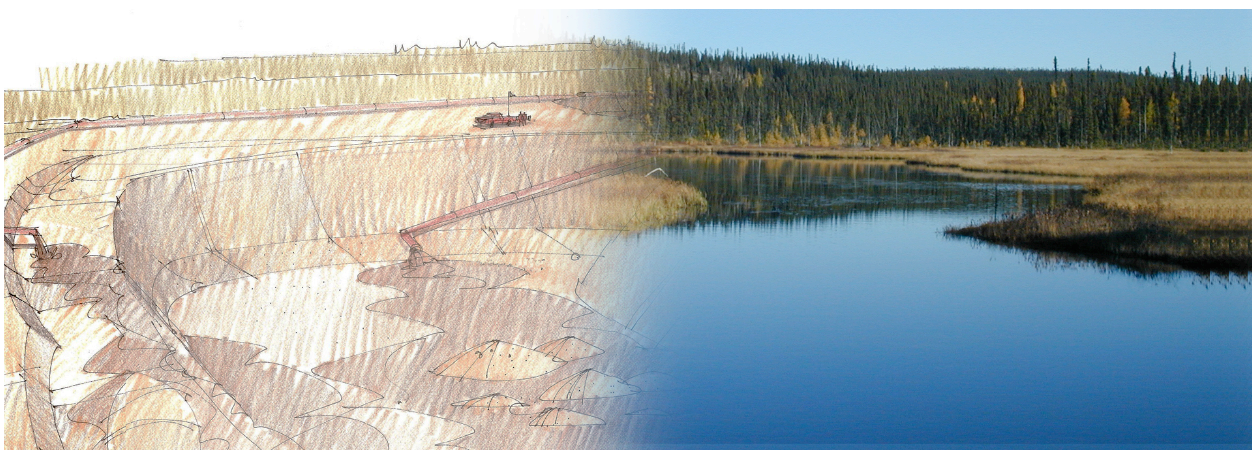
END PIT LAKES GUIDANCE DOCUMENT

2012



CUMULATIVE ENVIRONMENTAL MANAGEMENT ASSOCIATION

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PREFACE

End pit lakes (EPLs) have been proposed as permanent features of the final reclaimed landscape in the mineable oil sands region. No oil sands end pit lake currently exists, but about 30 are proposed. This document presents the scientific and engineering expertise to guide all reclamation activities associated with EPL design and construction. It provides practical technical guidance and supporting tools to be used by industry, specifically an interdisciplinary team of operational managers, mine planners, landform engineers and designers. It is also intended to be used as a primary reference by government regulators charged with overseeing the oil sands and designers of research and monitoring programs. It should be used in conjunction with other guidance documents involving oil sands reclamation. CEMA has produced similar guidance documents for wetlands, soils, revegetation, and riparian areas.

The objectives of EPLs as determined by stakeholders, operators, and government are covered in Chapter 2 and addressed as design criteria in Chapter 8. The experiences of coal, quarry, and metal mines with pit lakes, which operators and government regulators believe can be adapted to the oil sands to meet those objectives, are explored in Chapter 3. The chemistry, geography, and ecology that will determine the basic parameters and the future trajectory of each EPL can be found in Chapters 4, 5, and 6. Designers can find the full 100-year timeline and drivers for a typical EPL project in Chapter 7. Construction and operation are detailed in Chapter 9. When combined with good design and modelling, this Guide should provide enough information to create a conceptual-level EPL design, for collective management in the future.

Figure P-1: A futuristic look at EPLs in the oil sands.

Activity	Approximate Year of Project Timeline																									
	-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
Pre-mining lease development	●	●	●	●	●																					
Planning, design and construction teams	●	●	●	●		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Design stages			●	●				●	●	●					●					●	●	●	●	●	●	
Mine operations						●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Commissioning																			●					●	●	●
Operations, maintenance and certification																										
Modelling	●	●	●					●	●	●				●	●				●	●			●	●	●	●
Monitoring	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Activity	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
Pre-mining lease development																									
Planning, design and construction teams	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●					
Design stages																									
Mine operations	●																								
Commissioning		●	●	●	●																				
Operations, maintenance and certification		●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Modelling	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●								
Monitoring	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●

Figure P-2: EPL project timelines. A more detailed version is found as Table 7-2 in Chapter 7.

No definitive instruction manual exists for oil sands EPLs. The timelines outlined in the table above (and explored in more detail in Table 7-2) are only approximations for a typical EPL. Each project will involve its own challenges and present unique opportunities for integration into the greater watershed. It is not realistic, nor is it expected, that all EPLs will meet all objectives, at least not simultaneously. Oil sands operators will have to choose which objectives take priority, and in which order, as the century-long process unfolds. Engineering flexibility, within the statutory requirements of their leases, is the recurring theme.

However, the activities in the table above will be part of each EPL project. This is a technical *guidance* document, one that provides the information, direction, and the advice that the planners and engineers who will be responsible for turning about 30 pits into functioning, healthy aquatic ecosystems will require to carry out those activities. It draws on the latest scientific research and relevant experience from other mining sectors. It lays out the general principles behind EPL reclamation in the oil sands and explores the myriad considerations and challenges that each lake will pose. It is not an inviolable rulebook that must be followed to the letter. Indeed, the appendices on knowledge gaps and adaptive management techniques are in many ways just as valuable as the chapters devoted to design and construction.

The authors and editors have taken every effort to ensure the information in this document is accurate, up to date, and useful. The editorial process drew on a degree of collaboration and multidisciplinary cross-pollination that we hope will set a new standard. Government, non-government, and Aboriginal stakeholders were involved from the outset. Independent experts reviewed every chapter. But the science of EPLs – and the regulations that govern their construction and management – will continue to evolve. This document is intended to provide a base of knowledge, and direction, for EPL design and construction.

— David Wylynko, Managing Editor

PART ONE

END PIT LAKES IN CONTEXT

Returning mineable oil sands developments in the Athabasca oil sands region to a state functionally equivalent to the natural conditions that characterize the boreal forest of northern Alberta will involve a sophisticated suite of tools, techniques, and expertise. The end pit lake is an integral element of this task. The first three chapters of this guidance document explore the ecological, geographical, legislative, and historical contexts of the EPL as a novel reclamation tool for the oil sands. Chapter 1 introduces the two varieties of EPLs and the role each will play in reclamation of the oil sands mining landscape. It also reviews the events that led to the production of this document and content of the following eight chapters. Chapter 2 provides a detailed examination of the five primary objectives of EPLs – water flow management; water quality; bioremediation and tailings storage; sustainable aquatic ecosystem; and other uses – as determined by stakeholders, legislation and regulations. Chapter 3, drawing on the historical experience of other surface mining industries with pit lakes, supplies direction on the successful transformation of oil sands mine voids into EPLs that meet the objectives outlined in Chapter 2.

1. INTRODUCTION AND BACKGROUND

Gord McKenna
BGC Engineeering

+

James Hrynyshyn
West Hawk Associates

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1.1 Primary objectives of EPLs

Over the next 100 years, end pit lakes are expected to become common features of the Athabasca oil sands region. For this document, the authors reviewed available regulations and consulted numerous stakeholders to determine the primary objectives for these constructed lakes. Environmental Impact Assessments and Life of Mine Closure and Mine Reclamation Plans are typically designed with consideration for mine planning and material balances. From a mine planning perspective, key design elements and features of EPLs, such as location and geometry, should be considered as early as possible in the planning process. To achieve ecological and closure objectives for EPLs, landform designers and reclamation planners will need to influence the overall mine plan early in the process.

Landform designs need to be guided by clear objectives (Chapter 2) and design criteria (Chapter 8, Table 8-1). Research for this Guide has identified five primary objectives. These are based on legislative and regulatory documentation and interviews with the region's stakeholders, including Aboriginal communities, industry, and non-governmental organizations:

1. **Management of water flow (hydrology)**
2. **Ensure acceptable water quality**
3. **Store tailings and bioremediate process-affected waters**
4. **Function as a sustainable aquatic ecosystem**
5. **Support other economic, ecological, and societal uses**

Similar objectives were identified in 2005, and confirmed in 2011, by Alberta's Ministry of Sustainable Resource Development:

> *… end pit lakes have to be designed to fit the future landscape (whatever that may be) and to be a surface feature that can be used by the general public and any other land users, in a safe and appropriate (as specified by policy) manner. It must meet short-term, medium-term, and long-term water quality objectives to support fish populations, wildlife and migratory or seasonable waterfowl use, human use, and must meet recreational water quality guidelines* (Barker 2005).

In addition, provisions for reclamation set out in Alberta's *Environmental Protection and Enhancement Act* (EPEA 2000) require reclaiming disturbed lands to a state of equivalent land capability (i.e., similar to but not necessarily identical to what existed prior to mining). EPLs can meet this objective, while providing permanent containment of fine tailings solids under a freshwater cap. This proposal was approved by the Alberta Energy and Utilities Board (EUB, now the Energy Resources Conservation Board, ERCB), subject to industry demonstration.

The permanent placement of fine tailings solids in EPLs is approved for many oil sands mines, subject to demonstration, based on previous EUB Decisions including:

- Decision 94-5, which approved Syncrude's Base Mine Lake project, subject to successful demonstration of water capping.
- CNRL Horizon Decision 2004-005, which states that *"The Panel expects that this work would be completed in the next 15 years."*
- Imperial Oil Kearl Decision 2007-013 which states *"EPLs have been approved subject to successful full-scale demonstration of this reclamation method."*

1.2 Ecological and Geographical Context

Much of northern Alberta is part of the boreal plains ecozone, a 650,000-square-kilometre area of subdued topography, sedimentary bedrock, and a continental climate (Ecological Stratification Working Group, 1995). In general, the region is characterized by long cold winters and short, moderately warm summers. The region is located within the Western Canadian sedimentary basin. The surficial geology, ranging from 0 to 50 m thick, is made up of sediments of variable glacial, fluvial, and biogenic origin. The bedrock is sedimentary with significant amounts of carbonates and is often found at significant depths, although it can be shallower in the mining regions. The topography consists mainly of broad central lowland (Athabasca River lowland) which houses the Athabasca River. The surficial geology consists of a layer of sediments deposited by glacial and fluvial processes and glacial till forms a clay-rich mineral soil layer. In low-lying, poorly drained areas, organic peat soils have developed.

The 140,000-square-kilometre Athabasca oil sands region lies within this ecozone (Figure 1-1) and will host oil sands development consisting of over a dozen open-pit mines with about 30 end pit lakes, all draining to the northward-flowing Athabasca River (Figure 1-2).

Each oil sands surface mining lease can be thought of as a landscape-scale portion of the region, each one covering between 20 and 200 square kilometres, often within one or two watersheds.

