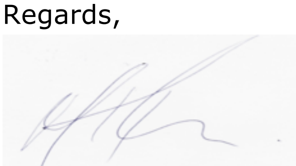
Lisette Ross is Native Plant Solution's Senior Wetland/Upland Specialist. Prior to joining Native Plant Solutions in July of 2010, Lisette worked with Ducks Unlimited Canada's (DUC's) Institute for Wetland and Waterfowl Research (IWWR) for 20 years as a Research Biologist concentrating on wetland ecology/hydrology and soils. She holds a Master of Science in Agriculture specializing in wetland ecology, soil development and hydrological modeling. She has spent most of her efforts researching Canadian wetlands with a focus on biodiversity, water quality and the influence of surface and sub-surface hydrology on wetland development and sustainability. Her work has taken her extensively across Canada with wetland projects in the western arctic, boreal forest, prairie Canada, and peatland systems in Eastern Canada. In addition to authoring the recommended national guidelines for assessing the functional status of wetlands in Canada with colleagues at Environment Canada, Lisette has authored 4 book chapters on wetland and native plant ecology. Within Ducks Unlimited Canada, she established the wetland design standards used by DUC staff across Canada and their national protocols for wetland restoration techniques and practices. Lisette will act as Native Plant Solutions representative on this project.

Glen Klobun is the Manager of Native Plant Solutions. Glen is an agronomist and Certified Crop Advisor with 20 years of experience in land stewardship. He has wide experience in agronomic and construction planning that covers soils and water, soil fertility, forages, crop/grassland production, and integrated weed management. Glen has been an agronomist with DUC's Native Plant Solutions for over 9 years and Manager since 2009. During that time he has implemented and coordinated several projects with emphasis on revegetation of a variety of landscapes with native grass species, ranging from the Boreal Forests to prairie systems. His projects have included major pipelines, mine site/tailings, brown field reclamation, landfill sites, revegetation of a hydro-carbon contaminated site, roadside stabilization and reclamation, constructed wetlands, naturalized upland public reserves, community beautification, creek and river bank stabilization, native prairie land management, eradication of invasive species, and plant species propagation. His wide knowledge of plant, agronomic and construction practices is vitally important to the success of Native Plants Solutions' upland and wetland projects.

6. Closure

This work plan has been developed based on CSL, NPS/DUC and Dr. John Rodgers and Dr. James Castle's best estimate of cost and scheduling for project completion. Should you have any questions or comments, please contact us. We look forward to working with you on this project.

Regards,



Monique Haakensen, PhD, PBiol
(on behalf of CSL, NPS/DUC, Dr. John Rodgers and Dr. James Castle)

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Doorman, L., Castle, J. W., & Rodgers, Jr., J. H. (2009) Performance of a pilot-scale constructed wetland system for treating simulated ash basin water. Chemosphere, 75(7), 939-947.

Johnson, B.M., Kanagy, L.E., Rodgers Jr., J.H., & Castle, J.W. 2008. Feasibility of a pilot-scale hybrid constructed wetland treatment system for simulated natural gas storage produced waters. Environmental Geosciences, 15, 91–104.

Kadlec, R.H. and Knight, R.L. Treatment Wetlands. Lewis Publishers. 1996.

Murray Gulde, C., Huddleston, III, G. M., Garber, K. V., & Rodgers, Jr., J. H. 2005. Contributions of *Schoenoplectus californicus* in a constructed wetland system receiving copper contaminated wastewater. Water, Air and Soil Pollution, 163, 355-378.

Murray Gulde, C.L., Bridges, W.C., & Rodgers Jr., J. H. 2008. Evaluating performance of a constructed wetland treatment system designed to decrease bioavailable copper in a waste stream. Environmental Geosciences, 15, 21–38.

Rodgers, Jr., J. H. & Castle, J. W. 2008. Constructed wetland systems for efficient and effective treatment of contaminated waters for reuse. Environmental Geosciences, 15(1), 1-8.

Sundaravadivel, M. & Vigneswaran, S. 2001. Constructed wetlands for wastewater treatment. Critical Reviews in Environmental Science and Technology, 31(4), 351-409.

Appendix A: Sampling Schedule

Parameter	1/week	1/every 2 weeks	1/month	Start and end of growing seasons	Start and end of Project
Plants					
Stem Density			X		
Plant Height			X		
Aboveground Biomass				X	
Belowground Biomass					X
Major/minor elements (ICP)				X	
Detritus accumulation				X	
Soil					
Major/minor elements (ICP)				X	
Cation exchange capacity			X		
Sodium adsorption ratio			X		
Nutrients (NPK)				X	
Redox potential	X				
Total Dissolved solids/EC				X	
Particle Size Analysis					X
TOC					X
Water					
Evaporation	X				
Depth	X				
Temperature	X				
Flow rate	X				
pH	X				
Alkalinity			X		
Hardness			X		
Dissolved oxygen	X				
Conductivity	X				
Major/minor elements (ICP)			X		
Chemical oxygen demand		X			
Total organic carbon		X			
Biological oxygen demand			X		
Phosphorous		X			
Ammonia		X			
TKN		X			
Nitrate		X			
Sulphate		X			
Total suspended solids		X			
Hydraulic Retention Time	X				
Microbes					
MPN (As, Sulphate,			X		
Micro Community Profile			X		
Microtox			X		

Appendix B: Proposed Timelines and Reporting Schedule for Phase 1[1]

		Year 1												Year 2												Year 3					
		S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F
Project management & reporting	Project initiation and scoping meetings	■																													
	Monthly updates	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
	Quarterly progress report			■			■			■						■			■			■						■			
	Annual and final reports												■												■						■
CWTS Design & Construction	Targeted constituents and performance goals	■	■	■																											
	Design of indoor pilot scale CWTS		■	■	■																										
	Assembly of indoor pilot scale CWTS				■	■																									
	Performance monitoring of indoor pilot CWTS					■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
	Design of outdoor pilot scale CWTS		■	■	■	■	■	■	■																						
	Assembly of outdoor pilot scale CWTS								■	■																					
	Performance monitoring of outdoor CWTS									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■			
	Data analysis and consideration of feasibility of demonstration scale CWTS; Consultation																											■	■	■	■

[1] Any changes to project expectations, timelines, and/or site requirements may result in a change of timelines for specific deliverables.

Appendix C: CVs of Key Personnel

John H. Rodgers, Jr.

BIRTHDATE:	February 1, 1950
PRESENT POSITION:	Professor School of Agricultural, Forest and Environmental Sciences Clemson University Director, Ecotoxicology Program Co-Director, Energy and Environment Program School of Agricultural, Forest and Environmental Sciences Clemson University
PRESENT ADDRESS:	School of Agricultural, Forest and Environmental Sciences PO Box 340317 261 Lehotsky Hall Clemson University Clemson, SC 29634-0317 Telephone: (864) 656-0492 Fax: (864) 656-1034 Cell-phone: (864) 650-0210 E-mail: jrodger@clemson.edu
EDUCATION:	Virginia Polytechnic Institute and State University, Blacksburg, VA, Ph.D. Degree, Botany, Aquatic Ecology, 1977. Clemson University, Clemson, SC, M.S. Degree, Botany, Plant Ecology, 1974. Clemson University, Clemson, SC, B.S. Degree, Botany, 1972.
PROFESSIONAL EXPERIENCE:	**Clemson University (1998-present):** Professor, School of Agricultural, Forest and Environmental Scie

Director, Ecotoxicology Program
2003 – Present.

Director, Clemson Institute of Environmental Toxicology
Chair, Department of Environmental Toxicology
Professor, Department of Environmental Toxicology
Co - Director, Clemson Environmental Institute
1998 - 2003.

University of Mississippi:
(Department of Biology)

Professor, Department of Biology,
1989 - 1998.
Director, Ecotoxicology Program,
1995 – 1998.
Adjunct Research Professor, Research Institute for Pharmaceutical Sciences,
1989 - 1998.
Director, Biological Field Station,
1990 – 1995.
Director, Center for Water and Wetland Resources,
1993 – 1995.
Associate Director, Biological Field Station,
1989 - 1990.

University of North Texas:
(Division of Environmental Sciences,
Department of Biological Sciences)
Director, Water Research Field Station,
1987 - 1989.
Associate Professor, Department of Biological Sciences,
1985 - 1989.
Associate Director, Institute of Applied Sciences,
1982 - 1988.
Assistant Professor, Department of Biological Sciences,
1982 - 1985.
Research Scientist II, Institute of Applied Sciences,
1979 - 1981.

East Tennessee State University:

(Department of Environmental Sciences,
Aquatic Ecology Section)

Assistant Professor, 1978 - 1979.

Virginia Polytechnic Institute and State University:
(Biology Department, Center for Environmental Studies)

Postdoctoral Research Associate, 1977 - 1978.
Research Assistant- Energy Research and Development Administration, 1975 - 1977.

Clemson University (1972-1974):
(Botany Department)

Research Assistant - Water Resources Research Institute, 1972 - 1974.
Laboratory Teaching Assistant – Plant Physiology, Plant Ecology, Biological Oceanology, Botany, 1972 - l974.

MILITARY SERVICE:

Distinguished Military Graduate, Clemson University, 1972.
U.S. Air Force Reserve, Second Lieutenant, 1972 - 1975.
U.S. Air Force Reserve, First Lieutenant, 1975 - 1978.
U.S. Air Force Reserve, Captain, 1978 - 1984.

U.S. Air Force (Active Duty), June 1 - August 29, 1976.
U.S. Air Force, Honorable Discharge, 1984.
Pilot Certificate - 34 hours, Single engine aircraft.

RESEARCH SUPPORT:

Clemson University (1972-1974):

Research Assistantship, Water Resources Institute, Project No. B-053-SC ($42,000), 1972 - 1974. Impact of Thermal Effluent from a Nuclear Power Plant on Reservoir Productivity.

Thesis Parts Award, USAEC, The E.I. DuPont de Nemours & Co., Savannah River Laboratory (Thermal Effects Laboratory), Aiken, S.C., 1973-1975. Effects of Elevated Temperatures on Periphyton Productivity in Lotic Aquatic Ecosystems.

Savannah River Laboratory, Research Assistantship, Research Contract USAEC Funding ($50,000), 1973-1975. Impacts of Ash from Coal Combustion on Swamp Receiving Systems.

Virginia Polytechnic Institute and State University:

Research Assistantship, Research Contract, American Electric Power Corporation Funding ($93,000), 1974-1975. Thermal Tolerances and Electivities of Fish Adjacent to a Coal-Fired Power Plant.

Research Assistantship, Research Contract, Energy Research and Development Administration Funding ($112,000),1975 - 1976. Structural and Functional Responses of Aquatic Communities to Power Generation.

Research Assistantship, Research Contract, Energy Research and Development Administration Funding ($132,000),1976 - 1977. Responses of Aquatic Communities to Perturbations Associated with Power Generation.

Co-principal Investigator, Research Contract, Water Resources Research Institute Funding ($68,000), 1977 - 1979. Environmental Tolerances of *Corbicula fluminea* from the New River, Virginia.

East Tennessee State University:

Principal Investigator, Research Contract, ETSU Research Development Committee Funding ($3,270), 1978 - 1979. Primary Production and Nutrient Dynamics in the Watauga River, Tennessee.

Oak Ridge Associated Universities Travel Contract, 1978 - 1979. Impacts of Power Production on Aquatic Ecosystems of Savannah River Laboratory.

University of North Texas:

Co-Principal Investigator, Research Contract, Chemical Manufacturers' Association Funding ($80,000), 1979 - 1980. Modeling the Fate of Chemicals in Aquatic Environments.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($4,000), 1979 - l980. Biotransformation of Xenobiotics in Aquatic Systems.

Co-principal Investigator, Research Contract, International Paper Company Funding ($149,530), 1980 - 1981. Impacts of Paper Mill Effluent on Aquatic Ecosystems.

Co-principal Investigator, Research Contract, Victor Equipment Company Funding ($5,000), 1980. Optimization of Packaged Waste Treatment System for Metal Removal.

Co-principal Investigator, Research Contract, International Paper Company Funding ($171,830),1980 - 1981. Investigation of Pre- and Post-Operational Effects of a Paper Mill on Aquatic Systems.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($4,620), 1980 - - 1981. Predicting Bioconcentration of Chemicals by Aquatic Organisms.

Co-principal Investigator, Research Contract, Chemical Manufacturers' Association Funding ($30,000), 1981. Validation of Chemical Fate Models for Aquatic Ecosystems.

Co-principal Investigator, Research Contract, U.S. Environmental Protection Agency Funding ($305,866), 1981 - 1983. Development of a Decision Support System for Integrated Management of Nuisance Aquatic Vegetation.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($3,600), 1981-1982. Fate and Effects of the Herbicide, Endothall, in Aquatic Systems.

Co-principal Investigator, Research Contract, Chemical Manufacturers' Association Funding ($59,985), 1981 - 1982. Studies of Fate and Effects of Chemicals in Aquatic Ecosystems.

Co-principal Investigator, Research Contract, International Paper Company Funding ($113,000), 1982. Effects of Paper Mill Effluent on Aquatic Ecosystems.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($24,500), 1982. Ecosystem Study of Pat Mayse Lake, A Southwestern Reservoir.

Co-principal Investigator, Research Contract, International Paper Company Funding ($348,926), 1982 - 1985. Further Studies of Effects of Paper Mill Effluent on Aquatic Ecosystems.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($3,500), 1982 - 1983. Proximate Oxygen Demand of Aquatic Plants.

Co-principal Investigator, Research Contract, U.S. Environmental Protection Agency Funding ($199,500), 1982 - 1983. Validation of Decision Support Systems for Integrated Management of Nuisance Aquatic Vegetation.

Co-principal Investigator, Research Contract, American Petroleum Institute ($83,809), 1981 - 1982. Bioavailability of Petroleum-Derived Chemicals in Aquatic Ecosystems.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($25,000), 1983. Further Studies: Pat Mayse Lake, A Southwestern Reservoir.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($1,000), 1983. Remote Sensing of Aquatic Vegetation in Pat Mayse Lake.

Co-principal Investigator, Research Contract, Shell Development Company Funding ($17,000), 1983. Impact of Petroleum Compounds on Aquatic Organisms.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($4,500), 1983 - - 1984. Threshold Responses of Aquatic Vegetation to Herbicides.

Co-principal Investigator, Research Contract, Shell Development Company Funding ($29,758),1984. Inter-Laboratory Comparison of Bioassays Using Freshwater and Marine Organisms.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($20,000), 1984. Water Quality Monitoring and Aquatic Vegetation in Pat Mayse Lake.

Principal Investigator, Research Contract, Pennwalt Corporation Funding ($11,500), 1984. Comparative Study of Two Aquatic Herbicides.

Principal Investigator, Research Contract, Shell Oil and Chemical Company Funding ($14,000). Aquatic Toxicology Studies for the Petrochemical Industry.

Principal Investigator, Research Contract, Dallas County Utility and Reclamation District Funding ($12,000), 1984 - 1985. Eutrophication Potential in an Impoundment Receiving Wastewater.

Co-principal Investigator, Research Contract, Shell Development Company Funding ($31,797), 1985. Development of Data on Proper Selection of Bioassay Species.

Co-principal Investigator, Research Contract, Texas Instruments, Inc. Funding (approximately $12,000, equipment), 1985. Development of Expert Systems for Water Quality Management.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($24,500), 1985. Development of a Water Quality Model and Lake Management Strategy for Pat Mayse Lake.

Co-principal Investigator, Research Foundation Award, Shell Research Foundation ($15,000), 1985. The Response of Marine and Freshwater Species to Xenobiotics.

Principal Investigator, Research Contract, NTSU Faculty Research Grant Funding ($2,700), 1986 - - 1987. Experimental Analysis of Bioassay Methods.

Co-principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($168,693), 1986 - 1987. Ecological Analysis of the Lake Ray Roberts Project Site.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding, ($68,000), 1986 - 1987. Coupling an Environmental Fate and Effects Model for 2, 4-D and Water Hyacinth.

Co-principal Investigator, Research Contract, Shell Research Foundation Funding ($15,000), 1986. Osmoregulation in Marine Bioassay Species.

Principal Investigator, Research Contract, American Petroleum Institute Funding ($8,000), 1986. Evaluation of Marine Bioassay Species.

Principal Investigator, Research Contract, American Petroleum Institute and U.S. Environmental Protection Agency Funding ($10,000), 1986. A Workshop on Culture and Life History of *Mysidopsis* sp.

Co-principal Investigator, Research Contract, Shell Research Foundation Funding ($20,000), 1987. Sediment Organic Carbon Content in Aquatic Systems of the U.S.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($24,500), 1987 - 1988. Endothall Fate and Effects on *Myriophyllum spicatum* in Pat Mayse Lake, Texas.

Co-principal Investigator, Research Contract Hoechst-Roussel Agri-Vet (Hoechst-Celanese) Co. Funding ($185,000), 1987 - 1988. Development of Mesocosms and Water Research Field Station.

Co-principal Investigator, Research Contract, City of Dallas Funding ($319,964), 1987 - 1989. Ecological Survey and Study of the Trinity River, Texas.

Co-principal Investigator, Research Contract, Hoechst-Roussel Agri-Vet (Hoechst-Celanese) Co. Funding ($325,000), 1988 - 1989. Fate and Effects of Tralomethrin in Mesocosms.

Co-principal Investigator, Research Contract, Hoechst Roussel Agri Vet (Hoechst-Celanese) Co. Funding ($185,000), 1988 - 1989. Further Development of Mesocosms and Water Research Field Station.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($24,500), 1988 - 1989. Further Development of a Water Quality Model and Lake Management Strategy for Pat Mayse Lake.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($24,550), 1988 - 1989. Research on SONAR in Pat Mayse Lake.

Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($107,000), 1988-1989. Water Research Field Station-Coupling a Herbicide Fate and Effects Model.

Principal Investigator, Research Contract, Pennwalt Corporation ($2,000), 1988-1989. Degradation of Endothall by Chlorine.

Co-principal Investigator, Research Contract, Mobay Corporation ($852,000), 1988-1990. Fate and Effects of Cyfluthrin in Mesocosms.

Co-principal Investigator, Research Contract, Shell Development Corporation ($55,000) 1989-1990. Bioavailability of Sediment-sorbed Chemicals to Freshwater Organisms.

University of Mississippi:

Principal Investigator, Research Contract U.S. Army Corps of Engineers - Tulsa District Funding ($24,500), 1988-1989. Limnology and Aquatic Botany of Pat Mayse Lake, Texas.

Principal Investigator, Research Contract, Shell Development Company Funding ($50,000), 1989-1990. Evaluation of Sediment Toxicity Testing Procedures.

Co-principal Investigator, Research Contract Soil Conservation Service Funding ($50,000), 1990-1991. Wetlands for Interception and Processing of Pesticides in Agricultural Runoff.

Co-principal Investigator, Research Contract Tennessee Valley Authority Funding ($171,410), 1990-1991. Analysis of Aquatic Herbicides in Lake Guntersville, Alabama for the Aquatic Plant Management Program.

Principal Investigator, Research Contract, Ciba Giegy Corporation Funding ($31,000), 1990. Effects of Atrazine on Aquatic Vascular Plants.

Co-principal Investigator, Research Contract, Dow-Elanco Corporation Funding ($40,000), 1990. Analysis of Fluridone in Florida Aquatic Plant Management Programs.

Principal Investigator, Research Contract, U.S. Environmental Protection Agency - Gulf of Mexico Program ($17,565) 1990-1991. Assistance with the Citizen's Advisory Group of the Gulf of Mexico Program.

Co-principal Investigator, CHP International, Inc. (U.S. Peace Corps) Funding ($22,000), 1990. Aquaculture Training Sessions for Volunteers for Africa.

Co-principal Investigator, University of Mississippi Funding ($1,000), 1989-1990. Water Systems for an Aquatic Toxicology Laboratory.

Principal Investigator, Internal Equipment Funding, University of Mississippi Associates Funding ($25,000), 1990-1991. Aquisition of an Ion Chromatograph/High Performance Liquid Chromatograph.

Principal Investigator, U.S. Army Corps of Engineers, Waterways Experiment Station Funding ($250,000), 1990-1993. Development of Controlled Release Herbicides for Aquatic Use.

Principal Investigator, American Petroleum Institute Funding, ($250,000), 1990 -1992. Reference Toxicants and Reference Sediments for Sediment Toxicity Testing.

Principal Investigator, Research Contract, Tennessee Valley Authority Funding ($168,000), 1991-1992. Aquatic Herbicides in Guntersville Reservoir, Alabama - National Demonstration Project.

Co-principal Investigator, Research Contract, U.S. Department of the Army, Vicksburg District, Corps of Engineers Funding ($96,036), 1991-1992. Monitoring Water Quality at Arkabutla, Enid, Grenada, and Sardis Lakes.

Principal Investigator, Research Contract, ABC Laboratories, Inc. and Zoecon Corporation Funding ($10,000), 1991. Outdoor Microcosm Study of an Insect Growth Regulator.

Co-principal Investigator, Research Contract, Shell Development Company Funding ($192,000), 1991-1993. Development of a Model Stream Facility and Evaluation of the Environmental Safety of a Surfactant.

Principal Investigator, Research Contract, U.S. Army Waterways Experiment Station Funding ($25,000), 1991-1992. Evaluation of New Herbicide Delivery System for Control of Aquatic Plants.

Principal Investigator, Research Contract, U.S. Army Waterways Experiment Station Funding ($64,000), 1992-1993. Evaluation of New Herbicide Delivery Systems for Control of Aquatic Plants.

Principal Investigator, Research Contract, American Petroleum Institute Funding ($100,000), 1992-1993. New Sediment Bioassays and Reference Sediments. Principal Investigator, Mississippi State Department Of Wildlife, Fisheries, and Parks Funding ($6,000), 1991-1993. Cooperative Agreement for Assistance with Walleye Culture.

Co-Principal Investigator, Research Contract, U.S. Army Corps of Engineers Funding ($100,848), 1992-1993. Monitoring of Water Quality at Arkabutla, Sardis, Enid, and Grenada Lakes.

Principal Investigator, Mississippi State Department of Wildlife, Fisheries and Parks Funding ($3,000), 1992-1993. Cooperative Agreement for Assistance with Walleye Culture.

Principal Investigator, Research Contract, U.S. Army Waterways Experiment Station Funding ($30,000), 1992-1994. Mobility and Bioavailability of Sediment Associated Contaminants.

Principal Investigator, Research Contract, U.S. Army Waterways Experiment Station Funding ($25,000), 1992-1993. Effects of Food Quantity on Fathead Minnow Survival, Growth and Reproduction.

Principal Investigator, Research Contract, Eastman Kodak and the Silver Coalition Funding ($53,183), 1992-1994. Evaluations of the Bioavailability and Toxicity of Silver in Sediments.

Principal Investigator, Research Contract, Shell Development Company Funding ($150,000), 1992-1993. Ecological Evaluation of a Non-ionic Surfactant in Model Stream Mesocosms.

Principal Investigator, Research Contract, Shell Development Company Funding ($30,342), 1993-1994. Assistance with Development and Construction of Constructed Wetlands for Tertiary Treatment of Refinery Effluent.

Principal Investigator, U.S. Department of Agriculture/ Cooperative State Research Service Funding ($1,377,400), 1994-1995. Center for Water and Wetland Resources (Year 4).

Co-Principal Investigator, Research Contract, International Paper Company Funding ($99,631), 1994-1995. Extensive Ecological and Toxicological Evaluation of the Arkansas River at Pine Bluff, AR.

Co-Principal Investigator, Research Contract, International Paper Company Funding ($99,631), 1994-1995. Extensive Ecological and Toxicological Evaluation of the Yazoo River near Vicksburg, MS.

Principal Investigator, Research Contract, Shell Development Company Funding ($150,000), 1994-1995. Ecological Evaluation of a Homologus Non-ionic Surfactant in Model Stream Mesocosms.

Principal Investigator, Research Contract, Shell Development Company Funding ($144,242), 1994-1996. Evaluation of Constructed Wetlands for Tertiary Treatment of Refinery Effluent.

Principal Investigator, Research Contract, Texaco, Inc. Funding ($20,000), 1995-1996. Evaluation of a Constructed Wetland for Removal of Ammonia from a Refinery Effluent.

Principal Investigator, Research Contract, Texaco, Inc. Funding ($20,000), 1995-1996. Evaluation of a Constructed Wetland for Removal of Trace Metals from a Refinery Effluent.

Clemson University (1998-present):

Principal Investigator, Assistance with Design and Construction of a Wetland for Wastewater Treatment Sponsored by Shell Oil Products from 4/1/98 to 4/1/00 ($10,000).

Principal Investigator, Evaluation of the Tombigbee River. Sponsored by Weyerhauser, Inc. 1/98 – 1/02 ($22,000).

Principal Investigator, Constructed Wetland for Wastewater Treatment at IP's Mansfield, LA Facility, Sponsored by International Paper Company 8/98 – 12/00 ($18,250).

Principal Investigator, Investigations of Pesticide Toxicity, Sponsored by Applied Biochemists, Inc. 1/00 – 1/01 ($10,000).

Principal Investigator, Wetlands for Wastewater Treatment at Savannah River Site Sponsored by DOE thru SCUREF (SC Universities Research and Education Foundation) from 1/14/99 to 2/28/00 ($28,088).

Principal Investigator, A-01 Outfall Constructed Wetlands Sponsored by DOE thru Westinghouse Savannah River thru SCUREF from 7/11/99 to 9/30/00 ($624,730).

Principal Investigator, Design and Construction of a Wetland for Effluent Treatment. Sponsored by International Paper Company 6/00 – 7/01 ($25,000).

Principal Investigator, Evaluation of Foam Products. Flexible Products, Inc Funding from 9/99 – 1/01 ($15,000).

Principal Investigator, US Department of Interior Funding ($43,106), 2002-2004. Renovating Water for Conservation and Reuse.

Co-Principal investigator, US Department of Agriculture Funding ($539,677), 2002-2004. Adhesion-Specific Nanoparticles for Removal of *Campylobacter jejuni* from Poultry.

Principal Investigator, Duke Energy Corporation Funding ($54,473). 2001. Evaluation of the Oconee Nuclear Station Conventional Waste Treatment System.

Principal Investigator, Chevron Texaco Inc. Funding ($24,000), 2001-present. Evaluation of Best Management Practices for Stormwater and Other Contaminated Waste Streams.

Principal Investigator, US Department of Energy Funding ($26,024). 2001-2003. A01 Constructed Wetland Treatment Facility Redox Probe Maintenance and Consultation for the Savannah River Site (from WSRC through SCUREF).

Principal Investigator, U.S. Department of Interior Funding ($43,106). 2002-2003. Renovating Water for Conservation and Reuse.

Principal Investigator, Sustainable Universities Initiative ($7,000). 2002-2003. A Constructed Wetland Treatment System: A Green and Sustainable Solution to Prevent Water Pollution on Campus.

Principal Investigator, Duke Energy Corporation in Cooperation with Progress Energy Funding ($187,000). 2003-2004. Treatment of Mercury, Selenium and Other Targeted Constituents in FGD Wastewater: A Constructed Wetland Pilot Study.

Principal Investigator, Chevron Corporation Funding ($33,600). 2003-2004. Panama Storm Water Treatment Wetland.

Principal Investigator, Griffin Corporation Funding ($20,0000). 2002-2003. Response of Aluminum from Boat Pontoons to Komeen Exposures in Lake Murray, SC Water (with Sediments and *Hydrilla*.

Principal Investigator, Alabama Power Company Funding ($75,000). 2004-2006. Development of Strategies for Controlling Nuisiance Growths of *Lyngbya* in Alabama Power Company Reservoirs.

Principal Investigator, Department of Energy Funding ($125,000) 2004-2005. Designing constructed wetlands to treat gas storage produced waters.

Principal Investigator, Duke Energy Corporation in Cooperation with Progress Energy Funding ($105,000). 2004-2005. Continuing Studies of Treatment of Mercury, Selenium and Other Targeted Constituents in FGD Wastewater Using a Constructed Wetland Treatment System.

