



CUMULATIVE ENVIRONMENTAL MANAGEMENT ASSOCIATION

Phase II 2005/2006 Pit Lake Work Plan

Working Group: Reclamation Working Group
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Golder Associates Ltd.

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Contract Name: PHASE II 2005/2006 PIT LAKE WORK PLAN

Consultant Name: Golder Associates Ltd.

This report was commissioned by the End Pit Lakes Subgroup (EPLSG) of the Reclamation Working Group (RWG) of the Cumulative Environmental Management Association (CEMA), in its tasks of developing an End Pit Lakes Guidance Document. Specifically, this project was intended to develop a workplan for the end pit lake toxicity modelling.

This report has been completed in accordance with the terms of reference issued by the EPLSG / RWG. The EPLSG / RWG has closed this project and considers this report final.

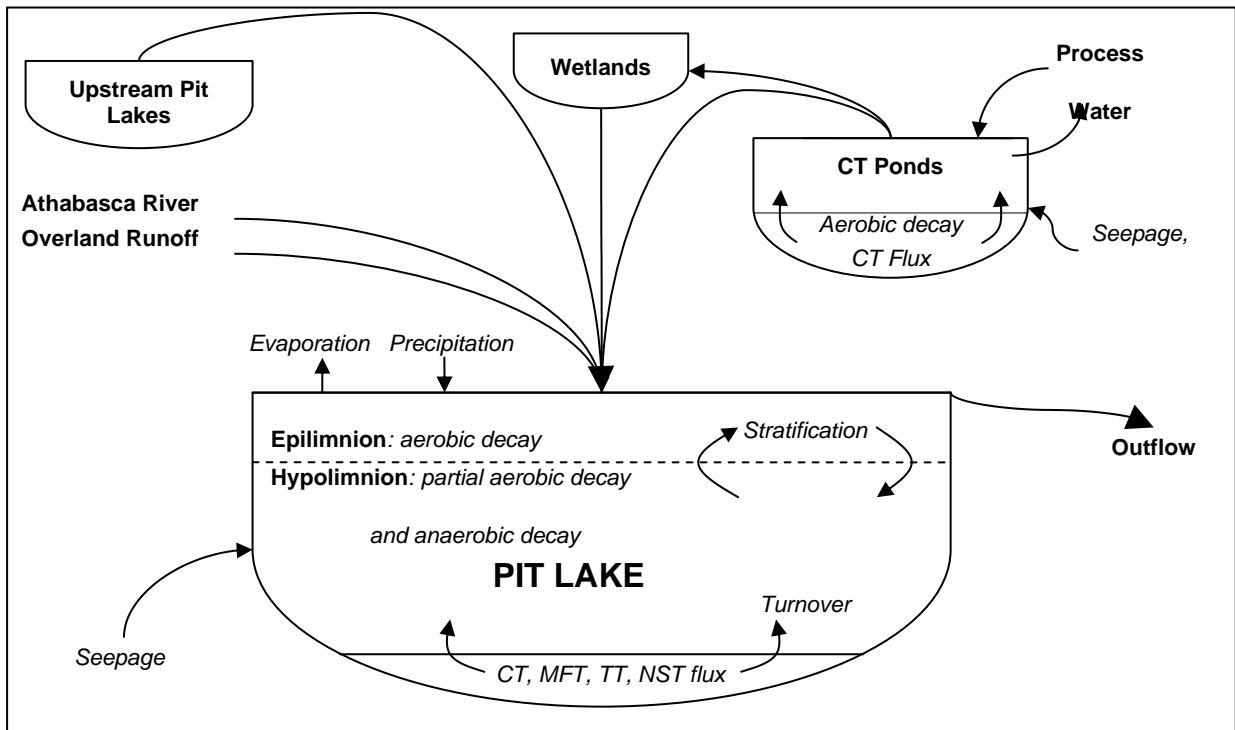
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For more information please contact CEMA at 780-799-3947.

**PHASE II 2005/2006 PIT LAKE
WORK PLAN**



Submitted to:

**EPL Sub-Group
Reclamation Working Group
Cumulative Environmental Management Association**

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1 INTRODUCTION

1.1 BACKGROUND

Pit lakes are proposed as a final remediation solution for oil sands reclamation and operational waters. The main objective of the Cumulative Environmental Management Association, Reclamation Working Group's End Pit Lake Sub-group is to establish design and management guidelines for these oil sands reclamation lakes¹. Ultimately, the extent to which these factors can be adjusted to achieve a desired level of stratification may establish important pit lake design parameters. While both biological and physical processes influence stratification potential, work to date has focused on pit lake size, depth, starting lake salinity concentrations, inflow rates and inflow salinity flux, primarily because of their expected dominant influence on density gradients.

For the purposes of this work plan, **salinity** is considered to be equivalent to total dissolved solids (TDS). Salinity is typically a measure of the dissolved salts in water measured as either Practical Salinity Units (PSU) or sometimes as TDS. PSU defines salinity in terms of the conductivity ratio of a sample to that of a solution of 32.4356 g of KCl at 15°C in a 1 kg solution.

An important term used in this work plan is **meromixis**, which describes the permanent condition whereby upper water layers do not mix with lower portions. In meromictic lakes the deeper, perennially isolated stratum of water, the **monimolimnion**, underlies the upper **mixolimnion**, which periodically circulates. The monimolimnion and the mixolimnion are separated by a steep salinity gradient, the **chemolimnion** and the associated plane of density change is called the **chemocline**. Freshwater lakes are more typically discussed in terms of their **hypolimnion** (lower layer), **epilimnion** (upper layer), separated by a steep thermal gradient, the **metalimnion**, and **thermocline** (plane of temperature change). **Monomictic** lakes circulate only once per year, usually only during a

¹ Purpose of EPL Sub-group: Develop guidelines and criteria for establishment of end pit lakes in the reclaimed landscapes, with input acquired from Department of Fisheries and Oceans, Alberta Environment, Alberta Sustainable Resources, Energy Utilities Board and Environment Canada.

EPL Sub-group General Work plan: The EPL Subgroup work scope is to complete an EPL Guidance Document. The guidance document, developed from established guidelines and criteria, will provide guidance on design factors that can be addressed and critical paths related to scientific and management needs for end pit lake planning. The document will be utilized by industry and government to guide planning and research, respecting the development and management of end pit lakes. The first phase in developing the Guidance Document is to initiate three modelling reviews: meromixic, toxicity and biophysical. The end pit lake modelling began in 2003 and will be completed by 2006.

brief ice-free period, and **dimictic** lakes typically circulate twice per year in the fall and spring. For the purposes of this work plan, if the pit lake does not result in turn-over on an annual basis, the lake is considered meromictic for that year.

One-dimensional modelling (RMA10 and DYRESM) and limited two-dimensional modelling (RMA10, CE-QUAL-W2) simulations were carried out to examine meromictic potential for a large range of pit lake configurations and conditions. The pit lake scenarios selected for modelling included numerous permutations of the following parameters: 3 lake sizes (1, 4 and 8 km²), 3 lake depths (5, 20 and 50 m), 2 lake starting salinities (1 and 5 parts per thousand [ppt]), 2 inflow rates (2 and 10 million m³/yr), 3 starting inflow salinity concentrations (1, 2 and 4 ppt) and 2 rates of influent salinity reduction (6- and 28-year half-life).

The modelling showed that fall is the governing season for determining whether meromixis will occur. The expelling of salt from saline water upon ice formation (salt-rejection) and its effect on stratification potential and the effect of fresh water loading on stratification potential during spring melt events were not found to be dominant factors governing meromictic potential, at least for the scenarios examined in this study.