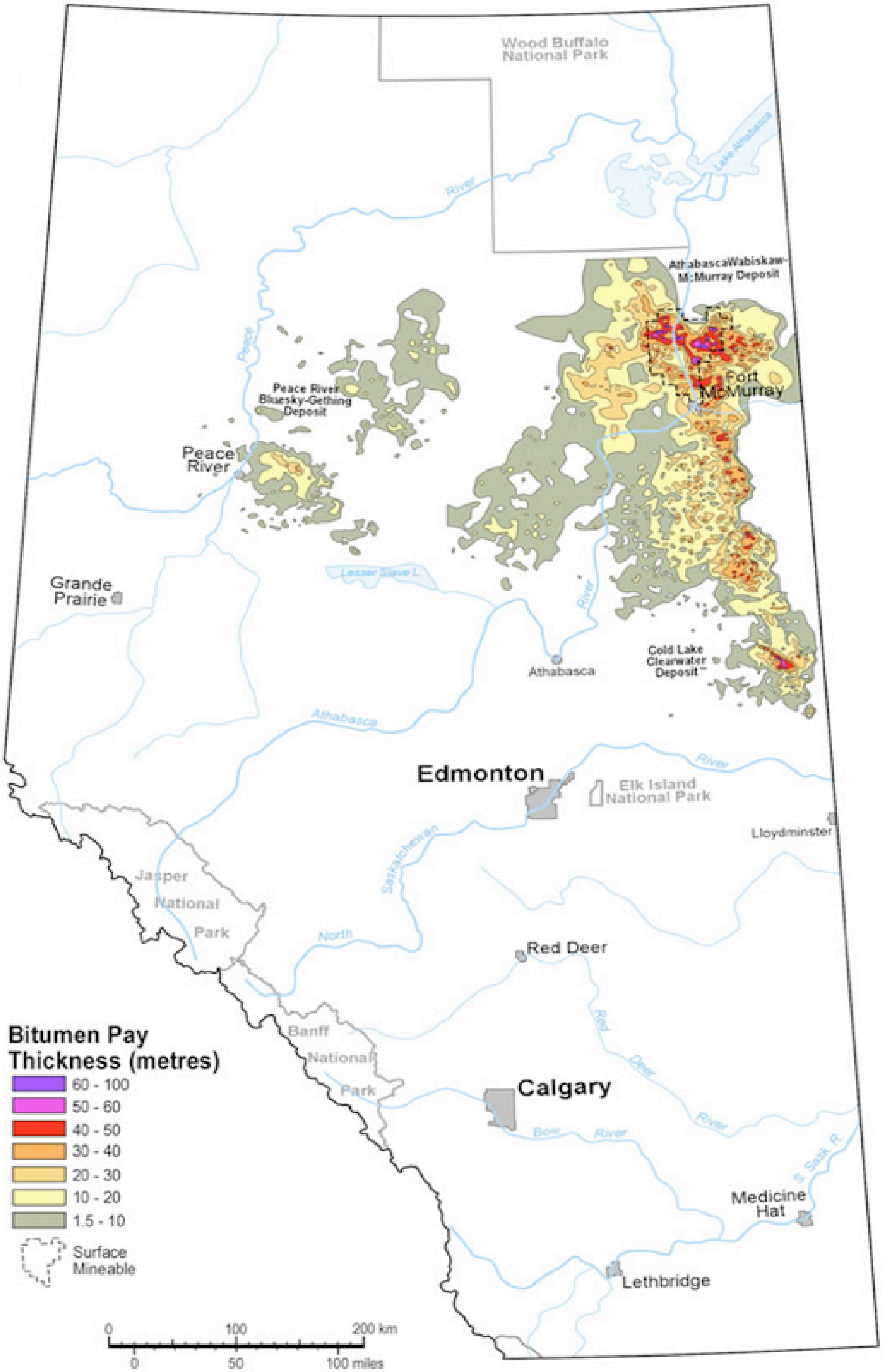

Figure 1-1: The oil sands in Alberta. ERCB map.

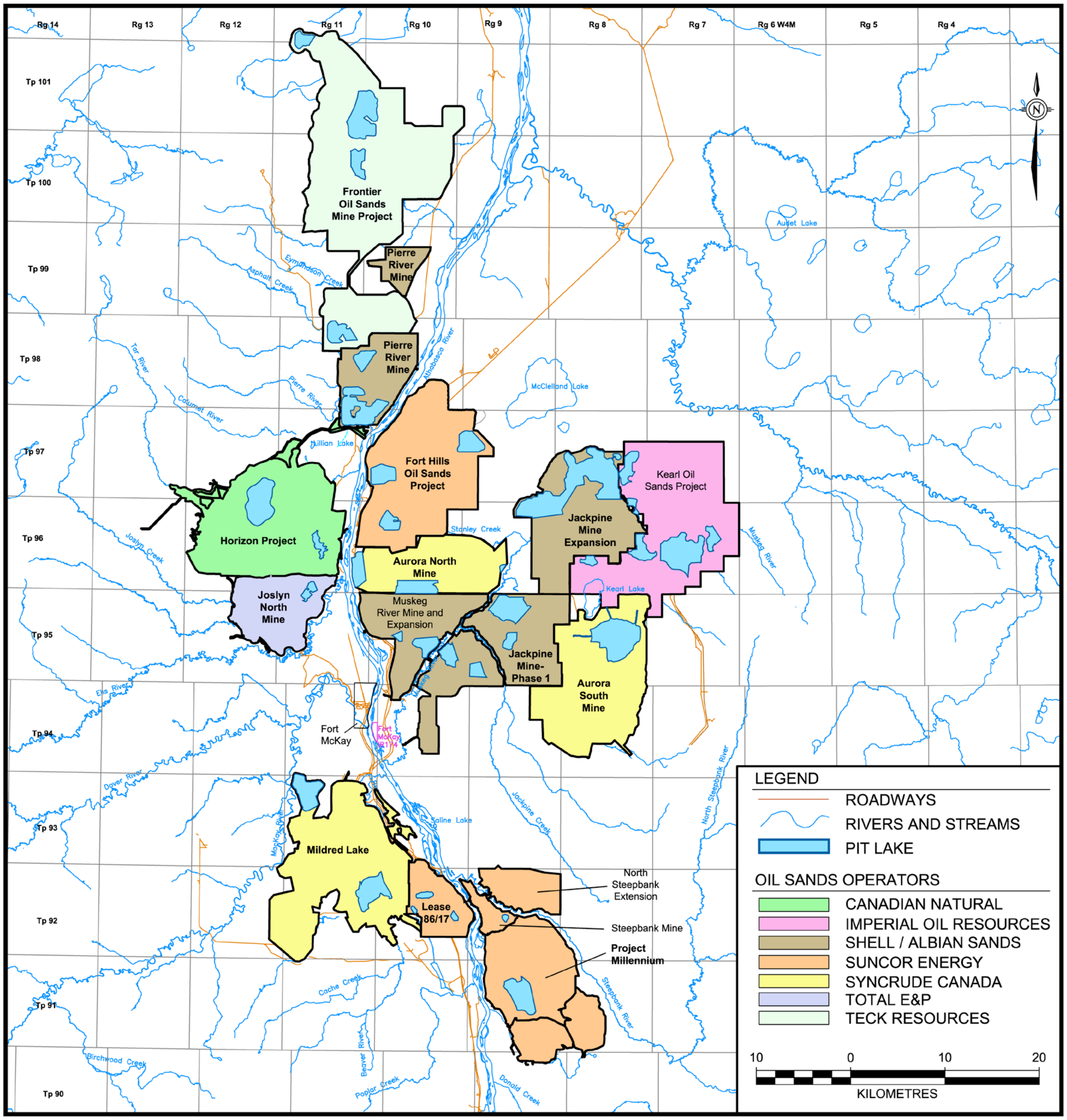

Figure 1-2: Planned EPLs in the Athabasca oil sands, according to closure plans filed by Decemeber 2011. Final shape and size of EPLs are subject to change. (Golder Associates map)

1.3 What is an End Pit Lake?

CEMA defines an oil sands EPL as:

> "*an engineered water body, located below grade in an oil sands post-mining pit. It may contain oil sands by-product material and will receive surface and groundwater from surrounding reclaimed and undisturbed landscapes. EPLs will be permanent features in the final reclaimed landscape, discharging water to the downstream environment*" (Westcott and Watson, 2007).

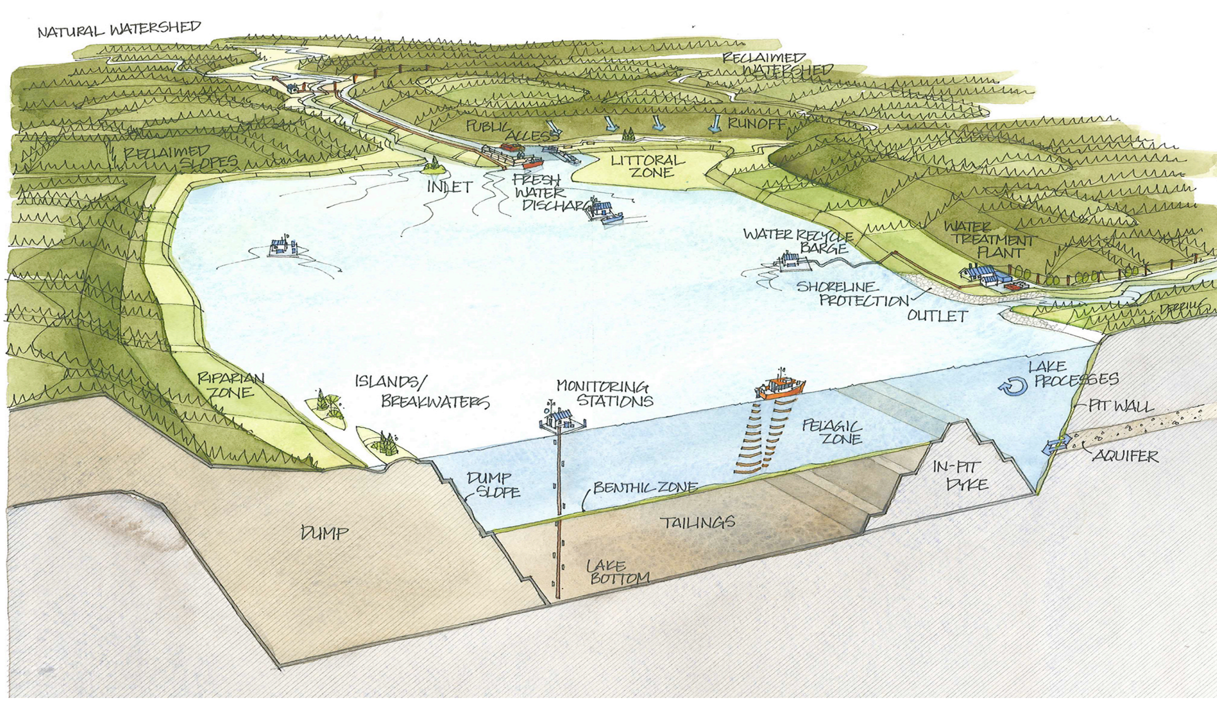

Figure 1-3: A conceptual mature EPL with tailings.

Throughout this document, the phrase "**end pit lake**" and the acronym EPL refer only to an end pit lake in an oil sands context. The unqualified term "**pit lake**" refers to pit lakes associated with mining in general, while the simple term "**lake**" is reserved for natural lakes.

To help explain how oil sands EPLs are designed, specifically with a focus on the overall mining process, the concept of a Virtual End Pit Lake (VEPL) set within a Virtual Oil Sands Mine (VOSM) is detailed in Section 1.6 and Appendix A. The VEPL represents a theoretical example of an oil sands EPL in a reclaimed and undisturbed watershed that captures the major elements of mining in the region.

EPLs may or may not contain tailings associated with mining and tailings operations. In general, two types of EPLs are anticipated for oil sands mine sites:

- **EPLs with tailings storage**: In this scenario, soft tailings such as fluid fine tailings (FFT) or thickened tailings (TT) are capped with a layer of freshwater. Inputs to the lake include surface runoff, precipitation, groundwater seepage, and consolidation waters from tailings deposits. Tailings become denser over time and release pore water to the cap water. Process-related materials that may be stored in the mined-out pits include soft tailings deposits, tailings sand, lean oil sands, overburden, petroleum coke and process-affected waters that remain at the end of mine operations.

- **EPLs without tailings storage**: The excavated mined-out pit is allowed to fill with surface runoff and groundwater once mining and dewatering activities cease. The list of design and management considerations of EPLs that do not contain tailings is significantly shorter than those that do store mine waste (see Section 9.3.13).

Much is made of the difference between the two types of EPLs. Both types will receive significant quantities of tailings seepage water from the reclaimed watersheds and saline groundwater from the surrounding bedrock. Most of the watershed and lake processes will be similar in each. As the tailings consolidate, EPLs with tailings storage become more and more like EPLs without tailings storage. Time will tell whether the presence of tailings substrates makes for fundamentally different EPLs, or only different in degree. Regardless, the presence of consolidating tailings in an EPL is a complication for designers.