Principal Investigator, U.S. Department of Energy Funding ($300,000) 2005-2008. Innovative Techniques for Remediation of Nontraditional Waters for Reuse in Coal-Fired Power Plants.

Principal Investigator, Duke Energy Corporation and ENTRIX Funding ($100,000) 2006-2007. Further Evaluations of Constructed Wetland Treatment Systems for Flue Gas Desulfurization Waters.

Co-Principal Investigator, Chevron-Texaco Funding ($50,000) 2006-2007. Evaluation of Boron Biogeochemistry in Constructed Wetlands.

Co-Principal Investigator, Monsanto Company Funding ($300,000) 2006-2008. Potential Effects of Glyphosate Formulations on Amphibians.

Principal Investigator, Florida Department of Environmental Protection Funding ($60,000) 2006-2008. Effects of Invasive Algae in Crystal River, FL and Potential Control Strategies to Protect the Florida Manatee.

Co-Principal Investigator, Chevron-Texaco Funding ($50,000) 2008. Specifically Designed Constructed Wetland Treatment Systems for Produced Water in Chad.

Principal Investigator, Duke Energy Corporation and ENTRIX Funding ($30,000) 2007-2008. Additional Evaluations of Constructed Wetland Treatment Systems for Flue Gas Desulfurization Waters.

Co-Principal Investigator, Clemson University Funding ($50,000) 2006-2008. Evaluation of Constructed Wetland Treatment Systems for Parking Lot Stormwater (with Dr. Rockie English).

Principal Investigator, Applied Biochemists, Inc. Funding ($36,000) 2008-2009. Approaches for Mitigation of Risks from Harmful Algal Blooms.

Co-Principal Investigator, Chevron-Texaco Funding ($50,000) 2008. Specifically Designed Constructed Wetland Treatment Systems for Specific Produced Water (San Ardo, CA).

Co-Principal Investigator, U.S. Department of Energy Funding ($800,000) 2009. Evaluation of Constructed Wetland Treatment Systems for Produced Waters. Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water (DE-NT0005682), Clemson University

Co-Principal Investigator, Chevron-Texaco Funding ($50,000) 2009. Specifically Designed Constructed Wetland Treatment Systems for Produced Water in Chad.

Co-Principal Investigator, U.S. Department of Energy Funding ($800,000) 2010. Carbon Capture and Sequestration Education (in partnership with the Southern States Energy Board). Clemson University

Co-Principal Investigator, Diamond-V Funding ($115,237) 2010. Enhancing Selenium Treatment in Waters. Clemson University

Co-Principal Investigator, U.S. Department of Energy Funding ($100,000) 2012. Evaluation of Constructed Wetland Treatment Systems for Produced Waters. Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water (DE-NT0005682), Clemson University

HONORS AND AWARDS:

Phi Sigma Doctoral Research Award, April, 1977.

Sigma Xi Doctoral Research Award, May, 1978.

Who's Who in the South and Southwest, 1979.

Personalities of the South, 1981.

International Who's Who, 1981.

Directory of Distinguished Americans, 1981.

Men of Achievement (International Biographical Center), 1981.

Phi Kappa Phi Honor Society, 1982.

Gordon Research Conference Travel Award, 1982.

NTSU President's Award to the Institute of Applied Sciences, 1985.

Mortar Board NTSU "Top Prof" Teaching Award, 1985.

Elected to NTSU Graduate Faculty, 1987.

Co-author - Best Student Paper (Burton Suedel and Phil Clifford), published in 1992 in *Environmental Toxicology and Chemistry*.

Certificate of Appreciation, 1993 Mississippi Region 7 Science and Engineering Fair. 1993.

Designated "Distinguished Southerner" by Editors Of *Southern Living*. Article on Water Watchdogs In April, 1994 edition of *Southern Living*.

Co-author - Best Student Paper (Arthur Dunn), Mid-South Aquatic Plant Management Society. Birmingham, AL. 1994.

Certificate of Appreciation, Environmental Biology Review Panel, U.S. EPA, January, 1995.

President, Oxford Exchange Club – Prevention of Child Abuse, 1996-1998.

Board of Directors, Society of Environmental Toxicology and Chemistry, 1989-1991; 1995-2001. Executive Committee 1997-2000. Vice President 1998-1999. President 1999-2000.

Member, Expert Advisory Committee, Canadian Network of Toxicology Centres. Environment Canada and Health and Welfare, 1992-2000.

Chair, Expert Advisory Committee, Canadian Network of Toxicology Centres, Environment Canada and Health and Welfare, 1996-1999.

Vice President's Award, Savannah River Technology Center. A-01 Outfall Wetland Treatment Confirmation Study, 2000.

Who's Who Among America's Teachers, 7th ed. 2002. p. 400.

Certificate of Appreciation for Outstanding Service to the Society of Environmental Toxicology and Chemistry, 2003.

Member, Canadian Foundation for Innovation, Science Review Panel, 2008 - 2009.

Chair, Canadian Foundation for Innovation, Science Review Panel, 2009.

Member of the Year, South Carolina Aquatic Plant Management Society, 2009.

Nominated for Governor's Research Award, 2010.

President's (USA) 'Closing the Circle' Environmental Award (with Savannah River Site) for Wetland Research and Application, 2010.

Clemson University Board of Trustees Award for Faculty Excellence, 2010.

Nominated for the 2011 Alumni Award for Outstanding Achievement in Research at Clemson University, 2011.

RESEARCH AND
TEACHING
INTERESTS:

Teaching Interests:
I have taught General Botany, General Biology Environmental Biology, Assessment of Water Quality, Water Quality Management, Environmental Analysis, Aquatic Toxicology, Limnology, Microbial Ecology, Radioisotopes, and Research Techniques, Aquatic Botany, Aquatic Microbiology, Sediment Toxicology, and Analysis of Biological Data, Ecological Risk Assessment, Plant Physiology, and Water Chemistry. My teaching interests also include: Plant Ecology, Wetland Ecology, and Phycology.

Research Interests:
Effects of heated effluents and other perturbations on primary productivity of vascular and non-vascular plants in terrestrial and aquatic systems.

In situ measurements of assimilatory sulfate reduction by periphytic organisms (algae, bacteria, and fungi), sulfur content and cycling in aquatic systems.

Physical models of aquatic systems as tools for the study of acute and chronic effects of industrial and power plant effluents on structural and functional aspects of aquatic microbial communities with emphasis on photosynthesis and sulfate assimilation.

Production, decomposition and role in nutrient cycling of aquatic macrophytes.

Impact of ash from industrial and power production processes on receiving systems and indigenous biota.

Decomposition and role of autochthonous and allochthonous detritus in aquatic and terrestrial systems with emphasis on the influences of macro-invertebrates, bacteria and fungi.

Invasion rates, population dynamics and elemental accumulation of the Asiatic Clam (*Corbicula fluminea*).

Extracellular products and other organic compounds as regulating factors of structural and functional aspects of aquatic microbial communities.

Benthic metabolism and physical and biological sediment characterization (using SCUBA-implemented techniques) as an index of eutrophication rates.

Electron transport system activity of benthic microflora as a pollution monitoring tool.

Serum enzymes of fish as an indicator of the quality and quantity of mixed effluents and their effects on receiving systems.

Ecosystem responses to stress in aquatic systems; Ecological risk assessment.

Relationships between carbon quantity and quality in ecosystems.

Responses of microbes (algae, bacteria, and fungi) to magnetic fields.

Ecological impacts associated with pulp and paper mills.

Biology and ecology of *Taxodium distichum* (Bald cypress) swamps in the Southwest.

Development of models for integrated control of nuisance aquatic vegetation and aquatic ecosystem management.

Microcosms and mesocosms as tools for ecological and environmental research.

Reservoir limnology and eutrophication.

Secondary aquatic plant products and biocontrol of aquatic plants.

Bioavailability of xenobiotic chemicals (e.g. pesticides) to aquatic organisms.

Sediments as sources and sinks for contaminants in aquatic ecosystems.

Population biology and physiological ecology of aquatic plants.

Artificial Intelligence in ecological problem solving.

Constructed wetlands for rehabilitation and wastewater treatment.

Metal speciation and bioavailability.

ORGANIZATIONS:

American Society of Limnology and Oceanography, Ecological Society of America, American Water Resources Association, North American Benthological Society, Water Pollution Control Federation, Phi Sigma Society Alpha Psi (VPI&SU) Chapter, Sigma Xi (VPI&SU) Chapter, American Institute of Biological Sciences, American Association for Advancement of Science, Phi Kappa Phi (NTSU) Chapter, Aquatic Plant Management Society, Society of Environmental Toxicology and Chemistry.

OTHER
PROFESSIONAL
ACTIVITIES:

Consulting Aquatic Ecologist Microbiology Department, Clemson University, 1973-1975.

Investigator on Facilities Use Agreement #15 at Savannah River Laboratory in conjunction with Clemson University and VPI & SU, 1973-1975.

Consulting Aquatic Ecologist to American Electric Power Service Corporation, Canton, Ohio, 1974 - 1975.

Investigator on Facilities Use Agreement #28 at Savannah River Laboratory in conjunction with University of Texas, School of Public Health and VPI&SU, 1975 - 1979.

Consulting Microbial Ecologist to Bioengineering Research and Development Group, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1977.

Consulting Aquatic Ecologist to Virginia State Water Control Board, Richmond, 1977.

Invited lecturer in Plant Ecology and Environmental Biology, Botany Department, Clemson University, 1977.

Consulting Aquatic Ecologist to Center for Environmental Studies VPI&SU, 1978 - 1979.

Participant in Savannah River National Environmental Research Park meeting on Aquatic Research, Aiken, S.C., 1978.

Grant Proposal Review for the Division of Environmental Biology of the National Science Foundation, 1978 - 1987.

Consulting Aquatic Ecologist to Tennessee Eastman Company, Kingsport, Tennessee, 1978 - 1979.

ETSU Research Development Committee Presidential Appointment 1978 - 1979.

Consulting Aquatic Ecologist to Victor Equipment Company, Denton, Texas, 1980 -1983.

Review of publications for American Society for Testing and Materials.

Consulting Aquatic Ecologist to Environmental Biology Group, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1980.

Gordon Research Conference Participant (Environmental Sciences - Water), 1980.

Participant in Workshop on the role of aquatic microcosms in evaluating ecosystem effects of chemicals under the Toxic Substances Control Act (USEPA sponsored), 1980.

NTSU representative to Texas Systems of Natural Laboratories. (Presidential Appointment), 1981 - 1986.

Consulting Aquatic Ecologist to Environmental Systems Branch, U.S. Environmental Protection Agency, 1981.

School of Community Service Computing Services Advisory Council (Dean's Appointment), 1981-1986.

NTSU Biosafety Committee (Presidential Appointment), 1980 - 1987.

Peer Review of Research Program for Environmental Systems Branch of the U.S. Environmental Protection Agency (with H.T. Odum), 1981.

Participant in Workshop on Modeling the Fate of Chemicals in the Aquatic Environment (USEPA sponsored), Pellston, MI, 1981.

Co-chaired session on Microcosm Testing in Aquatic Toxicology at the Society of Environmental Toxicology and Chemistry's Annual Meeting, Washington, D.C., 1981.

Elected to Editorial Board of Environmental Toxicology and Chemistry, 1981- 1983.

Research advisor to the Ecosystem Branch of the U.S. Environmental Protection Agency, Las Vegas, 1982.

Gordon Research Conference Participant (Environmental Sciences-Water), 1982.

President, Sigma Xi, NTSU Club, 1982-1983.

Chair, Employment Service Committee of the Society of Environmental Toxicology and Chemistry, 1982 - 1984.

Review of manuscripts for Ecological Society of America, 1981 - present.

College of Arts and Sciences Committee on Interdisciplinary Research (Dean's Appointment), 1983.

Department of Biological Sciences Radiation Safety Officer, 1983 - 1987.

Participant, Workshop on Bioavailability of Chemicals from Dredged Materials (U.S. Army Corps of Engineers sponsored) Vicksburg, Mississippi,1984.

Consulting Aquatic Ecologist to the City of Reno, Nevada, 1983 - Mitigation of Impacts of Population Growth and Development on Lake Tahoe, Truckee River and Pyramid Lake.

Consulting Aquatic Ecologist to the Las Colinas Development, 1983 - Impacts of Development on the Trinity River and Watershed.

School of Community Services Committee on Resources and Nontraditional Education (Dean's Appointment), l983 - l984.

Peer review of research programs of the Naragansett Bay, R.I., U.S. Environmental Protection Agency Research Laboratory (elected chairman of the review team), 1984.

North Texas State University Committee on Science and Technology (Presidential Appointment), 1984.

President, J.K. G. Silvey Society, North Texas State University, 1983 - 1984.

Invited Attendee, Society of Petroleum Industry Biologists, Annual Meeting, Houston, Texas, 1984.

Chair of the Annual Meeting of the Society of Environmental Toxicology and Chemistry, St. Louis, Missouri, Nov. 10-14, 1985.

Participant - Workshop on the Bioavailability of Sorbed Chemicals (U.S. Environmental Protection Agency and American Petroleum Institute sponsored) Florissant, Colorado, 1984.

Faculty Committee Member, Cooperative Education Program of the Institute of Applied Sciences, 1984.

Faculty Representative for the Sciences, elected to NTSU Faculty Senate, 1986.

Served as Chairman of Placement Committee of Aquatic Plant Management Society, 1987.

Peer review of research programs of the Gulf Breeze, FL., U.S. Environmental Protection Agency Research Laboratory (with H. Bergman and K. Solomon), 1987.

Consulting aquatic ecologist to the City of Dallas (Water Utilities), Algal Workshop, 1987.

Consulting aquatic toxicologist to the American Petroleum Institute, Bioavailability of Chemicals Sorbed to Sediments, 1987.

Consulting aquatic ecologist to the Association of Central Oklahoma Governments, Use Attainability Study of Crutcho Creek and the North Canadian River, 1987.

Chair, Professional Opportunities Committee (Placement) of the Aquatic Plant Management Society, 1987.

Co-chair (with L. Goodman), Workshop on Mysid Culture and Testing, at the Eighth Annual Meeting of the Society of Environmental Toxicology and Chemistry, Pensacola, FL, 1987.

Co-chair, sessions on Perspectives of Water Quality-Based Permitting and Field Validation of Laboratory Results, at the Eighth Annual Meeting of the Society of Environmental Toxicology and Chemistry, Pensacola, FL, 1987.

Appointed to the South Carolina Aquatic Plant Management Commission, 1987.

Presented short courses on Aquatic Plant Management in Texas, 1987.

Presented seminars at short courses on Aquatic Plant Management in Florida, Ft. Lauderdale and Orlando, FL, l987.

Advisor on American Petroleum Institute Study of Bioavailability of Sediment Bound Chemicals (with P. Chapman and C. Missimer), 1987 - 1988.

Participated in a Workshop on Mesocosm Research Sponsored by USEPA, Duluth, MN, 1987.

Promotion review team member for P.R. Parrish, Environmental Research Laboratory, Gulf Breeze, FL, 1987.

Chair, session on Sediment Criteria Development and Testing at the South Central Chapter Meeting of the Society of Environmental Toxicology and Chemistry, Houston, TX, 1987.

Scientific Advisory Group, Proctor and Gamble Corporation, Cincinnati, Ohio, 1988,

Scientific Advisory Group, Botanical Research Institute of Texas (BRIT). Fort Worth, TX, 1988.

Adjunct Faculty, University of Guelph. Guelph, Ontario, Canada, 1988-1990.

Invited participant, North American Benthological Society Annual Meeting. Blacksburg, VA, May 22, 1990.

Invited participant, Association of Southeastern Biologists Special Workshop on Teaching the Limnology Laboratory. Baltimore, MD, April 20, 1990.

Invited participant, Aquatic Plant Management Meeting. Mobile, AL, July 16, 1990.

Chair, Education Committee of the Society of Environmental Toxicology and Chemistry, 1989-1991.

Chair, Professional Opportunities Committee of the Aquatic Plant Management Society, 1989-1991.

Chair, Discussion session on Wetlands Toxicology At the Society of Environmental Toxicology and Chemistry Annual Meeting. Washington, D.C., November 12, 1990.

Member, Aquatic Effects Dialogue Group of the Conservation Foundation, 1989-1991.

Member, Advisory Group to the World Wildlife Fund,1989-1991.

Consulting Aquatic Ecologist and Toxicologist to Proctor and Gamble Company. Cincinnati, OH, 1989-1991.

Served on a discussion panel on the Future of Aquatic Plant Management with emphasis on regulatory issues regarding herbicides at the 25th Annual Meeting of the Aquatic Plant Control Research Program - U.S. Army Corps of Engineers. Orlando, FL, November 26-30, 1990.

Served on a discussion panel on the Future of Aquatic Plant Management with Emphasis on Simulation Technology and Modeling at the 25th Annual Meeting of the Aquatic Plant Control Research Program - U.S. Army Corps of Engineers. Orlando, FL. November 26-30, 1990.

Consulting Aquatic Toxicologist, U.S. Environmental Protection Agency, Ecorisk Program evaluation. 1990-1991.

Consulting Aquatic Toxicologist, International Paper Company. 1990-1991.

Consulting Aquatic Toxicologist, State of Mississippi. 1990-1991.

Consulting Aquatic Toxicologist, Environment Canada, Health and Welfare Canada - Canadian Network of Toxicology Centers, Expert Advisory Committee. 1991- 2001.

Consulting Aquatic Toxicologist, Ecorisk Forum on the Rocky Mountain Arsenal Refuge Technical Expert Advisory Panel. 1991-1992.

Consulting Biologist and Ecotoxicologist, Arkansas Department of Higher Education and Arkansas State University Ph.D. Program Development. 1991- 1998.

Invited participant, Tiered Testing Issues for Freshwater and Marine Sediments, sponsored by U.S. EPA Office of Water and Office of Research and Development. Washington, D.C., September 16-18, 1992.

Invited speaker, Workshop on the Bioavailability and Toxicity of Copper, sponsored by the University of Florida, Center for Aquatic Plants. Gainesville, FL, September 2-3, 1992.

Peer reviewer for U.S. EPA, Framework for Ecological Assessment, Risk Assessment Forum. Washington, D.C., 1992 (EPA/130/R-92/001 - February 1992).

Invited speaker, 4th Annual Meeting of the Soil and Water Conservation Society. Baltimore, MD, August 9-12, 1992.

Participant, U.S. EPA Workshop on Bioaccumulation of Hydrophobic Chemicals. Washington, D.C., June,1992.

Invited lecturer and participant, Young Scholars Program, NSF funded. Oxford, MS, 1992.

Counselor for summer interns with the Minorities Science Program, University of Mississippi funded. Oxford, MS, 1992.

Peer Review, Biology Peer Review Panel, U.S. EPA. Knoxville, TN, January, 1993.
Conference Co-organizer, First International Conference on Transport, Fate, and Effects of Silver in the Environment. University of Wisconsin, Madison, WI, August 8-10, 1993.

Chair, Exhibits Committee, 14th Annual Meeting of the Society of Environmental Toxicology and Chemistry. Houston, TX, November, 1993.

Consulting Aquatic Ecologist and Toxicologist to Weyerhaeuser Corporation. Columbus, MS, 1994 – 1999.

Member, Student Scholarship Committee, Mid-South Aquatic Plant Mangement Society. 1994 – 1997.

OSHA Safety Course. Norco, LA, 1994. Joint Agency Task Force Member, Guntersville Project. Guntersville, AL, April, 1994.

Featured speaker, Seminar on Pollution Prevention for Silver Imaging Systems. Lake Buena Vista, FL. May, 1994.

Conference Organizer, Second International Conference on Transport, Fate and Effects of Silver in the Environment. University of Wisconsin, Madison, WI, September 11-14, 1994.

Chair - Subcommittee, National Institute of Environmental Health Sciences (NIEHS) - Superfund Hazardous Substances Basic Research Program. Research Triangle Park, NC, October 16-19, 1994.

Discussion Panel Participant, 2nd International Conference on Environmental Fate and Effects Of Bleached Pulp Mill Effluents. Vancouver, B.C., Canada, November, 1994.

Genetic Toxicology Course (Audit). Oxford, MS, 1995.

Board of Directors, Society of Environmental Toxicology and Chemistry (elected), 1995.

Participant, U.S. EPA Environmental Biology Review Panel. Fort Worth, TX, January, 1995.

Participant, Society of Environmental Toxicology and Chemistry Workshop on Wetlands. Butte, MT, August, 1995.

Conference Organizer, Third International Conference on Transport, Fate and Effects of Silver in the Environment. Washington, D.C., August, 1995.

Featured Speaker, 1995 Scholars Conference, University of Mississippi. Oxford, MS, October, 1995.

Participant, Society of Environmental Toxicology and Chemistry Workshop on Whole-Effluent Toxicology. Pellston, MI, October, 1995.

Invited Participant, Round Table Discussion of Surfactant Toxicity in Aquatic Systems. Thornton, England, May, 1996.

Keynote Speaker, Mid-South Society of Environmental Toxicology and Chemistry (inaugural meeting). Memphis, TN, May, 1996.

Invited Speaker on Endocrine Disruption, Seminar on Emerging Water Issues, International Paper Company. Memphis, TN, June, 1996.

Instructor, Short Course on Constructed Wetlands, U.S. Army Waterways Experiment Station. Berkeley, CA. July, 1996.

Short Course on Constructed Wetland Design and Monitoring. Houston, TX, July, 1996.

Conference Organizer, Fourth International Conference on Transport, Fate and Effects of Silver in the Environment. Madison, WI, August, 1996.

Friends of Lake Keowee (FOLKS), Board of Directors (elected) and Member of the Technical Committee, 2003-present.

Bob C. Campbell Geology Museum, Clemson University, Board of Directors Member, 2003-present.

Associate Editor, Journal of Toxicology and Environmental Health Part B : Critical Reviews. 1999-2006.

Chair, Science Advisory Panel for the California Environmental Protection Agency – Aquatic Pesticides Committee, 2002-present.

Member, Science Advisory Panel, USDA Jimmy Carter Plant Materials Center, Americus, GA. 2003-present.

Member, Science Advisory Panel for the USEPA/ SETAC Whole Effluent Toxicity Testing Committee, 1998-2004.

Member, Science Advisory Panel for Proposal and Research Review, Water Environment Federation, 2001-present.

Member, Science Advisory Panel for the National Council for Air and Stream Improvement – Long Term Receiving Water Studies, 1999-present.

Member, Board of Directors – Aquatic Plant Management Society, (elected) 2003-2006.

Co-editor (with Dr. J.W. Castle), Special Issue of Environmental Geoscience on Constructed Wetland Treatment Systems, 2009.

Review of WET testing protocols, US EPA, 2009.

Member, Board of Directors – South Carolina Aquatic Plant Management Society, (elected) 2007-2009.

Vice-President and Annual Meeting Program Chair – South Carolina Aquatic Plant Management Society, (elected) 2008-2009.

Chair, ad hoc Committee on NPDES Permitting, South Carolina Aquatic Plant Management Society, 2008-2009.

Chair, Peer Review Panel, Canadian Foundation for Innovation, 2009.

Chair, Strategic Planning Committee, Aquatic Plant Management Society, 2008-2012.

Leader, Constructed Wetland Treatment Systems: A Short Course; presented at Synterra, Inc., Greenville, SC, June 14-18, 2010.

Chair, Peer Review Panel, Canadian Foundation for Innovation, 2010.

Peer Review Panel, Canadian Research Chairs, 2010.

Appointed Canada Review of University Environmental Programs, 2011.

Chair, Session on Components to reconstruct a successful wetland ecosystem at Key Factors to Successfully Reconstruct Boreal Wetland Ecosystems – An International Workshop. Chantilly, France. April 16-17, 2012.

Consulting Environmental Toxicologist, US Environmental Protection Agency, Science Advisory Panel, Problem Formulation and Risk Assessment, Washington,DC, June 11-14, 2012

BOOKS, BOOK CHAPTERS, AND MONOGRAPHS

M.Sc. Thesis: Rodgers, J.H., Jr. 1974. Thermal Effects on Primary Productivity of Phytoplankton, Periphyton, and Macrophytes in Lake Keowee, S.C. Botany Department, Clemson University. 88 pp.

Bi- weekly in situ determinations of Carbon-14 assimilation rates were made using SCUBA and chambers in a reservoir receiving thermal effluent from a nuclear power plant. Emphasis was placed upon relative contributions of each group of plants to the overall lake productivity and statistical correlations of productivity with water temperatures (1972-1974).

Ph.D. Dissertation: Rodgers, J.H., Jr.1977. Aufwuchs Communities of Lotic Systems: Nontaxonomic Structure and Function. Biology Department and Center for Environmental Studies, VPI&SU. 336 pp.

Six model streams were constructed to assess effects of typical industrial and municipal effluents on primary productivity, assimilatory sulfate reduction and structural aspects of assemblages of attached microorganisms. Net microbial productivity of aufwuchs and primary productivity were estimated by assimilatory (S35) sulfate reduction and carbon-14 fixation, respectively, with heterotrophic productivity being the difference. Concurrent laboratory studies verified the efficacy of these procedures. The ability of methods to discern perturbations was tested. Direct correlations between structural measurements and functions were ascertained by regression analysis. Field investigations of aufwuchs communities were inconclusive due to variability and the heterogeneous distribution of aufwuchs communities (1974 - 1977).

Guthrie, R.K., D.S. Cherry, and J.H. Rodgers, Jr. 1974. The Impact of Ash Basin Effluent on Biota in the Drainage System. *Proc. Seventh Mid-Atlantic Industrial Waste Conference*: pp. 17-43. Drexel University, Philadelphia, Pa.

Dickson, K.L., J. Cairns, Jr., J.R. Clark and J.H. Rodgers, Jr. 1978. Evaluating Pollution Stress on Ecosystems. In: K.C. Flynn and W.T. Mason (eds.) *The Freshwater Potomac - Aquatic Communities and Environmental Stress*. The Interstate Commission on the Potomac River Basin, Rockville, Maryland. pp. 80 - 83.

Rodgers, J.H., Jr., D.S. Cherry, K.L. Dickson, and J. Cairns, Jr. 1979. Invasion, Population Dynamics and Elemental Accumulation of *Corbicula fluminea* in the New River at Glen Lyn, Virginia. In: *Proc. First International Corbicula Symposium* J.C. Britton (ed.). Texas Christian University Research Foundation Publishers, Fort Worth, TX, pp. 99-110.

Rodgers, J.H., Jr., K.L. Dickson, and J. Cairns, Jr. 1979. A Review and Analysis of Some Methods Used to Measure Functional Aspects of Periphyton. In: R.L. Weitzel (ed.) *Methods and Measurements of Periphyton Communities:Review*. American Society for Testing and Materials, Philadelphia, Pennsylvania (ASTM STP 690), pp. 142-167.

Rodgers, J.H., Jr., D.S. Cherry, R.L. Graney, K.L. Dickson, and J. Cairns, Jr. 1980. Comparison of Heavy Metal Interactions in Acute and Artificial Stream Bioassay Techniques for the Asiatic Clam (*Corbicula fluminea*). In: J.G. Eaton, P.R. Parish, and A.C. Hendricks (eds.) *Aquatic Toxicology*. American Society for Testing and Materials, Philadelphia, PA. (ASTM STP 707), pp. 266-280.

Cherry, D.S., J.H. Rodgers, Jr., R.L. Graney, and J. Cairns, Jr. 1980. *Dynamics and Control of the Asiatic Clam in the New River,Virginia*. Bulletin 123, Virginia Water Resources Research Center. Virginia Polytechnic Institute and State University, Blackburg, VA. 72 pp.

Dillon, C.R. and J.H. Rodgers, Jr. 1980. *Thermal Effects on Primary Productivity of Phytoplankton. Periphyton. and Macrophytes in Lake Keowee. S.C.* Technical Report No. 81, Clemson University Water Resources Research Institute, Clemson, S.C. 115 pp.