The following additional conclusions were reached in this study:

- Shallow (i.e., 5 m deep or less) pit lakes will turn-over with each seasonal heating/cooling cycle regardless of size, starting salinity, inflow rate, starting inflow salinity or inflow salinity reduction over time.
- Moderately deep pit lakes (i.e., 20 m deep) demonstrate a meromictic potential, at least initially, that is inversely proportional to lake size and require as a prerequisite, a high starting salinity concentration of 5 ppt. The larger pit lakes in this case (i.e., 4 km² and 8 km²) also require a higher inflow rate of 10 million m³/yr to exhibit meromixis, but the largest cannot achieve meromixis with a starting inflow concentration of 2 ppt or above.
- With a 2 or 10 million m³/yr inflow rate and a 5 ppt starting salinity, a 50 m deep pit lakes will achieve (initial) meromixis at all three size ranges for the 2 and 4 ppt inflow starting concentrations simulated, and can achieve an emergently meromictic condition for some of the 1 ppt pit lake starting concentration scenarios.
- While very small differences in predictions occurred for different rates of decreasing influent salinities, none of the conclusions for meromictic potential were influenced by these differences suggesting that for the

ranges of parameters tested in this study, rate of influent salinity decrease was less important.

- Meromixis will be a temporary condition in all of the pit lake scenarios envisioned due to a lack of a constant, positive salt replenishment over the long term. There will be an inexorable progression towards non-meromictic lakes for all scenarios given this declining salt input over time.

1.2 APPROACH

In June of 2004, after completion of the Phase I modelling report (Golder 2004), the EPL Sub-group conducted a workshop to discuss the Phase I study, its recommendations (Appendix 1), and set priorities for modelling in 2005 and beyond (Appendix 2). Golder was tasked with developing a work plan from these priorities and the Phase I study recommendations. This work plan was reviewed by the Sub-group and subsequently reviewed by Drs. Ian King and Greg Lawrence.

Notwithstanding directional collaboration of data and predictions from Beaver Creek Reservoir and Base Mine Lake models with RMA10 and DYRESM in the Phase I study, it is recognized that given the unique aspects of oil sands pit lakes (depth, size, salinity, winter duration), there are no ideal natural or pit lake analogues upon which to obtain data for calibrating pit lake models. While use of approximate analogues will continue to be used, it is accepted that at this stage of pit lake model evolution, significant reliance must be placed on comparing predictions from similarly configured but different models (as was done in the Phase I study). Given the different approaches of the universally accepted candidate models in addition to the judicious employment of conservative assumptions in light of existing uncertainties, the EPL Sub-group must be confident that this modelling will not lead to under-predictions of water quality.

Therefore the 2005/2006 modelling program will focus on the comparison of results from four models.

1.2.1 RMA

RMA10 will continue to be the primary model for water quality simulations mainly because of its multi-dimensional capability, institutional familiarity, its coupled RMA11 water quality module, and the high degree of model support offered by its developer.

1.2.2 CE-QUAL-W2

The strategy proposed in this Work Plan, is to use RMA10, CE-QUAL-W2 and DYRESM to “validate” hydrodynamic conditions in a pit lake. The models used for “validating” RMA10 results must be significantly different from RMA10.

The 2-D vertical hydrodynamics (and water quality) model CE-QUAL-W2 is maintained by WES (the U.S. Army Corp. of Engineers Waterways Experiment Station). W2 has established a well-recognized reputation as an effective and practical modelling tool for lake and reservoir hydrodynamics. CE-QUAL-W2 has an ice module.

RMA10 and CE-QUAL-W2 are both established on mathematical formulations that make use of the continuity, momentum and Navier-Stokes equations. Also, the models can be configured in 1, 2 and 3D. However, the models have other components (e.g., mixing process, ice cover module, and wind effect considerations) that differ. The first significant difference is the discretization scheme for the model domain. RMA uses the finite elements methods while CE-QUAL-W2 employs the finite difference methods. The second significant difference is the numerical schemes used by the models to establish the hydrodynamic conditions of a lake. RMA uses an implicit numerical scheme based on the Newton-Raphson optimization methods, and CE-QUAL-W2 employs an ULTIMATE algorithm, known to have negligible numerical dispersion effects. Finally, a modeller has significant latitude to vary the grid spacing and time steps used in these models and thus control potential numerical dispersion problems.

1.2.3 DYRESM

DYRESM is a well established and internationally recognized pit lake model that requires a minimal level of calibration to successfully match observed pit lake dynamics. RMA10 was used to extend the conclusions of the one dimensional, dynamic model, DYRESM in Phase I. The version of DYRESM used in this study was limited because of a lack of an ice module which necessitated an only partially successful work around. It is assumed that DYRESM will be available with an ice module later in 2005.

1.2.4 GPLM

The 0 order, steady state, Golder Pit Lake Model (GPLM) will be used to check mass balances, perform extensive sensitivity and uncertainty analyses, and predict upper and lower bounds of water quality for selected substances. In the

past this model assumed a fully mixed water column without consideration for the level and duration of stratification and the concomitant effect that may have on oxygen concentrations and hence the proportion of anaerobic and aerobic decay rates, as well as temporary or permanent substance isolation from surface layers. Under this previous configuration occasional turn-over and its affect on water quality could not be ascertained. GPLM now allows the user to specify the time-step, the elevation and duration of stratification during and after pit lake filling, and the rate of anoxic formation in the hypolimnion. With specification of substance levels and inflow rates, decay rates, frequency, duration and elevation of stratification, GPLM can now define the upper and lower bounds of water quality for various substances while at the same time maintaining its relative simplicity and conservative mass balance properties. GPLM is also now configured to complete stochastic, Monte-Carlo simulations. A description of GPLM is fully detailed in Appendix 3.

1.2.5 Conceptual Flow Chart

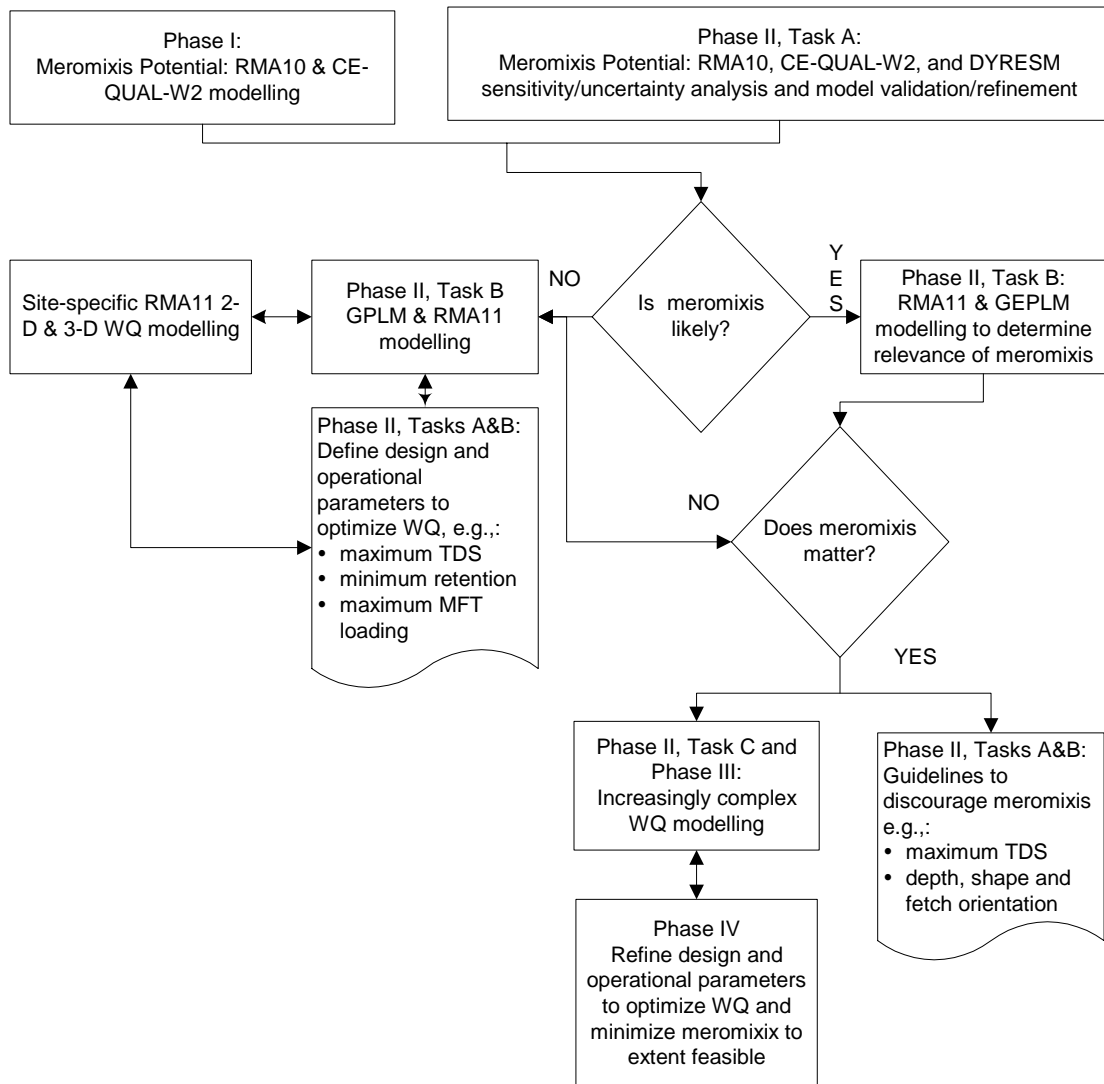
As discussed above, no pit lake exists that could be used to calibrate and model the range of pit lakes currently anticipated. The Sub-group's goal is to address two fundamental questions in Phase II:

1. Is meromixis likely to occur?
2. Will water quality be appreciably affected if meromixis did occur?

Phase I addressed question #1, and at least part of Phase II (Task A – to be described in the next section) will validate and refine the answer to this question. Whether meromixis matters appreciably to water quality will be addressed in Phase II (Task B).

If the simulated occurrence of meromixis does not appreciably affect water quality (this could hold for all situations; but is more likely to fit some proportion of pit lakes), modelling will focus on developing guidelines for optimizing water quality; focus may shift to loading scenarios. If Task B water quality modelling demonstrates that meromixis does have an appreciable bearing on water quality, modelling will continue to resolve the conditions under which it would occur and design and operational guidelines will be developed to discourage meromixis. Figure 1 conceptually illustrates this decision matrix.

Figure 1 Conceptual Pit Lake Modelling Matrix



1.2.6 Ongoing Peer Review

Another aspect of the 2005 modelling study will be the use of recognized experts in the field of lake modelling. Dr. Ian King, developer of RMA will be retained as an advisor and will review the RMA modelling. Dr. Greg Lawrence will be retained in a similar role for the DYRESM modelling.

The following sections describe the work plan for the 2005 Phase II modelling.

2 PHASE II 2005/2006 PIT LAKE WORK PLAN

In considering the recommendations from the Phase I study and the priorities set at the 2004 EPL Workshop, three tasks emerge to describe the 2005 Pit Lake work plan:

1. Task A: validate/refine existing RMA10 predictions with other models.
2. Task B: determine water quality relevance of meromixis using RMA11 and GPLM.
3. Task C: update assumptions and run new scenarios in RMA10 modelling.

A brief description of these tasks is provided below; more detailed explanations of each task immediately follow this.

The first task recognizes the importance of validating the existing Phase I model predictions to establish a solid foundation upon which subsequent modelling will be based. In the absence of data from representative oil sands pit lakes, validation confidence will be gained by comparing Phase I RMA10 model predictions to predictions from other established models. Task A will also involve completing sensitivity and uncertainty analyses.

Task B will address the role of meromixis in achieving suitable water quality, since the hypothesis that meromixis is relevant to achieving acceptable water quality has not been addressed to date.

While Phase I modelling predictions answer some key questions and define the upper bounds of stratification potential, there is a need to move towards increasingly refined modelling scenarios and predictions. Task C will see a refinement of input assumptions and additional modelling scenarios using RMA10 and CE-QUAL-W2 to achieve more accurate estimates of stratification regimes.

Given an assumed project commencement date of April 1, 2005, and a timely acquisition of DYRESM with an ice module, Task A can be accomplished by the end of October 2005, including the production of a report.

Tasks B and C may be able to proceed in parallel later in 2005 depending on budgetary constraints and the pace of work in Task A. In addition to Tasks B and C extending well into 2006, there are several recommendations in both the Phase I report and the 2004 workshop priorities that are planned for 2006. This will be known as Phase III. These include a possible calibration to other lakes;

littoral zone biological and possible 3-D modelling. However, the 2006 report will provide recommendations on a focussed Phase III program.

2.1 **TASK A: VALIDATE/REFINE EXISTING RMA RESULTS WITH OTHER MODELS**

Questions arose at the 2004 workshop and in the Phase I study about RMA10 1-D wind algorithms, fetch, the lateral dispersion coefficient used, the number of elements employed, time step selection, numerical dispersion potential, and computational efficiency. It is important that these fundamental issues be resolved and that the models and the model assumptions are validated and refined before proceeding to increasingly more sophisticated modelling. This validation should be preformed using existing model scenarios as the assumptions and the predictions represent fundamental areas of investigation (ranges of lake depths, sizes, salinity, and inflow rates) that form the foundation for future work.

A nomograph (*a chart or graph relating three or more scales across which a straightedge can be placed to provide a graphical solution for a particular problem*) illustrating the conditions that would lead to meromixis will be developed under this task. For example, the surface area to depth ratio, TDS starting concentrations, TDS influent conditions, retention time, and fetch considerations that may lead to meromixis will be defined.

There are several activities associated with Task A. The following activities will be completed (for the 4 km², 20 m depth, 10 Mm³ inflow, 2 ppt TDS starting inflow concentration using a 6 year half-life and a 5 ppt starting lake concentration):

- Complete sensitivity analysis for RMA10 started in Phase I study and address other issues raised during the workshop including:
 - Numerical dispersion
 - Lateral and vertical dispersion
 - Number of elements/dimensions
 - Effect of varying time steps
 - Computational efficiency/optimization
 - Effect of fetch (proportionally adjusting inflow volumes to achieve consistent surface layer thicknesses using a 1, and 8 km² lake size of 20 m depth)
- Set up and run RMA10, CE-QUAL-W2 and DYRESM (with ice module) using the same input parameters and assumptions for a 10-year

interval. The effort associated with this activity will mainly involve setting up CE-QUAL-W2.

- Compare the differences in the results for the different models, explain where the differences originate and resolve these differences as appropriate. Refine RMA10 assumptions if necessary.
- Conduct Study Design activities. This is a communication and an ongoing study design modification activity that is critical to an effective evolution of the kind of modelling used for this study. Elements of this activity include: meetings with the study team technical managers (Mike MacKinnon and Preston McEachern) in Calgary and Edmonton; presentations to the EPL Sub-group; discussions and communications with external reviewers; and investigations to support modelling decisions.
- Develop meromixis Nomograph.
- Prepare report.

This activity will start April 1, 2005 and be completed with a draft report by October 30, 2005.

2.2 TASK B: DETERMINE WATER QUALITY RELEVANCE OF MEROMIXIS

Appropriate effort must continue to be placed on understanding the factors that affect meromixis given the possibility that these factors may have to be controlled through design or operational modifications. However the assumption that a permanent or semi-permanently stratified pit lake water column could eventually turnover and lead to poor water quality is just that, an assumption.

Meromixis would lead to an increasingly anoxic hypolimnion retarding the degradation of organic material and maintaining cooler water temperatures, further exacerbating already slow degradation rates. Eventual turnover of such a lake could introduce poor water quality at the surface and in the discharge. However, water quality simulations could ultimately demonstrate that such an event would not seriously compromise water quality regardless of the degree of meromixis that may evolve – within currently envisioned pit lake design and operational parameters. The latter situation may be realized if the loading of substances into a lake are sufficiently low that the rate of degradation is not material to maintaining a high level of water quality.

While it is possible that bio-geochemical reactions could influence the conclusion (cannot be simulated at this stage of modelling), it may be possible to conclude

certain things, depending on the results. This investigation could contribute to our understanding of the degree of model accuracy that may ultimately be desirable.