Also, not all EPLs will be constructed from the final pits to be mined on an oil sands lease; some leases may have more than one EPL, and some may be constructed from mined out pits while mining continues elsewhere on site. Oil sands EPLs are also expected to contain some overburden and interburden (lean oil sands) deposited during mining.

1.3.1 EPLs from a Mining and Reclamation Perspective

EPLs are generally situated in the excavated mined-out pits that remain at the end of mining operations. They can store operational and reclamation waters and other mine waste materials where there is insufficient overburden material available to backfill the pit to a terrestrial state. Industry plans include the use of EPLs (in what is sometimes referred to as “water capping”) to manage the remaining fluid fine tailings (FFT), thickened tailings (TT), composite tailings (CT) or non-segregating tailings (NST) as part of the overall mine plan.

An EPL design is ultimately constrained by the mining configuration and the characteristics of the ore body deposit. As a result, many of the key design elements of an EPL are decided early on in the planning process, such as location, geometry, and lake content. Landform designers and reclamation planners will have the greatest influence on the design during the initial planning stages, as detailed in Chapter 7. Among the design parameters that must be considered are:

- **Hydraulic residence time**
- **Lake area, depth, and shape**
- **Orientation to prevailing winds**
- **Shoreline complexity**
- **Lake filling time**
- **Water sources for lake filling**
- **Salinity, process-water parameters and organics**
- **Hydrologic sustainability (integration with surface water and groundwater)**
- **Habitat features**
- **Human and wildlife access**
- **Climate change**

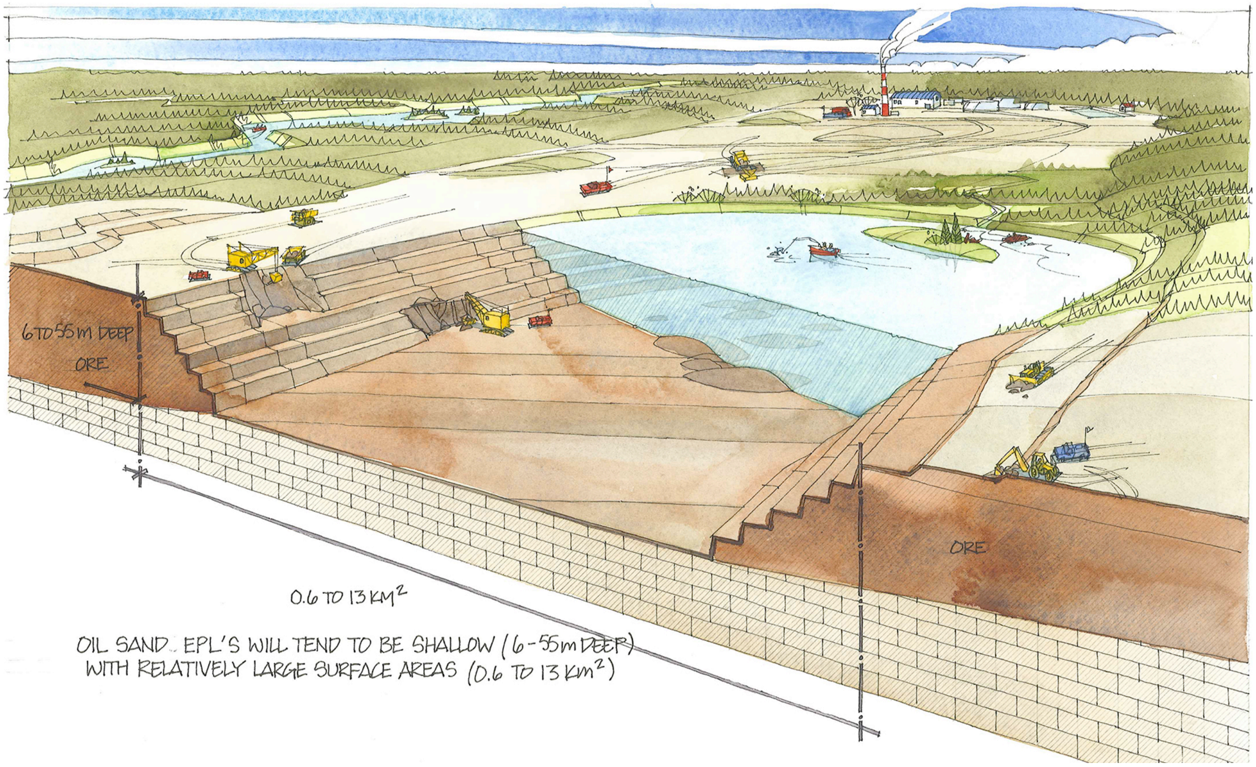

Figure 1-4: Cutaway view of a conceptual EPL.

From a reclamation perspective, EPLs are a central component of the reclaimed closure landscape. Most often they will be located at the lowest elevation on the mine site and the reclaimed topography, including overburden dumps and drainage channels, will be shaped to direct surface runoff toward the EPL. The final water-level elevation of the EPL can control the topography for the entire mine site and dictate reclamation activities both upstream and downstream of the EPL. In essence, EPLs are critical to both the long-range mine plan and the closure and reclamation plan. The EPL design will have to balance the objectives of the mine plan and material balance with landform performance and end land use objectives.

Each oil sands surface mining lease can be thought of as a *landscape-scale* portion of the region, each about 20 to 200 square kilometres, often within one or two watersheds. These are the building blocks of individual EPLs. All activities within the lease/watershed scale have impacts on lake design, construction, operation, and performance. Mine development, closure planning, and watershed reconstruction occur at this scale. The design of the reclaimed watersheds is critical to the success of the EPLs. This landscape scale has both a physical and ecological meaning.

Each watershed is comprised of a mosaic of *landforms* – natural (e.g., hills, plains, and rivers) and artificial (e.g., dumps, tailings ponds and dykes, reconstructed drainage systems, and EPLs). Most of the artificial landforms are 2 to 20 square kilometres in area. It is at this scale that mining takes place, disturbing watersheds, creating new landforms, and reclaiming those landforms, including EPLs.

It is useful for designers to subdivide landforms into *landform elements.* Examples of elements for terrestrial landforms such as a dump or a tailings structure include the plateau, ridges, slopes, and watercourses. For EPLs, elements can include the pelagic (deep water) and littoral (shallow water) zones, shoreline and riparian areas, inlets, outlets, and islands. These are largely elements of substrate, topography/geometry, and initial vegetation.

The water in the lake can be perhaps considered one of the elements. The water is subject to various lake processes including physical (inflows, outflows, mixing, overturning, eddies, currents, etc), chemical, and biological processes.

1.3.2 Planning and Design Frameworks

Mine planning involves design activity and scheduling that occur at different scales and degrees of detail.

- Closure planning is a common activity for mines worldwide, and involves the preparation of high-level designs for the disturbed watersheds. Closure plans typically include all the steps necessary to mine, stabilize, reclaim, and certify mining landscapes and include conceptual designs for each of the dozen to two dozen mining landforms (including EPLs) in each mining landscape. In particular, the watershed for an EPL is largely designed during closure planning activities. This is the focus of Chapter 7.
- Landform design (McKenna, 2002) involves the application of engineering and other applied sciences. It is considered a holistic approach to mine closure that works within an interdisciplinary team to set and achieve performance objectives and has been used for several large successful mine reclamation and wetland creation programs in the region. This design is the focus of Chapter 8. Landform design involves creating permit-level designs that can be submitted to regulators for permission to construct an individual landform, such as an EPL.
- Regional planning has been going on for many years (e.g. the Integrated Resource Plan, 2002), and is not yet a formal activity in the oil sands region, though many aspects of the regulation, approvals, monitoring, and collaborative work are already carried out at a regional scale. Yet there is much to be done at this regional scale in ways that will affect closure planning and EPL design. As discussed in Chapter 9, regional planning and design will be a necessary component for EPL design.
- Two methods are used for creating landform elements. To guide specific mining and tailings activities, short-range plans are developed – essentially week-to-week and day-to-day schedules for the operation staff. For more detailed work, drawings are prepared for items such as water treatment plants, littoral zone construction, and inlet and outlet construction. These involve higher levels of engineering.

Reclamation of oil sands open pit mines, and their transformation into sustainable lakes, is a developing technology. As a result, industry can draw on experiences from pit lakes created in other mining industries along with current research and literature reviews conducted within the region. Such experiences include Syncrude Canada's Base Mine Lake (BML) demonstration lake and test wetlands and CEMA's in-lake dynamics and water quality modeling and geotechnical stability analysis of EPL shorelines. The oil sands can also draw on experience from pit lakes created by other industries, such as Teck Coal's Sphinx Lake in Sparwood, British Columbia. Chapter 3 provides a literature review of pit lakes created in other industries.

1.4 Fundamental Principles of EPL Ecology

EPL ecosystems will be determined by complex interactions among terrestrial and aquatic features at multiple spatial and temporal scales. For example, regional-scale criteria control the distribution of fishes; that is, the regional species pool and the stream network control the dispersal of fish across the landscape. At the other end of the spectrum, local-scale criteria, such as structural complexity, water quality, and biotic interactions, control the maintenance of fish in an individual lake. These features operate on a lake ecosystem in a hierarchical manner; regional features (e.g., regional species pool) both constrain and set the context for local features (e.g., biotic interactions) (Tonn, 1990). In the early years, anthropogenic effects may dominate the EPL ecosystems.

The lake landscape context (LLC) framework (Soranno et al., 2009) incorporates, in a hierarchical manner, the terrestrial and aquatic features that together describe the hydrogeomorphic controls on lake water chemistry, hydrology, physics and biology. Such a framework is a useful tool particularly when a practitioner attempts to make sense of the behaviour of a lake where numerous landscape components exist. The LLC framework integrates the multitude of landscape components that influence lake ecosystems at different spatial scales in an organized and relatively simple way.

Indeed, successful construction and certification of EPLs will require a sophisticated understanding of the ecological context in which they will function. Mine managers and EPL designers and planners must recognize the degrees of control they will be able to exercise at each ecological level, with zero control of climate and precipitation on the one hand and maximum control of sediments and wetland characteristics on the other.

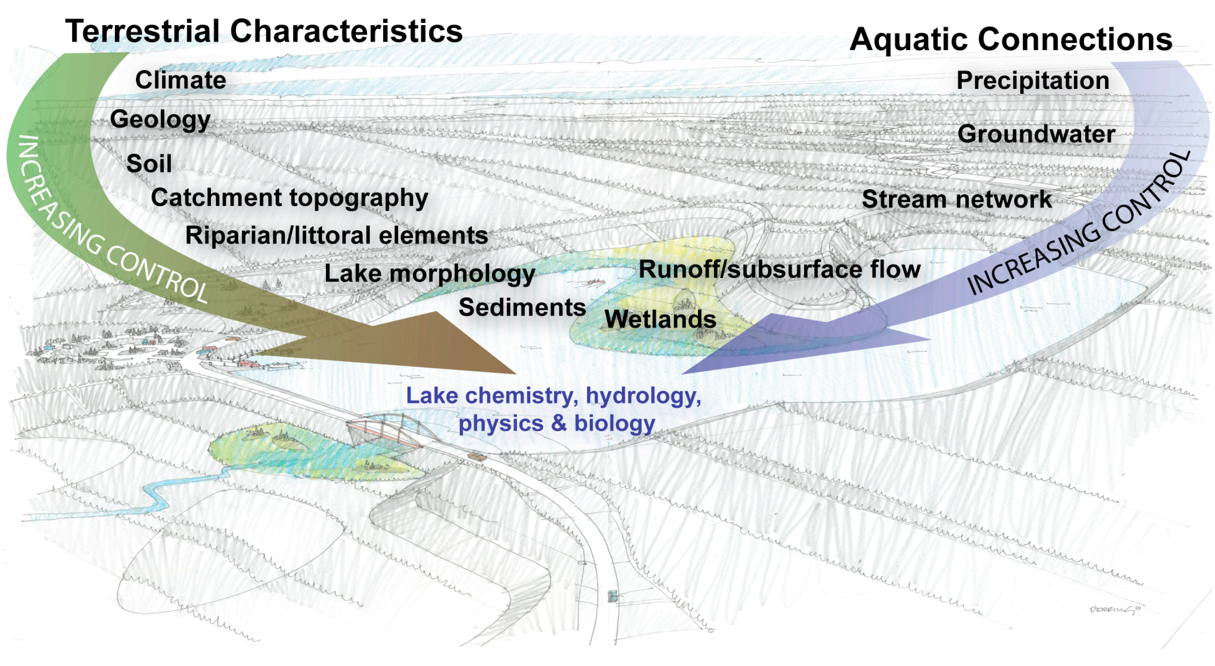

Figure 1-5: Lake landscape elements (modified by Théo Charette, Derrill Shuttleworth, and West Hawk Associates from Serrano et al., 2009).