Rodgers, J.H., Jr., J.R. Clark, K.L. Dickson, and J. Cairns, Jr. 1980. Nontaxonomic analyses of structure and function of aufwuchs communities in lotic microcosms. In: J.P. Geisy, Jr. (ed.). *Microcosms in Ecological Research*. USDOE (CONF-781101) pp. 625-643.

Lee, C.M., H. Bergman, W. Wood, and J.H. Rodgers, Jr. 1982. Workshop Summary and Conclusions. In: K.L. Dickson, A.W. Maki and J. Cairns, Jr. (eds.) *Modeling the Fate of Chemicals in the Aquatic Environment*, Ann Arbor: Ann Arbor Science Publ. pp. 397-407.

Cairns, J., Jr., A.L. Buikema, Jr., D.S. Cherry, E.E. Herricks, R.A. Matthews, B.R. Neiderlahner, J.H. Rodgers, Jr. and W.H. Van der Schalie. 1982. *Biological Monitoring in Water Pollution*. Pergamon Press: New York. 116 pp.

Rodgers, J.H., Jr., M.E. McKevitt, D.O. Hammerland, K.L. Dickson and J. Cairns, Jr. 1983. Primary production and decomposition of submergent and emergent aquatic plants of two Appalachian rivers. In: T.D. Fontaine III and S.M. Bartell (eds.) *Dynamics of Lotic Ecosystems*. Ann Arbor Science Publ. pp. 298-301.

Staples, C.A., K.L. Dickson, F.Y. Saleh, and J.H. Rodgers, Jr. 1983. A microcosm study of lindane and naphthalene partitioning for model validation. In: W. Bishop, R.D. Caldwell, and B.B. Heidolph (eds.) *Aquatic Toxicology and Hazard Assessment*. STP 802 ASTM Publications, Philadelphia, PA. pp. 26-41.

Rodgers, J.H., Jr. K.L. Dickson, and M.J. Defoer. 1983. Bioconcentration of lindane and naphthalene in bluegills (*Lepomis macrochirus*). In: W. Bishop, R.D. Cardwell, and B.B. Heidolph (eds.) *Aquatic Toxicology and Hazard Assessment*. STP 802. ASTM Publications, Philadelphia, PA. pp. 300-311.

Saleh, F.Y., K.L. Dickson, and J.H. Rodgers, Jr. 1984. Transport Processes of Naphthalene in the Aquatic Environment. In: L. Pawlowski, A.J. Verdier, and W.J. Lacy (eds.) *Chemistry for Environmental Protection*. Elsevier Publisher. pp. 119-131.

Vance, B.D. and J.H. Rodgers, Jr. 1984. *General Botany*, 2nd Ed. Hunter Textbooks, Inc., Winston - Salem, NC. 93 pp.

Staples, C.A., K.L. Dickson, J.H. Rodgers, Jr., and F.Y. Saleh. 1985. A Model for Predicting the Influence of Suspended Sediments on Bioavailability of Neutral Organics in the Water Compartment. In: R.D. Cardwell, R.C. Bahner and R.E. Purdy (eds.) *Aquatic Toxicology and Hazard Assessment*. ASTM STP 845, ASTM Philadelphia, PA. pp. 417-428.

Dickson, K.L. and J.H. Rodgers, Jr. 1985. Assessing the Hazards of Effluents in the Aquatic Environment. In: H. Bergman, A. Maki and R. Kimerle (eds.) *Assessing the Hazards of Effluents to Aquatic Life*. Pergamon Press.

Rodgers, J.H., Jr., K.L. Dickson, F.Y. Saleh, and C.A. Staples. 1987. Bioavailability of Sediment-bound Chemicals to Aquatic Organisms; Some Theory, Evidence and Research Needs. In: K.L. Dickson, A.W. Maki and W.A. Brungs (eds.) *Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems*. Pergamon: Elmsford, N.Y. pp. 245-266.

Anderson, J., W. Birge, J. Gentile, J. Lake, J.H. Rodgers, Jr. and R. Swartz. 1987. Biological Effects, Bioaccumulation, and Ecotoxicology of Sediment-associated Chemicals. In: K.L. Dickson, A.W. Maki, and W.A. Brungs (eds.) *Fate and Effects of Sediment-Bound Chemicals in Aquatic Systems*. Pergamon: Elmsford, N.Y. pp. 267-296.

Rodgers, J.H. Jr., P.A. Clifford and R.M. Stewart. 1991. Enhancement of HERBICIDE, the Aquatic Herbicide Fate and Effects Model. In: *Proceedings, 25th Annual Meeting, Aquatic Plant Control Research Program.* Misc. Paper A-91-3. pp. 279-282. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Rodgers, J.H. Jr. 1991. Herbicide Registration for Aquatic Use: A Look to the Future. In: *Proceedings, 25th Annual Meeting, Aquatic Plant Control Research Program.* Misc. Paper A-91-3. pp. 245-248. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Graney, R.L., J.H. Kennedy and J.H. Rodgers, Jr. (eds.). 1993. *Aquatic Mesocosm Studies in Ecological Risk Assessment.* Lewis Publishers, Baca Raton, FL. 723 pp.

Rodgers, J.H., Jr., A.W. Dunn and A.B. Jones. 1993. Triclopyr Concentrations in Eurasian Watermilfoil: Uptake Under Differing Exposure Scenarios. In: *Proceedings, 28th Annual Meeting, Aquatic Plant Control Research Program.* Misc. Paper A-94-2. pp. 249-259. U.S. Army Waterways Experiment Station, Baltimore, MD. November 15-18, 1993.

Rodgers, J.H., Jr. and A.W. Dunn. 1994. TVA - Guntersville Reservoir Herbicide Monitoring Survey 1991-1992. A Report to the Tennessee Valley Authority and U.S. Army Corps of Engineers Joint Agency Program. 116 p.

Solomon, K., D. Bright, P. Hodson, K.-J. Lehtinen, B. McKague and J. Rodgers, Jr. 1999. Evaluation of ecological risks associated with the use of chlorine dioxide for the bleaching of pulp. Report prepared for the Alliance for Environmental Technology. 86 pp.

Rodgers, J.H., Jr. and J.F. Thomas. 2004. Evaluations of the Fate and Effects of Pulp and Paper Mill Effluents from a Watershed Multistressor Perspective: Progress to Date and Future Opportunities. In: Pulp and Paper Mill Effluent Environmental Fate and Effects. D. L. Borton, T. J. Hall, R.P. Fisher, and J.F. Thomas (eds.). DEStech Publications, Lancaster, PA. pp.135-146.

PAPERS AND
PUBLICATIONS:

Rodgers, J.H., Jr., G.L. Powell, and J.F. Geldard. 1973. Triple-label Liquid Scintillation Radioassay: Possible or Impossible? Seventh Annual Regional Meeting (Oct . 5) Wilmington, N.C. 43 pp.

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Rodgers, J.H., Jr. 2010. Evaluation of the NPDES Permitting System. Presented at the 29th Annual Meeting of the Mid-South Aquatic Plant Management Society, October 12-14, 2010. Guntersville, AL.

Castle, J. W., Rodgers, J. H., Jr., Spacil, M., Alley, B., and Pardue, M. 2010. “A Pilot-Scale Study to Apply Biogeochemical Processes of Natural Wetlands to Treating Impaired Waters Using Constructed Wetland Treatment Systems,” Geological Society of America Annual National Meeting, Denver, CO, November 2010, Abstract published in Geological Society of America Abstracts with Programs, v. 42, no. 5, p. 640.

Rodgers, J.H. 2010. Common algal problems and their management. Presented at the 2010 NC Turfgrass Conference & Show. (Dec. 13-15, 2010) Greensboro, NC.

Rodgers, J.H. 2010. Changing regulation of aquatic herbicides applications: How NPDES affects you. Presented at the 2010 NC Turfgrass Conference & Show. (Dec. 13-15, 2010) Greensboro, NC.

Rodgers, J.H. and B. Willis. 2011. Algae on the move: Recent range expansion of Prymnesium parvum. Presented at the 31st Annual Meeting of the Midwest Aquatic Plant Management Society, Grand Rapids, MI. Feb. 27-Mar.2, 2011.

Rodgers, J.H. 2011. Responses of *Lyngbya wollei* to copper=based algaecides: The critical burden concept. Presented at the 12th Annual Meeting of the Northeast Aquatic Plant Management Society, Portsmouth, NH, MI. Jan. 18-20, 2011.

Rodgers, J.H., W.M. Bishop and B.E. Willis. 2011. Algae on the move: Recent range expansion of Prymnesium parvum. Presented at the 12th Annual Meeting of the Northeast Aquatic Plant Management Society, Portsmouth, NH, MI. Jan. 18-20, 2011.

Beebe, D. A., Castle, J. W., and Rodgers, J. H. 2010. "Evaluation of Clinoptilolite for Use as a Sorptive Microbial Carrier in Constructed Wetland Treatment Systems Designed to Treat Ammonia," Geological Society of America, South-Central Annual Meeting, New Orleans, LA, March 2011.

Alley, B., D.A. Beebe, J.H. Rodgers, Jr., and J.W. Castle. 2011. Chemical and physical characterization of produced waters from conventional and unconventional fossil fuel resources. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Beebe, D. A., J.W. Castle and J.H. Rodgers, Jr. 2011. Clinoptilolite as a dual purpose sorbent and microbial carrier in constructed wetland treatment systems designed to remove ammonia. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Jurinko, K., C.L. Ritter, J.W. Castle and J.H. Rodgers, Jr. 2011. Biogeochemical process in a pilot-scale constructed wetland treatment system designed to remove metals from produced water. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Pardue, M.J., J.W. Castle and J.H. Rodgers, Jr. 2011. Evaluation of a pilot-scale constructed wetland treatment system for treatment of a specific oilfield produced water. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Ritter, C.L., K.N. Jurinko, J.W. Castle and J.H. Rodgers, Jr. 2011. Biogeochemical processes in a constructed wetland treatment system designed for removal of selenium from energy produced water. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Castle, J. W., R. W. Falta, J. R. Wagner and J. H. Rodgers, Jr. 2011. Introduction to carbon capture and sequestration. Carbon Capture and Storage (CCS) Short Course. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Castle, J. W., R. W. Falta, J. R. Wagner and J. H. Rodgers, Jr. 2011. Role of water in carbon capture and sequestration. Carbon Capture and Storage (CCS) Short Course. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

Castle, J. W., R. W. Falta, J. R. Wagner and J. H. Rodgers, Jr. 2011. Carbon capture and sequestration: Opportunities and challenges. Carbon Capture and Storage (CCS) Short Course. Presented at the 19^{th} Annual David S, Snipes/ Clemson Hydrogeology Symposium. Clemson University, Clemson, SC. April 7, 2011.

John H. Rodgers, Jr. and Ben E. Willis. 2012. Algae on the move: Recent range expansion of *Prymnesium parvum.* Presented at the 32nd Annual Meeting of the Midwest aquatic plant Management Society. February 26-29, 2012. Milwaukee WI.

John H. Rodgers, Jr. [1], West M. Bishop[2] and Ben E. Willis . 2011. Algae on the move: Recent range expansion of *Prymnesium parvum*. Presented at the 13th Annual Meeting of the Northeast aquatic Plant Management Society. January 17-19, 2011. New Castle, NH.

Rodgers, J.H., R. Brown, D. Issacs, N. Long, W.A. Ratajczyk and J.C. Schmidt. 2011. Algae taste-and-odor issues in a drinking water supply lake: Intervention and results. Presented at the 51st Annual Meeting of the Aquatic Plant Management Society, Baltimore, MD. July 24-27, 2011.

Rodgers, J. H., Jr., J.W. Castle, M. M. Spacil and Christina Ritter. 2011. Treating Selenium in Energy-Derived Produced Waters for Surface Water Discharge Using Constructed Wetland Treatment Systems. Presented at the Annual Meeting of the Geological Society of America. October 9-13, 2011. Minneapolis, MN.

John H. Rodgers, Jr., J.W. Castle, M. M. Spacil and Christina Ritter. 2011. Constructed Wetland Treatment Systems for Energy-Derived Produced Waters: Treating Selenium for Surface Water Discharge. Presented at the 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry. November 13-17, 2011. Boston, MA.

Beebe, D. A., Song, Y., Castle, J. W., and Rodgers, J. H. Jr. 2011. Pilot Study of Constructed Wetland Treatments Systems for Ammonia in Water Produced from Oil Extraction. Presented at the 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry. November 13-17, 2011. Boston, MA.

Bethany L. Alley[1], John H. Rodgers, Jr. [1], and James W. Castle . 2011 Renovating Fresh Oilfield Produced Waters for Beneficial Uses: Managing Constructed Wetland Treatment Systems for Performance. Presented at the 32nd Annual Meeting of the Society of Environmental Toxicology and Chemistry. November 13-17, 2011. Boston, MA.

Rodgers, J.H. 2011. Presidential address: Aquatic plant management: The new normal. Presented at the 33rd Annual Meeting of South Carolina Aquatic Plant Management Society, Inc., Clemson, SC, August 17-19, 2011.

Willis, B. and J.H. Rodgers. 2011. Measuring copper residues from algaecide and herbicide applications. Presented at the 33rd Annual Meeting of South Carolina Aquatic Plant Management Society, Inc., Clemson, SC, August 17-19, 2011.

Rodgers, J.H. and R. Richardson. 2011. Update on NPDES for the SCAPMS region. Presented at the 33rd Annual Meeting of South Carolina Aquatic Plant Management Society, Inc., Clemson, SC, August 17-19, 2011.

Rodgers, J.H. 2012. Algae and Taste-and-Odor Issues in a drinking water supply lake: Intervention and Results. Presented at the Midwest Aquatic Plant Management Society, 32nd Annual Conference, Milwaukee, WI. February 26-29, 2012.

Rodgers, J.H. 2012. Use of peroxyhydrate algicide (Phycomycin) in water resource management. Presented at the 22nd Annual Conference of the Pennsylvania Lake Management Society. State College, PA. March 7-8, 2012.

Rodgers, J.H. 2012. Problematic cyanobacteria in water resources: Strategy for Intervention and Case Studies. Presented at the 22nd Annual Conference of the Pennsylvania Lake Management Society. State College, PA. March 7-8, 2012.

Rodgers, J.H. 2012. Toxicology of herbicides. Presented at Minnesota Aquatic and Invasive Species Workshop. Minneapolis, MN. March 19-20, 2012.

Pardue, M., J.W.Castle, G.M. Huddleston and J.H. Rodgers. 2012. Treatment of oilfield produced water using a constructed wetland treatment system. Presented at the 20th Annual David S. Snipes / Clemson Hydrogeology Symposium. Clemson, SC. April 12, 2012.

Alley, B., B. Willis, J.H. Rodgers, Jr. and J.W. Castle. 2012. Water depth and treatment performance of free water surface constructed wetland treatment systems for simulated fresh oil-field produced water. Presented at the 20th Annual David S. Snipes / Clemson Hydrogeology Symposium. Clemson, SC. April 12, 2012.

Beebe, A., B. Alley, J.W. Castle, and J.H. Rodgers, Jr. 2012. Evaluation of coal-bed methane produced water in western Alabama for use as a water resource during drought. Presented at the 20th Annual David S. Snipes / Clemson Hydrogeology Symposium. Clemson, SC. April 12, 2012.

Van Heest, P., J.H. Rodgers, Jr., J.W. Castle, and M.M. Spacil. 2012. Treatment of selenium in pilot-scale constructed wetland treatment systems: Effects of temperature and nutrient-amendment mass loading. Presented at the 20th Annual David S. Snipes / Clemson Hydrogeology Symposium. Clemson, SC. April 12, 2012.

Willis, B. and J.H. Rodgers, Jr. 2012. Bioavailability and analytical measurements of copper residuals in sediments. Presented at the 20th Annual David S. Snipes / Clemson Hydrogeology Symposium. Clemson, SC. April 12, 2012.

Rodgers, J.H., Jr. 2012. Criteria used to measure wetland reconstruction success. Presented at Key Factors to Successfully Reconstruct Boreal Wetland Ecosystems – An International Workshop. Chantilly, France. April 16-17, 2012.

James W. Castle

PERSONAL DATA

Professor, Department of Environmental Engineering and Earth Sciences, Clemson University

EDUCATION

Ph.D., University of Illinois, Urbana-Champaign, Illinois - 1978, Geology (Sedimentology)
M.S., University of Wisconsin, Madison, Wisconsin - 1974, Geology (Structural Geology)
B.S. (Honors), Allegheny College, Meadville, Pennsylvania - 1972, Geology

PROFESSIONAL REGISTRATION

Professional Geologist, Pennsylvania, 1995, No. PG-001555-G

PROFESSIONAL EXPERIENCE

Clemson University, 2007 - present, Professor, Environmental Engineering and Earth Sciences
Clemson University, 2001 - 2007, Associate Professor, Geological Sciences

Clemson University, 1995 - 2001, Assistant Professor, Geological Sciences

Cabot Oil & Gas Corporation, Pittsburgh, Pennsylvania, 1988-1995, Senior Staff Geologist
Chevron U.S.A., Denver, Colorado, 1985-1988, Chief Development Geologist's Staff
Chevron Geosciences Company, Houston, Texas, 1982-1985, Development Geologist
California State University, Fullerton, 1981, Lecturer in Geological Sciences
Chevron Oil Field Research Company, La Habra, California, 1978-1982, Research Geologist

MEMBERSHIPS

Member, American Association of Petroleum Geologists (AAPG), (1978 -)
Member, American Geophysical Union (AGU), (1995 -)
Member, Geological Society of America (GSA), (1979 -)
Member, Society for Sedimentary Geology (SEPM), (1975 -)
Member, Society of Petroleum Engineers (SPE), (1995 -)

PROFESSIONAL SERVICE

Member, Advisory Board, SECARB-ED, Southeast Regional Carbon Sequestration Technology Training Program (2010 -)
Member of the Regional Carbon Sequestration Partnership (RCSP) Water Working Group, a national advisory group affiliated with the U.S. Department of Energy (2009 -)
Associate Editor, *South Carolina Geology* journal (2007 -)

Member of the South Carolina Geological Advisory Committee for the National Cooperative Geologic Mapping Program of the U.S. Geological Survey (1996 -)
Member of the Jocassee Gorges Professional Management and Research Working Group (2002 -)
Editor-in-Chief, *Environmental Geosciences*, an international peer-reviewed journal (elected to 2008-2010 term)
Member, Executive Committee, Division of Environmental Geosciences, American Association of Petroleum Geologists (2008-2010)
Chair, Publications Committee, Division of Environmental Geosciences, American Association of Petroleum Geologists (2008-2010)
Co-Editor, Special Issues (two) of *Environmental Geosciences* journal (March 2008 and September 2008) – Constructed Wetland Treatment Systems
Member of the Board of Directors, Carolina Geological Society (2000 - 2001)
Member of the Research Committee, American Association of Petroleum Geologists (1997 - 2000)

Other Professional Service (since 1995):

2012 Manuscript reviewer for *Bioresource Technology* journal
2012 Manuscript reviewer for *Critical Reviews in Environmental Science & Technology*
2011 Manuscript reviewer for *Journal of Sedimentary Research* journal
2011 Manuscript reviewer for *Environmental Science & Technology* journal
2011 Manuscript reviewer for *Applied Geochemistry* journal
2011 Invited speaker, University of South Carolina - Aiken
2011 Manuscript reviewer for *Tectonophysics* journal
2010 Technical Session Chair, "Produced Water Treatment Technologies," 17th Annual International Petroleum and Biofuels Environmental Conference: Environmental Issues and Solutions in Exploration, Production, Refining & Distribution of Petroleum, San Antonio, TX
2010 Technical Session Co-Chair, "Produced Waters from Development and Generation of Energy: Characterization, Treatment, and Beneficial Use," Goldschmidt International Conference on Earth, Energy, and the Environment, Knoxville, TN
2010 Technical Session Co-Chair, "Environmental Remediation and Hydrogeological Characterization", Annual Meeting of American Association of Petroleum Geologists, New Orleans, LA
2009 Interviewed by Leonard Lopate on New York Public Radio (WNYC)
2009 Invited speaker, Saskatchewan Research Council, Saskatoon, Saskatchewan, Canada
2009 Invited speaker, Clean Coal Technology Briefing, American Coalition for Clean Coal Electricity, Columbia, SC
2008 Proposal reviewer for the National Science Foundation
2008 Manuscript reviewer for *Geological Society of America Bulletin*
2008 Manuscript reviewer for *Bioresource Technology* journal
2007 Manuscript reviewer for *Geological Society of America Bulletin*
2007 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2007 Consultant for Dominion Exploration and Production Company, Indiana, PA
2007 Manuscript reviewer for *Geological Society of America Special Publication* (book)

2006 Manuscript reviewer for *Sedimentary Geology* journal
2006 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2006 Organizer and Co-Chair of Special Technical Session, Clemson University Hydrogeology Symposium
2006 External member of doctoral committee, Virginia Tech University, Blacksburg
2005 Proposal reviewer for the National Science Foundation
2005 Invited speaker, US Department of Energy Petroleum Technology Transfer Council, Washington, PA
2005 Manuscript reviewer for *Sedimentary Geology* journal
2005 External member of doctoral committee, Old Dominion University, Norfolk, Virginia
2005 Consultant for Dominion Exploration and Production Company, Indiana, PA
2004 Proposal reviewer for the National Science Foundation
2004 Invited keynote speaker for 20th Anniversary Meeting of the Pittsburgh Association of Petroleum Geologists, Pittsburgh, PA
2004 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2004 Nominated for election and ran for Executive Council of the Gas Storage Technology Consortium
2004 Manuscript reviewer for *Sedimentary Geology* journal
2004 External member of doctoral committee, Virginia Tech University, Blacksburg
2003 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2003 Proposal reviewer for the National Science Foundation
2003 Manuscript reviewer for *Journal of Sedimentary Research*
2002 Moderator and Presenter, US Department of Energy Petroleum Technology Transfer Council, Bakersfield, CA
2002 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2002 Manuscript reviewer for *Environmental and Engineering Geoscience* journal
2001 External evaluator for endowed chairholder, SCANA Chair in Physical Sciences, University of South Carolina-Aiken
2001 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
2001 Proposal reviewer for the National Science Foundation
1999 Consultant for STATOIL Energy, Alexandria, VA
1999 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
1999 Invited speaker, Central Savannah River Geological Society, Aiken, SC
1998 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
1998 Invited speaker, US Department of Energy Petroleum Technology Transfer Council, Pittsburgh, PA
1997 Proposal reviewer for the American Chemical Society-Petroleum Research Fund
1997 Invited field trip participant and USGS Volunteer, United States Geological Survey, Reston, VA
1996 Invited speaker, Westinghouse Savannah River Company, Savannah River Site, South Carolina
1996 Manuscript reviewer for *Environmental Geochemistry and Health* journal
1996 Reviewer of textbook chapters for John Wiley & Sons, publisher
1995 Invited speaker, South Carolina Geological Survey, Columbia

PUBLICATIONS

Refereed Publications

Horner, J. E., Castle, J. W., Rodgers J. H., Jr., Murray Gulde, C. L., and Myers, J. E., "Design and Performance of Pilot-Scale Constructed Wetland Treatment Systems for Treating Oilfield Produced Water from Sub-Saharan Africa," Water, Air, & Soil Pollution, in press. DOI 10.1007/s11270-011-0996-1.

Pham, M. P. T., Castle, J. W., and Rodgers, J. H., Jr., "Application of Water Quality Guidelines and Water Quantity Calculations to Decisions for Beneficial Use of Treated Water," Applied Water Science, v. 1, p. 85-101 (2011).

Alley, B., Beebe, A., Rodgers, J. H., Jr., and Castle, J. W., "Chemical and Physical Characterization of Produced Waters from Conventional and Unconventional Fossil Fuel Resources," Chemosphere, v. 85, p. 74-82 (2011).

Pham, M. P. T., Castle, J. W., and Rodgers, J. H., Jr., "Biogeochemical Process Approach to the Design and Construction of a Pilot-Scale Wetland Treatment System for an Oilfield Produced Water," Environmental Geosciences, v. 18, p. 157-168 (2011).

Spacil, M. M., Rodgers, J. H., Jr., Castle, J. W., and Chao, W. Y., "Performance of a Pilot-Scale Constructed Wetland Treatment System for Selenium, Arsenic, and Low Molecular Weight Organics in Simulated Fresh Produced Water," Environmental Geosciences, v. 18, p. 145-156 (2011).

Spacil, M. M., Rodgers, J. H., Jr., Castle, J. W., Murray Gulde, C. L., and Myers, J. E., "Treatment of Selenium in Simulated Refinery Effluent Using a Pilot-Scale Constructed Wetland Treatment System," Water, Air, & Soil Pollution, v. 221, p. 301-312 (2011). DOI 10.1007/s11270-011-0791-z.

Horner, J. E., Castle, J. W., and Rodgers J. H., Jr., "A Risk Assessment Approach to Identifying Constituents in Oilfield Produced Water for Treatment Prior to Beneficial Use," Ecotoxicology and Environmental Safety, v. 74, p. 989-999 (2011). DOI 10.1016/j.ecoenv.2011.01.012

Castle, J. W., and Rodgers J. H., Jr., "Reply to Discussion on Hypothesis for the Role of Toxin-Producing Algae in Phanerozoic Mass Extinctions Based on Evidence from the Geologic Record and Modern Environments," Environmental Geosciences, v. 18, p. 58-60 (2011).

Dorman, L., Rodgers J. H., Jr., and Castle, J. W., "Characterization of Ash Basin Waters from a Risk-Based Perspective," Water, Air, & Soil Pollution , v. 206, p. 175-185 (2010). DOI:10.1007/s11270-009-0094-9

Iannacone, M. M., Castle, J. W., and Rodgers, J. H., Jr., “Role of Equalization Basins of Constructed Wetland Systems for Treatment of Particulate-Associated Elements in Flue Gas Desulfurization Waters,” Water, Air, & Soil Pollution, v. 203, p. 123-137 (2009). DOI:10.1007/s11270-009-9996-9

Iannacone, M. M., Castle, J. W., and Rodgers, J. H., Jr., “Characterization of Flue Gas Desulfurization Particulates in Equalization Basins,” Fuel, v. 88, p. 1580-1587 (2009). DOI:10.1016/j.fuel.2009.02.035

Castle, J. W., and Rodgers J. H., Jr., “Hypothesis for the Role of Toxin-Producing Algae in Phanerozoic Mass Extinctions Based on Evidence from the Geologic Record and Modern Environments” Environmental Geosciences, v. 16, p. 1-23 (2009). DOI:10.1306/eg.08110808003

Dorman, L., Castle, J. W., and Rodgers J. H., Jr., “Performance of a Pilot-Scale Constructed Wetland Treatment System for Treating Simulated Ash Basin Water” Chemosphere, v. 75, p. 939-947 (2009). DOI:10.1016/j.chemosphere.2009.01.012

Kanagy, L. E., Johnson, B. M., Castle, J. W., and Rodgers J. H., Jr., “Hydrosoil Conditions in a Pilot-Scale Constructed Wetland Treatment System for Natural Gas Storage Produced Waters,” Environmental Geosciences, v. 15, p. 105-114 (2008). DOI:10.1306/eg.11150707016

Johnson, B. M., Kanagy, L. E., Rodgers J. H., Jr., and Castle, J. W., “Feasibility of a Pilot-Scale Hybrid Constructed Wetland Treatment System for Simulated Natural Gas Storage Produced Waters,” Environmental Geosciences, v. 15, p. 91-104 (2008). DOI:10.1306/eg.06220707004

Johnson, B. M., Kanagy, L. E., Rodgers J. H., Jr., and Castle, J. W., “Chemical, Physical, and Risk Characterization of Natural Gas Storage Produced Waters,” Water, Air, & Soil Pollution, v. 191, p. 33-54 (2008). DOI:10.1007/s11270-007-9605-8.

Kanagy, L. E., Johnson, B. M., Castle, J. W., and Rodgers J. H., Jr., “Design and Performance of a Pilot-Scale Hybrid Constructed Wetland Treatment System for Natural Gas Storage Produced Water,” Bioresource Technology, v. 99, p. 1877-1885 (2008). DOI:10.1016/j.biortech.2007.03.059.