It is desirable to simulate a high TDS meromictic scenario modelled under the Phase I study. GPLM will be similarly configured and the stratification depth, duration and aerobic/anaerobic decay rates will be “calibrated” based on the output from the RMA11 modelling. This will enable more flexible sensitivity and uncertainty analyses to be undertaken with GPLM and hence strengthen/modify conclusions reached with RMA11. Therefore (for 4 km², 20 m depth, 10 Mm³ inflow, 2 ppt TDS starting inflow concentration using a 6 year half-life and a 5 ppt starting lake concentration):

- Configure RMA11 to simulate oxygen depletion due to chemical and organic decay based on a range of ultimate chemical oxygen demand (COD) and biochemical oxygen demand (BOD) decay rates (upper and lower) to be obtained from Mike Mackinnon.
- Simulate aerobic and anaerobic decay of naphthenic acids and chronic toxicity based on the level of DO resulting from the COD and BOD decay rates applied (of naphthenic acids and chronic toxicity decay rates to be obtained from the latest EIA simulations).
- Configure and “calibrate” GPLM using the same assumptions and output from RMA11.
- Compare and contrast the results of the two models to determine the acceptability of the water quality.
- Run extensive sensitivity analysis on GPLM to quantify the largest contributing factors to change in water quality. For example, simulate upper and lower bound input concentrations of naphthenic acids, chronic toxicity, decay rates, depth and duration of stratification.

2.3 TASK C: UPDATE ASSUMPTIONS IN RMA10 MODELLING

The 2004 workshop priorities (Appendix 2) suggested configuring more realistic bathymetric profiles and running the models to simulate various filling, MFT loading, and climatic scenarios.

Phase I modelling used generic lake sizes and depths using cylindrical representations. Parabolic bathymetries for a small and a large planned pit lake will instead be used. Before proceeding with model configuration, the EPL Sub-group will approve these configurations.

The method of filling can significantly influence the level of stratification if highly saline waters are introduced through initial reclamation water fluxes and through the loading of significant volumes of MFT (reduces retention time primarily; secondarily contributes highly saline pore water). The filling stage will also have a significantly reduced wind influence, at least for some period of its filling life because of wall effects. After a pit lake is filled, basal aquifer heads will typically be lower than lake surface elevations, therefore basal water loading will be absent or negligible at that time. These influences on meromixis potential will be simulated in Task C.

The most critical period of pit lake performance will be during the first decade of operation when influent water quality and quantity will be most dynamic. The influent waters change in both quantity and quality as the pit lakes initially fill and subsequently commence releasing. Climatic conditions may have an appreciable influence during this relatively short initial period. The climate record used for the Phase I modelling may not reflect the range of climate influences that could occur. Therefore site-specific annual surface wind from the available regional weather record will be synthesized. Upper and lower bound worst-case climatology will be created. Sensitivities will be run to define upper bound and lower bounds of effects on select scenarios.

Additional lines of investigation identified in the 2004 report recommendations and the 2004 workshop priorities included addressing questions about varying salinity sources, levels, and flow rates.

In summary, the following activities will be carried out for a 10-year simulation period:

- Configure bathymetries for a small and a large planned pit lake in RMA10.
- Apply more representative TDS inflow concentrations and flow rates (based on the most recent EIA information).
- Run RMA10 and CE-QUAL-W2 to simulate the various filling scenarios, with MFT and basal water loading alternatives on the level and duration of stratification.
- Site-specific annual surface wind climatology from the available regional weather record will be synthesized. Upper and lower bound worst-case climatology will be created. Sensitivities will be run to define upper bound and lower bounds of effects on select scenarios.

All of the above influences will be considered for modifying the nomograph developed under Task A.

3 DELIVERABLES

A number of distinct deliverables will be produced from this study:

1. Validation of meromixis scenarios and sensitivity analysis;
2. Nomograph(s) interrelating the major factors influencing the development of meromixis;
3. Design and operational guidelines for pit lakes including filling guidelines, etc;
4. Fully configured models;
5. Draft and final reports;
6. Recommendations on a focussed Phase III program.

4 REPORTING

There are several aspects to reporting for the Task A modelling study.

Brief monthly email progress reports will be submitted on behalf of the study team to the EPL Sub-group study project manager.

Drs. King and Lawrence will be consulted at each stage of model set-up and runs. Fully configured models will be provided for their review.

Task A will be presented in a draft report to the Sub-group October 30, 2005. The report will be finalized December 15, 2005. Tasks B and C will proceed depending on budget availability in 2005 and extend to the summer of 2006.

5 FLOWCHART

Figure 2 Work Plan Flow Chart

KEY INVESTIGATIVE AREA	MODELLING AND REPORTING			COMMENTS	Timeline
PHASE II, Task A: Validate/Refine Existing RMA Results with Other Models	RMA10	CE-QUAL-W2	DYRESM	Scenario used for all comparisons: 4 km ² , 20 m depth, 10 Mm ³ inflow, 2 ppt TDS starting inflow concentration using a 6 year half-life and a 5 ppt starting lake concentration based on most detailed Phase I model results	Apr-05
	RMA10 Sensitivity Analysis	Compare results and resolve discrepancies		Complete sensitivity analyses focusing on lateral & vertical dispersion; numerical dispersion, etc. sensitivity to varying fetch configurations	Oct-05
PHASE II, Task B: Determine Water Quality Relevance of Meromixis	RMA11 based on above parameters for selected water quality parameters	Sensitivity & uncertainty analysis	GPLM using same input parameters	BOD/COD decay; chronic toxicity; naphthenic acids; aerobic and anaerobic conditions. Compare to GPLM results.	Dec-05
		Compare results		Test sensitivity of varying stratification on results. Run MFT placement scenario if budgetary constraints.	Feb-06
					May-06
PHASE II, Task C: Update Modelling Assumptions	RMA10 and CE-QUAL-W2 Update	Sensitivity & uncertainty analysis	GPLM using same input parameters	Apply parabolic Pit Lake configuration which achieves identical volume, surface area and depth for each model	Dec-05
				Effect of varying climatic conditions: create synthetic climate record that would maximize the potential for stratification during first critical 10 year discharge period.	Feb-06
				Effect of TDS concentrations in the 1000 mg/L range: based on inflows predicted for EIA planned Pit Lake; Evaluate MFT Influx of TDS; Evaluate basal influx of TDS; Examine effect of filling on stratification potential at discharge.	Apr-06
		Compare results and resolve discrepancies		Examine the effect of wind by evaluating varying fetch configurations if the answer to this question is relevant based on findings from Task A and above Task B work.	Jun-06
Reporting	Draft and final reports	October 30, 2005 PHASE II, Task A Draft Report; December 1, 2005 Final Report		Prepare and submit Task A draft and final reports to EPL Sub-group on October 15, 2005 and December 1, 2005, respectively.	01/10/2005; 01/12/05
		June 30, 2006 PHASE II, Tasks B&C Draft Report		PHASE II Tasks B&C draft and final reports submitted to EPL Sub-group June 30, 2006 and September 30, 2006, respectively.	30/06/2006; 30/09/06

6 REFERENCES

Golder Associates Ltd. 2004. Modelling Assessment of End Pit Lakes Meromictic Potential. Submitted to CEMA EPL Sub-group.