Figure 1-5 shows a conceptual model specifically for Boreal Plain lakes that can be applied to EPLs. This framework is based largely on a framework (Soranno et al., 2009) that integrates a number of existing landscape frameworks and filter models describing the distribution and behaviour of hydrological and biological features on the landscape (Tonn, 1990; Kratz et al., 1997). Minor modifications have been made according to DeVito and Mendoza (2008) and the importance of sediment characteristics on lake ecosystems in Alberta has been emphasized. Soranno's "human activities" feature has been excluded, as it was not considered relevant to early-stage EPL scenarios.

In this framework, "Terrestrial Characteristics" affect the amount and quality of materials that are transported from land to water. For example, the movement of water through land is a function of two terrestrial components: the land surface form (shape, size, slopes of the earth's surface) and the hydraulic properties of the geology (Winter, 2001). Hydraulic connections determine how materials and organisms are transported among lakes. For example, the position in the hydrological flow system can influence baseline solute concentrations, while the presence of connected wetlands can influence water quality and surface water connections provide biota refuge from disturbances ranging from winterkill to glaciation (Tonn, 1990).

Chapters 4 through 6 closely follow the hierarchy established in Figure 1-5, in order to provide the reader with a sequential introduction to the natural and artificial forces that will determine the fate of an EPL. Chapter 4 deals with the landscape-scale processes, from climate and geology to catchment topography. Chapter 5 addresses lake morphology and sediment characteristics, which are specific to disturbed landscapes in a mining environment. Chapter 6 explores the physics, chemistry, and biology of in-lake processes.

1.5 Adaptive Management Framework

Decision-making for environmental management necessarily involves uncertainty and the potential for unanticipated adverse environmental and social impacts. As a result, several guiding principles have been advanced. Two prominent examples are the precautionary principle and the principle of adaptive management.

The precautionary principle requires that when scientific uncertainty is high and the potential for substantial negative and environmental and/or social impacts exists – a likely scenario for EPLs – decision-makers and designers should err on the side of caution. This guide is written with this principle in mind.

Adaptive management acknowledges that scientific understanding of any system (in this case, an ecosystem) will always be incomplete. However, as scientific knowledge of the system in question improves, so too will the accuracy and reliability of decision-makers' ability to predict outcomes associated with the design, construction and "operation" of an EPL. Viewed in this light, decisions about the EPL should be considered opportunities to enhance our understanding of the ecosystem. Specifically, management interventions should be designed as experiments: hypotheses should be expressed; controls should be put in place and opportunities for replication should be seized. Moreover, the results of any EPL "intervention" should be assessed in a timely manner and the knowledge derived should be used to inform subsequent decision making in order to drive continual improvement. Using an adaptive management approach is also a central theme and strategy in this guide, as introduced below and detailed in Chapter 9.

This Guide introduces a robust adaptive management approach to all levels of design, from the region to the landscape/mine lease to the EPL and its landform elements. Worldwide, adaptive management has a poor track record of performance, but will be a necessary component for construction of a successful “lake district” in the oil sands. Methods to make it successful are detailed in Chapter 9. The phases of adaptive management used in this Guide are:

- Define the problem and objectives
- Establish governance (including truly independent review)
- Design the lake and its monitoring plan
- Implement the design (construct the lake)
- Monitor and observe performance
- Assess and evaluate the performance of the design against the objectives
- Revise design/operation (cycle back)

It should be noted that revising the design or operation implies that some of the decisions and actions can be practically changed, and that if the lake is performing poorly there is a list of practical, reasonable, affordable, and timely interventions that have already been assessed and documented. If the potential effects are serious, undesirable, and practically irreversible, then the precautionary approach would apply. A lack of such planning and assessment is often the shortcoming of other adaptive management approaches.

1.6 The Virtual End Pit Lake (VEPL)

In this document, the concept of a virtual end pit lake set within a reclaimed watershed will be used as a worked example of an oil sands EPL (Appendix A). The VEPL is used to explain the process for EPL design and creation, specifically with a focus on the overall mining process. The virtual oil sands mine (VOSM) places the VEPL within an actual watershed and provides a conceptual mine plan that is volumetric and mass balanced.

The concept of a virtual mine has been used in other contexts within the oil sands region, specifically in the mid-1990s. Golder Associates and Suncor Energy jointly developed a document (OSRIN, 2011) that had one of every kind of landform proposed in oil sands closure landscapes, with relevant biogeochemical and mining information. More recently, Devenny (2010) considered a “generic” oil sands project producing 100,000 barrels per day of synthetic crude oil in a tailings technology screening assessment.

Table 1-2 provides a summary of the specific EPL characteristics proposed in the region, according to industry closure plan submissions to 2006. The median values reported in this table were used as the base case for the VEPL in Appendix A. The initial design parameters considered the range of characteristics for currently planned EPLs from the CEMA 2007 Review Document (Wescott and Watson, 2007), and the VEPL dimensions are close to the median values for planned EPLs.

Table 1-2: Summary of Virtual End Pit Lake design (VEPL) parameters.

Design Parameters	Units	VEPL Values	Planned EPLs*		
			Minimum	Median	Maximum
Length	km	3			
Width	km	1.5			
Surface area	km^2	4.5	0.6	3.7	13
Watershed area	km^2	90			
Initial water depth	m	25	6	27	55
Initial tailings depth	m	25			
Minimum freeboard height	m	10			
Volumes					
Water	Mm^3	112.5	4.3	115	427
Tailings	Mm^3	112.5	0	70-100	400
Time to fill	years	8	1	8.2	20
Residence time	years	8.7	1.1	21	155
Initial lake salinity	ppm	190	114	190	808
Salinity of inflow	ppm	200	110	200	527
Freshwater inflow rate	Mm^3/yr	13	0.5	13	53
Outflow	Mm^3/yr	15	0.03		0.082

* Values from Table 2.1 (Wescott and Watson, 2007).

Appendix A provides a summary VEPL design. Figures A-1 through A-4 provide a conceptual design for the VEPL.

1.7 Alternatives to EPLs

Stakeholders, regulators and Aboriginal groups have expressed concerns about the future performance of EPLs, both with and without tailings substrates. There are two main alternatives to EPLs as reclamation tools for the oil sands. Both are costly. First, each mine can rehandle tailings or overburden from dykes, beaches, or dumps, and use these materials to backfill the pit, either up to the original ground level or to such an elevation that the surface water can drain back to the environment safely without ponding. At present, most pits are backfilled with overburden or tailings, but using one-time placement rather than rehandling. The costs of rehandling material to backfill a mine void can run to billions or tens of billions of dollars for each pit and may involve deconstructing reclaimed landforms for material volumes for backfill.

Second, operators can work together, staging their development to allow other operators to put their overburden or tailings into final pits on nearby leases as these voids become available. This raises issues for long-term joint responsibility for overburden and tailings placed on another lease; it imposes costs and risks associated with transporting tailings and overburden long distances to other pits. In some cases, the opportunity costs of delaying operations while waiting on pits to become available could be significant.

A third possibility would be to create an EPL, then substantially modify or even backfill it, if it did not meet its intended performance goals. This would likely be the most expensive option. Mine operators work opportunistically where it makes economic sense. In either of the two main options, however, the capacity for biodegradation of naphthenic acids and other contaminants of concern is severely compromised, making water treatment necessary for decades or centuries. This can result in long-term costs and continuation of industrial activity in the region.

1.8 Scope and Development of the Guide

This Guide provides practical technical guidance and supporting tools to be used by industry, specifically an interdisciplinary team of operational managers, mine planners, landform engineers and designers. It is also intended to be used as a primary reference by government regulators charged with overseeing the oil sands. It is also a reference for Aboriginal and other stakeholders with an interest in the future of the region. It should be used in conjunction with other guidance documents for oil sands reclamation. CEMA has also produced guides for wetlands, soils, revegetation, and riparian areas. The timescale for each EPL project involved is measured in decades, meaning each project will outlast any team member, and making a common reference source essential.

CEMA published an earlier edition of the guide in 2007 (Westcott and Watson, 2007). An extensive review of that document (CH2M HILL, 2009) provided direction for development of this edition. A key recommendation from the review was that the next edition would benefit from a rigorous peer-review process and the selection of an independent, external managing editor. Specific recommendations included:

> *"The next edition of the EPLTGD must be a multi-author, peer-reviewed document. The complexity of the subject matter and complex array of stakeholder concerns place authorship beyond the capacity of any single institution or consultant. Both authors and peer reviewers must be recognized experts in areas relevant to document content."*

In 2010, the group selected West Hawk Associates, an Ottawa-based communications consultancy with experience in producing environmental and regulatory documents, to serve as managing editor for the production of the this version of the document. Gord McKenna of BGC Engineering was selected to provide technical advice. Authors and reviewers for this edition of the guide were selected through the following process:

1. West Hawk contacted the list of reviewers selected by CH2M HILL (2009) to review the previous edition.
2. West Hawk worked with Gord McKenna to select individuals with local oil sands experience as authors and reviewers for the next edition.
3. As well, authors and reviewers with international experience were selected to expand the range of experience beyond the oil sands region.
4. Authors were assigned specific chapters by West Hawk and the task group.
5. Advisors for each chapter and three global reviewers were also selected.

6. Authors, reviewers, and task group members were invited to attend a workshop on Nov. 4 and 5, 2010, in Edmonton to present and review the chapter outlines. They met again on April 19, 2011, in Calgary and September 15, 2011, in Calgary to present and discuss their chapter content. Following revisions and editing, the global reviewers met in Calgary on February 28, 2012 to discuss revisions to the document. Additional revisions were made in preparation for the task group review, which occurred during the month of May, 2012.

West Hawk and the authors then selected academics and engineers with relevant expertise to provide technical advice on specific chapters and three global reviewers for the entire document.

The Guide was also subjected to a cold-eye review by experienced professionals from various areas of expertise relevant to the oil sands. They supplied written comments and suggestions for consideration by the authors. More information on the editorial process used to assemble this document, and information on authors, advisors, and global and cold-eye reviewers, can be found in Appendix E.

1.9 Organization of the Guide

1.9.1 Chapter by Chapter

Table 1-3 provides a visual representation of the structure of the Guide, the lead authors and the reviewers for each chapter. The task group and global reviewers served as advisers on all chapters.

Table 1-3: Guide structure.