Rodgers J. H., Jr., and Castle, J. W., “Constructed Wetland Treatment Systems for Efficient and Effective Treatment of Contaminated Waters for Reuse,” Environmental Geosciences, v. 15, p. 1-8 (2008). DOI:10.1306/eg.11090707019.

Molz, F. J., Kozubowski, T. J., Podgorski, K., and Castle, J. W., “A Generalization of the Fractal/Facies Model,” Hydrogeology Journal, v. 15, p. 809-816 (2007).

Poterala, S. F., and Castle, J. W., “Stratigraphic Investigation of Braided Stream Deposits (Pleistocene) from the Upper Piedmont of South Carolina,” South Carolina Geology, v. 45, p. 17-23 (2007).

Mikhailova, E. A., Post, C. J., Magrini-Bair, K., and Castle, J. W., "Pedogenic Carbonate Concretions in the Russian Chernozem," Soil Science, v. 171, p. 981-991 (2006).

Castle, J. W., and Byrnes, A. P., "Petrophysics of Lower Silurian Sandstones and Integration with the Tectonic-Stratigraphic Framework, Appalachian Basin, U.S.A.," American Association of Petroleum Geologists Bulletin, v. 89, p. 41-60 (2005).

Castle, J. W., Molz, F. J., Lu, S., and Dinwiddie, C. L., "Sedimentology and Fractal-Based Analysis of Permeability Data, John Henry Member, Straight Cliffs Formation (Upper Cretaceous), Utah, U.S.A.," Journal of Sedimentary Research, v. 74, p. 270-284 (2004).

Dinwiddie, C. L., Molz, F. J., and Castle, J. W., "A New Small Drillhole Minipermeameter Probe for *In Situ* Permeability Measurement: Fluid Mechanics and Geometrical Factors," Water Resources Research, v. 39, no. 7, 1178 (2003). DOI:10.1029/2001WR001179.

Bridges, R. A., and Castle, J. W., "Local and Regional Tectonic Control on Sedimentology and Stratigraphy in a Strike-Slip Basin: Miocene Temblor Formation of the Coalinga Area, California, U.S.A.," Sedimentary Geology, v. 158, p. 271-297 (2003).

Lu, S., Molz, F. J., Fogg, G. E., and Castle, J. W., "Combining Stochastic Facies and Fractal Models for Representing Natural Heterogeneity," Hydrogeology Journal, v. 10, p. 475-482 (2002).

Castle, J. W., "Appalachian Basin Stratigraphic Response to Convergent-Margin Structural Evolution," Basin Research, v. 13, no.4, p. 397-418 (2001).

Castle, J. W., "Foreland-Basin Sequence Response to Collisional Tectonism," Geological Society of America Bulletin, v. 113, no. 7, p. 801-812 (2001).

Warlick, C. M., Clendenin, C. W., and Castle, J. W., "Geology of the Cliffs at Glassy Development, Southern Saluda 7.5-Minute Quadrangle, Greenville County, South Carolina," South Carolina Geology, v. 32, p. 37-47 (2001).

Castle, J. W., and Miller, R. B., "Recognition and Hydrologic Significance of Passive-Margin Updip Sequences: An Example from Eocene Coastal-Plain Deposits, U.S.A.," Journal of Sedimentary Research, v. 70, no. 6, p. 1290-1301 (2000).

Castle, J. W., "Recognition of Facies, Bounding Surfaces, and Stratigraphic Patterns in Foreland-Ramp Successions: An Example from the Upper Devonian, Appalachian Basin, U.S.A.," Journal of Sedimentary Research, v. 70, no. 4, p. 896-912 (2000).

Miller, R. B., Castle, J. W., and Temples, T. J., "Deterministic and Stochastic Modeling of Aquifer Stratigraphy," Ground Water, v. 38, no. 2, p. 284-295 (2000).

Castle, J. W., and Byrnes, A. P., "Petrophysics of Low-Permeability Medina Sandstone, Northwestern Pennsylvania, Appalachian Basin," The Log Analyst, v. 39, no. 4, p. 36-46 (1998).

Castle, J. W., "Regional Sedimentology and Stratal Surfaces of a Lower Silurian Clastic Wedge in the Appalachian Foreland Basin," Journal of Sedimentary Research, v. 68, no. 6, p. 1201-1211 (1998).

Kelly, J. M., and Castle, J. W., "Red Wash Field - U.S.A. Uinta Basin, Utah," in N. H. Foster and E. A. Beaumont, eds., Stratigraphic Traps III: American Association of Petroleum Geologists Treatise of Petroleum Geology, Atlas of Oil and Gas Fields, p. 231-256 (1992).

Castle, J. W., "Sedimentation in Eocene Lake Uinta (Lower Green River Formation) Northeastern Uinta Basin, Utah," in B. J. Katz, ed., Lacustrine Basin Exploration - Case Studies and Modern Analogs: American Association of Petroleum Geologists Memoir 50, p. 243-263 (1990).

Castle, J. W., and Craddock, C., "Deposition and Metamorphism of the Polarstar Formation (Permian), Ellsworth Mountains," Antarctic Journal of the United States, v. 10, no. 5, p. 239-241 (1975).

Conference Proceedings (Unreviewed)

Brame, S. E., Castle, J. W., Fuwami, O. K., and Falta, R. W., "History Matching of Heavy Oil Production for Comparing New Approaches to Generating Reservoir Property Distributions, West Coalinga Field, California," Society of Petroleum Engineers Paper no. 93469, SPE/DOE Symposium on Improved Oil Recovery, Tulsa, Oklahoma, April 2006.

Castle, J. W., Bruce, D. A., Brame, S. E., Brooks, D. A., Falta, R. W., and Murdoch, L. C., "Design and Feasibility of Creating Gas-Storage Caverns by Using Acid to Dissolve Carbonate Rock Formations," Society of Petroleum Engineers Paper no. 91436, SPE Eastern Regional Meeting, Charleston, WV, September 2004.

Byrnes, A. P., and Castle, J. W., "Comparison of Core Petrophysical Properties between Low-Permeability Sandstone Reservoirs: Eastern U.S. Medina Group and Western U.S. Mesaverde Group and Frontier Formation," Society of Petroleum Engineers Paper no. 60304, SPE Rocky Mountain Regional/Low Permeability Reservoirs Symposium, Denver, CO, March 2000.

Other Scholarly Publications

Beebe, D. A., Alley, B., Castle, J. W., and Rodgers, J. H., Jr., "Potential for Beneficial Use of Coal-Bed Methane Produced Water in Western Alabama to Augment Water Supplies during Intense Drought," Geological Society of America Abstracts with Programs, v. 44, no. 4, p. 66, April 2012.

Van Heest, P. J., Rodgers, J. H., Jr., Castle, J. W., and Spacil, M. M., "Treatment of Selenium in Energy-Derived Waters Using a Nutrient-Amended Pilot-Scale Constructed Wetland Treatment System," Geological Society of America Abstracts with Programs, v. 44, no. 4, p. 70, April 2012.

Alley, B. L., Willis, B., Rodgers, J. H., Jr., and Castle, J. W., "Water Depth and Treatment Performance of Free Water Surface Constructed Wetland Treatment Systems for Simulated Fresh Oilfield

Produced Water," Clemson University 20th Annual Hydrogeology Symposium Abstracts with Program, p. 2, April 2012.

Beebe, D. A., Alley, B., Castle, J. W., and Rodgers, J. H., Jr., "Evaluation of Coal-Bed Methane Produced Water in Western Alabama for Use as a Water Resource during Drought," Clemson University 20th Annual Hydrogeology Symposium Abstracts with Program, p. 4, April 2012.

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Castle, J. W., and Mattox, C. A., "Laboratory Measurement of Hydraulic Properties," Clemson University Sixth Annual Hydrogeology Symposium Abstracts with Program, April 1998.

Miller, R. B., Castle, J. W., Temples, T. J., and Christopher, R. A., "Three-Dimensional Stochastic and Deterministic Modeling of Subsurface Properties within a Sequence Stratigraphic Framework for the M Area, Savannah River Site, South Carolina," Clemson University Sixth Annual Hydrogeology Symposium Abstracts with Program, April 1998.

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RESEARCH REPORTS

Castle, J. W., Rodgers, J. H., Johnson, B. M., Ober, L. E., Brame, S., Huddleston, G. M., and Mooney, F. D., "Renovation of Produced Waters from Underground Natural Gas Storage Facilities: Demonstration-Scale Constructed Wetland Treatment System," Design Report for Gas Storage Technology Consortium (USDOE) Project #3039-CU-DOE-1779, 8 p. plus drawings, 2006.

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Castle, J. W., "Reservoir Geology Study with Emphasis on Sandstone Petrography and Diagenesis, Well Baang No. 1, Sudan," Chevron report, 19 p. plus figures, 1982.

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Castle, J. W., "Reservoir Geology Study, Well Unity No. 1, Upper Nile District, Sudan," Chevron report, 47 p. plus figures, 1980.

PRESENTATIONS

Castle, J. W., "Carbon Capture and Storage: Opportunities and Challenges," Carbon Capture and Storage Workshop," Clemson University 19th Annual Hydrogeology Symposium Abstracts with Program, April 1, 2011.

Castle, J. W., Rodgers, J. H., Jr., and Wagner, J. R., "Carbon Capture and Storage: Opportunities and Challenges," invited seminar speaker, Department of Forestry and Natural Resources, Clemson University, February 23, 2011.

Castle, J. W., Rodgers, J. H., Jr., and Wagner, J. R., "Carbon Capture and Storage: Opportunities and Challenges," University of South Carolina, Aiken, SC, February 4, 2011.

Castle, J. W., Rodgers, J. H., Jr., Spacil, M., Horner, J. E, Alley, B., and Pardue, M., "Pilot-Scale Constructed Wetland Systems for Treating Energy-Produced Waters," Ground Water Protection Council Annual Forum, Water & Energy in Changing Climates, Pittsburgh, PA, September 29, 2010.

Castle, J. W., and Rodgers, J. H., Jr., "Constructed Wetland Treatment Systems for Environmentally Friendly Drilling," 16th International Petroleum and Environmental Conference, Houston, Texas, November 2009.

Castle, J. W., and Rodgers, J. H., Jr., "Geochemical Interactions of Constructed Wetland Systems for Treatment of Uranium, Arsenic, Radionuclides, and Low pH AMD," Saskatchewan Research Council Workshop, Saskatoon, Saskatchewan, Canada, September 2009.

Castle, J. W., "Utilization of Produced Waters: Research at Clemson University," Clean Coal Technology Briefing, American Coalition for Clean Coal Electricity, Columbia, SC, April 2009.

Castle, J. W., and Rodgers, J. H., Jr., "Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water," USDOE National Energy Technology Laboratory, Pittsburgh, PA, January 2009.

Castle, J. W., and Rodgers, J. H., Jr., "An Innovative System for the Efficient and Effective Treatment of Non-traditional Waters for Reuse in Thermoelectric Power Production: Final Year Results," University Coal Research and HBCU Review and Conference, US Department of Energy, Pittsburgh, PA, June 2008.

Castle, J. W., and Rodgers, J. H., Jr., "An Innovative System for the Efficient and Effective Treatment of Non-traditional Waters for Reuse in Thermoelectric Power Production," University Coal Research Contractors Review Meeting, US Department of Energy, Pittsburgh, PA, June 2007.

Castle, J. W., and Rodgers, J. H., Jr., "Design Parameters for Full-Scale Constructed Wetland Treatment Systems for Produced Waters from Underground Gas Storage," Gas Storage Technology Consortium, Proposal Review and Progress Update Meeting, Buffalo, NY, May 2007.

Castle, J. W., and Rodgers, J. H., Jr., "Demonstration-Scale Constructed Wetland System for Treatment of Produced Waters from Underground Gas Storage," Gas Storage Technology Consortium Annual Meeting, Pittsburgh, PA, November 2006.

Castle, J. W., “Sedimentology and Petrology of the Upper Devonian Lock Haven Formation in Pennsylvania,” Workshop on Recent Developments in Upper Devonian Sandstone Plays sponsored by US Department of Energy Petroleum Technology Transfer Council, Washington, PA, 2005.

Castle, J. W., Rodgers, J. H., Eggert, D.A., and Iannacone, M. M., “Specifically Designed Constructed Wetlands: A Novel Treatment Approach for Scrubber Wastewater,” University Coal Research Contractors Review Meeting, US Department of Energy, Pittsburgh, PA, 2005.

Castle, J. W., “Petrophysics of Medina and Tuscarora Sandstones and Integration with the Tectonic-Stratigraphic Framework, Appalachian Basin, U.S.A,” Invited Speaker for 20th Anniversary Meeting of the Pittsburgh Association of Petroleum Geologists, Pittsburgh, PA, 2004.

Castle, J. W., and Rodgers, J. H., “Renovation of Produced Waters from Underground Natural Gas Storage Facilities: A Feasibility Study Using Hybrid Constructed Wetland Technology,” Gas Storage Technology Consortium, Morgantown, WV, 2004.

Castle, J. W., “Fracture Dissolution of Carbonate Rock: An Innovative Process for Gas Storage,” National Energy Technology Laboratory, Morgantown, WV, 2002.

Castle, J. W., Molz, F. J., and Falta, R. W., “Quantitative Methods for Reservoir Characterization and Improved Recovery: Applications to Heavy Oil,” National Petroleum Technology Office, USDOE, Oil Technology Program Contractor Review Meeting, Denver, CO, 2000.

Castle, J. W., “Siliciclastic Sequence Development in a Paleozoic Foreland (Ramp-Type) Basin: Responses to Tectonic and Eustatic Processes,” Central Savannah River Area Geological Society, Aiken, SC, 1999.

Castle, J. W., “Sequence Stratigraphy of the Lower Silurian Medina Group and Tuscarora Sandstone,” US Department of Energy Petroleum Technology Transfer Council, Pittsburgh, PA, 1998

Castle, J. W., “Clemson University Petrophysics Laboratory: Measurement of Physical Properties that Control Fluid Flow,” Clemson University Fourth Annual Hydrogeology Symposium, 1996.

Castle, J. W., “Application of Subsurface Geologic Investigations to Numerical Simulation of Flow: A Case Study,” Westinghouse Savannah River Company, Savannah River Site, South Carolina, 1996.

Castle, J. W., “Sequence Stratigraphy and Depositional Systems of the Lower Silurian Medina Group, Northern Appalachian Basin,” South Carolina Geological Survey, Columbia, South Carolina, 1995.

Castle, J. W., “Sequence Stratigraphy and Depositional Systems of the Lower Silurian Medina Group, Northern Appalachian Basin,” Pittsburgh Association of Petroleum Geologists, Pittsburgh, Pennsylvania, 1993.

Castle, J. W., “Sequence Stratigraphy and Depositional Systems of the Lower Silurian Medina Group, Northern Appalachian Basin,” Buffalo Association of Professional Geologists, Buffalo, New York, 1992.

Castle, J. W., “Sequence Stratigraphy and Depositional Systems of the Lower Silurian Medina Group, Northern Appalachian Basin,” University of Pittsburgh, Department of Geology, Pittsburgh, Pennsylvania, 1992.

Castle, J. W., “Computer Applications to Formation Evaluation,” Exploration and Production Technical Conference, Cabot Oil & Gas Corporation, Morgantown, West Virginia, 1992.

Castle, J. W., “Applications of Petrographic Analysis,” Exploration and Production Technical Conference, Cabot Oil & Gas Corporation, Morgantown, West Virginia, 1992.

Castle, J. W., “Geological Reasons for the Political and Economic Power of Middle East Oil,” Pittsburgh Geological Society, Pittsburgh, Pennsylvania, 1991.

Castle, J. W., “Sedimentology of the Green River Formation, Utah,” Indiana University of Pennsylvania, Department of Geoscience, Indiana, Pennsylvania, 1991.

Castle, J. W., “Sedimentological Model for Lacustrine Shoreline Deposition, Lower Green River Formation (Eocene), Northeastern Uinta Basin, Utah,” Rocky Mountain Association of Geologists, Denver, Colorado, 1988.

Castle, J. W., “Application of PROGRESS to Development Geology - Studies of Rangely Field,” Production Workstation User's Conference, Chevron Geosciences Company, Houston, Texas, 1988.

Castle, J. W., “Integrated Geological and Engineering Case History for Reservoir Management,” Reservoir Geology Seminar, Chevron Corporation, La Habra, California, 1988.

Castle, J. W., “Safaniya Field-Khafji Reservoir: An Integrated Geological and Engineering Study for Reservoir Simulation,” Stratigraphy Seminar for Engineers, Chevron Corporation, Santa Barbara, California, 1988.

Castle, J. W., “Sedimentation in Eocene Lake Uinta (Lower Green River Formation), Northeastern Uinta Basin, Utah,” American Association of Petroleum Geologists Research Conference on “Lacustrine Exploration: Case Study and Modern Analogs”, Snowbird, Utah, 1988.

Castle, J. W., “Reservoir Management - Formation Evaluation Considerations,” Advanced Formation Evaluation Seminar, Chevron Corporation, Laguna Beach, California, 1986.

Castle, J. W., “Application of Depositional Environment Interpretations to Reservoir Management,” Aramco Technology Conference, Dhahran, Saudi Arabia, 1985.

PATENTS AND INVENTIONS

“Manufactured Caverns in Carbonate Rock”: United States Patent No. US 7,156,579 B2, January 2, 2007, Co-inventors: Castle, J. W., Bruce, D. A., Falta, R. W., and Murdoch, L. C.

"Small Drill-Hole Gas Mini-Permeameter Probe": U.S. Statutory Invention Registration No. US H2052 H, December 3, 2002, Co-inventors: Molz, F. J., Dinwiddie, C. L., Murdoch, L. C., and Castle, J. W.

HONORS AND AWARDS

Certificate of Merit, American Association of Petroleum Geologists, 2010.

Clemson University Board of Trustees Award for Faculty Excellence, 2008.

Clemson University Board of Trustees Award for Faculty Excellence, 2007.

Clemson University Board of Trustees Award for Faculty Excellence, 2005.

Vincent E. Nelson Memorial Best Poster Award presented by American Association of Petroleum Geologists Eastern Section Meeting - "Regional Assessment of Carbonate Formations in the Appalachian Basin Using GIS: Application to Creating Gas Storage Caverns by Dissolution of Carbonate Rock" (co-author), 2005.

Clemson University and Clemson University Research Foundation Certificate of Excellence in Research, 2005.

Clemson University Board of Trustees Award for Faculty Excellence, 2003.

A. I. Levorsen Memorial Best Paper Award presented by American Association of Petroleum Geologists Eastern Section Meeting - "Sequence Stratigraphy and Depositional Systems of the Lower Silurian Medina Group, Northern Appalachian Basin," 1991.

Harold T. Stearns Fellowship Award of the Geological Society of America, 1976.

SPONSORED RESEARCH

"Treatment of Selenium in Energy Process and Produced Waters Using a Pilot-Scale Constructed Wetland Treatment System," Diamond V (2011-), Co-Investigator (with John H. Rodgers, Principal Investigator), $115,237 ($57,618).

"Southeast CO_2 Sequestration Training – Produced Waters," U.S. Department of Energy through subcontract with Southern States Energy Board (2009-), Principal Investigator, $72,000 ($24,480).

"Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water," U.S. Department of Energy (2008-), Principal Investigator, $689,532 ($344,766).

"Pilot Constructed Wetland Treatment System for a Specific Produced Water (Phase II)," Chevron Corporation (2008-2010), Co-Investigator (with John H. Rodgers, Principal Investigator), $49,994 ($24,997).

"Pilot Constructed Wetland Treatment System for Ammonia Removal (Phase I)," Chevron Corporation (2008-2009), Co-Investigator (with John H. Rodgers, Principal Investigator), $49,950 ($24,975).

"Pilot Constructed Wetland Treatment System for a Specific Produced Water (Phase I)," Chevron Corporation (2007-2008), Co-Investigator (with John H. Rodgers, Principal Investigator), $49,978 ($24,989).

"Evaluate Treatment of Boron in Constructed Wetland Treatment Systems (Phase II)," Chevron Corporation (2007-2008), Co-Investigator (with John H. Rodgers, Principal Investigator), $45,527 ($22,763).

"An Innovative System for the Efficient and Effective Treatment of Non-Traditional Waters for Reuse in Thermoelectric Power Generation," U.S. Department of Energy (2005-2008), Co-Investigator (with John H. Rodgers, Principal Investigator), $199,721 ($79,888).

"Demonstration-Scale Constructed Wetland System for Treatment of Produced Waters from Underground Gas Storage," U.S. Department of Energy through the Gas Storage Technology Consortium (2005-2007), Principal Investigator, $134,537 ($67,268).

"Research Grant," ENTRIX, (2005-), Principal Investigator, $4,000 ($4,000).

"Evaluate Treatment of Boron in Constructed Wetland Treatment Systems (Phase I)," Chevron Corporation (2005-2006), Co-Investigator (with John H. Rodgers, Principal Investigator), $15,000 ($6,000).

"Renovation of Produced Waters from Underground Natural Gas Storage Facilities: A Feasibility Study Using Hybrid Constructed Wetland Technology," U.S. Department of Energy through the Gas Storage Technology Consortium (2004-2005), Principal Investigator, $97,468 ($48,734).

"Specifically Designed Constructed Wetlands: A Novel Treatment Approach for Scrubber Wastewater," U.S. Department of Energy (2004-2005), Co-Investigator (with John H. Rodgers, Principal Investigator), $49,982 ($19,993).

"Kestrel Horizons Assistantship in Hydrogeology," Kestrel Horizons, LLC (2003-2004), Principal Investigator, $13,500 ($13,500).

"Fracture Dissolution of Carbonate Rock: An Innovative Process for Gas Storage," U.S. Department of Energy (2002-2006), Principal Investigator, $708,176 ($177,044).

"Geologic Mapping in Anderson South 7.5-Minute Quadrangle, South Carolina," U.S. Department of the Interior/U.S. Geological Survey (2002-2003), Principal Investigator, $11,025 ($11,025).

"Development of Geological Models and Integration with Geophysical Results," U.S. Department of Energy through subcontract with Virginia Tech (2000-2004), Principal Investigator, $158,960 ($158,960).

"Applications of Advanced Geological Modeling to the Environmental Industry"- Amendment and Extension, U.S. Department of Energy through SCUREF (1999-2001), Principal Investigator, $45,727 ($45,727).

"Quantitative Methods for Reservoir Characterization and Improved Recovery: Application to Heavy Oil Sands," U.S. Department of Energy (1998-2002), Principal Investigator, $588,707 ($294,353).

"Geological Mapping of the Tigerville Area, Piedmont of South Carolina," Blue Ridge Water Company (1998-1999), Principal Investigator, $16,550 ($16,550).

"Three-Dimensional Geologic Modeling Feasibility Study, Beaufort County, South Carolina," South Carolina Department of Health and Environmental Control (1998-1999), Principal Investigator, $4,150 ($4,150).

"Minipermeameter Testing of M-Area Cores" funded as a supplement to the existing SCUREF Task Order #236 – "DNAPL Characterization Program: DNAPL Transport Modeling" (R.W. Falta, PI), Westinghouse Savannah River Company through SCUREF (July-September 1998), Investigator, $13,812 ($13,812).

"Applications of Advanced Geological Modeling to the Environmental Industry," U.S. Department of Energy through SCUREF (1997-1999), Principal Investigator, $94,438 ($94,438).

"Multiphase Flow and Saturation Properties of Depositional Facies, Lower Silurian Medina Group," American Chemical Society (1997-2000), Principal Investigator, $25,000 ($25,000).

OTHER SPONSORED ACTIVITY

"ERLE (Energy Related Laboratory Equipment) Grant," U.S. Department of Energy (1999), Principal Investigator, $138,287 ($138,287).

GRADUATE STUDENT ADVISING

Graduated

Michael Pardue, "Treatment of Oilfield Produced Water Using a Pilot-Scale Constructed Wetland Treatment System," (Thesis), May 2012, MS in Hydrogeology

John Kroon, "Biomarkers in the Lower Huron Shale (Upper Devonian) as Indicators of Organic Matter Source, Depositional Environment, and Thermal Maturity," (Thesis), August 2011, MS in Hydrogeology

Brittany Heisler, August 2011, MS in Hydrogeology (non-thesis option)

J. E. Horner, "Evaluation of a Pilot-Scale Constructed Wetland Treatment System for Renovation of a Specific Oilfield Produced Water for Beneficial Use," (Thesis), December 2010, MS in Hydrogeology

Y. Song, "Pilot-Scale Constructed Wetland Treatment System for Ammonia Removal from Oilfield Produced Water," (Thesis), December 2010, MS in Hydrogeology

Michael Bone, December 2009, MS in Hydrogeology (non-thesis option)

M. P. T. Pham, "Water Quality Guidelines and Water Quantity Analysis with Application to Construction of a Pilot-Scale Wetland Treatment System," (Thesis), May 2009, MS in Hydrogeology

L. C. Dorman, "Evaluation of a Pilot-Scale Constructed Wetland Treatment System for Ash Basin Water," (Thesis), May 2008, MS in Hydrogeology

M. M. Iannacone, "Evaluation of Equalization Basins as Initial Treatment for Flue Gas Desulfurization Waters," (Thesis), December 2007, MS in Hydrogeology

L. E. Ober (Kanagy), "Evaluation of a Pilot-Scale Hybrid Constructed Wetland Treatment System for Natural Gas Storage Produced Water," (Thesis), May 2006, MS in Hydrogeology

J. T. Atteberry, "An Assessment of Carbonate Formations in the Appalachian Basin for Gas Storage Using Acid Dissolution," (Thesis), August 2005, MS in Hydrogeology

Y. Yang, "GIS Analysis of Carbonate Formations in Six Northeastern States for a Suitability Assessment of Using a New Technology to Develop Natural Gas Storage" (Thesis), December 2004, MS in Hydrogeology

C. M. Warlick, "Structural Geology and Aquifer Characterization of Glassy Mountain, South Carolina Piedmont" (Thesis), May 2004, MS in Hydrogeology

J. L. Piver, "Integration of Geologic Models and Seismic Data to Characterize Interwell Heterogeneity of the Miocene Temblor Formation, Coalinga, California" (Thesis), May 2004, MS in Hydrogeology

A. Soricelli, "Geologic Controls on Groundwater in the Vicinity of Little Mountain, Anderson South 7.5-Minute Quadrangle, Anderson County, South Carolina" (Thesis), December 2003, MS in Hydrogeology

K. L. Mize, "Development of Three-Dimensional Geological Modeling Methods using Cores and Geophysical Logs, West Coalinga Field, California" (Thesis), December 2002, MS in Hydrogeology

C. L. Current, "Characterization of Geologic Controls on Permeability and their Incorporation into a Three Dimensional Geologic Model of the Temblor formation, Coalinga, California" (Thesis), December 2001, MS in Hydrogeology

C. L. Hann, "Sedimentology and Three-Dimensional Geological Modeling of Vadose Zone Units in the M Area, Savannah River Site, South Carolina" (Thesis), August 2001, MS in Hydrogeology

C. A. Taylor, "Flow Characteristics of Saprolite in the Piedmont" (Thesis), August 2001, MS in Hydrogeology

R. A. Bridges, "Sedimentology and Reservoir Characterization of the Miocene Temblor Formation, Coalinga, California" (Thesis), May 2001, MS in Hydrogeology

R. B. Miller, "Three-Dimensional Stochastic and Deterministic Modeling of Subsurface Properties within a Sequence Stratigraphic Framework for the M Area, Savannah River Site, South Carolina" (Thesis), May 1998, MS in Hydrogeology

Current Graduate Advising

D. Beebe (PhD in Environmental Engineering & Science), "Characterization of Produced Waters and Process-Based Design of a Constructed Wetland Treatment System," August 2013

S. E. Brame (PhD in Environmental Engineering & Science), "Innovative Methods for Design and Evaluation of the Fracture/Dissolution Process of Natural Gas Storage," August 2013