APPENDIX 1
RECOMMENDATIONS IN PHASE I STUDY

APPENDIX 1 RECOMMENDATIONS IN PHASE I STUDY

The following tasks and/or areas of focus are recommended for the next phase of modelling:

- A limited investigation was undertaken to examine the effect of model time-step and horizontal element (grid) size changes to quantify the potential influence of horizontal processes, numerical dispersion and computational cost. A more comprehensive element (vertical layers and 2-D expansion) and time-step optimization study should however, be further explored as a follow-up activity in the next phase of modelling. While the current conclusions are felt to be robust enough to withstand differences in predictions based on such future optimization, this activity would enable a higher degree of confidence in future predictions. This enhancement may be particularly important when trying to distinguish more subtle changes associated with more refined assumptions (e.g., smaller differences in concentrations and flows).
- Prepare 2-D and 3-D bathymetric profiles for EPL Sub-group review and subsequent 2- and 3-D simulations.
- Extend the 1-D RMA10 to 2-D RMA10 modelling for key scenarios to include the updated model optimizations and to examine the differences that may emerge with 2-D modelling.
- It is likely that the most critical period of pit lake performance will be during the first decade of operation when influent water quality and quantity will be most dynamic. The influent waters change in both quantity and quality as the pit lakes initially fill and subsequently commence releasing. Climatic conditions that may have an appreciable influence during this relatively short initial period may not be reflected in any one consecutive 5- or 10-year period in the climatic record. Synthesize site-specific annual surface wind climatology from the available regional weather record for EPL Sub-group review. Create upper and lower bound worst-case climatology. Run sensitivities to define upper bound and lower bounds of effects on select scenarios.
- Pit lake dimensions, salinity concentrations and inflow rates presented in the most recent EIAs were compared to the parameters considered in this study. An examination of these parameters suggests that the next phase of modelling may want to be focused on lower lake starting salinities, lower influent water salinities and higher inflow rates.
- Calibrate the RMA10 model to an existing, similar Alberta lake or reservoir.
- Prepare a list of substances to model for the next phase of modelling for EPL Sub-group review; include decay coefficients under anaerobic and anaerobic conditions, adjusted for temperature.

- Extend the 2-D RMA10 to 2-D RMA11 to include basic water quality parameters (e.g., chronic toxicity, naphthenic acids, and possibly DO).
- Examine the effect of pit lake filling on stratification.
- Extend the modelling to 3-D for select periods to better simulate the effect of varying bathymetric conditions and in particular littoral zones, short-circuiting (inlet and outlet pathways as well as the effect on hydraulic retention for influent waters).
- Simulate MFT/CT/TT pore water release from the bottom of pit lakes to examine salinity dynamics from this source and to evaluate its role in strengthening and prolonging stratification and meromictic conditions in deeper pit lakes.

Appropriate effort must continue to be placed on understanding the factors that affect meromixis given the assumption that these factors may have to be controlled through design or operational modifications. However it is very important to keep in mind that this potential need for limiting permanent or semi-permanent stratification is only an assumption. Future water quality simulations could demonstrate that such control is not necessary and that water quality could be maintained regardless of the degree of meromixis that may evolve. The latter situation may be realized if the loading of substances into a lake are sufficiently low that the rate of degradation or dilution is not material to maintaining a high level of water quality.

It is ultimately important that the physical factors affecting pit lake hydrodynamics are as accurately represented in the RMA10 model as possible, because aside from the importance of stratification and its potential affect on water quality, all developers will eventually be required to demonstrate that their specific pit lakes will be able to achieve appropriate end land uses and be able to attain acceptable water quality upon initial and extended discharge. Such site-specific assessments will require a refined model.

While the accurate simulation of water quality is dependent on an accurate RMA10 model, it is likely appropriate even at this stage in the modelling to consider evaluating one or two key water quality parameters using RMA11 under select meromictic and non-meromictic scenarios to begin to evaluate the level of concern associated with meromixis or the degree of model accuracy that may be ultimately desirable. Therefore, the following steps should be considered in parallel to the above recommended work:

- Select a single EIA pit lake but represent its bathymetric profile only approximately using the same approach as in this study (e.g., cylindrical representation), but achieving exactly the same proposed volume.

- Consider two water quality parameters to simulate in conjunction with the EPL Sub-group (possibly chronic toxicity and naphthenic acids).
- Simulate identical inflow rates and parameter concentrations as represented in the EIA for the pit lake in question.
- Simulate two RMA11 scenarios that will result in annual dimictic and annual meromictic (with eventual turn-over in say 8 years) conditions.
- Evaluate the output to contrast the results and to determine the acceptability of the water quality.
- Compare the results to the EIA steady-state model results to determine the relative differences.

APPENDIX 2
PRIORITIES FROM JUNE 2004 WORKSHOP

APPENDIX 2 PRIORITIES FROM JUNE 2004 WORKSHOP:

- 1) *Examine filling process*
 - *Model different time sequences (inflow rates and concentration of inflows)*
 - *Use both models (1D mode)*
 - *Do this with and without bottom deposits (30 to 300 Mm³ of tails)*
 - *Consider heat content and transfer from MFT (12 – 15°C)*

- 2) *Deal with impact of salt from bottom deposits*
 - *Try this in zero dimension first*
 - *Do this in 1D mode*
 - *Use both RMA10 and DYRESM*

- 3) *Repeat 1 and 2 for water quality*

- 4) *Look at impact of shape (2D) in relative length and width vs. depth*
 - *Base this on plan views of the Pit Lakes. Typical is 1x1 to 2 x 1 and 4 to 8 km typical size*
 - *Sensitivity analysis to mixing parameters used.*

- 5) *Constraints for littoral zone*
 - *Propose what should be done for a potential phase 3 (scope of work for biological and possible 3D modelling)*
 - *Percent of lake area (3 to 25%)*
 - *Examine impacts on physics and quality*

- 6) *Test cases*
 - *Identify sites with similar meromictic characteristics (e.g., Equity, Faro, Colomac).*
 - *Simulate if appropriate using both models*

- 7) *Climatology*
 - *Evaluate current climate record and determine representative conditions*
 - *Evaluate potential climate change impacts*

- 8) *Ice characteristics*

Ensure models can capture ice dynamics

APPENDIX 3
GOLDER END PIT LAKE MODEL

APPENDIX 3 GOLDER END PIT LAKE MODEL

3.1 PIT LAKE (PL) DESCRIPTION

When the last economically-viable oil sands deposits have been removed within a sub-watershed for an oil sands operation, the final mine pit will become a pit lake. Overburden, tailings and other solid materials will be placed in the pit. The lake itself is formed from remaining process water, CT flux water, precipitation, and surface runoff from the reclaimed landscape and surrounding undisturbed areas (Figure A3-1). The majority of chemicals in the pit lake will originate from tailings deposited in the lake and seepage from reclaimed areas. Flux from tailings occurs as the materials that have been placed in the pit lake consolidate and release pore water. Seepages from the surrounding landscape migrate with subsurface flow and enter the pit lake directly or after some residence time in a reclaimed wetland.

Time-dependent water quality in the pit lake was predicted using a flow and mass balance model. Inflows included surface runoff, Athabasca River water, tailings flux waters, precipitation and seepages from tailings sand, surficial groundwater, basal water, external tailings area and in pit areas. Water from tailings flux was estimated for Consolidated Tailings (CT), Non-segregated Tailings (NST), Mature Fine Tailings (MFT) and Thickened Tailings (TT) release water and for CT pond water. The model accounted for water loss through evaporation, and lake outflow volumes were assumed to be equal to net inflows after the lake had filled up.