<table>
<tr><th colspan="2">Chapter and Description</th><th>Authors</th><th>Advisers</th></tr>
<tr><td>1. Introduction</td><td>Introduces the Guide and provides context for the remaining chapters</td><td>Gord McKenna,
BGC Engineering Inc.
+
James Hrynyshyn,
Senior Writer/
Researcher,
West Hawk Associates</td><td rowspan="3">George Dixon,
University of Waterloo

Clint McCullough,
Edith Cowan University,
Australia

Gord McKenna,
BGC Engineering

Rob Abbott,
BGC Engineering

Theo Charette,
CPP Environmental</td></tr>
<tr><td>2. Objectives and Regulations</td><td>Provides a summary of end land use objectives and regulatory framework</td><td>James Hrynyshyn,
West Hawk Associates</td></tr>
<tr><td>3. Experiences from Non-oil Sands Pit Lakes</td><td>Describes other pit lakes and lessons from the industry's experience with them.</td><td>Devin Castendyk, Earth Science Department, State University of New York, College at Oneonta</td></tr>
<tr><td>4. Regional Geography and Ecology</td><td>Describes natural lakes in the region including physical, chemical and biological conditions</td><td>Theo Charette,
CEMA Technical Program Manager
+
Brent Mooder,
Senior Hydrogeological Engineer, BGC</td><td>Carl Mendoza,
University of Alberta

Joe Rasmussen,
University of Lethbridge</td></tr>
</table>

Chapter and Description		Authors	Advisers
		Engineering Inc.	
5. Watersheds in the Mining Environment	Describes end pit lake water balance (inputs and outputs)	Brent Mooder	Carl Mendoza, University of Alberta
6. In-lake Processes	Examines physical, chemical, and biological processes within end pit lakes	Jerry Vandenberg, Water Quality Specialist, Golder Associates Inc.	Julia Foght, University of Alberta Mike McKinnon, OSPM Solutions Ltd.
7. Planning	Overview of the planning process from a mining perspective	Aaron Sellick, Vice-President, Mining & Tailings, Norwest Corporation	George Dixon Clint McCullough Jerry Vandenberg
8. Design Considerations	Overview of the design process from a mining perspective	Angela Kupper, Principal Geotechnical Engineer, Vice President, Geotechnical, AMEC Earth & Environmental	
9. Construction and Operation	Describes operational and risk management strategies for EPLs	Gord McKenna, Jerry Vandenberg	George Dixon Clint McCullough Jerry Vandenberg

1.9.2 Chapter 2: Objectives and Regulations

The chapter describes the objectives for EPLs as conveyed by government agencies, Aboriginal organizations and communities, non-governmental organizations, and industry. It also spells out regulations and legislation relevant to EPLs. It is organized according to the five primary objectives, with a section dedicated to each one that highlights stakeholder views and relevant regulations and legislation. It is followed by a discussion of the challenges posed by the evolving nature of the regulatory environment – with particular attention paid to two provincial directives – and the potential for conflict between the objectives derived from governmental regulations and those based on other stakeholders' perspectives.

1.9.3 Chapter 3: Experiences from Non-Oil Sands Pit Lakes

In this chapter, a review of the nature and distribution of non-oil sands EPLs – with special emphasis on existing northern-latitude pit lakes in North America – introduces the lessons to be learned from elsewhere in the mining industry. The remainder of the chapter discusses similarities and differences between non-oil sands pit lakes and future oil sands EPLs, factors influencing the sustainable ecological development of EPLs, and key information for policy-makers and planners. It presents seven case studies of existing pit lakes, including four existing coal mine pit lakes in Alberta that were designed to support productive fisheries.

1.9.4 Chapter 4: Geography and Ecology of the Athabasca Boreal Forest

This chapter provides an exploration of the geography and ecology of the region in which EPLs will be built, focusing on water flow and water quality. The chapter identifies landform design that considers upland and wetland topographic ratios and configurations as critical to successful management of surface and groundwater interactions and long-term landscape sustainability. A section is devoted to the principles governing lake levels, littoral zones, and habitat complexity.

1.9.5 Chapter 5: Watersheds in the Mining Environment

As EPLs will not be constructed in the unaltered landscapes described in Chapter 4, this chapter supplies descriptions of the physical, hydraulic, and chemical descriptions of the disturbed soil, peat, overburden, fines and tailings, various sources of water, and other materials that will be used. Also covered are the impacts of watershed topography, drainage, and the forces at work in the consolidation of tailings.

1.9.6 Chapter 6: In-Lake Processes

In the absence of an existing oil sands EPL, this chapter draws on studies of other pit lakes, oil sands tailings facilities, and experimental projects for a review of similar and relevant systems involved in physical, chemical and biological processes that will influence the behaviour of EPLs. Included are: littoral zone processes; meromixis; sediment processes and biogenic gas production; sloughing of pit walls; toxicity and degradation of napthenic acids; establishment of aquatic ecosystems; and nutrient uptake. The chapter includes an overview of limnological processes, as well as sections on modelling, monitoring, and design considerations.

1.9.7 Chapter 7: Timelines and Drivers

This chapter provides guidance on project management strategies. Activities related to EPLs at various stages of a theoretical oil sands mine development and closure schedule are presented to help planners, designers, regulators, and stakeholders manage or monitor the design and construction process. It identifies nine stages of the EPL process and provides a flexible schedule, in the form of Table 7-2. It then provides guidance on the expertise and tasks required at each stage of the process, from pre-production lease development through active mining operation to abandonment and certification. An accompanying section describes issues that tend to act as drivers for mine plans, at times exerting strong influences that can be either consistent with or contrary to optimum EPL design and construction strategies. It also explores the trade-offs and compromises that are often necessary for managing conflicting goals.

1.9.8 Chapter 8: Design Elements and Considerations

This chapter sets out the design approach and criteria for EPLs, working from the objectives identified in Chapter 2. In particular, this chapter emphasizes the importance of the creation and maintenance of the physical integrity of the EPL. It offers a design approach that takes into account the likelihood that not all objectives will be met simultaneously, addresses the different levels of control designers can exercise, and acknowledges the iterative process that will be necessary, particularly in the early stages. Technical considerations and design elements for all aspects of the EPL construction process are covered, from site geology and lake contents to slope stability and littoral zones.

1.9.9 Chapter 9: Construction and Operation

The final chapter describes the actions needed to apply the design approach for each stage of the process, through to reclamation certification. Included are sections on preparation of a permit-level design, configuration of the overall watershed, pit walls, littoral zones, riparian areas, water infilling, management of water levels and water quality, and certification. Sections on monitoring, risk assessment and failure modes, and adaptive management follow.

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2. OBJECTIVES AND REGULATIONS

James Hrynyshyn
West Hawk Associates

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Chapter 2 Table of Contents

2.1 Introduction

This chapter describes the current objectives for end pit lakes (EPLs) in the Athabasca oil sands, as conveyed by stakeholders in the region who agreed to participate in the information-gathering process: government agencies, Aboriginal and non-governmental organizations, and industry. It does not represent the views of all potential stakeholders, as a comprehensive survey or formal consultative process was beyond the project's mandate. However, certain key stakeholders and CEMA members who collectively represent all major groups with an interest in oil sands reclamation took part in detailed discussions on a wide range of relevant issues, concerns, and priorities. As best as possible, it also details relevant regulations and legislation.

The government and industry views were gathered through telephone, email, in-person interviews, and documentary research. Aboriginal views were expressed at half-day workshops with the Fort McKay First Nation and the CEMA Aboriginal Caucus. The views of non-governmental organizations were conveyed in the course of a half-day workshop held with the CEMA NGO Caucus in Fort McMurray. On the instructions of the EPL task group, the interviews were fairly open-ended. Interviewees directed the discussion toward the topic areas of most interest to them. The interviewees were provided with a questionnaire (Section 2.9), but typically the conversation ran to the main areas of interest at each session. Although the interviewees approached the subject from disparate perspectives, they focused on areas of such similarity that five key and distinct objectives emerged:

- Water flow management;
- Water quality;
- Bioremediation of process-affected waters and storage of tailings;
- Sustainable aquatic ecosystem;
- Other uses (fisheries, economic development, and greenhouse gas elimination).

This chapter is organized according to these five objectives, with a section dedicated to each that highlights stakeholder positions and relevant regulations and legislation. It is followed by a discussion of the challenges posed by the evolving nature of the regulatory environment – with particular attention paid to two provincial directives (see sections 2.7.1 and 2.7.2) – and the potential for conflict between the objectives derived from regulations and those based on other stakeholders' perspectives. The same objectives inform the design criteria in Chapter 8.

More information on the editorial and stakeholder interview process is presented in Appendix E.

2.1.1 Stakeholders

The authors consulted the federal, provincial, and regional government authorities with a legislative mandate and authority to protect the land and water that lie within the oil sands development area. Where possible, government interviewees were authorized to convey official departmental policy, although in many cases it was clear that government positions on EPLs are evolving and subject to modification. A similar process was applied to industry operators actively mining in the region and several other stakeholders who have an interest in the future of reclaimed oil sands mines (Section 2.9).

2.1.1.1 Government Authorities

To date, EPLs in an oil sands context are not addressed specifically in legislation or regulations. However, under federal and provincial legislation, an agreement on the end uses of all oil sands mines must be attained between regulatory agencies and the oil sands operators. This agreement requires a dialogue between regulators and oil sands operators, beginning with the submission of an Environmental Impact Assessment through the regular submission and review of updated reclamation and closure plans, through the life of the project and in accordance with regulatory approvals issued under the *Environmental Protection and Enhancement Act (EPEA*) by Alberta Environment and Sustainable Resource Development (AESRD). Several recent decisions of the Alberta Energy and Utilities Board — now the Energy Resources Conservation Board (ERCB) – and joint decisions of the ERCB and the Canadian Environmental Assessment Agency (CEAA) that were approved at the ministerial level, have included conditions of approval dealing specifically with EPL design and management. Consequently, oil sands operators are accountable for construction of an EPL through approved development plans; they are also responsible for all reclamation and monitoring activities from the cessation of mining to reclamation certification. Water quality and science- and technology-based limits may be imposed on EPL water discharges to the natural environment or perhaps to EPLs downstream.

Several pieces of federal and provincial legislation contain provisions applicable – though often indirectly – to EPL construction and certification:

The **Government of Canada** exercises its interest primarily through:

- The *Fisheries Act* (2005), which prohibits the deposition of deleterious substances into and disturbance of fish habitat;
- The *Canadian Environmental Protection Act* (CEPA, 1999), which provides a framework for management of toxic substances;
- The *Canadian Environmental Assessment Act* (CEAA, 1992), which governs the project review and approval process;
- The *Indian Act* (2005), which applies to northern and reserve lands;
- The *Migratory Birds Convention Act* (1994), which protects the avian species that may use EPLs; and
- *The Navigable Waters Protection Act* (1985), which is administered by Transport Canada.

The **Province of Alberta** applies a philosophy of integrated resource management to its management of public land and natural resources. It recognizes that the use of one resource can affect another (Alberta Sustainable Resource Development, 2002):

- The province's *Environmental Protection and Enhancement Act* (EPEA, 2000), its associated regulations, and the operating approvals that flow from the *Act* set industry construction and operational standards and monitoring and reporting requirements related to air, land, water, and waste;

- EPEA governs activities that result or may result in surface or aquatic environmental disturbance. Its provisions for reclamation require returning disturbed lands to a state of equivalent land capability similar to but not necessarily identical to what existed prior to mining. The Conservation and Reclamation Regulation also requires that the approval holder receive a reclamation certificate for the disturbed land;
- EPEA also provides for environmental impact assessments of major projects such as oil sands mining operations (these are conducted jointly with the Canadian Environmental Assessment Agency where a federal review has been triggered);
- The *Water Act* (2000) provides a licensing and approval process for water withdrawals, releases, and enforcement measures;
- All water use and water diversion requires authorization by Alberta Environment and Sustainable Resource Development under the *Water Act*;
- All oil sands mine activities must be approved by the province's Energy Resources Conservation Board (ERCB, 2008);
- All water use and water diversion requires authorization by Alberta Environment and Sustainable Resource Development;
- Ultimate approval of oil sands activities is undertaken through a coordinated process involving both the ERCB and Alberta Environment and Sustainable Resource Development (EUB, 1996);
- The *Public Lands Act* and related regulations set out the land use and environmental management obligations of industrial users of public lands. Under the *Act,* an operator receives access to the surface of the land;
- The *Alberta Land Stewardship Act* (2010) and the Cumulative Effects Management System (CEMS) authorize the development of regional plans, including the applicable Fort McMurray-Athabasca Oil Sands Subregional Integrated Resource Plan (Alberta Environment, 2002) and the Lower Athabasca Regional Plan (LARP, currently in draft). They provide opportunities for an adaptive, collaborative, results-based environmental management framework to focus more resources on higher-risk environmental impacts.
- Alberta's *Oil Sands Conservation Act* (2009) sets out environmental and economic objectives to conserve and maximize oil sands resource recovery. In addition, Section 27 (b) of the *Oil Sands Conservation Regulations* (2010) requires operators to ensure their activities do not endanger public health and that they "maximize the recovery of all oil sands within the mine site," a consideration that must be taken into account during EPL design.