R. Coffey (MS in Hydrogeology), "Design and Performance of a Demonstration Constructed Wetland Treatment System," August 2013

J. Schwindaman (MS in Hydrogeology), "Removal Pathways of Arsenic in a Constructed Wetland Treatment System," August 2013

T. Taylor (MS in Hydrogeology), "Subsurface Lithostratigraphic and Petrophysical Analysis of the Middle Devonian Marcellus Interval at the Mamont Prospect, Westmoreland County, Pennsylvania," August 2013

A. Yonkofski (MS in Hydrogeology) non-thesis option, May 2013

C. J. DeMarco (MS in Hydrogeology) non-thesis option, August 2012

C. Ritter (MS in Hydrogeology), "Biogeochemical Pathways in a Constructed Wetland Treatment System Designed for Removal of Selenium from Energy Produced Water," December 2012

P. Van Heest (MS in Hydrogeology), "Treatment of Selenium in Energy-Derived Waters Using a Pilot-Scale Constructed Wetland Treatment System," August 2012

K. Jurinko (MS in Hydrogeology), "Biogeochemical Processes in a Pilot-Scale Constructed Wetland Treatment System Designed to Remove Metals from Produced Water," August 2012

S. Gould (MS in Hydrogeology) non-thesis option, August 2012

N. Garland (MS in Hydrogeology) non-thesis option, August 2012

TEACHING

Courses Taught

Geol. 100 - Current Topics; Spring 97, Spring 01

Geol. 112 - Earth Resources; Spring 96, Spring 97, Summer 97, Spring 99, Spring 01, Spring 02, Spring 03

Geol. 302, 302L - Structural Geology and Structural Geology Lab; Fall 95, Fall 96, Fall 97, Fall 98, Fall 99, Fall 00, Fall 01, Fall 02, Fall 03, Fall 04, Fall 05, Fall 06, Fall 07, Fall 08, Fall 09, Fall 10, Fall 11

Geol. 314, 314L - Sedimentary Petrology and Sedimentary Petrology Lab; Fall 95, Fall 96, Fall 97, Fall 99, Fall 01, Spring 04, Spring 06

Geol. 401/601, 401L/601L - Applied Geophysics and Applied Geophysics Lab (Team Taught); Spring 99

Geol. 411 - Research Problems; Fall 95, Fall 97, Spring 98, Summer 98, Fall 98, Spring 99, Summer 99, Fall 00, Spring 02, Fall 08, Spring 09

Geol. 411H - Honors Research Problems; Spring 02, Fall 02

Geol. 451 – Selected Topics; Spring 10

Geol. 475/875 - Hydrogeology Field Camp (in part – 2 days); Summer 96, Summer 97, Summer 98

Geol. 651, 651L – Selected Topics and Selected Topics Lab; Spring 11

Geol. 850, 850L – Selected Topics and Selected Topics Lab; Summer 11, Spring 12

Geol. 851 - Geology Seminar; Spring 97, Spring 00, Spring 03, Spring 05

Geol. 876 - Applied Hydrogeology (in part - 3 hours lecture); Fall 96

New Courses Developed and Taught

Geol. 313, 313L - Sedimentology & Stratigraphy and Sedimentology & Stratigraphy Lab; Spring 08, Spring 10, Spring 2012

Geol. 375 - Bahamian Field Studies; Summer 01, Spring 05, Spring 07, Spring 09, Spring 11

Geol. 375H - Bahamian Field Studies (Honors); Spring 07, Spring 09, Spring 11

Geol. 806 - Aquifer Characterization; Spring 96, Spring 98, Spring 00, Fall 02, Fall 04, Fall 06, Fall 08, Fall 10

Geol. 814 - Environmental Sedimentology; Fall 03, Fall 05, Fall 07, Fall 09, Fall 11

UNIVERSITY SERVICE

Committees

Department: Member, Honors and Awards Committee (2012 -)
Member, Vision Committee (2009 - 2010)
Member, Department Chair Search Committee (2007-2008)
Member, Post-Tenure Review Committee (2002 -), Chair (2005)
Member, Curriculum Committee (1995 - 2003), Chair (1995-1998)

College: Member, Dean's Task Force on Characteristics of Next Dean (2004)
Member, Curriculum Committee (1995 - 1998)

University: Graduate Admissions Task Force (2003 -)

Other Service

Department: Graduate Coordinator of Hydrogeology Program (1999 -)
Undergraduate Academic Advisor (1998 -)
Faculty Advisor of the Geology Club (1996 - 1999)
Recording Secretary (1995 - 1996)

Community: Judge, Anderson-Oconee-Pickens Regional Science Fair, sponsored by Clemson University and other organizations (2003, 2006)

Monique Haakensen, PhD, PBiol

CURRENT WORK ADDRESS:
15-410 Downey Road
Saskatoon, Saskatchewan, S7N4N1
Phone: 1-306-978-3111
Cell: 1-306-227-8632
Email: mhaakensen@contangostrategies.com

EDUCATION:

2004 – 2009
Doctor of Philosophy
Focus on applied microbiology, genetics/genomics and bioinformatics
University of Saskatchewan

2006
Certificate in Bioinformatics (Bioinformatics, Genomics, and Proteomics)
Canadian Bioinformatics Workshops

2000 – 2004
Bachelor of Science with Honours
Department of Microbiology and Immunology
University of Saskatchewan

MEMBERSHIPS: Professional Biologist (PBiol), Alberta Society of Professional Biologists (ASPB)

LANGUAGES: Fluent in English and French (written, read, spoken)

PROFESSIONAL WORK EXPERIENCE:

President and Principal Scientist
November 2010 - present
Contango Strategies Limited
Applied and environmental microbiology contract research and development for natural resources and energy sectors.
www.contangostrategies.com

Adjunct Professor
2010 – present
School of Environment and Sustainability, University of Saskatchewan

Academic Lead & Core Course Revision Team
June 2010 – present (part time)
University of the Arctic
Academic Lead of the Circumpolar Studies Core Course 312: Lands and Environments of the Circumpolar North II. And member of Core Course Revision Team.

Research Scientist
Nov 2009 – Nov 2010
Saskatchewan Research Council
Focus on Constructed Wetland Treatment Systems. Bridging between various areas of research such as mining and minerals, oil and gas, geology, water toxicology, and environment through use of industrial, applied, and genomic/bioinformatic microbiology techniques. Working with clients to find applied scientific solutions through research and development. Project management in areas such as bioremediation, bioleaching, biogeochemistry, source control and adaptive management of contaminated waters. Also active in research and development pertaining to fermentation and value-added products within biofuels industries.

Professional research associate
January – November 2009
University of Saskatchewan, Applied Microbiology
Design and optimization of laboratory techniques for microbial bioconversion for scale up to industrial application. Supervision and trouble shooting of graduate and summer student's daily activities. Assembly, analysis, and presentation of data. Writing of grants, proposals, and manuscripts. Coordination of interdisciplinary collaborative efforts. *Topic 1*: Characterization of microbial communities associated with uranium mine tailings at a Northern Saskatchewan uranium tailings management facility. Key Methodologies: Collaborative biogeochemical studies pertaining to reductive dissolution potential of bacteria, bioinformatics, biostatistics, design of group-specific molecular probes, multi-locus sequence analysis, phylogenetics, polyphasic taxonomy, clone libraries, anaerobic cultivation techniques, culture based identification and characterization of bacterial metabolisms with particular attention to iron-, arsenate-, and sulfur-reducing or oxidizing bacteria. *Topic 2*: Microbial production of value added products for biofuels industries. Key Methodologies: Bacterial cultivation, characterization, and identification. Nuclear magnetic resonance techniques. Use of the Canadian Light Source spectromicroscopy beamline.

Research assistant
October 2008 – January 2009 (term)
Vaccine and Infectious Disease Organization

Teaching assistant
2003-2008 Department of Microbiology and Immunology
Multiple teaching assistant positions held, including two introductory microbiology laboratory courses, and correcting assignments for upper year medical virology.

HONORS AND AWARDS:

2012

- Finalist for Saskatoon Awards for Business Excellence (SABEX) New Business Venture Category.

2011

- Named as one of Profit Magazine's Top 20 Future Entrepreneurial Leader's under the age of 30 (Canadian).

2009

- Nominated for award of most distinguished thesis (University of Saskatchewan).

2008

- University of Saskatchewan, Graduate Scholarship (declined due to undertaking of concurrent full-time employment)
- American Society of Brewing Chemists, Miller Brewing Company Graduate Scholarship
- College of Medicine Graduate Travel Scholarship
- Departmental Travel Bursary
- University of Saskatchewan Student Travel Award
- World Brewing Congress Student Scholarship
- First place in the "Microbiology" category at the 15th Annual Life & Health Sciences Research Day at the University of Saskatchewan

2007

- University of Saskatchewan, Graduate Scholarship
- American Society of Brewing Chemists, Cargill Malt Graduate Scholarship
- University Graduate Travel Scholarship
- University of Saskatchewan Student Travel Award
- American Society of Brewing Chemists Foundation, Graduate Student Travel Grant

2006

- University of Saskatchewan, Graduate Scholarship
- CIHR Institute of Genetics, grant for short-term research visits (x2)
- American Society of Brewing Chemists, Coors Brewing Company Graduate Scholarship
- Burroughs Wellcome Fund bursary to attend bioinformatics workshops
- First place in Poster Competition at 13th Annual Life & Health Sciences Research Day at the University of Saskatchewan

2005

- University Scholarship

OTHER
PROFESSIONAL
ACTIVITIES:

Graduate Student Advisory Committee Member

- Amir Muhammadzadeh, M.Sc. candidate Computer Sciences (Bioinformatics Focus), University of Saskatchewan 2011-current.
- Viorica Bondici, M.Sc. candidate Food and Bioproduct Sciences, University of Saskatchewan 2009 – 2011 (transferred to PhD)
- Kornsulee Ratanapariyunach, Ph.D. candidate, Food and Bioproduct Sciences, University of Saskatchewan 2009-current.

***Ad Hoc* Reviewer**

Canadian Journal of Microbiology
PLoS One
Journal of Applied and Environmental Microbiology

University Committee Involvement

- 2007-2008, Member; Endowed Funds Committee for the Department of Pathology and Laboratory Medicine.
- 2007-2008, Member; Steering Committee for the 16th Annual Life and Health Sciences Conference (University of Saskatchewan). Responsibilities included acting as master of ceremonies, media-relations liaison, and coordinating judges and student judging assistants.
- 2007, Chair; 1st Annual Scientific Careers round table discussion series for College of Medicine Graduate Student's Society.
- 2006-2008, Member; working committee for the Academic Health Sciences Building Project.
- 2006-2007, Member; committee for the development of a program for a Master's and Ph.D. in Health Sciences at the University of Saskatchewan.
- 2006-2007, Vice-chair; University of Saskatchewan College of Medicine Graduate Student's Society.
- 2006, Member; Review Committee for the position of Associate Dean of Research and Graduate Studies, College of Medicine.
- 2005-2008, Representative for the Department of Pathology and Laboratory Medicine; University of Saskatchewan College of Medicine Graduate Student's Society.
- 2003-2004, Co-President; Microbiology and Immunology Undergraduate Student's Association.

Project History

Scientific lead on projects for industry and government funded research in the areas of industrial and environmental microbiology, genomics, genetics, and applied bioinformatics. These projects involve coordination and integration of industry, academic, international, and government partners, multi-year phasing, and integration of data from these various partners. These projects are summarized as:

Scientific Lead and Project Manager (2010-present)

- Microbial assessment for value-added environment and natural resources (MAVEN) Uranium Milling Pilot Project
- Microbial genome sequencing and assembly
- Microbial influences on selenium cycling
- Microbial conversion of biodiesel and bioethanol wastes to platform chemicals
- Numerous small feasibility studies and technical development R&D projects

Project manager and scientific lead (2009-2010)

- Microbially enhanced hydrocarbon recovery and biomining of oilshales
- Evaluation of carbon-based microbial carriers for remediation applications
- Use of microalgae for selenium remediation in extreme environments
- Enhanced flocculation of potash fine tailings

Team member or consultant (2009-present)

- Feasibility study for use of constructed wetland treatment systems for remediation of effluents at northern mine sites
- Development of enhanced potash processing methods
- Development of strategic program for mineral processing and metallurgical testing facilities

SCHOLARLY ACTIVITY

PATENTS GRANTED
OR PENDING
Reaney, M., Haakensen, M., Ratanapariyanuch, K., Korber, D.R., and Tanaka, T. Proprietary processes and organisms for conversion of glycerol to 1,3-propanediol. Submitted. December 3, 2009.

BOOKS, BOOK
CHAPTERS, AND
MONOGRAPHS
Swanston, T. Haakensen, M., Walker, E., and Deneer, H. Microbial DNA Analysis of Kwäday Dän Ts'ìnchí tissues. *In* Kwäday Dän Ts'ìnchí – Long Ago Person Found. Royal BC Museum Press. Victoria Canada. (In Press)

PAPERS AND
PUBLICATIONS:

Articles published in peer-reviewed refereed journals

Pittet, V., Abejunde, T., Marfleet, T., Haakensen, M., Morrow, K., Jayaprakash, T., Schroeder, K., Trost, B., Byrns, S., Bersveinson, J., Kusalik, A., and Ziola, B. 2012 Genome and plasmid sequences

for the beer-spoilage organism *Pediococcus claussenii* ATCC BAA-344^{T}. Journal of Bacteriology 194(5):1271-1272.

Haakensen, M., Pittet, V., and Ziola, B. Reclassification of *Paralactobacillus selangorensis* (Leisner *et al.*, 2000) as *Lactobacillus selangorensis* comb. nov. 2011 International Journal of Systematic and Evolutionary Microbiology. 61:2979-2983.

Swanston, T., Haakensen, M., Deneer, H., and Walker, E. 2010 The characterization of *Helicobacter pylori* DNA associated with ancient human remains recovered from a Canadian glacier. PLoS One, published 16 Feb 2011 10.1371/journal.pone.0016864

Trost, B.*, Haakensen, M.*, Pittet, V., Dobson, C.M., Kusalik, A., and Ziola, B. 2010 Analysis and comparison of the pangenomic properties of sixteen well-characterized bacterial genera. *Both authors contributed equally. BMC Microbiology, 10:258. Highly Accessed

Pittet, V., Haakensen, M., and Ziola, B. 2010. Rapid screening for gram-negative and gram-positive beer-spoilage *Firmicutes* using real-time multiplex PCR. Journal of the American Society of Brewing Chemists, 68(2):89-95. *selected as the “JASBC Editor’s Pick” in the June 2010 edition of the American Society of Brewing Chemists News Capsule.

Haakensen, M., Vickers, D.M., and Ziola, B. 2009. Susceptibility of *Pediococcus* isolates to antimicrobial compounds in relation to hop-resistance and beer-spoilage. BMC Microbiology. 9:190.

Haakensen, M., Pittet, V., Morrow, K., Schubert, A., Ferguson, J., and Ziola, B. 2009. Ability of novel ATP-binding cassette multidrug resistance genes to predict growth of *Pediococcus* isolates in beer. Journal of the American Society of Brewing Chemists. 67(3):170-176. *selected as the “JASBC Editor’s Pick” in the September 2009 edition of the American Society of Brewing Chemists News Capsule.

Haakensen, M., Schubert, A., and Ziola, B. 2009. Broth and hop-gradient plates used to evaluate the beer-spoilage potential of *Lactobacillus* and *Pediococcus* isolates. International Journal of Food Microbiology. 130: 56-60.

Haakensen, M., Dobson, C.M., Hill, J.E., and Ziola, B. 2009. Reclassification of *Pediococcus dextrinicus* (Coster and White 1964) Back 1978 (Approved Lists 1980) as *Lactobacillus dextrinicus* comb. nov., and emended description of the genus *Lactobacillus*. International Journal of Systematic and Evolutionary Microbiology. 59:615-621.

Haakensen, M., Dobson, C.M., Deneer, H., and Ziola, B. 2008. Real-time PCR detection of bacteria belonging to the *Firmicutes* phylum. International Journal of Food Microbiology. 125(3): 236-241.

Haakensen, M., Schubert, A., and Ziola, B. 2008. Multiplex PCR for putative *Lactobacillus* and *Pediococcus* beer-spoilage genes and ability of gene presence to predict growth in beer. Journal of the American Society of Brewing Chemists. 66(2): 63-70. *selected as the “JASBC Editor’s Pick” in the May 2008 edition of the American Society of Brewing Chemists News Capsule.

Haakensen, M., and Ziola, B. 2008. Identification of novel *horA*-harbouring bacteria capable of spoiling beer. Canadian Journal of Microbiology. 54(4): 321-325.

Haakensen, M. C., Butt, L., Chaban, B., Deneer, H., Ziola, B., and Dowgiert, T. 2007. A *horA*-specific real-time PCR for detection of beer-spoilage lactic acid bacteria. Journal of the American Society of Brewing Chemists. 65(3):157-165. *selected as the “JASBC Editor’s Pick” in the October 2007 edition of the American Society of Brewing Chemists News Capsule.

PUBLISHED
ABSTRACTS AND
PRESENTATIONS:

Invited presentations

Haakensen, M. (September 13, 2012) Small Things Doing the Heavy Lifting. TEDxWinnipeg. Winnipeg, MB.

Haakensen, M. (March 7 & 8, 2012) Facilitating Remediation Efforts Through Applied Microbiology. SEIMA (Saskatchewan Environmental Industry and Managers Assocation). Regina & Saskatoon SK.

Haakensen, M. (September 24, 2009) Title: Beer, Bacteria, and Bioinformatics: exploring interconnections of science. Event: National Biotechnology Week Event, “Biotech and Beer at Boffins” hosted by Ag-West Bio Inc. Saskatoon, SK.

Haakensen, M. (April 27, 2007) Title: Beer, Bacteria, and Bioinformatics: Discussing the increasing importance of interdisciplinary scientific research. Event: Holy Cross High School Science Festival. Saskatoon, SK.

Haakensen, M.C. and Ziola, B. (April 19-22, 2007) Title: The *horA* brewing-industry related multi-drug resistance gene is found in bacteria relevant to human health. Event: Canadian Genetic Diseases Network 17th Annual Scientific Meeting. St. Sauveur, QC.

Scientific Posters and Presentations

Guran, V., Bondici, V.F., Lin, B., Haakensen, M., Wolfaardt, G.M., Korber, D.R., Kotzer, T., and Lawrence, J.R. (Aug 15-18, 2010). Microbial aggregate formation and activity in the Deilmann tailings management facility at Key Lake, Saskatchewan. Uranium 2010. Saskatoon, SK. (Presented by V.F. Bondici)

Bondici, V., Haakensen, M., Shaw, S., Hendry, J., Kotzer, T.G., Lawrence, J.R., Korber, D.R. (Aug 15-18, 2010) Biogeochemical potential of bacteria isolated from the Deilmann Tailings Management Facility. Uranium 2010. Saskatoon, SK. (Presented by V. Bondici)

Bondici, V., Haakensen, M., Lawrence, J.R., Korber, D.R. (Aug 15-18, 2010) Characterization of bacterial diversity in the Deilmann Tailings Management Facility. Uranium 2010. Saskatoon, SK. (Presented by V. Bondici)

Bondici, V.F., Haakensen, M., Wolfaardt, G.M., Guran, V., Kotzer, T., Lawrence, J.L., Korber, D.R. (June 14-17, 2010) Characterization of microbial diversity in uranium tailings at Key Lake, Saskatchewan. 60th Annual Conference of the Canadian Society of Microbiologists, Hamilton, ON. (Presented by V. Bondici)

Guran, V., Bondici, V.F., Lin, B., Haakensen, M., Wolfaardt, G.M., Korber, D.R., Kotzer, T., and Lawrence, J.R. (June 14-17, 2010). Microbial aggregate formation and activity in the Deilmann tailings management facility at Key Lake, Saskatchewan. 60th Annual Conference of the Canadian Society of Microbiologists, Hamilton, ON. (Presented by V. Guran)

Pittet, V., Haakensen, M., Chaban, B., and Ziola, B. (June 15-18, 2009) Save the Beer! Rapid detection and identification of beer-spoilage *Pectinatus* organisms. 59th Annual Conference of the Canadian Society of Microbiologists. Montreal, QC. (Presented by V. Pittet)

Haakensen, M., Bondici, V., Dumitrache, R., Lawrence, J.R., Wolfaardt, G.M., and Korber, D.R. (June 15-18, 2009) Survey of unique high pH, low temperature environment yields an abundance of new extremophilic species. 59th Annual Conference of the Canadian Society of Microbiologists. Montreal, QC. (Presented by D.R. Korber)

Pittet, V., Haakensen, M., and Ziola, B. (June 6-10, 2009) Detection of beer-spoiling gram-negative *Firmicutes* using real-time PCR. 73rd Annual Meeting of the American Society of Brewing Chemists. Tucson, AZ, USA. *accepted as oral presentation (Presented by B. Ziola)

Pittet, V., Haakensen, M., Chaban, B., and Ziola, B. (March 13, 2009) Differentiation between gram-negative beer-spoilers *Pectinatus* and *Selenomonas* based on a surface accessible major outer membrane protein gene. University of Saskatchewan 16th Annual Life & Health Sciences Research Conference. Saskatoon, SK. (Presented by V. Pittet)

Marfleet, T.W., Pittet, V., Paramel, T., Abegunde, T., Haakensen, M., Kusalik, T., and Ziola, B. (March 13, 2009) Plasmids of the beer-spoilage bacterium *Pediococcus claussenii*. University of Saskatchewan 16th Annual Life & Health Sciences Research Conference. Saskatoon, SK. (Presented by T.W. Marfleet)

Swanston, T., Haakensen, M., Deneer, H., and Walker, E. (October 19-22, 2008) The analysis of *Helicobacter pylori* DNA associated with frozen human remains recovered from a glacier in northern Canada. AncientDNA9: The 9th International Conference on Ancient DNA and Associated Biomolecules. Pompeii, Italy. (Presented by T. Swanston)

Pittet, V., Haakensen, M., Chaban, B., and Ziola, B. (August 18, 2008) Surface accessible major outer membrane protein sequences from beer-spoiling *Pectinatus* isolates. Natural Sciences and Engineering Research Council Undergraduate Student Research Awards 2008 Poster Event. Saskatoon, SK. (Presented by V. Pittet)

Morrow, K., Haakensen, M., Pittet, V., Schubert, A., Ferguson, J., and Ziola, B. (August 18, 2008) Presence of ATP-binding cassette multi-drug resistance gene *bsrB* increases the probability of beer-spoilage by *Pediococcus* isolates. Natural Sciences and Engineering Research Council Undergraduate Student Research Awards 2008 Poster Event. Saskatoon, SK. (Presented by K. Morrow)

Haakensen, M., and Ziola, B. (August 2-6, 2008) *bsrA*, a genetic marker for beer spoilage ability of *Pediococcus* isolates. 2008 World Brewing Congress. Honolulu, HI, USA.

Haakensen, M., Schubert, A., and Ziola, B. (August 2-6, 2008) Agar gradient-plate technique for determining beer-spoilage ability of *Lactobacillus* and *Pediococcus* isolates. 2008 World Brewing Congress. Honolulu, HI, USA. *accepted as an oral presentation, awarded Graduate Student Travel Grant for submission of abstract.

Haakensen, M., Dobson, C.M., Hill, J.E., and Ziola, B. (June 1-5, 2008) Proposed subdivision of the genus *Lactobacillus* based upon a multilocus sequence analysis. 108th General Meeting of the American Society of Microbiologists. Boston, MA, USA.

Swanston, T., Haakensen, M., Deneer, H., and Walker, E. (April 25-26, 2008) *Helicobacter pylori* DNA amplified from the stomach tissue of Kwäday Dän Ts'ìnchí. 61st Annual Northwest Anthropological Conference. Victoria, BC. (Presented by T. Swanston)

Pittet, V., Haakensen, M., and Ziola, B. (March 14, 2008) Gene sequences for the surface-accessible major outer membrane proteins from *Pectinatus cerevisiiphilus* and *Pectinatus frisingensis*. University of Saskatchewan 15th Annual Life & Health Sciences Research Conference. Saskatoon, SK. (Presented by V.Pittet)

Haakensen, M. and Ziola, B. (March 14, 2008) Susceptibility of *Pediococcus* isolates to antimicrobial agents using lactic acid bacteria susceptibility test medium. University of Saskatchewan 15th Annual Life & Health Sciences Research Conference. Saskatoon, SK. *Awarded first place in the Microbiology category.

Pittet, V., Haakensen, M., and Ziola, B. (August 16, 2007) Novel ATP-binding cassette multi-drug resistance gene found in an isolate of *Pediococcus claussenii*. Natural Sciences and Engineering Research Council Undergraduate Student Research Awards 2007 Poster Event. Saskatoon, SK. (Presented by V. Pittet)

Haakensen, M., Schubert, A., and Ziola, B. (June 16-20, 2007) Multiplex PCR for putative Lactobacillus and Pediococcus beer-spoilage genes and ability of gene presence to predict spoilage. 71st Annual Meeting of the American Society of Brewing Chemists. Victoria, BC.

Haakensen, M. and Ziola, B. (June 4-6, 2007) The multi-drug resistance gene *horA* is found in fuel ethanol *Lactobacillus* contaminants. Food and Fuel: The Implications for Agricultural Research Policy. Saskatoon, SK.

Haakensen, M.C. and Ziola, B. (March 16, 2007) Presence of the multi-drug resistance gene horA in three novel bacterial genera. University of Saskatchewan 14th Annual Life & Health Sciences Research Conference. Saskatoon, SK.

(The following posters were presented under my maiden name of Simair)

Simair, M., Dobson, M., Deneer, H., and Ziola, B. (June 18-21, 2006) A sensitive and specific real-time PCR system for detecting beer-spoilage *Firmicutes*. 56th Annual General Meeting of the Canadian Society of Microbiologists. London, ON. (Presented by B. Ziola)

Simair, M.C., Dobson, C.M., Deneer, H., and Ziola, B. (March 17, 2006) *Firmicutes*-specific detection system to aid in saving the world's beer (from contaminating microbes). University of Saskatchewan 13th Annual Life & Health Sciences Student Research Conference. Saskatoon, SK. *Awarded first place in the Food Sciences & Nutrition Poster Category.

Simair, M., Wright, L., Chaban, B., Dowgiert, D., Deneer, H., and Ziola, B. (June 13-15, 2005) Rapid detection of the *horA* hop-resistance gene in beer-spoilage bacteria. 55th Annual General Meeting of the Canadian Society of Microbiologists. Halifax, NS. (Presented by H. Deneer)

Simair, M., Wright, L., Chaban, B., Dowgiert, T., and Ziola, B. (June 21-23, 2004) The horA hop-resistance gene is found in Pediococcus brewing spoilage bacteria. 54th Annual General Meeting of the Canadian Society of Microbiologists. Edmonton, AB.

Simair, M., Wright, L., Chaban, B., Dowgiert, T., and Ziola, B. (May, 2004) Presence of the hop-resistance gene *horA* in brewing spoilage pediococci. University of Saskatchewan 11th Annual Life & Health Sciences Student Research Conference. Saskatoon, SK.

LISETTE C.M. ROSS

7.1. I. PERSONAL INFORMATION

Work Address: Native Plants Solutions – Ducks Unlimited Canada
Unit A-1238 Chevrier Blvd
Winnipeg, Manitoba R3T 1Y3

Phone: 204-953-8205
E-MAIL: l_ross@ducks.ca

7.2. II. EDUCATION

M.Sc. – 2009, Department of Agriculture – Soil Science, University of Manitoba, Winnipeg
Thesis Title: Vegetation and soil properties as indicators of the hydrology and ecological health of northern prairie wetlands in native and agricultural landscapes.
B.Sc. - 1985, Department of Zoology, University of Manitoba, Winnipeg
Concentration: Zoology/Microbiology
Diploma in Non-Profit Management – 1994, University of Manitoba, Winnipeg
Human Resource Management Certificate – 1989, University of Winnipeg, Winnipeg

III. EMPLOYMENT HISTORY

7.3. Senior Wetland/Upland Specialist - Winnipeg

7.4. Native Plant Solutions

July 2010 to Present

- Responsible for leading a multi-disciplinary team of national wetland and upland restoration and research projects using the best available science on wetland and surrounding upland ecology.
- Responsible for a wide range of multitasked duties related to NPS industry, extension, public, and private initiatives, including the coordination of wetland and upland projects and support in the delivery of all wetland and upland programs within NPS.
- Accountable for maintaining expertise related to wetland and upland ecology, as well as keeping current on government (Federal, Provincial, Municipal) regulations and policies regarding wetland and upland enhancement or restoration activities.
- Develop, encourage, and support industry adoption for best management and research practices that utilize native plant systems.