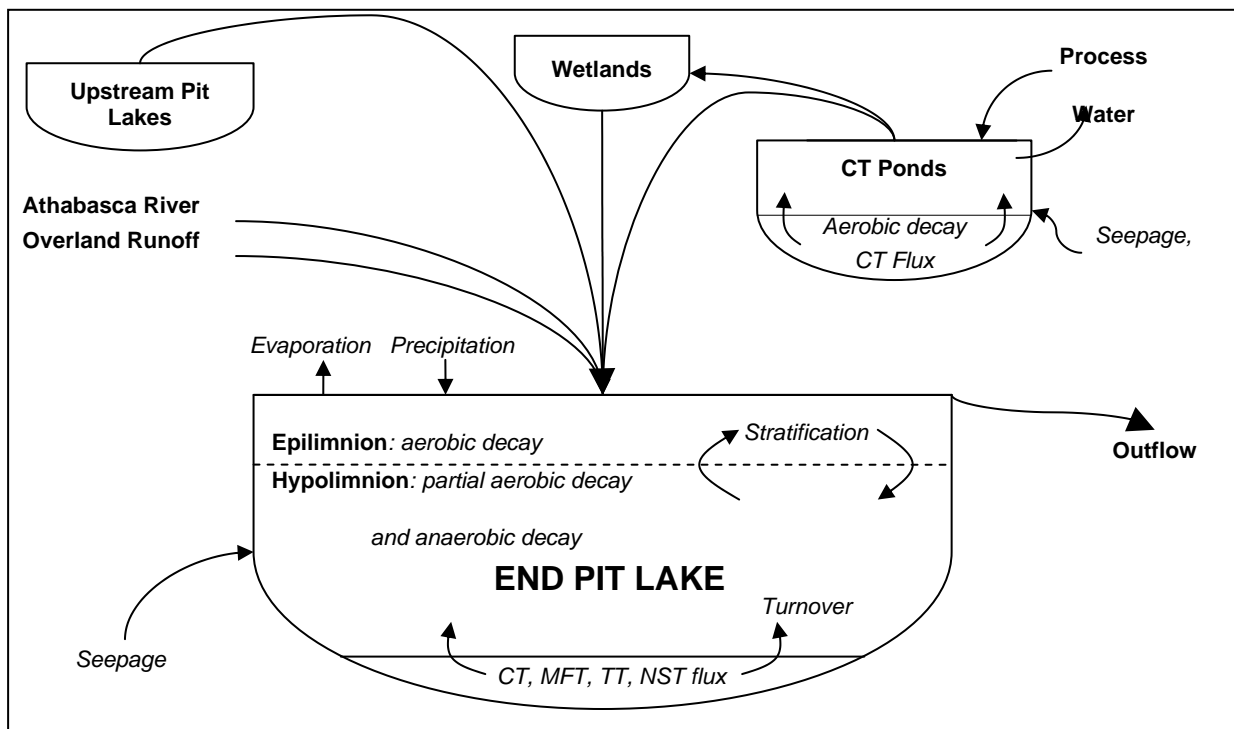
Due to the large size of the pit lake and consequently long residence time, mean annual flows and substance loads were used for continuous simulation of substance concentrations over the life of the Project and beyond to the far-future. The long residence time makes the pit lake less sensitive to short-term variability of inflow loads; substance concentrations of these lakes are dependent on long-term average loading.

A pit lake is designed to support a viable aquatic ecosystem, with a vegetative zone around the perimeter of the lake. A combination of atmospheric re-aeration and biological activity in the surface layer (the epilimnion) will maintain dissolved oxygen levels and improve the natural biodegradation of organic chemicals released through mine activities.

3.1.1 Stratification and Turnover

Because the pit lake is quite deep, it can become stratified for periods of time if a vertical density gradient is established between the epilimnion and the deeper layer of water (the hypolimnion) due to salinity or thermal differences. When the pit lake is stratified, water from tailings materials at the bottom of the lake will be isolated from the surface waters. If oxygen is consumed before the pit lake turns over, some of these chemicals will degrade more slowly in the hypolimnion. Lakes turn over when wind action or convective mixing energy overcomes density gradients and the vertical layers mix. This typically occurs in spring or fall. Turnover has the beneficial effect of replenishing oxygen to the hypolimnion, which accelerates degradation, but it also introduces the poorer quality waters from the hypolimnion to the epilimnion, and therefore to the lake outflow. Consequently, the concentration of certain chemicals in the outflow is expected to rise after each lake turnover.

Figure A3-1 End Pit Lake Conceptual Model



When the pit lake is stratified, the transfer of chemicals between layers is minimal. Thus, the accumulation and degradation of chemicals depends on which layer they enter and the turnover frequency. For example, seepages and within-lake tailings fluxes will enter the hypolimnion, where they will typically

degrade more slowly. Conversely, surface runoff and wetlands outflows will enter the epilimnion, where some of the toxic substances will degrade relatively quickly. Degradation will further improve if the substances pass through a series of wetlands and multiple pit lakes.

3.1.2 Model Overview

The pit lake model simulates the accumulation and degradation of chemicals as they pass through the system described above. It calculates the mass balance for the volume of water and the mass of substances. Model inputs include volumes and concentrations for the source waters described in Figure A3-1. The model incorporates the processes of tailings consolidation, water recycling, aerobic and anaerobic decay, lake stratification and turnover, hypolimnetic oxygen depletion, and groundwater seepage and attenuation. Model outputs include pit lake volume, outflow discharge rate, and outflow concentration at the end of each three-month timestep.

3.1.2.1 Mass Balance

A mass balance equation was applied to each substance in the pit lake, including organic compounds, metals, nutrients, major ions, whole effluent toxicity and fish tainting. During periods of complete vertical mixing (lake turnover), pit lake outflow concentrations were estimated for each substance as follows:

$$C_{oi} = \frac{M_i}{V_i} \quad (1)$$

where,

C_{oi} = concentration in outflow at end of timestep 'i' ($\text{g}\cdot\text{m}^{-3}$)

M_i = mass of substance in entire lake at end of timestep 'i' (g)

V_i = water volume in entire lake at end of timestep 'i' (m^3)

During periods of stratification, concentrations and processes are calculated separately for the epilimnion and hypolimnion and outflow is based on epilimnion concentrations.

The mass loading of substances into each layer was defined as follows:

$$L_{ri} = t \sum_{k=1}^n C_{ki} Q_{ki} \quad (2)$$

where,

L_{ri} = mass loading into layer r during timestep 'i' (g)

t = length of timestep (y)

C_{ki} = concentration of substance in source water 'k' during timestep 'i'
($g \cdot m^{-3}$)

Q_{ki} = discharge (inflow) of source water 'k' during timestep 'i' ($m^3 \cdot y^{-1}$)

The volume of water in each layer was estimated as follows:

$$V_{ri} = V_{ri-1} - Q_{ori}t + t \sum_{k=1}^n Q_{ki} \quad (3)$$

where,

V_{ri} = volume of water present in layer 'r' at end of timestep 'i' (m^3)

V_{ri-1} = volume of water in layer 'r' at end of timestep 'i-1' (m^3)

Q_{ori} = outflow leaving layer 'r' at timestep 'i' ($m^3 \cdot y^{-1}$)

Loadings into the epilimnion included runoff from the following sources:

- overland release of CT, NST and TT waters from reclaimed land areas;
- direct transfer of process-affected water from tailings and CT ponds;
- overland runoff;
- water from Athabasca River and other streams; and
- flux from the hypolimnion.

Mass and volume loadings into the hypolimnion included mine-related water releases from the following sources:

- seepages from tailings ponds, tailings sand, surficial groundwater, basal water, waste overburden, external tailings area and in pit areas; and
- MFT, CT, NST and TT flux from tailings material deposited in the pit lake.

Seepage sources are assumed to have a constant discharge while the lake is filling, then a lower constant discharge once the lake is filled and the hydraulic gradient between seepage sources and the pit lake decreases.