These pieces of provincial and federal legislation are collectively responsible for ensuring the responsible use of water and land resources in the oil sands area. They require structured analyses before approval of major developments, effectively setting goals and objectives regarding how water and other natural resources are used, both individually and cumulatively.

2.1.1.2 Aboriginal Interests

Federal and provincial governments have a constitutional duty to consult with First Nations where land management and resource development could affect First Nations rights and traditional uses of Crown lands. The right to hunt, trap, and fish should be accounted for in any development, including EPLs and other efforts to reclaim disturbed land. Traditional uses include burial grounds, hunting, trapping, and gathering areas, and historic or ceremonial locations (Government of Alberta, 2005). Aboriginal groups whose rights could be affected include both First Nations and Métis. The Athabasca Tribal Council represents five First Nations in the Athabasca area: the Athabasca Chipewyan FN, Chipewyan Prairie FN, Mikisew Cree FN, Fort McKay FN and Fort McMurray #468 FN. The Wood Buffalo Métis and other Métis locals also have an interest. The Aboriginal organizations and members of the CEMA Aboriginal Caucus interviewed for this chapter can be found listed in Section 2.9.

2.1.1.3 Non-Governmental Organizations

CEMA's NGO Caucus includes environmental organizations, research groups and other groups with an interest in the sustainable development of the oil sands and the conservation of the province's natural resources. A list of NGOs interviewed for this document can be found in Section 2.9. Several other NGOs have expressed an interest in the fate of the oil sands landscape, including the Pembina Institute and the Friends of the Athabasca.

2.1.1.4 Industry

Industry members of CEMA include both oil sands developers and providers of mining services. A list of members can be found in Section 2.9.

2.2 Objective: Water Flow Management

As in many conventional mining operations, an ideal EPL will be situated below grade, or at the lowest point in a watershed. As EPLs will receive process-affected water, provincial and federal regulations make it necessary to control the discharge and to treat water from EPLs to minimize contamination of the surrounding ecosystem until the water no longer poses a threat to flora and fauna. In effect, EPLs will become, among other things, flow valves for the mine site watershed. Managing this water flow will require accounting for the precipitation and evaporation rates of the local hydrological cycle, lake depth, and the percentage of lake occupied by littoral zones, slope, and shoreline complexity.

Table 2-1: Summary of stakeholder perspectives on water flow management.

Government	Aboriginal	NGO	Industry
Hydrodynamics is a concern as it affects water quality. Should evolve rapidly toward a stable system or be on a trajectory toward stability. Fish habitat disturbance to be avoided. Should be returned to state that allows for public use. Use as flow valve is unavoidable.	Must be free flow of water through watersheds as rapidly as possible. Should include multiple inflow sources. Should contribute to hydrological stability.	Must be monitored closely through filling and discharge stages. Skeptical of suggested timeframes to ensure stability.	No preferred alternative to manage water flow. Fill material not available for all EPLs; water filling necessary as material deficit will leave a hole. Will be deeper that most local lakes. As with all mining activities, must lead to stability of watershed.

2.2.1 Government Objectives

Federal government interests in the geographical features of the post-mining landscape are primarily limited to the effect of any disturbance on fish habitat and on flora and fauna listed in the *Species at Risk Act* (SARA), rather than slopes, littoral zones or embayment options. The Alberta government is also more concerned with the quality of the water and ecological health of the local watersheds. Both jurisdictions have an interest in ensuring EPLs are designed to evolve as rapidly as possible toward a state that can support fish and other species of wildlife. All features of EPLs should serve to reach that objective, according to the specifics of the local geography and using best management practices.

2.2.1.1 Environment Canada

Oil sands projects are subject to assessment under the *Canadian Environmental Assessment Act* (CEAA, 1992), which is administered by Environment Canada and the Canadian Environmental Assessment Agency. The CEAA process is designed to integrate environmental considerations into project planning and governs the federal environmental assessment process. In particular, CEAA applies to EPLs as a consequence of Fisheries and Oceans Canada's regulatory responsibilities (see Section 2.1.1.1) and to endangered, threatened and vulnerable species through SARA (2002). The CEAA mandate with respect to the physical parameters of oil sands mining reclamation is relatively broad. An assessment is required for "any change that the project may cause in the environment, including any change it may cause to a listed wildlife species, its critical habitat or the residences of individuals of that species."

2.2.1.2 Fisheries and Oceans Canada

Fisheries and Oceans Canada (DFO) manages the *Fisheries Act* (2005), which protects Canada's fisheries and fish habitat. Approvals under the Act are required for activities in areas of fish habitat and are applied to all Canadian waters. EPLs reclaimed as fishery habitat and those that have the potential to affect receiving waterbodies are subject to the *Fisheries Act* and its regulations.

Section 35(1) of the *Fisheries Act* prohibits the unauthorized harmful alteration, disruption or destruction (HADD) of fish habitat. It is defined by DFO as: "any change in fish habitat that reduces its capacity to support one or more life processes of fish." To comply with the *Fisheries Act*, the project must either avoid HADD or the resulting HADD must be authorized. A Section 35(2) authorization of a HADD triggers a CEAA assessment of fish habitat and techniques to minimize impacts on fish and fish habitat.

One concern expressed by DFO in terms of EPLs is the lack of functioning examples to verify predictions in Environmental Impact Assessments (EIAs) regarding the viability of these water bodies as fish habitat. DFO has expressed concern that without real-life examples supporting the performance of EPLs, there may be a lack of viable options at the time of mine closure, requiring all stakeholders to make EPL research a priority.

2.2.1.3 Transport Canada

Transport Canada administers the *Navigable Waters Protection Act* (1985), which protects the public right of navigation by prohibiting the building or placement of any "work in, upon, under, through, or across a navigable water" without authorization. The NWPA may apply to EPL outlet channels should an existing navigable waterway be affected.

2.2.1.4 Alberta Environment and Sustainable Resource Management

The provincial *Environmental Protection and Enhancement Act* (1993) contains provisions covering construction, operation, and reclamation of an oil sands mine and plant site. The Act requires proponents to prepare and submit an Environmental Impact Assessment (EIA) for review along with an application for approval under EPEA. Such approvals typically require periodic status and progress reports, along with various other reports and plans. EPEA approvals provide direction regarding conservation and reclamation of the physical environment, including activities affecting stabilization, contouring, soil placement, revegetation, biodiversity and establishment of wildlife habitat.

Approval for certain elements of EPL design and construction may also be required under the *Water Act* (1999). The Act applies to any activity that "changes, may change or may become capable of changing the location of water or the direction of flow of water." Activities or infrastructure including initial filling, creation and alteration of drainage patterns, control structures, inlet and outlet structures, dams or ditches may be subject to review.

Alberta Environment and Sustainable Resource Development (AESRD) also administers the *Public Lands Act* (1996), which requires approval for modifications to beds and shores of watercourses. Under the Act, EPLs must meet the basic requirements for a self-sustaining land-water interface and display certain characteristics at the time of discharge. A major concern of AESRD is the return of the bed and shore of the EPL to the province in a manner that allows for public use. Also of concern is how the lakes are integrated into the overall landscape. EPLs must be part of the functional watershed and be self-sufficient in terms of maintenance of structures, landforms or facilities, with the exception of specific public use sites. EPLs are expected to provide habitat and supply water for rivers and streams. Shorelines must be stable with “erosion characteristics similar to natural water bodies in the region” (Barker, 2005).

2.2.2 Aboriginal Objectives

Water quality is a paramount concern for Aboriginal fishers, hunters and others who depend on the affected lands, lakes and rivers. The federal *Indian Act* (2005) requires operators to consult with First Nations if EPL construction results in any changes to waterways that provide access to First Nations lands. Some members of the CEMA Aboriginal Caucus have expressed the view that it is essential to return disturbed lands – as soon as possible – to a state that allows for the free flow of water through entire watersheds. Free-flowing lakes are seen as purifiers of the land and water. To that end, some Aboriginal Caucus members have suggested that EPLs should include multiple inflow sources. In addition, a functional EPL should be a source of, and depository for, water of acceptable quality. Regardless of the nature of the options used to create and fill EPLs, Aboriginal representatives agree that EPLs should contribute to the hydrological stability of a watershed, rather than hamper it. For this reason, they are unsupportive of plans to use EPLs as storage or remediation facilities for tailings.

2.2.3 NGO Objectives

NGO representatives share many of the concerns of Aboriginals and government agencies when it comes to the capacity for EPLs to generate clean water for release into the greater ecosystem, and whether such cleansing can occur within a reasonable timeframe. They recommend that EPLs be controlled and monitored throughout much of the initial filling stage and during discharge to downstream aquatic environments to ensure proper flow management.

2.2.4 Industry Objectives

A key industry objective is to ensure that mining activities, including the resulting landscape, contribute to the overall stability of the watershed. Given the nature of the mining activity, these lakes are generally expected by industry to be deeper than natural lakes in the area. Water will accumulate on the mine site and runoff will find its way to the lowest point, making proper design of both the EPL and the surrounding topography essential. The need to attenuate runoff and manage water release into the watershed is highly desirable.

2.3 Objective: Water Quality

The quality of the water that drains into an EPL will vary according to the water quality from natural and mining landforms in the watershed and the relative proportion of natural and process-affected waters, inputs from groundwater, and the source of the water cap. As a result, the ability of EPLs to successfully treat water will vary. Water released from the EPL to the surrounding landscape must meet all prescribed regulatory standards and allow for the evolution of a sustainable, functioning ecosystem in the watershed. Salts and the compounds known collectively as naphthenic acids constitute the primary compounds of concern in tailings and process-affected water (Oil Sands Water Release Technical Working Group, 1996).

Table 2-2: Summary of stakeholder perspectives on water quality.

Government	Aboriginal	NGO	Industry
Water quality is prime concern. Cannot harm fish and wildlife or the greater ecosystem. No deleterious substances in fish and wildlife habitat. Zero-discharge policy for process-affected water released to watershed. Considered temporary treatment facilities.	Restoration of ecosystem should be an overriding concern. Goal should be the preservation of fresh water for wildlife and base of food web for communities. Presence of tailings is not compatible with achieving acceptable water quality.	Quality of outflow should be a top priority. Directive 74 could be considered applicable to EPLs, making tailings treatment problematic.	Believe risk of contamination of greater watershed is acceptably low. Committed to conforming to water quality guidelines. EPL should provide a method of achieving water quality targets.

2.3.1 Government Objectives

Water quality is a primary concern of agencies responsible for enforcing the *Fisheries Act* (2005) and other relevant federal and provincial legislation and regulations. Fisheries and Oceans Canada and Environment Canada are charged with ensuring that the connection of any EPL to the greater watershed does not harm fish and their habitat. The provincial government shares that responsibility, but must weigh habitat considerations against the comparative risks of process-affected water being discharged to the environment.

2.3.1.1 Environment Canada

The *Canadian Environmental Protection Act* (1992), which is administered by Environment Canada (in conjunction with Health Canada) protects water quality, sediment quality, aquatic organisms and human health, from toxic substances and other pollutants. The Canadian Environmental Quality Guidelines, which were updated in 2011, have set recommended levels for several substances within water, sediment and tissue (Canadian Council of Ministers of the Environment, 2011). Many EPLs will likely contain several toxic or potentially toxic substances (Environment Canada and Health Canada, 2001), which are subject to federal environmental control.

The National Pollutant Release Inventory (NPRI) is Canada's legislated, publicly accessible inventory of pollutants released into the air, water and land, as well as disposals and transfers for recycling. The NPRI is managed by Environment Canada and currently tracks over 300 substances and groups of substances, and covers any operation that generates tailings and waste rock. Reporting to the NPRI is mandatory under CEPA (Environment Canada, 2009).