Research Biologist - Wetland Hydrology/Ecology and Wetland Soils
Institute for Wetland and Waterfowl Research - Ducks Unlimited Canada
July 1990 to June 2010

- *Expertise:* Wetland ecology and hydrology, soils, upland and wetland plant ecology, invertebrates, invasive species, hydrological modelling, wetland delineation and classification, and impacts of surrounding land management.
- *Responsibilities included:* identifying Ducks Unlimited Canada's (DUC) wetland information needs (both conservation and research); developing, designing and managing wetland/upland research programs across Canada in an applied approach; serving as external reviewer for scientific journals, graduate student proposals, and government documents; serving as liaison between DUC's scientific and non-scientific audiences; publishing and presenting information on wetland ecology in various formats to internal and external audiences.

7.5.

7.6. **Research Portfolio as Principal Investigator**

- The vegetation of prairie wetlands in native and agricultural landscapes (2006-2010): Implications for wetland health and restoration: a study on the vegetative communities in wetlands and the role that anthropogenic practices have on community change and the spread of invasive species resulting from changes in soil properties, soil hydrology and plant competition.
- Modeling of spring hydrology dynamics in northern wetlands in relation to vegetation, soil properties and land-use (2006-2009): this study explored the spatial relationships that exist between wetland hydrology, wetland vegetation and soil formation and soil/water movement with implications for the impacts of policy and climate change.
- Restoration of a mined peat lands in northern New Brunswick (2002-2008): a cooperative project with the University of Laval studying and planning the restoration of coastal peat mining sites affected by salt water intrusion.
- Lesser Scaup / White-winged Scoter Initiative (2001-2004): Research on Western arctic wetlands in the North West Territories studying continental population declines in relation to wetland characteristics and food availability.
- Boreal Forest Initiative (2000-2003): a cooperative project with the University of Alberta investigating the hydrology, water quality, water bird use, vegetation dynamics and insect populations of boreal wetlands in Northern Alberta.
- Prairie Canada Invertebrate Study (1996-1999): research on the relationship between wetland vegetation characteristics, water quality, hydrology and surrounding land-use on mallard brood movements and survival.
- Sheet water wetlands (1996): a look at the effects of hydrology and surrounding land use on invertebrate populations in spring sheet water ponds in the Prairie region.
- Marsh Ecology Research Program (1985-1998): a 10-year research project studying the wet/dry cycle in prairie wetlands and its effect on invertebrate communities, vegetative change, soil dynamics, water bird use, algal populations, hydrology, water chemistry and muskrat populations.

7.7. Wetland Biologist - Delta Waterfowl and Wetlands Research Station
Portage La Prairie, Manitoba

1985 to 1990

- Coordinated and managed 30 to 40 staff in all aspects of the largest prairie wetland research program conducted in North America.
- This included familiarizing and training staff on invertebrate, marsh and waterfowl ecology, training technicians on sampling and identification techniques, developing and refining field and laboratory techniques and supervising all aspects of data compilation, data analysis and publications.

Research Assistant - Canada Biting Fly Centre
University of Manitoba, Winnipeg, Manitoba

Summer 1985

- Determined the survival of *Bacillus thuringiensis* in two Saskatchewan rivers as part of a study looking at blackfly control for Canada's National Department of Defence.

Research Assistant
Department of Fisheries and Oceans, Freshwater Institute
Winnipeg, Manitoba

Summers 1981 to 1984

- Studied the effects of herbicides on insects and stream fish in Ducks Mountain Provincial Park and assessed the success of a re-introduction program of Walleye (*Stizostedion vitreum*) to Dauphin Lake. Responsibilities included insect collection and identification, sampling coordination, hydrological measurements and chemistries.

7.7.1. IV. PEER REVIEWED PUBLICATIONS

Ross, L.C.M., Pennock, D.J., Lobb, D.A., Goldsborough, L.G., and Armstrong, L.M. Submitted to *Wetlands*. The vegetation of prairie wetlands in native and agricultural landscapes: implications for wetland health and restoration.

Ross, L.C.M. and Wrubleski, D.A. 2011. Aquatic Invertebrates of prairie wetlands: community composition, ecological roles and impacts of agriculture. Pages 91-116 *in* K. Floate (editor). Arthropods of Canadian Grasslands (Volume 2): Inhabitants of a Changing Landscape. Biological Survey of Canada.

Ross, L.C.M. 2009. Vegetation and soil properties as indicators of the hydrology and ecological health of northern prairie wetlands in native and agricultural landscapes. Thesis, University of Manitoba. 141 pp.

Hanson, A., Swanson, L., Ewing, D., Graba, G., Meyer, S., Ross, L., Watmough M., and Kirby, J. 2009. Wetland ecological functions assessment: an overview of approaches. Environment Canada Report Series 497. 64 pp.

Ross, L.C.M. and Murkin, H.R. 2009. Wetland conditions and requirements for maintaining economically valuable species: waterfowl, furbearers, fish and plants. Pages 802-820 *in* E.D. Maltby and T. Barker (editors). The Wetlands Handbook. Wiley-Blackwell Publications, London, UK. 800 pp.

Ross, L.C.M., Lobb, D.A., Pennock, D.J., Goldsborough, L.G., and Armstrong, L.M. 2009. Vegetation and soil properties as indicators of the hydrology of prairie wetlands in native and agricultural landscapes. Proceedings of the 52nd Conference of the Manitoba Society of Soil Scientists.

Norlin, J.I., Bayley, S. and Ross, L.C.M. 2006. Zooplankton composition and ecology in western boreal shallow-water wetlands. Hydrobiologia 560: 197-215.

Norlin, J.I., Bayley, S. and Ross, L.C.M. 2005. Submerged macrophytes, zooplankton and the predominance of low- over high-chlorophyll states in western boreal, shallow-water wetlands. Freshwater Biology 50: 868–881.

Gabor, T.S, Kiers North, A., Ross, L.C.M., Murkin, H.R., Anderson, J.S., Turner, M.A. and Raven, M. 2004. Natural Values: The importance of wetlands & upland conservation practices in watershed management – function and values for water quality and quantity. 54 pp. [Online available: http://www.ducks.ca/conserve/wetland_values/pdf/nvalue.pdf].

Gabor, T.S, Kiers North, A., Ross, L.C.M., Murkin, H.R., Anderson, J.S., and Turner, M.A. 2001. Beyond the pipe - the importance of wetlands and upland conservation practices in watershed management: functions and values for water quality and quantity. Report to the Ontario Walkerton Inquiry Commission, Ottawa, ON. 52pp. [Online available: http://www.ducks.ca/aboutduc/news/archives/pdf/pipefull.pdf].

Murkin, H.R. and Ross, L.C.M. 2000. Invertebrates in Prairie Wetlands. 2000. Pages 201-248 *in* Prairie Wetland Ecology, H.R. Murkin et al. (editors). Iowa State University Press, Ames, IA.

Murkin, H.R and Ross, L.C.M. 1999. Northern Prairie Marshes: Macro-invertebrate responses to a simulated wet/dry cycle. Pages 121-136 *in* Invertebrates in Freshwater Wetlands in North America, D. Batzer et al. (editors). John Wiley and Sons, Inc. New York, NY.

Murphy, T.P., Lawson, A., Nalewajko, C., Murkin, H., Ross, L., Oguma, K. and McIntyre, T. 2000. Algal toxins - initiators of avian botulism. Environmental Toxicology 15:558-567.

Ross, L.C.M. and Murkin, H.R. 1993. The effect of above-normal flooding of a northern prairie marsh on *Agraylea multipunctata* Curtis (Trichoptera: Hydroptilidae). Journal Freshwater Ecology 8: 27-35.

Wrubleski, D.A. and Ross, L.C.M. 1989. Diel periodicities of adult emergence of Chironomidae and Trichoptera from the Delta Marsh, Manitoba, Canada. Journal of Freshwater Ecology 5:163-169

Ross, L.C.M and Murkin, H.R. 1989. Invertebrates. Marsh Ecology Research Program: long-term monitoring procedures manual. Pages 35-38 *in* Delta Waterfowl and Wetlands Research Station, Technical Bulletin 2, Portage la Prairie, MB.

7.7.2. *V. NON-PEER REVIEWED PUBLICATIONS (selected)*

External Reports - Ducks Unlimited Canada

Ross, L.C.M., Grieef, P., and Kading, M. 2010. Oak Hammock Marsh Leased Lands Long-term Management Plan. Ducks Unlimited Canada Internal Report. 60 pp.

Ross, L.C.M. 2009. Review of Canard River Environmental Assessment, Ontario: Implications for Ducks Unlimited Canada's Involvement in Wetland Restoration and Creation. 34 pp.

Ross, L.C.M. 2009. Data Archiving Protocols for Ducks Unlimited Canada. 12 pp.

External Reports – Native Plant Solutions

Ross, L.C.M. and Rose, P.K. 2012. A survey of avian and vegetation communities in the littoral and riparian zones of the south basin of Lake Winnipeg, Manitoba. *Prepared for* the Lake Winnipeg Foundation.

Bloom, P. and Ross, L.C.M. 2011. Waterfowl of the Western Canadian Arctic: A report on the status, trends and threats to arctic waterfowl. *Prepared for* Ocean's North Canada.

Ross, L.C.M. 2011. Minimal ecological management of constructed wetland systems in the Oil Sands Region. *Prepared for* CEMA – Aquatics Subgroup of the Reclamation Working Group, Fort McMurray, Alberta. 89 pp.

Ross, L.C.M. 2011. Shoreline vegetation and re-vegetation strategy for Wuskwatim Generating Station. *Prepared for* Manitoba Hydro, Winnipeg, Manitoba. 37 pp.

Ross, L.C.M. 2009. A Review of the "Alberta Wetland Classification System. *Prepared for* Alberta Environment, Edmonton, Alberta.

Popular Articles

Wetlands as Treatment Technology. 2008. Wetland Proceedings, Port Said, Egypt. 21 pp.

Water and Health: Canada's Liquid Assets. March 2004. The Conservator, pages 16-21. [Online available at: http://www.ducks.ca/aboutduc/news/conservator/264/h20.pdf].

Small Wonders. March 2004. The Conservator, pages 14-20. [Online available at: http://www.ducks.ca/aboutduc/news/conservator/251/251bug.pdf].

West Nile Virus in North America: Information and recommendations for Ducks Unlimited Canada staff. April 2004. 27 pages.

Putting a Price Tag on Canada's Good Fortune. Spring 2003. The Conservator, pages 34-37. [Online available at: http://www.ducks.ca/aboutduc/news/conservator/241/241.pdf].

Glen Koblun

I. PERSONAL INFORMATION

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II. EDUCATION

CPESC – 2007, Certified Professional in Erosion and Sediment Control (in Training)
CCA – 2001, Certified Crop Advisor Program
Dip. Ag – 1990, Department of Agriculture, University of Manitoba

III. EMPLOYMENT HISTORY

Manager: Native Plant Solutions / Ducks Unlimited Canada, Winnipeg, MB

January 2009 to Present

- Responsible for developing technologies, project tracking and management systems, concept development, site assessment, pre-plant land preparation requirements, design site appropriate native seed mixtures, design of habitat management projects.

Installation Supervisor: Plant Materials Agronomist - Native Plant Solutions / Ducks Unlimited Canada, Winnipeg, MB

September 2002 to January 2009

- Responsible for turnkey native plant establishment through site design and sound agronomic and plant practices. Development of project schedules, timelines, action plans, and budgets related to native plant establishment. Providing agronomics for soil fertility, soil amendment, integrated pest management, establishment and maintenance. Sourcing seed, supplies, and contractors and providing all on site direction throughout site preparation, establishment, and maintenance.

Senior Agrologist: Agricore United – Souris, MB

December 1998 – September 2002

- Extension programming and delivery working directly with producers in the field, providing agronomic recommendations, and ensuring that producers are aware of the proper agronomic technologies.

Agrologist: Twin Lakes Soil Conservation, Killarney, MB

March 1990 – December 1998

- Responsible for managing a research and extension project aimed at promoting soil conservation; water quality research and enhancement; reduction in agricultural pollution and waste; integrating agriculture and wildlife through development of compatible agricultural practices; preservation and enhancement of natural resources, through joint action programming.

7.7.3.

7.7.4. *IV. RELATED EXPERIENCE*

- Successful installation of native grass mixes throughout all soil zones of the western Canada
- Successful team installations of wetland and upland native vegetation on several urban disturbed construction sites
- Knowledge and experience with agricultural production in all soil zones and eco-regions of the Prairies
- Results orientated in project implementation and delivering conservation programs
- Highly experienced with contractor/client relations and negotiations

- Experienced in the commercialization/development/agronomics of native grass seed and plant production
- Expertise in native plant and weed identification
- Expertise in the design of weed control strategies for disturbed sites
- Experienced in the development and installation of erosion and sediment control plans

7.7.5. *V. PEER REVIEWED PUBLICATIONS*

Wark. D.B., Gabruch, L.K., Penner, C., Hamilton, R.J., and Koblun, T.G. 2007. Revegetating with Native Grasses in the Northern Great Plains.

Attachment B

Summary of Baseline and Post-closure Receiving Water Quality Modelling Predictions

Attachment B: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions

		CCME Fresh Water Aquatic Life	Site Specific Water Quality Objectives	Nico Lake			Peanut Lake					Burke Lake					Marian River				
				Measured Baseline	Post-Closure		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
				(as presented in DAR)	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Parameter	**Units**	**Guidelines**	**(June 2012)**	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
Major Ions and TDS																					
Calcium	mg/L	-	-	9.6405	10.2	10.2	8.3847	9.4	9.4	8.3	8.3	8.9430	9.3	9.3	8.9	8.9	22.9460	22.7	22.7	22.7	22.7
Chloride	mg/L	120	353	1.2206	7.67	7.67	1.5273	2.93	2.93	2.97	2.97	1.9339	2.14	2.14	2.15	2.15	2.7161	2.56	2.56	2.56	2.56
Magnesium	mg/L	-	-	4.1793	4.96	4.96	3.8720	4.24	4.24	3.74	3.74	3.8383	3.82	3.82	3.62	3.62	10.0197	9.8	9.8	9.8	9.8
Potassium	mg/L	-	-	1.1945	22.16	22.16	1.3750	6.24	6.24	6.99	6.99	1.3255	3.82	3.82	4.12	4.12	1.7499	1.83	1.83	1.84	1.84
Sodium	mg/L	-	-	2.6586	4.50	4.50	2.9924	3.28	3.28	3.59	3.59	2.9143	3.07	3.07	3.19	3.19	3.5794	3.41	3.41	3.42	3.42
Sulphate	mg/L	-	500	4.4892	21.4	21.4	1.5541	7.6	7.6	9.6	9.6	2.1905	4.7	4.7	5.5	5.5	18.3700	18.2	18.2	18.3	18.3
Total Dissolved Solids	mg/L	-	-	73.9357	95.2	95.2	67.3750	58.5	58.5	56.7	56.7	72.3412	49.0	49.0	48.3	48.3	132.2000	111	111	111	111
Nutrients																					
Nitrate	mg N/L	2.93	6.09	0.1008	0.14	0.14	0.0889	0.08	0.08	0.08	0.08	0.0729	0.06	0.06	0.06	0.06	0.0547	0.06	0.06	0.06	0.06
Ammonia	mg N/L	1.1	-	0.0595	0.115	0.115	0.0314	0.043	0.043	0.043	0.043	0.0398	0.032	0.032	0.032	0.032	0.0276	0.027	0.027	0.027	0.027
Total Kjeldahl Nitrogen	mg N/L	-	-	0.8887	0.62	0.62	0.6897	0.59	0.59	0.59	0.59	0.7704	0.59	0.59	0.59	0.59	0.7348	0.72	0.72	0.72	0.72
Total Phosphorus	mg P/L	-	-	0.0248	0.020	0.020	0.0171	0.021	0.021	0.015	0.015	0.0201	0.017	0.017	0.015	0.015	0.0137	0.010	0.010	0.010	0.010
Total Metals																					
Aluminum	mg/L	0.005-0.1	-	0.0473	0.743	0.140	0.1125	0.256	0.110	0.246	0.105	0.0786	0.172	0.099	0.168	0.097	0.0801	0.055	0.052	0.054	0.052
Antimony	mg/L	0.006	0.03	0.0002	0.00294	0.00157	0.0002	0.00103	0.00061	0.00150	0.00085	0.0003	0.00062	0.00042	0.00081	0.00052	0.0002	0.000041	0.000034	0.000049	0.000038
Arsenic	mg/L	0.005	0.05	0.0230	0.044	0.013	0.0044	0.0137	0.0050	0.0226	0.0085	0.0038	0.0072	0.0030	0.011	0.0044	0.0007	0.00061	0.00046	0.00075	0.00051
Barium	mg/L	-	1	0.0091	0.019	0.012	0.0112	0.013	0.010	0.017	0.013	0.0100	0.011	0.0097	0.013	0.011	0.0157	0.014	0.014	0.014	0.014
Beryllium	mg/L	-	-	0.0006	0.000115	0.000061	0.0006	0.000113	0.000061	0.000034	0.000022	0.0006	0.000054	0.000032	0.000023	0.000016	0.0006	0.000012	0.000011	0.000011	0.000011
Boron	mg/L	1.5	-	0.0204	0.021	0.013	0.0215	0.014	0.0100	0.021	0.014	0.0208	0.0091	0.0074	0.012	0.0089	0.0257	0.016	0.016	0.016	0.016
Cadmium	mg/L	0.000017	-	0.0002	0.000071	0.000028	0.0002	0.000050	0.000027	0.000032	0.000018	0.0002	0.000027	0.000017	0.000020	0.000013	0.0001	0.000016	0.000016	0.000016	0.000016
Cadmium	ug/L			0.225173	0.070501	0.028276	0.171334	0.050311	0.027167	0.032125	0.018075	0.177850	0.027089	0.016743	0.019859	0.013129	0.120846	0.016474	0.016081	0.016186	0.015937
*CWQG adjusted for hardness**	*ug/L*			*0.015284*	*0.015284*	*0.015284*	*0.014474*	*0.014474*	*0.014474*	*0.014474*	*0.014474*	*0.013951*	*0.013951*	*0.013951*	*0.013951*	*0.013951*	*0.032743*	*0.032743*	*0.032743*	*0.032743*	*0.032743*
Chromium	mg/L	0.0089	-	0.0014	0.00154	0.00093	0.0015	0.00114	0.00079	0.00074	0.00059	0.0015	0.00084	0.00068	0.00068	0.00060	0.0016	0.00040	0.00039	0.00039	0.00039
Cobalt	mg/L	-	0.01	0.0010	0.0049	0.0022	0.0007	0.0050	0.0016	***0.031***	0.0016	0.0008	0.0022	0.00075	***0.013***	0.00075	0.0007	0.00018	0.00012	0.00059	0.00012
Copper	mg/L	0.002	-	0.0019	0.0034	0.0022	0.0010	0.0017	0.0013	0.0020	0.0014	0.0014	0.0015	0.0013	0.0016	0.0013	0.0008	0.0007	0.0007	0.0007	0.0007
Iron	mg/L	0.3	1.5	0.7536	***3.41***	0.70	0.3556	1.06	0.42	1.04	0.41	0.7255	0.73	0.41	0.72	0.40	0.1799	0.15	0.14	0.15	0.14
Lead	mg/L	0.001	0.001	0.0007	***0.00144***	0.00029	0.0007	0.00068	0.00022	0.00042	0.00013	0.0008	0.00036	0.00014	0.00025	0.00011	0.0005	0.00008	0.00007	0.00007	0.00007
Manganese	mg/L	-	0.7	0.0816	0.072	0.045	0.0426	0.036	0.029	0.039	0.030	0.1378	0.031	0.028	0.032	0.028	0.0270	0.026	0.026	0.026	0.026
Mercury	mg/L	0.000026	0.00026	0.0001	0.000022	0.000014	0.0001	0.000024	0.000016	0.000020	0.000014	0.0001	0.000015	0.000012	0.000014	0.000011	0.00004	0.000012	0.000012	0.000012	0.000012
Molybdenum	mg/L	0.073	-	0.0017	0.00457	0.00234	0.0016	0.00154	0.00083	0.00251	0.00132	0.0016	0.00082	0.00049	0.00121	0.00068	0.0016	0.00023	0.00021	0.00024	0.00022
Nickel	mg/L	0.025	-	0.0009	0.00139	0.00089	0.0010	0.00114	0.00091	0.00273	0.00171	0.0009	0.00090	0.00079	0.00153	0.00111	0.0011	0.00072	0.00072	0.00074	0.00073
Selenium	mg/L	0.001	0.0035	0.0003	***0.00462***	0.00092	0.0003	0.00130	0.00038	0.00173	0.00059	0.0003	0.00071	0.00025	0.00088	0.00033	0.0003	0.00020	0.00019	0.00021	0.00019
Silver	mg/L	0.0001	-	0.0007	0.000144	0.000074	0.0007	0.000286	0.000146	0.000051	0.000028	0.0008	**0.000120**	0.000063	0.000027	0.000016	0.0005	0.000008	0.000005	0.000004	0.000004
Thallium	mg/L	0.0008	-	0.0061	0.00130	0.00065	0.0067	0.00031	0.00016	0.00038	0.00019	0.0075	0.00016	0.00008	0.00018	0.00009	0.0044	0.000007	0.000004	0.000008	0.000005
Uranium	mg/L	0.015	-	0.0063	0.0263	0.0066	0.0068	0.0065	0.0018	0.0067	0.0018	0.0077	0.00337	0.00101	0.00345	0.00104	0.0051	0.00088	0.00079	0.00088	0.00080
Vanadium	mg/L	-	0.006	0.0005	0.00083	0.00054	0.0005	0.00053	0.00042	0.00065	0.00048	0.0021	0.00048	0.00043	0.00053	0.00045	0.0006	0.00046	0.00046	0.00046	0.00046
Zinc	mg/L	0.03	-	0.0028	0.0233	0.0132	0.0041	0.0090	0.0063	0.0130	0.0083	0.0053	0.0068	0.0055	0.0084	0.01	0.0068	0.01	0.01	0.01	0.01

Parameter	Units	CCME Fresh Water Aquatic Life Guidelines	Site Specific Water Quality Objectives (June 2012)	Nico Lake			Peanut Lake					Burke Lake					Marian River				
				Measured Baseline	Post-Closure		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Measured Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
				(as presented in DAR)	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
				Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
Dissolved Metals																					
Aluminum	mg/L	0.005-0.1	0.41	0.025	0.328	0.062	0.044	0.113	0.048	0.109	0.046	0.040	0.076	0.044	0.074	0.043	0.016	0.027	0.025	0.027	0.025
Antimony	mg/L	0.006	-	0.00023	0.00207	0.00110	0.00018	0.00072	0.00043	0.00106	0.00060	0.00018	0.00044	0.00030	0.00057	0.00036	0.000018	0.000030	0.000025	0.000036	0.000028
Arsenic	mg/L	0.005	-	0.011	0.037	0.011	0.0034	0.0114	0.0042	0.0188	0.0071	0.0023	0.0060	0.0025	0.0089	0.0036	0.00035	0.00051	0.00039	0.00063	0.00043
Barium	mg/L	-	-	0.0068	0.0162	0.0106	0.0079	0.0111	0.0089	0.0150	0.0109	0.0077	0.0093	0.0083	0.0109	0.0091	0.013	0.012	0.012	0.012	0.012
Beryllium	mg/L	-	-	0.000009	0.000082	0.000044	0.000008	0.000080	0.000043	0.000024	0.000015	0.000008	0.000038	0.000023	0.000016	0.000012	0.000008	0.000009	0.000008	0.000008	0.000008
Boron	mg/L	1.5	-	0.0058	0.0174	0.0107	0.0059	0.0113	0.0081	0.0174	0.0112	0.0050	0.0074	0.0060	0.0099	0.0072	0.014	0.014	0.013	0.014	0.014
Cadmium	mg/L	0.000017	-	0.000005	0.000028	0.000011	0.000004	0.000020	0.000011	0.000013	0.000007	0.000004	0.000011	0.000007	0.000008	0.000005	0.000007	0.000008	0.000007	0.000007	0.000007
Chromium	mg/L	0.001	-	0.00022	0.00077	0.00046	0.00028	0.00057	0.00039	0.00037	0.00029	0.00029	0.00042	0.00034	0.00034	0.00030	0.00021	0.00022	0.00021	0.00021	0.00021
Cobalt	mg/L	-	-	0.00024	0.0033	0.0014	0.00013	0.0033	0.0011	***0.0209***	0.0011	0.00011	0.0015	0.0005	0.0084	0.0005	0.00007	0.00012	0.00009	0.00041	0.00009
Copper	mg/L	0.002	0.022	0.0013	0.0024	0.0015	0.0008	0.0012	0.0009	0.0014	0.0010	0.0009	0.0010	0.0009	0.0011	0.0009	0.0005	0.0005	0.0005	0.0005	0.0005
Iron	mg/L	0.3	-	0.21	***1.89***	0.39	0.21	0.59	0.23	0.58	0.23	0.21	0.40	0.23	0.40	0.22	0.082	0.090	0.084	0.090	0.083
Lead	mg/L	0.001	-	0.00004	0.00086	0.00017	0.00004	0.00041	0.00013	0.00025	0.000079	0.00005	0.00021	0.00008	0.00015	0.00006	0.00004	0.00005	0.00004	0.00005	0.00004
Manganese	mg/L	-	-	0.013	0.042	0.026	0.014	0.021	0.017	0.023	0.018	0.014	0.018	0.016	0.019	0.017	0.019	0.016	0.016	0.016	0.016
Mercury	mg/L	0.000026	-	0.0000018	0.0000047	0.0000030	0.0000019	0.0000050	0.0000033	0.0000043	0.0000030	0.0000019	0.0000032	0.0000025	0.0000029	0.0000023	0.0000030	0.0000034	0.0000033	0.0000034	0.0000033
Molybdenum	mg/L	0.073	-	0.00041	0.00381	0.00195	0.00019	0.00129	0.00069	0.00210	0.00110	0.00017	0.00069	0.00041	0.0010	0.00057	0.00017	0.00019	0.00018	0.00020	0.00019
Nickel	mg/L	0.025	-	0.0004	0.0011	0.0007	0.0006	0.0009	0.0007	0.0021	0.0013	0.0006	0.0007	0.0006	0.0012	0.0008	0.00078	0.00056	0.00056	0.00058	0.00057
Selenium	mg/L	0.001	-	0.00012	***0.0039***	0.00079	0.00012	0.0011	0.00032	0.0015	0.00051	0.00011	0.00061	0.00021	0.00075	0.00029	0.00016	0.00018	0.00016	0.00018	0.00017
Uranium	mg/L	0.015	-	0.0003	0.0219	0.0055	0.0002	0.0054	0.0015	0.0055	0.0015	0.00019	0.00281	0.00084	0.00287	0.00087	0.00073	0.00075	0.00068	0.00075	0.00068
Vanadium	mg/L	-	-	0.00018	0.00044	0.00029	0.00018	0.00028	0.00022	0.00034	0.00025	0.00021	0.00025	0.00023	0.00028	0.00024	0.00025	0.00026	0.00026	0.00026	0.00026
Zinc	mg/L	0.03	-	0.0026	0.0132	0.0075	0.0025	0.0051	0.0036	0.0074	0.0047	0.0025	0.0039	0.0031	0.0048	0.0036	0.0043	0.0044	0.0044	0.0044	0.0044

* hardness adjustment based on maxium hardness during open water condition in baseline studies.

Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

Bold Predicted concentration exceeds baseline and SSWQO

Attachment C

Summary of Baseline and Post-closure Receiving Water Quality Modelling Predictions – Compared to Health Canada Drinking Water Guidelines

Attachment C: Summary of Baseline and Post-Closure Receiving Water Quality Modelling Predictions for the Fortune NICO Project - Compared to Health Canada Drinking Water Guidelines

		CCME	Grid Ponds		Nico Lake			Peanut Lake					Burke Lake					Marian River				
		Drinking	Baseline		Baseline	Post-Closure		Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Baseline	Post-Closure Initial Discharge		Post-Closure Steady State		Baseline	Post-Closure Initial Discharge		Post-Closure Steady State	
		Water	Grid Pond	Little Grid Pond	(as presented in DAR)	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands	(as presented in DAR)	Without Wetlands	With Wetlands	Without Wetlands	With Wetlands
Parameter	**Units**	**Guidelines**	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average	Average
Total Metals																						
Aluminum	mg/L	0.1	0.069	0.056	0.056	**0.743**	**0.140**	0.099	**0.256**	**0.110**	**0.246**	0.105	0.090	**0.172**	0.099	**0.168**	0.097	0.032	0.055	0.052	0.054	0.052
Antimony	mg/L	0.006	0.00111	0.00094	0.00032	0.00294	0.00157	0.00025	0.00103	0.00061	0.00150	0.00085	0.00025	0.00062	0.00042	0.00081	0.00052	0.000025	0.000041	0.000034	0.000049	0.000038
Arsenic	mg/L	0.01	**0.213**	**0.177**	0.014	**0.044**	0.013	0.0040	**0.0137**	0.0050	**0.0226**	0.0085	0.0028	0.0072	0.0030	**0.011**	0.0044	0.00041	0.00061	0.00046	0.00075	0.00051
Barium	mg/L	1	0.010	0.010	0.0078	0.019	0.012	0.0092	0.013	0.010	0.017	0.013	0.0090	0.011	0.0097	0.013	0.011	0.015	0.014	0.014	0.014	0.014
Beryllium	mg/L	NG	0.000443	0.000440	0.000013	0.000115	0.000061	0.000011	0.000113	0.000061	0.000034	0.000022	0.000011	0.000054	0.000032	0.000023	0.000016	0.000011	0.000012	0.000011	0.000011	0.000011
Boron	mg/L	5	0.018	0.017	0.0070	0.021	0.013	0.0073	0.014	0.0100	0.021	0.014	0.0061	0.0091	0.0074	0.012	0.0089	0.017	0.016	0.016	0.016	0.016
Cadmium	mg/L	0.005	0.000117	0.000112	0.000011	0.000071	0.000028	0.000010	0.000050	0.000027	0.000032	0.000018	0.0000097	0.000027	0.000017	0.000020	0.000013	0.000016	0.000016	0.000016	0.000016	0.000016
Chromium	mg/L	0.05	0.00124	0.00102	0.00043	0.00154	0.00093	0.00055	0.00114	0.00079	0.00074	0.00059	0.00058	0.00084	0.00068	0.00068	0.00060	0.00038	0.00040	0.00039	0.00039	0.00039
Cobalt	mg/L	NG	0.0075	0.0066	0.00036	0.0049	0.0022	0.00020	0.0050	0.0016	0.031	0.0016	0.00017	0.0022	0.00075	0.013	0.00075	0.00010	0.00018	0.00012	0.00059	0.00012
Copper	mg/L	1	0.0113	0.0075	0.0018	0.0034	0.0022	0.0011	0.0017	0.0013	0.0020	0.0014	0.0012	0.0015	0.0013	0.0016	0.0013	0.0006	0.0007	0.0007	0.0007	0.0007
Iron	mg/L	0.3	0.28	**0.35**	0.38	**3.41**	**0.70**	**0.37**	**1.06**	**0.42**	**1.04**	0.41	**0.38**	**0.73**	0.41	**0.72**	0.40	0.14	0.15	0.14	0.15	0.14
Lead	mg/L	0.01	0.00052	0.00049	0.00007	0.00144	0.00029	0.00007	0.00068	0.00022	0.00042	0.00013	0.00008	0.00036	0.00014	0.00025	0.00011	0.00007	0.00008	0.00007	0.00007	0.00007
Manganese	mg/L	0.05	0.017	0.019	0.022	**0.072**	0.045	0.024	0.036	0.029	0.039	0.030	0.025	0.031	0.028	0.032	0.028	0.031	0.026	0.026	0.026	0.026
Mercury	mg/L	0.001	0.000046	0.000045	0.0000084	0.000022	0.000014	0.0000088	0.000024	0.000016	0.000020	0.000014	0.0000087	0.000015	0.000012	0.000014	0.000011	0.000011	0.000012	0.000012	0.000012	0.000012
Molybdenum	mg/L	NG	0.00273	0.00294	0.00049	0.00457	0.00234	0.00022	0.00154	0.00083	0.00251	0.00132	0.00021	0.00082	0.00049	0.00121	0.00068	0.00021	0.00023	0.00021	0.00024	0.00022
Nickel	mg/L	NG	0.00133	0.00101	0.00052	0.00139	0.00089	0.00079	0.00114	0.00091	0.00273	0.00171	0.00073	0.00090	0.00079	0.00153	0.00111	0.00100	0.00072	0.00072	0.00074	0.00073
Selenium	mg/L	0.01	0.00024	0.00024	0.00014	0.00462	0.00092	0.00014	0.00130	0.00038	0.00173	0.00059	0.00013	0.00071	0.00025	0.00088	0.00033	0.00018	0.00020	0.00019	0.00021	0.00019
Silver	mg/L	NG	0.000433	0.000433	0.000006	0.000144	0.000074	0.000006	0.000286	0.000146	0.000051	0.000028	0.000006	0.000120	0.000063	0.000027	0.000016	0.000003	0.000008	0.000005	0.000004	0.000004
Thallium	mg/L	NG	0.00361	0.00361	0.0000017	0.00130	0.00065	0.0000016	0.00031	0.00016	0.00038	0.00019	0.0000015	0.00016	0.00008	0.00018	0.00009	0.0000013	0.000007	0.000004	0.000008	0.000005
Uranium	mg/L	0.02	0.0067	0.0071	0.00032	**0.0263**	0.0066	0.00020	0.0065	0.0018	0.0067	0.0018	0.00023	0.00337	0.00101	0.00345	0.00104	0.00086	0.00088	0.00079	0.00088	0.00080
Vanadium	mg/L	NG	0.00061	0.00047	0.00033	0.00083	0.00054	0.00034	0.00053	0.00042	0.00065	0.00048	0.00040	0.00048	0.00043	0.00053	0.00045	0.00042	0.00046	0.00046	0.00046	0.00046
Zinc	mg/L	5	0.0070	0.0063	0.0044	0.0233	0.0132	0.0044	0.0090	0.0063	0.0130	0.0083	0.0045	0.0068	0.0055	0.0084	0.01	0.01	0.01	0.01	0.01	0.01

Wetland treatment for metals only, to SSWQO values or 50 percent of influent concentrations, whichever is lower.

Bold Concentration exceeds both Drinking Water Guidelines from Health Canada and baseline + 10%

Attachment D

Golder's Simulation of Pit-lake Filling with Active Pumping from the Marian River

TECHNICAL MEMORANDUM

DATE August 20, 2012 **PROJECT No.** 09-1373-1004

TO Rick Schryer
Fortune Minerals Ltd.

CC Jen Gibson, Lasha Young, Jason Parvianen, John Faithful

FROM Ross Phillips and Brent Topp **EMAIL** ross_phillips@golder.com

SIMULATION OF PIT-LAKE FILLING WITH ACTIVE PUMPING FROM THE MARIAN RIVER

Introduction

In Appendix IV of the Fortune Minerals Ltd. NICO Project Developer's Assessment Report, the length of time required for natural inflows to fill the Pit Lake was evaluated and presented. The purpose of the present assessment is to 1) evaluate the volume of water that could be sustainably withdrawn from the Marian River within current regulations and based on this volume of water; and 2) evaluate the length of time required to actively fill the open pit with inflows pumped from the Marian River. Uncertainty and probability of error in both of these evaluations is discussed.

The four scenarios presented differ based on the volume of water pumped to the pit from an alternative source:

- The first scenario assessed in the model allows the pit to fill with natural inflows and inflows pumped from Lou Lake but no additional pumping from the Marian River.
- The second scenario assessed includes the addition of approximately 200 litres per second (L/s) pumped from the Marian River between May and October.
- The third scenario assessed involves pumping 5% of median monthly flows from the Marian River from May to October.
- The fourth and final scenario simulates extractions as 5% of Marian River flows during observed flows between 1975 and 2009. To fit within expected pumping constraints, the pumping rate in Scenario 4 is limited to a maximum of 200 L/s. Larger pumping rates may be possible with additional pumps providing the maximum 5% of flow value constraint is respected.

All scenarios are simulated based on the following conditions:

- Inputs to the pit include groundwater seepage, precipitation to the water surface and pit walls, runoff from the natural drainage and runoff from the Co-Disposal Facility (CDF).
- Losses from the pit include evaporation from the water surface and outflow which begins when the pit fills to the Full Supply Level (FSL) at elevation 260 meters above sea level (masl) which coincides with the ramp.

- Surface areas used in the assessment include an open pit area of 51 hectares (ha), the natural ground surface drainage reporting to the pit of 34 ha and the drainage reporting from the CDF of approximately 80 ha.

The sustainability of the four scenarios is discussed in terms of impacts on Marian River flows and water levels. One scenario is recommended based on minimizing time required to fill the Pit-Lake while minimizing impacts on Marian River flows and levels.

Methods

The assessment included establishing acceptable withdrawal rates, simulating the filling of the Pit Lake, and evaluating changes to Marian River flows and levels.

Pumping Rates

Withdrawals from the Marian River for the active filling of the Pit-Lake should be conducted in a manner that meets pertinent regulations and is sustainable for local hydrology.

A 2005 guideline document issued by Fisheries and Oceans Canada (DFO), allows for the withdrawal of 5% of instantaneous flows from an ice covered water course and 5% of total under ice volume from an ice covered waterbody (Cott et al. 2005). Acceptable withdrawals from an ice covered waterbody were increased to 10% of under-ice volumes when the guideline was updated (DFO 2010) but there was not mention of withdrawals from ice covered watercourses. This is the only regulation limiting water withdrawal in the Northwest Territories without application for a water license. Thus, for the purposes of this assessment acceptable water withdrawals from the Marian River are taken to be 5% of instantaneous flows. Limiting pumping activities to summer months and the adoption of guidelines for under ice conditions during summer months is considered a conservative measure.

Streamflows in the region are highly variable according to dynamic contributions of runoff from the landscape governed by variable contributing areas (Phillips et al. 2011, Spence et al. 2010). Such variability in the Marian River is captured by summary statistics of mean monthly flows in the synthesized record for the Marian River between 1975 and 2009 (Golder Associates Ltd [Golder] 2010) in Table 1 below. A range of pumping rates associated with a 5% withdrawal allowance during different flows are also presented in Table 1. When flows in the Marian River are high, the corresponding acceptable withdrawal rates are high (Table 1). However the ability of the water course to supply water is diminished when flows are low.

Table 1: Discharge Statistics and Withdrawal Allowance for the Marian River (m^3/s)

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Max	7.55	5.30	3.78	3.71	35.6	124	86.6	28.6	13.9	10.8	11.9	10.1	28.5
75th Percentile	2.87	2.19	1.62	1.48	7.63	12.9	18.0	8.69	6.42	4.99	4.62	3.70	6.26
Average	1.98	1.51	1.17	1.09	6.49	15.8	12.7	6.56	4.32	3.579	3.31	2.66	5.1
Median	1.46	1.21	1.07	0.991	3.77	6.31	6.21	4.34	3.05	2.49	2.01	1.88	2.9
25th Percentile	0.700	0.55	0.44	0.379	0.713	2.07	1.74	1.13	1.02	1.21	1.00	0.836	0.982
Min	0.282	0.209	0.130	0.091	0.374	0.265	0.116	0.055	0.086	0.178	0.289	0.334	0.201

Table 1: Discharge Statistics and Withdrawal Allowance for the Marian River (m^3/s) (continued)

Rank	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
5% Withdrawal Allowance													
75th Percentile	0.14	0.11	0.08	0.07	0.38	0.65	0.90	0.43	0.32	0.25	0.23	0.19	0.31
Average	0.10	0.08	0.06	0.05	0.32	0.79	0.64	0.33	0.22	0.18	0.17	0.13	0.26
Median	0.07	0.06	0.05	0.05	0.19	0.32	0.31	0.22	0.15	0.12	0.10	0.09	0.15
25th Percentile	0.04	0.03	0.02	0.02	0.04	0.10	0.09	0.06	0.05	0.06	0.05	0.04	0.05

m^3/s = cubic metres per second

Four scenarios are presented for pumping from the Marian River. Scenario 1 is the null alternative in which no water is pumped from the Marian River and the pit fills naturally due to local inflows and 112,000 cubic metres per year (m^3/yr) pumped form Lou Lake. In Scenario 2, a constant pumping rate of 200 L/s is prescribed between May and October. This withdrawal rate is just under the 5% of the May-October average median monthly flow in the Marian River. In Scenario 3, in each month from May to October, a monthly pumping rate equal to 5% of median monthly flows is adopted. Scenario 4 has been introduced to account for the potential coincidence of a drought with the filling of the Pit-Lake. In Scenario 4a, monthly withdrawals from the Marian River are limited to 5% of mean monthly flows in the flow record starting in 1975 during a drought period. In Scenario 4a, monthly withdrawals from the Marian River are limited to 5% of mean monthly flows starting in November 1999 during a wet period. In Scenario 4 pumping adapts to expected flows in the river during a dry period: withdrawals are lower during low flow years and higher during high flow years. Expected pumping capacity is accounted for by capping pumping rates at a maximum of 200 L/s. The 1975-2009 monthly record is repeated to generated longer simulation periods.

Filling of the Pit Lake

The Pit-Lake model has been assessed through several iterations due to changes in the site layout, geometric configuration of the CDF, geometric configuration of the open pit and perceived closure scenarios which differed by operating circumstances. Significant changes through the development of the model included changes to the operating circumstances and configuration of the CDF (November 13, 2010 as per Technical Memorandum issued on October 1, 2010 regarding Site Water Management for NICO Project [Version 2] by Golder) and changes to the pit configuration (November 29, 2010 as per the revised pit configuration issued in August, 2010 by P&E Consultants).

The following list details assumptions and calculations which were used in the assessment:

- During the period of Pit Lake filling, the intake, lines, and pumps used to withdraw water from Lou Lake during the construction and operations periods will still be in place. This would enable the withdrawal of 112, 000 m^3/yr from Lou Lake at a constant rate to be pumped to the Pit Lake. The effects of freshwater extraction on Lou Lake are evaluated in Appendix 11.II of the DAR (Golder 2010).
- Precipitation is based on the Undercatch Corrected data set available for the Yellowknife Airport from 1953 to 2007 (Golder 2010). Precipitation is used in the model as monthly average values where an average year is repeated throughout the model. Precipitation is assumed to fall and accumulate as snow from November to April inclusive. The average monthly precipitation values are presented in Table 2.

Table 2: Monthly Average Precipitation and Gross Evaporation

Month	Total Precipitation (mm)	Gross Evaporation (mm)
January	21.5	0.0
February	19.5	0.0
March	19.0	0.0
April	14.5	0.0
May	20.5	0.0
June	25.2	118.6
July	40.1	154.4
August	44.1	120.7
September	36.0	66.8
October	38.8	18.0
November	37.1	0.0
December	27.1	0.0
Total	**343.4**	**478.5**

mm = millimetre

- Runoff to the pit is calculated using runoff coefficients for the natural ground surface and CDF (Table 3). Both surfaces use the same runoff coefficients in anticipation that the CDF will be characteristically similar with regard to infiltration, evaporation and runoff in the closure condition.

- Seepage to the pit is controlled by the water level in the pit whereby seepage to the pit is greatest when there is no water in the pit and smallest when the pit is at the FSL at 260 masl. The hydraulic conductivity of the bedrock is assumed to be 5 x 10^{-9} metres per second.

Table 3: Runoff Coefficients

Month	Coefficient
January	0.6
February	0.6
March	0.6
April	0.6
May	0.5
June	0.4
July	0.3
August	0.3
September	0.3
October	0.4
November	0.6
December	0.6

- In Scenarios 2, 3, and 4 water is actively pumped from the Marian River. The magnitude of the pumped inflow in Scenario 2 and 3 from the Marian River begins in May of each year and lasts for a six month period. In Scenario 2, the rate of pumping is constant and 200 L/s. A long term record developed for the Marian River (Golder 2010) indicates that this volume generally falls within 10% of the total discharge for the median monthly flow condition (Table 3). Scenario 3 is a variable rate of monthly withdrawal in which the monthly rate is 5% of the median monthly flows in the Marian River.

- Monthly gross evaporation from the water surface is presented in Table 1. The monthly gross evaporation is calculated using the Meyer's formula (Golder, 2010).
- The water balance for evaluating the volume reporting to the pit is based on a monthly time step where the following rules apply:
- Precipitation as snowfall reports to surfaces and is accumulated through the winter months of November to April. Snowmelt runoff occurs in May along with precipitation for the month of May. Sublimation and other losses from the snowpack are assumed in the runoff coefficients. Infiltration and evapotranspiration from the ground and CDF surfaces are also assumed in the runoff coefficients. For the open season, precipitation (mostly rainfall) is reported to the pit (or collection ponds) as a runoff which is calculated as a product of the volume of precipitation and the runoff coefficient for that month and the contributing drainage area.
- Evaporation occurs for the lake surface only as the lake fills up the pit. The magnitude of evaporation from the pit changes as the surface water area of the lake increases or decreases based on the overall change of volume of the lake. Evaporation is the only loss of water from the pit until the pit fills and spills over.
- Seepage reporting to the pit is controlled by the water level in the pit.
- In the pit-lake water balance the volume at the start of the month controls the lake elevation and surface area that define the magnitudes of seepage, evaporation and volume of precipitation falling directly within the pond for that month. For evaluating the final volume for each month, the net change in the volume of the pit is calculated from the inputs and losses and applied to the volume at the beginning of the next month. The final volume for one month becomes the initial volume for the next month which controls the next surface area and lake elevations for the next calculations.
- The pit fills until the lake elevation is 260 masl where a spill over occurs. The volume discharged from the pit is the excess water that must be discharged to maintain an elevation of 260 masl. The lake elevation of 260 masl corresponds to a lake depth of 166 m.

Impact on Marian River Flows and Levels

Because water will be withdrawn directly from the Marian River, it is expected that flows will be reduced by the amount withdrawn. The impact of withdrawals on expected water levels are calculated according to the Stage-Discharge relationship developed by Golder (2010) and presented in Equation 1 below relating water level, $Z_{w.s.}$ in units of metres above a local datum (mald), to flow in the Marian River, Q in cubic metres per second, cubic metres per second (m^3/s).

$$Z_{w.s.} = 98.0241 + 0.1026 \cdot Q^{0.6988} \quad \textbf{(1)}$$

Results and Discussion

The simulated variation in Pit Lake depth over time during Scenario 1 is presented in Figure 1 and the results from Scenarios 2 to 4 in which water is actively pumped from the Marian River are presented in Figure 2. Scenario 1, which allows the pit-lake to fill without any pumping from the Marian River, requires approximately 81 years before the pit will overflow from the ramp at a depth of 166 m. The pit-lake would require approximately 120 years under natural climatic conditions without inflows pumped from Lou Lake.

In Figure 2, Scenarios 2 to -4 involving withdrawal of water from the Marian River are presented. Under Scenario 2, the Pit would require 8.5 years assuming that the monthly pumping rate could be withdrawn. Under Scenario 3, the Pit would require 7.7 years to fill assuming that the prescribed monthly pumping rates could be satisfied each month. Under Scenario 4 the Pit Lake is expected to fill over between 8.9 and 13.6 years during wet and dry periods respectively.

Scenarios 2 and 3 have rates developed from longer term trends and during low flow periods may in some circumstances exceed allowable flows defined by the 5% criteria. Under these circumstances flow rates would need to be reduced or stopped.

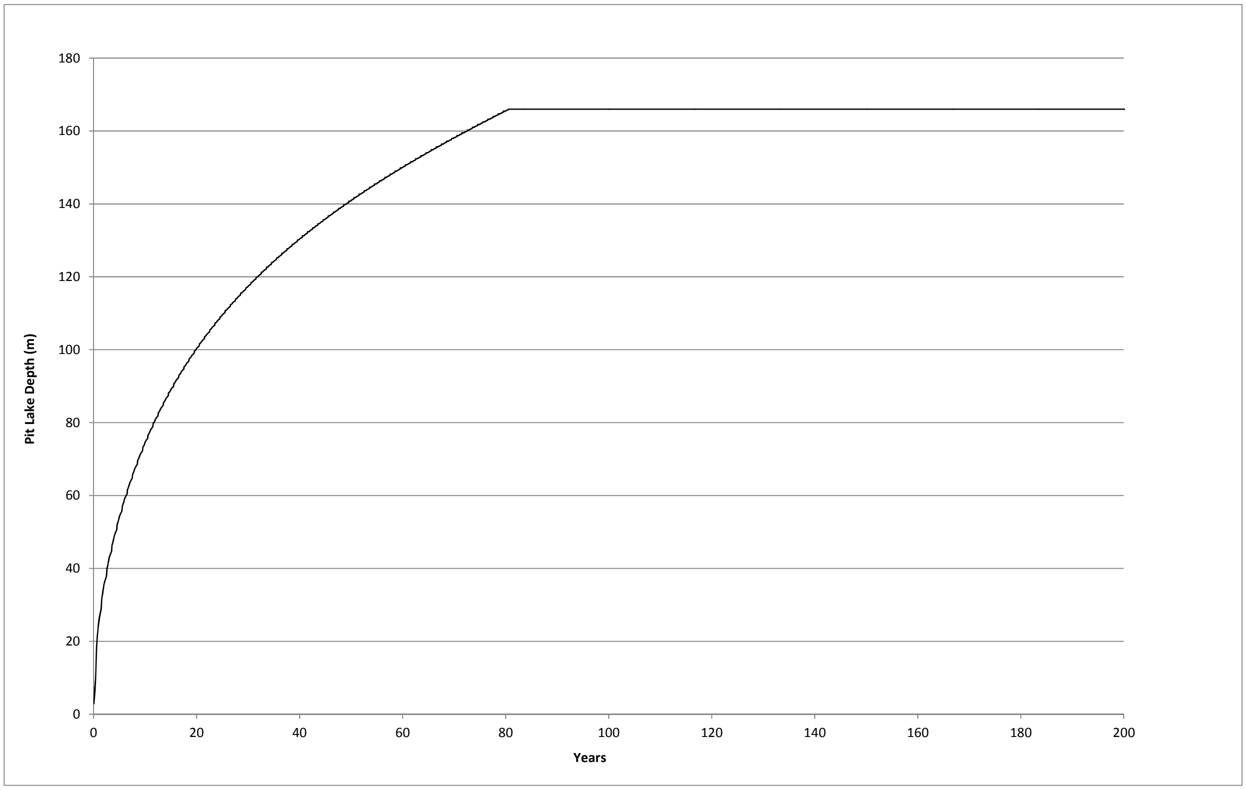

Figure 1: Scenario 1 Pit-Lake Filling Results by without Inflows from the Marian River.

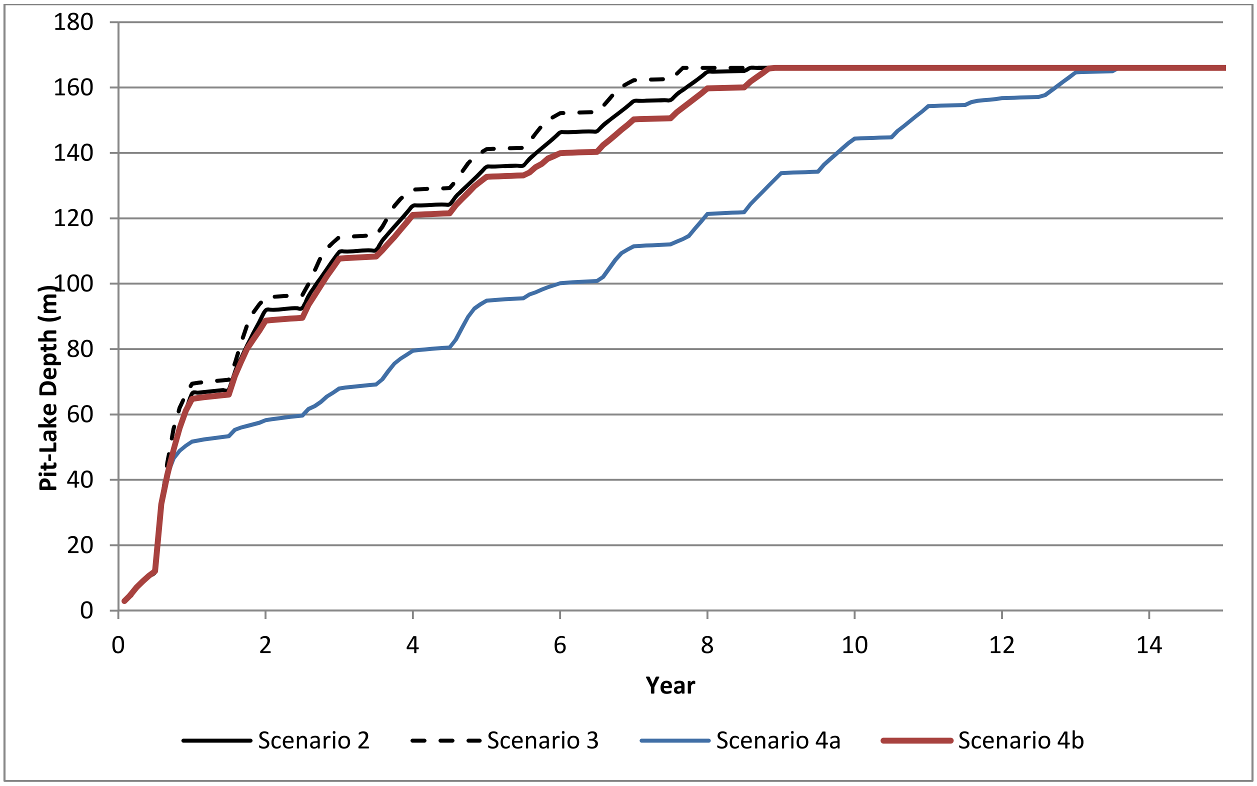

Figure 2: Pit-Lake Filling Results for Scenarios 2-4 with Active Pumping from the Marian River.

Impact on the Marian River

Scenario 1 is expected to have no direct impact on water quantity in the Marian River. Scenarios 2, 3, and 4 incorporate water withdrawals which are expected to reduce Marian River flow by the pumping rate and water levels are expected to decrease according to the stage-discharge relationship (Equation 1). Natural water levels in the Marian River are presented in Figure 3 alongside the changes to water levels expected due to withdrawals. In Figure 3 simulations were initiated during a period of low flows and therefore Scenario 4b which occurs during a high flow period are not shown. In Scenarios 2 and 3 rates are developed from longer term summary statistics and lead to elevated decreases in levels during periods of low flows and lower impacts during high flows (Figure 3). Conversely, Scenario 4 in which the rate at which water is pumped is influenced by flows at the time of pumping, decreases in water levels are highest when river levels are highest.