3.1.2.2 Chemical Degradation

Since compounds are continuously entering the lake during this period, time-averaged decay rates are used for substances during the timestep in which they enter the pit lake. The mass of each substance in the epilimnion was determined by:

$$M_{ei} = \frac{(L_{ei} + M_{ei-1}e^{-k_o t}) + (L_{ei}e^{-k_o t} + M_{ei-1}e^{-k_o t})}{2} - M_{oi} \quad (4)$$

where,

- M_{ei} = mass of substance in epilimnion at end of timestep 'i' (g)
- L_{ei} = mass loading of substance into epilimnion from all sources during timestep 'i' (g)
- M_{ei-1} = mass of substance in epilimnion at end of timestep 'i-1' (g)
- M_{oi} = mass of substance in outflow during timestep 'i' (g)
- k_o = aerobic first-order decay constant (y^{-1})

The mass of each substance in the hypolimnion was determined by:

$$M_{hi} = D_i \frac{(L_{hi} + M_{hi-1}e^{-k_o t}) + (L_{hi}e^{-k_o t} + M_{hi-1}e^{-k_o t})}{2} + (1 - D_i) \frac{(L_{hi} + M_{hi-1}e^{-k_a t}) + (L_{hi}e^{-k_a t} + M_{hi-1}e^{-k_a t})}{2} \quad (5)$$

where,

- M_{hi} = mass of substance in hypolimnion at end of timestep 'i' (g)
- D_i = fraction of hypolimnion that is oxygenated at end of timestep 'i'
- L_{hi} = mass loading of substance into hypolimnion from all sources during timestep 'i' (g)
- M_{hi-1} = mass of substance in hypolimnion at end of timestep 'i-1' (g)
- k_a = anaerobic first-order decay constant (y^{-1})

3.1.2.3 Oxygen Depletion

When the pit lake becomes stratified, aerobic decay of chemical and organic matter can result in oxygen depletion in the hypolimnion. Consequently, the decay processes in the hypolimnion will shift from aerobic to anaerobic over time. Therefore, the model estimates degradation using aerobic rates during lake turnover and anaerobic rates after oxygen is depleted in the hypolimnion. During periods of oxygen depletion, an intermediate rate that is proportional to the time elapsed since the previous turnover is applied. The oxygenated fraction of the

hypolimnion (D_i) was assumed to be one during periods of vertical mixing, then linearly decrease throughout the oxygen depletion time, then remain at zero until the next turnover.

3.1.2.4 Tailings Consolidation

The most significant source of many compounds was expected to be flux from tailings deposited directly into the pit lake. The model estimates the volume of flux from MFT, CT, NST and TT assuming a first-order consolidation rate of the tailings once they are placed inside the lake. The volume of water entering the pit lake from each tailings placement is the difference in tailings volume from the previous timestep, calculated as follows for each tailings source:

$$V_{fi} = V_{ci-1} - V_{ci-1} e^{-k_c t} \quad (6)$$

where,

V_{fi} = volume of flux from tailings source during timestep 'i' (m^3)

V_{ci-1} = volume of tailings at end of timestep 'i-1' (m^3)

k_c = consolidation rate constant (y^{-1})

3.1.2.5 MFT Decay

All flux water concentrations were assumed to be constant over the modelled timeframe except for MFT release water, in which degradable substances are expected to undergo anaerobic decay. Consequently, first-order anaerobic decay rates were applied to MFT release water concentrations throughout the modelled timeframe, as follows:

$$C_{fi} = C_0 e^{-k_a t} \quad (7)$$

where,

C_{fi} = concentration of substance in MFT flux at end of timestep 'i' ($g \cdot m^{-3}$)

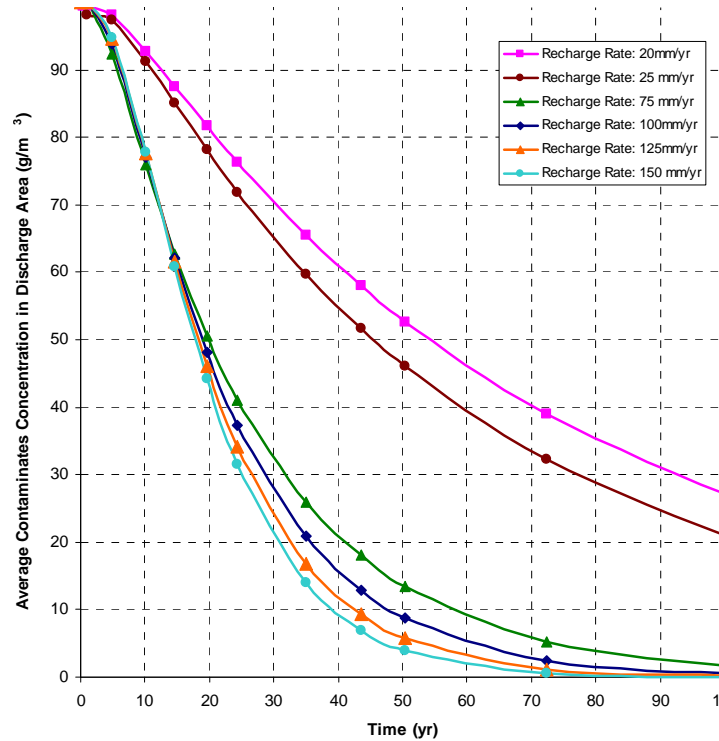
C_0 = initial concentration of substance in MFT flux ($g \cdot m^{-3}$)

3.1.2.6 Loading from Reclaimed Land Areas

The mine landscape will be reclaimed in a sequence of cells, and each cell will include wetlands to provide initial treatment to the water prior to entering the pit lake. The main inputs to the wetlands will be flux from reclaimed CT pits, recharge from subsurface flow, and overland runoff. CT flux was calculated for

individual placements using the consolidation equation (6). Input from subsurface water entering the cells was estimated using attenuation rates modelled separately in SEEP/W (Yuxing Xiao Memo; Figure A3-2).

Figure A3-2 Seepage Constituent Attenuation ($K = 5 \times 10^{-6} \text{ m}\cdot\text{s}^{-1}$)



Once the subsurface water and CT flux reaches the reclaimed wetland, aerobic decay is expected to occur during ice-free periods. Therefore, first-order decay rates (7) were applied to concentrations within the cells during the second and third quarter of each year. Because the water in these cells is recycled as process water, discharge from these ponds into the pit lake was assumed to be zero until the cell is reclaimed.

3.1.2.7 Upstream Pit Lakes

To further improve the quality of water entering the receiving environment, pit lakes can be linked in sequence. The model accepts model output from upstream pit lake as direct inputs.

3.1.3 Model Application

Project specific.

3.1.4 Model Assumptions

3.1.4.1 Water Quality

Water quality profiles were developed for each inflow using available water quality information and mean values from the resulting distributions. Selected water quality profiles are summarized in Table A3-1. The water quality profile for the Athabasca River inflow was developed using available water quality data collected from the Athabasca River between the Muskeg and Steepbank rivers. The water quality profile for surface runoff was developed using available water quality data collected from local streams corresponding to undisturbed or reclaimed land areas draining into the pit lake. Each source water profile was generated using a standardized screening process that removed outliers and identified an appropriate probability distribution for each substance.

3.1.4.2 Decay Rates

Decay rates were incorporated for some substances within the pit lake water column because of the long residence time. The model incorporated decay of sulfide, ammonia, organic substances and their associated acute and chronic toxicity and tainting potential of process affected waters.

3.1.4.3 Consolidation Rates

The consolidation rates used for CT are based on consolidation observed by mine planners. As a measure of conservatism, CT flux volume was estimated using the following assumptions and boundary conditions:

- CT deposits take seven years for nearly complete consolidation;
- CT deposits will undergo a 3% porosity change during the first seven years of consolidation;
- CT deposits undergo an additional 1% porosity change in the following 100 years;
- consolidation starts in the timestep in which CT is added to the in-pit deposit; and
- CT water quality was assumed to remain constant during movement through reclamation wetlands;

The potential influence of TT flux waters on surrounding surface waters was assessed using the following assumptions and boundary conditions:

- TT deposits take 100 years for complete consolidation;
- TT deposits will undergo a 9% porosity change during consolidation;
- consolidation starts in the timestep in which TT is added to the in-pit deposit; and
- TT water quality is assumed to remain constant during movement through reclamation wetlands.

The potential influence of MFT flux waters on surrounding surface waters was assessed using the following assumptions and boundary conditions:

- initial deposits of MFT are similar in character to aged MFT;
- MFT placed into the East Pit Lake will continue to consolidate at 0.0074 units/y for the first 20 years, and at a rate of 0.0046 units/y after that (from EMA 1993); and
- substances in MFT flux are assumed to attenuate at anaerobic rates.