Environment Canada also administers Section 36 (3) of the *Fisheries Act*, which prohibits the discharge of a "deleterious substance of any type in water frequented by fish" unless otherwise authorized. This Section would presumably apply to any releases to natural surface waters from

EPLs, and to EPLs expected to provide fish habitat. Environment Canada has acknowledged the environmental risks of EPLs and has raised concerns regarding the possibility of poor quality water being released into fish-bearing waters (Westcott and Watson, 2007). Any unauthorized release, direct or indirect, of potentially toxic constituents from EPLs into fish-bearing waters could feasibly trigger enforcement action against an operator by Environment Canada.

Environment Canada's Canadian Wildlife Service has an interest in EPL construction and other land disturbances that could involve the removal of migratory birds or their nests, through the *Migratory Birds Convention Act* (1994). As the Canadian response to an international agreement, the Act allows for prescriptions of protected areas for migratory birds and nests and the control and management of such areas.

2.3.1.2 Alberta Environment and Sustainable Resource Development

The EPEA (1993) defines "conservation" as "protecting the essential physical, chemical and biological characteristics of the environment against degradation." It forbids the release of pollutants "in an amount, concentration or level or at a rate of release that causes or may cause a significant adverse effect." This directive has been interpreted to mean a zero-discharge policy for oil sands process-affected water (Giesy et al., 2010). However, the regulatory stricture against the discharge of oil sands process-affected water simply reflects the scope of existing approvals and is not a policy per se. As well, all approved oil sands closure plans ultimately provide for the discharge of process-affected water in the reclamation and closure context, provided the water meets applicable standards. A primary objective of EPLs is ensuring that any water released into the greater watershed meets those standards. Specific guidelines covering releases of industrial effluent are detailed in the *Water Quality Based Effluent Limits Procedures Manual* (Alberta Environmental Protection, 2005), which is based on the Technical Support Document for Water Quality Based Toxics Control (US Environmental Protection Agency, 1991). The EPEA approvals generally regulate water quality and release, as well as the drainage design of the closure landscape. Under EPEA and the *Public Lands Act* (1996), EPLs will be expected to display certain characteristics at the time of drainage integration and water discharge. Generally, the criteria for assessing reclamation certificate applications will be based on whether an EPL is built in compliance with the specifics of the EPEA approval and the subsequent authorized plans.

The province's *Water Act* (1991) also supports and promotes the management, wise allocation and use of water, although its provisions are directed primarily at conservation quantity rather than quality.

2.3.1.3 Joint Government Authorities

Recent EUB, EUB/ERCB and Joint EUB/CEAA Review Panel Reports on oil sands applications have acknowledged the necessity of ensuring EPLs serve as temporary water treatment facilities and exhibit all the features of a functioning ecosystem (EUB, 2006, EUB/CEAA, 2006). Any released water would need to meet applicable Alberta Surface Water Quality Guidelines (Alberta Environment, 1999) in force at the time of release and may be required to meet additional loading limits for substances specific to oil sands process water.

2.3.2 Aboriginal Objectives

Members of the Fort McKay FN and the CEMA Aboriginal Caucus have expressed a passionate concern for the water quality in the Athabasca River, and they fear severe ecological consequences from EPL water being released into natural waterways. The Fort McKay FN no longer relies on the Athabasca River for drinking water and fishing, using the Ells River instead. The community's traplines are also no longer productive due to habitat fragmentation. This represents a significant change for the community, as members are forced to travel greater distances to access the natural resources on which their culture depends.

One of Fort McKay's top priorities is the restoration of the ecosystem. Consequently, the community recommends that if EPLs must be built, they should be constructed and managed in a way that ensures they become part of a natural functioning ecosystem where the water quality is sufficient to allow healthy wildlife to thrive in affected watersheds. For their part, members of the Aboriginal Caucus noted that achieving maximum water quality may preclude the deposition of oil sands tailings in some or all EPLs. The overriding principle governing EPL design and maintenance should be minimizing the risk of contamination of the water that flows through EPLs and out into the watershed. In all cases, Caucus members would prefer to see the water caps of all EPLs treated before release to the surrounding watershed.

2.3.3 NGO Objectives

Members of the CEMA NGO Caucus are opposed to the storage of tailings in EPLs, because of the risk to water quality in the region. They suggest that the spirit of ERCB Directive 074 (ERCB, 2009) could be interpreted to preclude the deposition of tailings in EPLs. However, even a lake without tailings will contain process affected water from tailings in the watershed. The Caucus believes – like the Fort McKay FN – that designers must make the quality of outflow from EPLs a top priority.

2.3.4 Industry Objectives

Oil sands operators recognize that water released from a mine site into the Athabasca River is expected to be of suitable quality to support an aquatic ecosystem. It is expected by some operators that EPLs will provide an efficient method of improving the quality of water recovered from the mine site before release occurs. Each EPL will be designed according to the geographical, hydrological, and ecological characteristics of the site and the limitations of the overall closure plan. Operators are committed to managing their EPLs until acceptable water quality, or a suitable trajectory, have been achieved, and the lakes have been certified as reclaimed.

2.4 Objective: Bioremediation and Tailings Storage

The long-term storage of tailings and bioremediation of process-affected waters is under consideration for EPLs, although not all EPLs are expected to serve as tailings storage facilities (EUB, 2004a). Over several decades, it is anticipated that aerobic and anaerobic bacterial digestion of naphthenic acids, polycyclic aromatic hydrocarbons, salts, and other compounds of concern produced in the oil sands extraction process should transform process-affected waters to the point where they pose no significant risk to the flora and fauna that colonize the EPL or the greater ecosystem that receives outflow from the EPL. Meanwhile, consolidation and normal sediment deposition processes should isolate the tailings. Bioremediation of tailings is generally not considered an objective of water-capping, although it is expected that anaerobic degradation of hydrocarbons will occur to some extent. It is possible that mature fine tailings will prove to be an acceptable barrier with which to line EPLs and minimize water leakage.

Table 2-3: Summary of stakeholder perspectives on storage and bioremediation.

Government	Aboriginal	NGO	Industry
Conditional approval water capping of tailings Criteria for successful demonstration of water-capping approach have yet to be identified; requires proof of efficacy from industry before more general approval from province. Timeline for demonstration of effective treatment prior to certification is critical. Plans to treat EPL waters that do not meet guidelines is preferred.	Doubtful of concept. Skeptical of scientific basis. Water outflow quality should be overriding concern. Bioremediation ruled out by Directive 074.	Doubtful of concept. Skeptical of scientific basis. Concerned about stratification issues; Wind-driven mixing should be avoided. Must distinguish between EPLs with and without tailings. More research needed.	Confidence in the concept. Committed to doing what is necessary to bring EPLs into being. Depends on the project and nature of the tailings.

2.4.1 Government Objectives

Alberta has conditionally approved the use of EPLs as components of a reclaimed landscape subject to the successful demonstration of their ability to establish functional aquatic ecosystems. While provincial agencies recognize that certain grades of tailings pose more of a challenge than others, some EPLs may be able to successfully degrade organics, dilute salts, and generate water of acceptable quality to be released into the Athabasca watershed.

The federal government is more concerned about the chances of water released from an EPL posing a threat to aquatic ecosystems than with the details of the bioremediation activity itself. Decisions of recent Alberta and federal-provincial joint panels reviewing oil sands projects have concluded that significant adverse environmental effects associated with EPLs are unlikely, if all panel recommendations are followed.

2.4.1.1 Environment Canada

The federal government's authority under CEPA (1999) covers the entire aquatic environment, including lake bed sediment. An ultimate objective of any EPL bioremediation plan will likely involve creating a lake ecosystem bed that supports the aquatic ecosystem or, through the food web, human health. This implies a distinction between the objectives of an EPL during the filling stage and the post-certification phase, at which time hydraulic communication will be established with the greater watershed. Given the absence of a successful demonstration EPL, Environment Canada would prefer that operators submit a "functional plan to hold and treat end pit lake waters that do not meet release criteria" (ERCB, 2011).

2.4.1.2 Fisheries and Oceans Canada

DFO has expressed the concern that EPLs may not degrade tailings toxins within an acceptable timeframe (EUB/CEAA, 2004), but has not opposed the concept in principle. Its position will be revisited upon completion of EPL demonstration projects.

2.4.1.3 Joint Government Authorities

Joint Review Panel reports from the EUB and CEAA address the unproven concept of EPLs, and typically order operators to participate in industry research efforts on the efficacy of EPLs. Since 1994, the panels have conditionally approved water capping of tailings in EPLs, subject to a successful demonstration (EUB, 1994; EUB, 2006; EUB/CEAA, 2004; EUB/CEAA, 2006).

2.4.2 Aboriginal Objectives

Members of the Fort McKay FN are categorically opposed to the deposition of wet tailings into EPLs, noting the uncertainties regarding the capacity of EPLs to successfully degrade tailings toxins to a benign state. They consider the threat those toxins pose to the health of aquatic ecosystems too great. Similarly, Aboriginal Caucus members are skeptical about EPLs and recommend further investigation of alternative reclamation strategies, including dry tailings management (although dry tailings are considered preferable to wet tailings).

2.4.3 NGO Objectives

NGO representatives have a general concern over the use of tailings in EPLs. At the very least, they believe that an overriding goal for any tailings management tool should be the successful separation of tailings from the cap water. EPLs should be designed to minimize mixing due to wind and other natural factors. At the same time, the potential of a lake to reach a state of meromixis is also a cause for concern and a source of much uncertainty. More research is required into this issue, as is research into the biological mechanisms involved in bioremediation in general.

2.4.4 Industry Objectives

Each oil sands mine closure plan is unique. Tailings deposition in EPLs may be a logical choice for some mine sites, but not for others. Similarly, thoughts on the suitable method of disposing of and treating process tailings also vary, as does the selection of the grade of tailings deemed appropriate for each lake. Based on the interviews for this chapter, some operators believe that

EPLs should remain an acceptable option for storage and bioremediation of tailings, should the circumstances permit.

According to Syncrude, company research suggests that, even with tailings, EPLs should be capable of producing an aquatic environment suitable to serve as fish habitat. At the current time, it is believed that EPLs can be an effective method of eliminating the compounds of concern found in process-affected water. That position may change should current research result in alternatives that eliminate output of aqueous tailings.

2.5 Objective: Sustainable Aquatic Ecosystem

The ultimate objective – upon which all stakeholders concur – is that EPLs contribute to the eventual evolution of a self-sustaining aquatic ecosystem that serves as habitat for wildlife, particularly fish species. Most, if not all, EPLs will differ significantly in size and topography from the natural lakes that predominate in the Wood Buffalo region. Regulatory and legislative directives governing reclamation strategies require the construction of lakes capable of filling similar ecological roles to those that dominated pre-disturbance landscapes and waterways. It is widely understood that a healthy and sustainable aquatic ecosystem can be characterized by the successful colonization of species at upper trophic levels, such as large fish and waterfowl. No interviewees were inclined to provide specific views on the dimensions of the lakes (e.g., littoral zone, depths, and dimensions).

Table 2-4: Summary of stakeholder perspectives on sustainable aquatic ecosystems.

Government	Aboriginal	NGO	Industry
Emphasis on fish to measure sustainability, but also other wildlife. Habitat connectivity essential. Not necessary that EPLs closely resemble natural lakes of region. Demonstration necessary. Overall goal is integration into the final regional drainage system.	Large fish, waterfowl and terrestrial predators (hunting prey) should be able to thrive. Watershed perspective rather than EPL-focused.	Watershed perspective rather than EPL-focused. Reclamation of adjacent forest may also be necessary. Colonization by upper-trophic level predators, aquatic and terrestrial, should be a gauge of success.	It is likely that the EPL will be on an evolutionary trajectory toward a sustainable aquatic ecosystem at certification. Measures of success will vary from lake to lake.