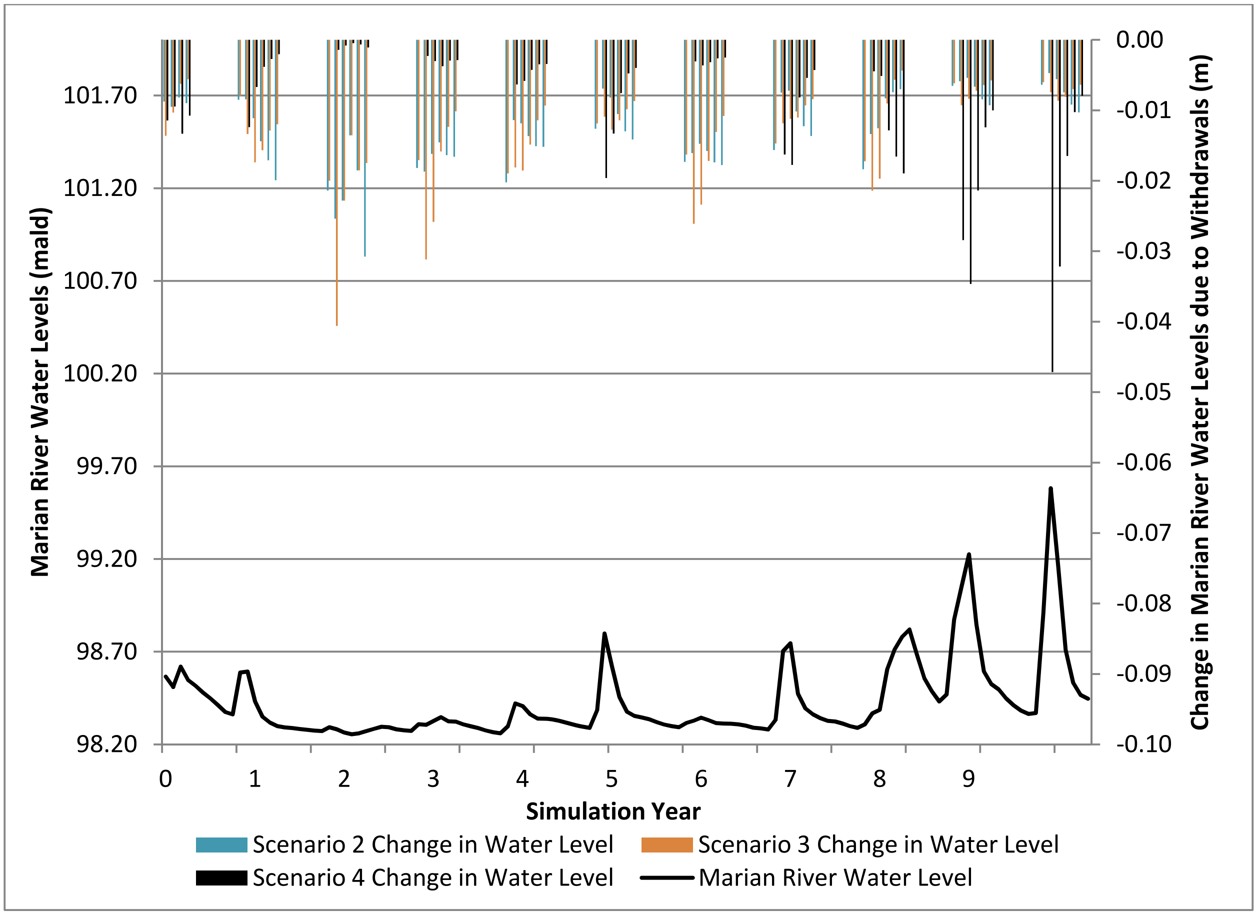

Figure 3: Natural levels in the Marian River during the 10 year simulation period required to fill the Pit Lake for Scenarios 2, 3, and 4.

Uncertainty and Probability of Error

The probability of error in predictions can be addressed for estimations filling time for the Pit-Lake as well as the amount of water that can be sustainably withdrawn from the Marian River. Probability of error in both estimates is influenced by the scenario in question, the data used to support estimates, as well as the variability of flow rates in the Marian River.

The probability of error in estimates of Pit Filling is expected to be low. The method used to estimate time required to fill the Pit-Lake uses an accepted standard water balance modelling approach that incorporates the best available average climate data available for the site, runoff coefficients, and hydro-geological modeling. The primary source of uncertainty in modelling Pit Lake levels is the potential deviation of actual climatic patterns from the averages used during modelling at the time of filling. Also affected by the variability of climate are acceptable withdrawal rates which will be discussed below. The probability of error with respect to modelling approach and climate data is thought to be mitigated to the extent practicable and acceptable due to diligence in the preparation of average values and methods used in modelling.

It is possible that the actual withdrawal allowance may deviate from assumed Published information on guidelines governing withdrawals from rivers in the Northwest Territories: The guidelines adopted here are directed at winter conditions not summer. The guideline (DFO 2005) is intended for the protection of aquatic species during ice covered conditions and the application of winter guidelines to summer conditions is intended to afford the same level of protection during the open water season. Winter flows are typically low and under ice volume is reduced by the presence of ice cover and thus more vulnerable to impacts associated with water withdrawals than during ice free conditions. Also, in all scenarios the NICO Project is assumed to be the only user. Possible future water withdrawal requirements from the Marian River by other users may affect the withdrawal allowance available.

The probability of error associated with estimating acceptable withdrawals from the Marian River is different for each scenario. It is probable that for some scenarios the prescribed pumping rates may occasionally exceed assumed allowable withdrawals and in some cases historical flows. Given that the pumping rate in Scenario 3 is based on the median flow value, probability that the pumping rate (5% of the median) will exceed 5% of monthly flows is 50% for any given month. Because the pumping rate in Scenario 2 is static and based on an average of median mean monthly flows, the probability that pumping rates will exceed 5% of monthly flows is more variable than that for Scenario 3: It ranges from a low of 40% in July when flows are highest to 63% in October but is on average 50%. In Scenarios 2 and 3 there is a probability of 4% that pumping rates in any given pumping month will exceed mean monthly Marian River. The probability of error in estimating pumping rates for Scenario 4 is expected to be low to nonexistent because of the manner in which monthly pumping rates were defined. The probability is low because in highly variable periods (spring freshet) it is likely that the 200 L/s cap on pumping rates would take effect. The probability of error during low flow periods is low because during low flow periods flow rates are steady and do not typically vary significantly.

The adoption of Scenario 4 would require continuous monitoring of flows in the Marian River using a pressure transducer and the rating curve presented in Equation 1. It is likely possible to automate a pump that pumping rates are automatically varied to be 5% of flows derived from a pressure transducer combined with a rating curve.

Summary and Conclusion

Four scenarios were assessed according to the time required to fill the Pit-Lake and impact on the Marian River (Table 4). Under only natural climatic conditions, without any additional inflows from Lou Lake or the Marian River, the Pit Lake will require 120 years to fill. In Scenario 1, in which there are no inflows from the Marian River, only inflows from Lou Lake and natural climatic conditions the Pit Lake would require 81 years to fill. In Scenario 2, a constant pumping rate was assumed to be pumped from the Marian River between May and October of each year. Under favourable flow conditions, it would require 8.7 years to fill the pit lake. However, in this scenario there was a high probability that any given month would experience insufficient flows to sustainably support the pumping rate and realistically would take longer as a result of delayed or reduced withdrawals. In Scenario 3, a monthly variable withdrawal rate was prescribed for the months between May and October based on median mean monthly Marian River flows. Under favourable flow conditions, the Pit Lake would require 7.7 years to fill. However, during simulations this scenario encountered several months in which flows would be insufficient to satisfy the pumping rates and assumed withdrawal allowance guidelines.

Table 4: Summary of Results for Scenarios 1-4

Scenario	Pumping Rate from Marian River	Pumping Months	Years to Fill Pit Lake
1	No Pumping	N/A	81
2	200 L/s	May-October	8.7
3	5% of Historic Median	May-October	7.7
4a	5% of Monthly Flows to a maximum of 200L/s	May-October	13.6
4b	5% of Monthly Flows to a maximum of 200L/s	May-October	8.9

L/s = litres per second; % = percent

It is recommended that Scenario 4 is adopted. This pumping regime is deemed to be sustainable and meets the guidelines adopted for guidance in this regard. In Scenario 4 in which the pumping rate is variable and capped at 200 L/s the Pit Lake could be filled in a probable minimum of approximately 9 years and a probable maximum of 14 years based on historic climate records. Scenario 4 limits the impact to flows and levels in the Marian River during periods of low flow. The largest withdrawals and corresponding decreases to levels coincide with periods of high flow (Figure 3). This will decrease the probability of adverse effects on the Marian River and unplanned reductions to or curtailment of pumping during low flow periods. As a result of the adaptability of pumping rates in Scenario 4 it is expected that the probability of error is low.

Closure

The method used to estimate the time required to fill the Pit-Lake at the proposed Fortune Minerals NICO Project incorporates average climatic parameters, runoff coefficients and a standard water balance approach. Under natural climatic conditions, the Pit Lake is expected to require 120 years to fill. Without any pumping from the Marian River, but allowing for pumping from Lou Lake, the Pit Lake will require 81 years to fill. Under a sustainable pumping scenario, Scenario 4, including constant rate withdrawals from Lou Lake and a variable pumping rate that adapts to the ability of the Marian River to supply water, the Pit Lake would require between 8.9 and 13.6 years to fill, a minimum of 106 years less than under natural conditions and 67 years less than if water was pumped from Lou Lake alone. This scenario has the least probability of error, fits within assumed guidelines, and is deemed to be sustainable.

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RP/BT/jlb/rz

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Attachment E

Lorax's NICO Pit Lake Water Balance Review

MEMORANDUM

To: **Rick Schryer (Fortune Minerals Ltd.)** **Date: August 16, 2012**
From: **Silvano Salvador** **Project #: A309-1**
David Flather

Subject: NICO Pit Lake Water Balance Review

1. Introduction

As part of the Developer's Assessment Report (DAR) for the NICO Cobalt-Gold-Copper Bismuth Project (NICO Project), Fortune Minerals Limited (Fortune) was required by the Mackenzie Valley Review Board (MVRB) to assess the potential for the open pit at the proposed NICO PROJECT to fill with water under natural climatic influences in the closure condition of the mine. Fortune commissioned Golder Associates Ltd. (Golder) to perform the pit lake assessment and the determination was made that under natural climatic conditions with drainage diverted to the pit from the waste rock and tailings areas, the pit would overflow in approximately 120 years. Fortune has requested that Lorax Environmental Services Ltd. (Lorax) conduct a review of the pit filling water balance methodology by Golder and verify the resulting conclusions. The following memorandum provides a summary of the salient findings of the verification evaluation.

2. Pit Filling and Water Balance Review Methods

Initially, the Golder water balance model was assessed by reproducing the original results in a separate spreadsheet model using the same inputs described by the aforementioned pit filling scenario. Second, the correctness of the volume storage and surface area formulations used in the Golder model was assessed by independently generating a volume-elevation curve (VEC) from topographical pit contours and applying new curve-fitting formulations for water surface area vs. depth and depth vs. volume. The final stage of the verification assessed that information extracted from hydrological baseline studies has been interpreted correctly and implemented accurately by the pit filling model. Following the verification of published results, additional sensitivity analyses were conducted to evaluate steady-state conditions in the pit lake when pit wall runoff coefficients are included in the water balance and when runoff from the CDF is diverted to the receiving environment (i.e. not discharged to the pit lake).

The evaluations performed as part of the verification assessment included:

- **Scenario 1:**
  Re-run of Golder water balance (unmodified);
  - utilized Golder catchment areas
  - assumes diversion of CDF runoff to open pit

- **Scenario 2:**
  Verification of Golder VEC (volume elevation curve)
  - utilized Lorax calculated VEC
  - utilized Golder catchment areas
  - assumes diversion of CDF runoff to open pit

- **Scenario 3:**
  Lorax VEC and Lorax Catchments
  - utilized Lorax calculated VEC
  - utilized Lorax catchment areas
  - assumes diversion of CDF runoff to open pit

- **Scenario 4:**
  Pit Wall and Lake Surface Adjustments for Sublimation
  - utilized Lorax calculated VEC
  - utilized Lorax catchment areas
  - assumed 40% sublimation of snowpack on pit walls and lake surface
  - assumes diversion of CDF runoff to open pit

- **Scenario 5:**
  Diversion of CDF Runoff to Environment and *No Prior Fast Fill*
  - utilized Lorax calculated VEC
  - utilized Lorax catchment areas
  - assumed 40% sublimation of snowpack on pit walls and lake surface
  - assumes diversion of CDF runoff to receiving environment directly
  - assumes pit lake is empty at start of simulation

- **Scenario 6:**
  Diversion of CDF Runoff to Environment and *Prior Fast Fill*
  - utilized Lorax calculated VEC
  - utilized Lorax catchment areas
  - assumed 40% sublimation of snowpack on pit walls and lake surface
  - assumes diversion of CDF runoff to receiving environment directly
  - assumes pit lake is largely full at start of simulation

2.1 Scenario 1 - Golder Water balance Verification

This verification was designed to assess correctness of the methodology implemented in the Golder spreadsheet model which included groundwater seepage, precipitation to the water surface and pit walls, runoff from natural drainage, and runoff from the Co-Disposal Facility (CDF). Golder estimated the time to fill the pit using these inputs at approximately 120 years. This scenario was verified and duplicated in a new spreadsheet model using the same source terms and runoff areas. A minor difference in the approach to computing groundwater inflow was introduced to test the assumption that incorporating the two groundwater inflow contributions (bottom and sides) directly into the volume summation would not produce results significantly different than those derived by Golder. The Golder scheme converted the two groundwater components into a single term through the use of a predetermined curve-fit polynomial function. The final Lorax result yielded a similar pit filling period of approximately 120 years. A comparison of average monthly overflow volumes between the original Golder pit filling model and the Golder verification model is presented in Table 2-1.

Table 2-1:
Monthly Flooded Pit Overflow Volumes for Scenario 1

Month	Original Golder Overflow Volumes (m^3/month)	Golder Verification Overflow Volumes (m^3/month)
Jan	10,965	10,967
Feb	9,945	9,947
Mar	9,690	9,692
Apr	7,395	7,397
May	117,011	117,013
Jun	0	0
Jul	0	0
Aug	0	0
Sep	0	0
Oct	0	0
Nov	0	0
Dec	13,580	13,665

The very minor discrepancy between overflow volumes is due to the different methods used to compute groundwater seepage between the two approaches.

Of importance to note is the "predicted" overflow during the months of December to April. These predicted overflows during the ice-on period are an artifact of the assumptions used in the Golder water balance with respect to precipitation accumulation on the pit walls and pit lake surface during the winter months. Specifically, Golder assumed that precipitation (as snowfall) falling on the pit walls and pit lake surface directly would immediately add to the volume of water accumulating in the pit lake. In reality, this would not occur, but rather snowfall would accumulate during the winter months and be released as water during the spring freshet. Golder correctly handled this with respect to runoff from natural ground and the CDF by not assuming runoff during the period of November to April; this water was instead accumulated during the winter months and released in May. The rationale for handling runoff differently in the pit void for winter was not determined from review of available material.

The "addition" of water to the pit lake during the winter months artificially created an excess accumulation of water as overflow as lake evaporation during the months of November to April is assumed to be zero when ice is covering the lake. During summer months, a negative climate water balance exists with evaporation exceeding the total contributions of precipitation, groundwater inflows and total catchment runoffs to the pit lake. These assumptions are corrected in Scenarios 4 through 6 below but are not adjusted in the analysis of Scenarios 1 through 3.

The total annual excess overflow volume for the Golder water balance is approximately 168,700 m^3. See electronic Excel file "**Lorax NICO Pit Lake Water Balance.xlsx**" Tab *WB Lorax Summary (Scenarios).*

2.2 Scenario 2 – Verification of Golder Volume Elevation Curve (VEC)

In this verification, a new volume elevation curve was derived by Lorax from the closure pit elevation contours. From this analysis, a table comprised of elevations, depths, volumes, 2D planar areas and 3D surface areas at 1 metre increments was generated. Curve-fitted 6^{th} order polynomial functions were derived from the VEC for water surface area vs. depth and depth vs. volume.

These formulations were applied in the water balance comparison using the same source terms as in section 2.1. The Golder VEC included an artificial pit bottom at 94 m and assigned a volume and planar surface area equal to zero at this level. From the pit contours provided to Lorax, the minimum elevation given is 95 m and is ultimately defined as the pit bottom in the Lorax VEC. The final result using the new VEC formulations yielded a nearly similar pit filling period of approximately 121 years. Average monthly overflow volumes from the Golder VEC verification model is presented in Table 2-2 and are similar to Scenario 1. The overflow artifact described previously has not been altered. The total annual excess overflow volume calculated for Scenario 2 is approximately 164,250 m^3.

Table 2-2:
Monthly Flooded Pit Overflow Volumes for Scenario 2

Month	Lorax VEC with Golder Catchment Areas Overflow Volumes (m^3/month)
Jan	10,965
Feb	9,945
Mar	9,690
Apr	7,395
May	117,011
Jun	0
Jul	0
Aug	0
Sep	0
Oct	0
Nov	0
Dec	9,252

2.3 Scenario 3 - Revised Surface Runoff Catchment Areas

Surface areas for runoff draining to the open pit have been provided by Golder in the form of GIS polygons (Figure 2-1). These were found to differ from those originally used in the Subject of Note (SON) Flooded Open Pit Filling Scenarios appendix. The comparison between the two sets of runoff areas are listed in Table 2-3.

Table 2-3:
Surface runoff Areas Draining into Open Pit

	SON Golder Modelling Areas (ha)	Lorax Areas (ha)
Open Pit	51	49.8
Natural Ground	34	40.4
CDF	80	74.3

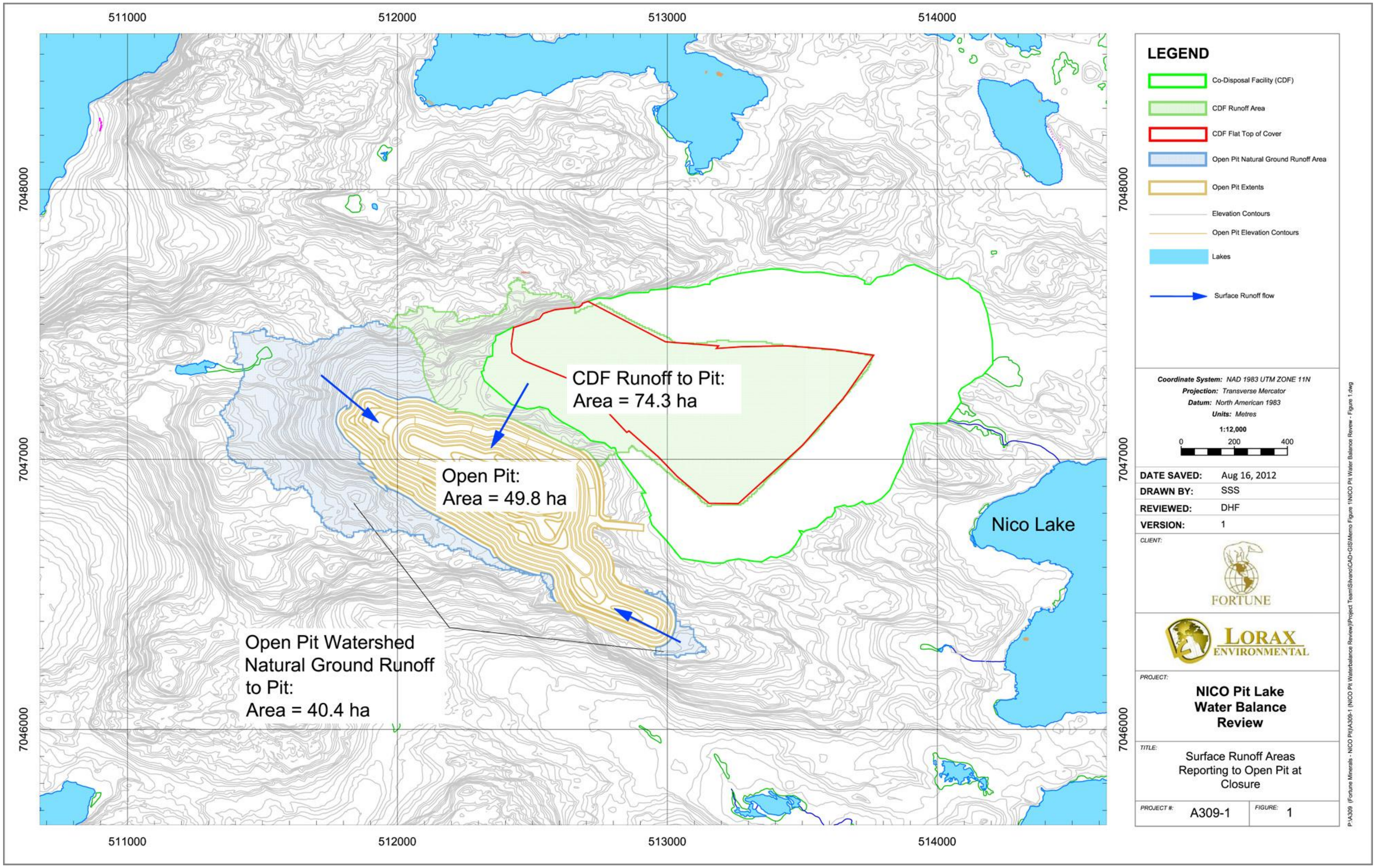

Figure 2-1: Surface Runoff Areas Reporting to Open Pit at Closure

The discrepancy arises from the fact that catchment areas adjacent to the open pit were updated as a result of more recent water quality modelling conducted by Golder since the original pit filling scenarios were computed. Although the divisions between the pit, natural ground, and CDF areas had changed, the total of these three areas was virtually the same. As a result, the pit filling time using the same filling criteria yielded a nearly similar filling time of approximately 122 years. Table 2-4 contains average monthly steady-state pit overflow volumes based on the 122 year filling scenario.

Table 2-4:
Monthly Flooded Pit Overflow Volumes for Scenario 3

Month	Overflow Volumes (m^3/month)
Jan	10,707
Feb	9,711
Mar	9,462
Apr	7,221
May	117,419
Jun	0
Jul	0
Aug	0
Sep	0
Oct	0
Nov	0
Dec	6,705

The total annual excess overflow volume calculated for Scenario 3 is approximately 161,200 m^3.

2.4 Scenario 4 – Sublimation Adjustments

A sensitivity was conducted to determine pit filling times using different modelling criteria and assumptions. The first sensitivity considered the assumption that precipitation falling on the pit walls and to the water surface should be adjusted due to sublimation and also be stored and released during the spring melt in May. This method has been used in the Golder water balance model for calculating runoff from natural ground and the CDF catchment areas.

The Golder flooded pit filling model assumed a pit wall runoff coefficient equal to 1, hence, all precipitation falling on the pit walls reported to the pit lake. Also, the Golder model assumed that all precipitation falling directly on the surface of the lake reported to the lake evenly throughout the year. Based on professional judgement and values used in projects in similar environments, the monthly pit wall runoff coefficients listed in Table 2-5 were adopted. The values in red indicate the recommended coefficients in the Golder water management plan for the cold season. However, in those months Lorax opted to reduce the coefficient to 0.6 to more closely resemble the values used for natural ground and CDF catchment runoffs. As for precipitation falling on the lake surface in the cold season, we adopted a sublimation reduction of 40%. This adjustment is consistent with published results in Nunavut (Déry and Yau, 2002. *Large-scale mass balance effects of blowing snow and surface sublimation*. J. Geophysical Research. Vol. 107, No. 23. American Geophysical Union).

Table 2-5:
Pit wall Runoff Coefficients Used in Sensitivity Water Balance Scenarios

Month	Pit Wall Runoff Coefficient
Jan	.6 (.9)
Feb	.6 (.9)
Mar	.6 (.9)
Apr	.6 (.9)
May	.7
Jun	.7
Jul	.7
Aug	.7
Sep	.7
Oct	.7
Nov	.6 (.9)
Dec	.6 (.9)

The inclusion of sublimation and accumulation of snow in the pit over the winter months resulted in significant changes to predicted overflow from the pit lake. Utilizing these revised assumptions, annual overflow volumes are reduced to approximately 123,900 m^3 and all of this flow is predicted to occur in May. During the period of June to October, evaporation rates exceed input flows and discharge does not occur. Table 2-6 provides a summary of the predicted results.

Table 2-6:
Monthly Flooded Pit Overflow Volumes for Scenario 4

Month	Overflow Volumes (m^3/month)
Jan	0
Feb	0
Mar	0
Apr	0
May	123,904
Jun	0
Jul	0
Aug	0
Sep	0
Oct	0
Nov	0
Dec	0

2.5 Scenario 5 – Sublimation Adjustments and CDF Diversion to Receiving Environment and No Prefilling of Pit Lake

The second sensitivity analysis performed included the sublimation adjustments and assumes that all surface runoff flow from the CDF area is directed to the receiving environment outside of the open pit. The model evaluation also assumes that the pit void is empty at the start of the simulation. The result of the CDF diversion indicates that the pit will not reach the overflow spillway over the course of the approximately 300 year modelling period.

2.6 Scenario 6 – Sublimation Adjustments and CDF Diversion to Receiving Environment with Prefilling of Pit Lake

This scenario considers that the NICO pit is initialized with a rapid fill of 24,000,000 m^3. Under this scenario, considering the same assumption of CDF diversion to the receiving environment and sublimation adjustments, the annual overflow volume from the pit lake is substantially reduced to approximately 8,700 m^3; this entire volume is predicted to occur during the month of May. Table 2-7 provides a summary of the results.

**Table 2-7:
Monthly Flooded Pit Overflow Volumes for Scenario 4**

Month	Overflow Volumes (m^3/month)
Jan	0
Feb	0
Mar	0
Apr	0
May	8,696
Jun	0
Jul	0
Aug	0
Sep	0
Oct	0
Nov	0
Dec	0

3. Summary and Conclusions

Verification of the original NICO pit lake water balance developed by Golder has been performed. Minor modifications to the water balance have also been conducted by Lorax relating to the handling of water additions during the winter months. The following key conclusions from the analysis can be advanced:

- The Golder water balance for the NICO pit lake has been verified and reproduced. Under the base case assumptions of diversion of the CDF runoff to the open pit, the NICO pit is predicted to overflow in approximately 120 years. Total annual overflow volumes are estimated at approximately 168,000 m^3.
- The base case Golder water balance assumed that snowfall added to the pit lake and pit walls during the winter months added directly to the water volume changes in the pit lake. This resulted in predicted overflows during the winter months of November to April when evaporation rates were assumed to be zero. This is not considered to be an accurate representation of what occurs with the winter snowpack and discharges during the ice-on period are not anticipated.
- Lorax modified the base case assumptions by considering snowpack accumulation and sublimation during the winter months. Sublimation of approximately 40% based on a literature review were applied. In addition, all snow water equivalent was accumulated during the period of November to April and subsequently released in May. Under this scenario with sublimation included for the pit lake

and pit walls, total annual discharge volumes were reduced to roughly 123,900 m^3 or a reduction in total flows of roughly 25%. All overflow occurs during the month of May. These overflow volumes are considered to be more accurate for the base case (e.g. CDF diversions to the pit lake) scenario.

- Lorax also evaluated the scenario in which the CDF runoff is diverted directly to the receiving environment. This scenario also included the sublimation adjustments. In this case, total annual overflow volumes do not exceed 9,000 m^3 and are predicted to occur all in the month of May. This equates to a discharge flow rate of roughly 3 L/s for the one month period of overflow.
- While not included in the Lorax scope of evaluation, it is likely that with the overflow period coincident with the spring freshet that discharge water quality would be acceptable for direct discharge. Experience has shown that snow melt waters are typically very low in total dissolved solids (e.g. low salinity and low density) and often do not mix with underlying pit lake waters. The result of this limited mixing is that freshet waters "ride" over the surface of the pit lake waters and are generally of good quality.
- If additional pit lake work is contemplated, consideration should be given to developing a synthetic climate record that includes variable precipitation totals. The existing Golder water balance utilizes monthly mean precipitation totals that are repeated each year. As such, climate variabiltiy is not explicity included in the model predictions. Use of climate generator models such as CLIMEGEM or equivalent is recommended.