3.1.5 Model Calibration and Validation

The end pit lakes to be modelled in the EIA are not currently constructed; therefore, there is no observed data for calibration and validation. However, the model predictions are based on a well-established mass balance equation and measured parameters. The predicted concentrations are strongly dependent on mass loadings. Because it is impossible to conduct model calibration and validation, sensitivity of model predictions to input loadings of important water quality constituents will be performed as discussed earlier. These constituents will include whole effluent toxicity, naphthenic acids and substances predicted to have concentrations close to guideline or threshold values.

3.1.6 Sensitivity Analysis

Sensitivity analyses were conducted by running simulations using acute and chronic toxicity concentrations under a range of values for key variables. The specific values used for sensitivity analysis were as follows: hypolimnetic oxygen depletion rates of zero to eight years, epilimnion depths of two to eight meters and vertical mixing frequencies including amictic, monomictic, dimictic, biannual and unstratified.

Table A3-1 Water Chemistry for Various Pit Lake Input Waters

Water Type	Units	Muskeg OB	CT	Sand Seepage	Surficial Ground Water	Basal Water	Tailings Water	Athabasca River Spring	Runoff	NST	TT Water	Pit Lake	MFT	Other
Aluminum	mg/L	0.265	0.13	0.314	0.265	0.0142	6.79	1.54	0.0672	0.13	0.13	0.13	6.79	0.0672
Ammonia	mg/L	0.206	1.77	2.6	0.206	1.92	5.83	0.0217	0.0244	1.77	1.77	1.77	5.83	0.0244
Antimony	mg/L	0.000188	0.00148	0.000153	0.000188	0.000246	0.00502	0.000118	0.00026	0.00148	0.00148	0.00148	0.00502	0.00026
Arsenic	mg/L	0.00131	0.00399	0.00231	0.00131	0.00153	0.0133	0.0012	0.000991	0.00399	0.00399	0.00399	0.0133	0.000991
Barium	mg/L	0.164	0.0875	0.0902	0.164	1.7	0.127	0.0811	0.0522	0.0875	0.0875	0.0875	0.127	0.0522
Boron	mg/L	0.108	2.65	1.73	0.108	4.19	1.13	0.0296	0.103	2.65	2.65	2.65	1.13	0.103
Cadmium	mg/L	0.000387	0.00112	0.0029	0.000387	0.000343	0.0227	0.000072	0.000286	0.00112	0.00112	0.00112	0.0227	0.000286
Calcium	mg/L	78.9	96.2	30.8	78.9	210	6.04	35.1	50	96.2	96.2	96.2	6.04	50
Chloride	mg/L	4.08	57.7	61.5	4.08	15300	62	3.7	18.1	57.7	57.7	57.7	62	18.1
Chromium	mg/L	0.0029	0.00208	0.00134	0.0029	0.0178	0.0287	0.0046	0.00206	0.00208	0.00208	0.00208	0.0287	0.00206
Conductivity	µS/cm	569	2530	1870	569	27000	1430	257	425	2530	2530	2530	1430	425
Copper	mg/L	0.00198	0.00299	0.00424	0.00198	0.00216	0.0264	0.0042	0.00152	0.00299	0.00299	0.00299	0.0264	0.00152
Dissolved Organic Carbon	mg/L	13.1	48	33.6	13.1	6.79	58.6	10.8	28.6	48	48	48	58.6	28.6
Iron	mg/L	2.17	0.231	1.19	2.17	0.0777	1.76	3.3	1.28	0.231	0.231	0.231	1.76	1.28
Lead	mg/L	0.00175	0.00871	0.0102	0.00175	0.000918	0.0514	0.00279	0.00062	0.00871	0.00871	0.00871	0.0514	0.00062
Magnesium	mg/L	20.6	27.3	13	20.6	222	4.72	8.32	17.8	27.3	27.3	27.3	4.72	17.8
Manganese	mg/L	0.381	0.0338	0.149	0.381	0.119	0.069	0.0996	0.0513	0.0338	0.0338	0.0338	0.069	0.0513
Mercury	mg/L	0.0000273	0.0000571	0.000025	0.0000925	0.00005	0.000065	0.000021	0.000004	0.0000571	0.0000571	0.0000571	0.000065	0.000004
Molybdenum	mg/L	0.00232	0.672	0.00232	0.00232	0.000787	0.0951	0.000129	0.000403	0.672	0.672	0.672	0.0951	0.000403
Naphthenic Acids	mg/L	0.917	67.5	54.1	0.917	19.5	97.9	0.00147	0.425	67.5	67.5	67.5	97.9	0.425
Nickel	mg/L	0.00541	0.0194	0.00256	0.00541	0.00603	0.055	0.00778	0.00221	0.0194	0.0194	0.0194	0.055	0.00221
Potassium	mg/L	2.95	21.4	8.5	2.95	56.8	13.9	1.73	2.72	21.4	21.4	21.4	13.9	2.72
Selenium	mg/L	0.000471	0.00135	0.000294	0.000471	0.00837	0.00765	0.000172	0.000246	0.00135	0.00135	0.00135	0.00765	0.000246

Water Type	Units	Muskeg OB	CT	Sand Seepage	Surficial Ground Water	Basal Water	Tailings Water	Athabasca River Spring	Runoff	NST	TT Water	Pit Lake	MFT	Other
Silver	mg/L	0.000055	0.00015	0.00015	0.00115	0.0003	0.000267	0.0000198	0.00001	0.00015	0.00015	0.00015	0.000267	0.00001
Sodium	mg/L	35.5	466	474	35.5	9520	324	10.3	32.3	466	466	466	324	32.3
Strontium	mg/L	0.218	1.59	0.228	0.218	11.3	0.371	0.216	0.151	1.59	1.59	1.59	0.371	0.151
Sulphate	mg/L	7.74	742	30.6	7.74	467	196	23.5	25	742	742	742	196	25
Sulphide	mg/L	0.0222	0.00578	0.00512	0.0222	9.86	1.44	0	0.0106	0.00578	0.00578	0.00578	1.44	0.0106
Total Dissolved Solids	mg/L	457	1690	1330	457	26600	1250	175	289	1690	1690	1690	1250	289
Total Nitrogen	mg/L	1.62	2.63	7.72	1.62	2.83	13.3	0.74	1.63	2.63	2.63	2.63	13.3	1.63
Total Phenolics	mg/L	0.00304	0.00478	0.00222	0.00304	0.0217	0.378	0.00383	0.00502	0.00478	0.00478	0.00478	0.378	0.00502
Total Phosphorus	mg/L	0.113	0.028	0.219	0.113	0.461	0.0736	0.257	0.138	0.028	0.028	0.028	0.0736	0.138
Vanadium	mg/L	0.00169	0.0159	0.00601	0.00169	0.0517	0.0338	0.00528	0.000702	0.0159	0.0159	0.0159	0.0338	0.000702
Zinc	mg/L	0.0369	0.0273	0.0594	0.0369	0.024	0.0956	0.0134	0.0156	0.0273	0.0273	0.0273	0.0956	0.0156
Fish Health Index	FHI	0	33.3	33.3	0	0	33.3	0	0	33.3	33.3	33.3	33.3	0
Acute Toxicity	TUa	0	1.54	2.11	0	1.29	11	0	0	1.54	1.54	1.54	11	0
Chronic Toxicity	TUc	0.564	5.17	4.22	0.564	29.3	25.3	0	0	5.17	5.17	5.17	25.3	0
Beryllium	mg/L	0.000521	0.000815	0.00154	0.000521	0.000486	0.00287	0.00032	0	0.000815	0.000815	0.000815	0.00287	0
Benzo(a)anthracene	µg/L	0.00346	0	0	0	0	0.102	0	0	0	0	0	0.102	0
Benzo(a)pyrene	µg/L	0.00118	0	0	0	0	0.256	0	0	0	0	0	0.256	0
Total PAHs	µg/L	0.485	0	0	0	0	4.51	9	0	0	0	0	4.51	0
Monomer	mg/L	0	0	0	0	0	0	0	0	0	0.01	0	0	0
Polymer	mg/L	0	0	0	0	0	0	0	0	0	35	0	0	0
Tainting Potential	TPU	0	100	100	0	0	1000	0	0	100	1000	100	1000	0