There is considerable discussion and debate as to when (or whether) each EPL will provide good fish habitat. Several potential scenarios can be quickly listed:

- EPL water quality supports thriving fish populations and is suitable for integration into the landscape and discharge soon after filling;

- EPL supports thriving fish population but water quality does not meet discharge requirements;
- EPL has water suitable for discharge, but not of sufficient quality for thriving fish populations;
- EPL water requires long-term water treatment (either in-lake, at the inlet, or at the outlet) for discharge;
- EPL has thriving fish populations, but the fish are not suitable for human consumption.
- EPL has thriving fish populations and water quality suitable for discharge, but operators do not wish to give up control, and regulators are hesitant to allow discharge or certification, stakeholders and First Nations are hesitant to fish or recreate on it.

Clearly these and other outcomes will need to be considered in planning, design, and regulation of the EPLs.

2.5.1 Government Objectives

The federal and provincial governments both require that EPLs eventually reach a state that can support aquatic habitat. The federal position is focused largely on deriving healthy fish populations, while the province is interested in protecting aquatic life more generally. The safety of migratory birds must also be taken into account. Alberta Environment and Sustainable Resource Development expects operators to incorporate habitat connectivity into mine reclamation and closure plans and return the land to a self-sustaining boreal forest ecosystem. Neither the federal nor provincial governments have published any regulations specifying that EPLs must contain water suitable for human consumption, but both have stated that they should fulfill other ecological roles. EPLs are not expected to closely resemble existing lakes in the region.

2.5.1.1 Environment Canada

Federal objectives for a sustainable aquatic habitat derive primarily from the *Fisheries Act* (2005), which deals with the protection of “spawning grounds and nursery, rearing, food supply and migration areas on which fish depend directly or indirectly in order to carry out their life processes.” CEPA (1999), meanwhile, prohibits activities that “interfere with the functioning of an ecosystem or degrade or alter, or form part of a process of degrading or altering, an ecosystem to an extent that is detrimental to its use by humans, animals or plants.”

The Canadian Wildlife Service administers the *Migratory Birds Convention Act* (1994), an international agreement that prohibits the killing, taking and removal of migratory birds or their nests. The Act also allows for prescriptions of protected areas for migratory birds and nests and the control and management of such areas. This Act could be relevant if active migratory birds are affected as a result of EPL development.

2.5.1.2 Alberta Environment and Sustainable Resource Development

The concept of “equivalent land capability” drives much of the provincial legislation applicable to the oil sands, and is integral to the Athabasca Oil Sands Sub-Regional Integrated Resource Management Plan (Alberta Environment, 2002). It is defined in the *Conservation and*

Reclamation Regulation (1993) under *EPEA* as "similar to the ability that existed prior to an activity being conducted on the land, but that the individual land uses will not necessarily be identical."

It is important to note that EPEA regulations do not require the reclamation end state to meet the original land capability; rather, the project proponent must identify what they believe to be "equivalent" in their reclamation and closure plans and the regulators must accept or request modification of the plans (Oil Sands Research and Information Network, 2011).

Clearly there will be an ongoing dialogue on the application of this "equivalent land capability" to the mosaic of natural and constructed landforms (EPLs, wetlands, riparian areas, and uplands in the region). Naturally, expectations will continue to change and evolve over the coming decades and beyond.

AESRD's accepted long-term objective for EPLs is the evolution of viable fish habitat that is "fully integrated into a functioning reclamation landscape with functional shorelines and riparian areas." They should also provide habitat for a variety of aquatic microbial and invertebrate species, and supply water to rivers and streams in the greater watershed that does not exhibit bioaccumulation of toxins. Self-sustaining aquatic ecosystems, as set down in the *Alberta Public Lands Act*, require viable, stable shorelines and littoral zones (Barker, 2005).

2.5.1.3 Joint Government Authorities

The 2011 ERCB/CEAA Joint Panel Review of the Total E&P Joslyn North mine notes that the concept of EPLs, even those without mature fine tailings, remain unproven. Due to an absence of "any sound evidence to indicate that end pit lakes work as functional self-sustaining aquatic ecosystems," a successful demonstration EPL is a priority objective (ERCB, 2011).

2.5.2 Aboriginal Objectives

Members of the Aboriginal Caucus share the government's scientific perspective on how to assess the sustainability of an EPL ecosystem. Central to that perspective is the successful colonization and reproduction by upper-trophic-level fish and waterfowl species, with which Aboriginal cultures have a close relationship. Many species of terrestrial fauna also depend on a clean source of water and Aboriginal representatives suggest that sustainability objectives should include the surrounding boreal forest and the larger watershed ecosystem. The successful return of beaver, muskrat, and other species commonly targeted by Aboriginal trappers should be a goal of any watershed restoration plan, and operators should take advantage of Aboriginal expertise to identify ecologically important species. To this end, it is essential to evaluate whether any plan for the handling and disposal of tailings is compatible with the long-term ecological health of the watershed.

2.5.3 NGO Objectives

In the absence of successfully "restored" boreal forest peatlands and bogs, members of the NGO Caucus find it unlikely that a fully functioning aquatic ecosystem derived from an EPL can be successfully constructed, particularly those containing tailings. Still, a viable part of a boreal forest ecosystem remains the ultimate objective. Like Aboriginal groups, NGOs place a strong emphasis on ensuring the ecological health of the larger watershed within which the EPL is constructed, including the forest in the riparian zone and beyond that zone, rather than focusing more narrowly on the EPL.

2.5.4 Industry Objectives

Operators will be responsible for the design, construction and management of EPLs until the point of certification. In many cases, it is likely that the EPL will be on an evolutionary trajectory toward a sustainable aquatic ecosystem at certification, although a fully functioning ecosystem could be many years off. The objective is to ensure the EPL has all the elements necessary to take it to a stable and sustainable state before certification is granted. The criteria for what constitutes an acceptable trajectory toward sustainability – such as rate of change in biodiversity, species profiles, and productivity – will be determined through consultation with government agencies and stakeholders, and will vary from lake to lake.

2.6 Objective: Other Uses

Most stakeholders believe an EPL could serve other functions in addition to serving as a sustainable aquatic ecosystem. While the federal Department of Fisheries and Oceans is interested in working with oil sands operators on closure plans, its primary concern lies in ensuring that any supplementary uses do not conflict with the *Fisheries Act*, which applies to any EPLs that host fish populations. All levels of government support community consultations to determine what human uses are involved. In some cases, constitutional access issues may be invoked through the *Indian Act* to ensure First Nations are consulted.

Table 2-5: Summary of stakeholder perspectives on other uses.

Government	Aboriginal	NGOs	Industry
Human usage to be decided case-by-case. Must not conflict with ecological function of the integrated watershed; water quality. Economic contribution of EPL to local economy may be considered. Greenhouse emissions potential to be considered.	Traditional and historical use and access rights by local community must be considered. Aesthetics and recreation are valid considerations.	Aesthetics and recreation should be considered. Community consultation needed.	Stakeholder consultation to provide direction.

2.6.1 Recreation

Among the most frequently mentioned uses of reclaimed EPLs is recreation, for water sports, camping, and fishing. Some operators have committed to taking such requests from stakeholders into account when planning each lake. First Nations and NGOs have both identified aesthetics and recreation as desirable uses, and government bodies are not opposed to such uses if human health and safety are not compromised. If economically feasible, EPL designs could include landscaping to accommodate campsites, road access to boat launches, and swimming areas. As of yet, none have been proposed. Provisions of the federal *Navigable Waters Protection Act* (1985) may apply if EPLs provide a recreational, commercial or transportation function for watercraft. The potential economic opportunities presented by recreational activities are also of interest to Aboriginal communities.

2.6.2 Fisheries

At present, most lakes in northern Alberta do not support significant recreational fisheries. To create one in an EPL would therefore constitute a novel use. The bathymetry and topology of some EPLs may present opportunities to introduce services such as fisheries that are scarce in the region and could prove popular with stakeholders. As long as these supplementary objectives pose no conflicts with the core objectives of maximizing resources, minimizing pollution and the creation of viable ecosystems, they are considered viable options. Species native to local rivers and lakes include walleye, lake whitefish, northern pike, burbot, suckers, yellow perch, goldeye, and mountain whitefish (Alberta Environment, 2006). Lake chub, used as bait fish for many Aboriginal fisheries, may also be a desired addition to lake ecosystems.

While AESRD requires that EPLs eventually reach an ecological state that can support fish, the department recognizes that significant challenges remain before recreational or commercial fisheries can be added to the list of acceptable end uses. In addition, EPLs cannot be treated as compensation for lost fish habitat until the EPL concept has been demonstrated successfully (Barker, 2005).

2.6.3 Economic Development

The Regional Municipality of Wood Buffalo believes that EPL design and end use should be consistent with the economic development of the reclaimed landscape. The forest beyond a lake's riparian zone, for example, should be capable of supporting silviculture or tree-harvesting projects that could make a contribution to the local economy.

2.6.4 Greenhouse Gas Elimination

The bacterial breakdown of hydrocarbons remaining in process water and tailings will emit greenhouse gases (GHGs), the atmospheric accumulation of which is a primary cause of global climate change. As part of government and operators' commitments to reducing the carbon footprint of the industry, it is important to evaluate the net GHG potential of EPLs. The provincial government has suggested that further research into this topic is necessary. If, for example, water-capping of tailings results in the lowest emissions scenario of all possible tailings treatment options, the case for EPL bioremediation or storage may be strengthened. If the opposite is the case, methods of mitigating those emissions may be necessary. The GHG potential of each EPL scenario may vary. However, GHG volume is directly proportional to the amount of unrecovered hydrocarbons in the tailings, and represents lost revenue for operators. Operators therefore have an added incentive to make EPLs a key part of their climate change mitigation strategy by reducing the amount of unrecovered hydrocarbons in the tailings they place in the EPLs.

2.7 Regulations in Context

Ideally, this section would provide a listing of all requirements for oil sands EPL design, construction, monitoring, and performance relevant to EPL qualification for abandonment and certification. However, the technology and science of EPLs, and consequently the regulatory environment, is not developed to a state that enables such a listing. In reality, the regulatory environment is in a state of exploration and flux; EPL planning/design teams will have to expend considerable effort to keep informed about EPL regulatory framework developments by building relationships with regulators from the beginning.

As a starting point, Table 2-6 below provides a list of selected federal and provincial policy, regulatory, and guidance documents that comprise a part of the oil sands mine regulatory framework as of 2011. In some cases, the documents listed in the table provide statements related directly to EPLs while in others the documents relate to mining or other aspects of operations that could influence the ultimate configuration of EPLs. It is expected that, in the absence of a consolidated set of EPL regulations, the EPL planning teams will inform themselves regarding requirements, policies, and regulatory trends by reviewing these and other relevant documents, and updating the list as the currency of those listed expire and/or are replaced with more current policies and regulations.

2.7.1 Interim Directive 2001-7: Resource Recovery

The conservation of energy resources in Alberta is central to the mandate of the ERCB, and the performance of mine operators with respect to the conservation requirements that have been established in that regard are monitored. Oil sands resource recovery is regulated by the ERCB in accordance with its responsibility to enforce the requirements specified in the *Oil Sands Conservation Act*.

In 2001, the ERCB (then the EUB) issued Interim Directive, 2001-7 (ID 2001-7), which standardized the expected minimum level of resource recovery for oil sands mining projects. According to the ID, four criteria would be used to estimate the minimum quantity of bitumen that should be recovered from a deposit, including cut-off grade, minimum mining thickness, cut-off TVBIP ratio (total volume to bitumen in place; for determining pit limits), and processing plant recovery. Operators are able to change the individual criteria as long as overall bitumen recovery is equal to or more than that which would be estimated using the four specified criteria.

While ID 2001-7 makes no explicit mention of EPLs, the directive is applicable to the challenges facing EPL planning teams. Situations may arise wherein a team would prefer to leave bitumen resources unrecovered. For example, landform geometry and/or stability in some EPLs could be improved by stopping short of the required pit limit or by using shallower slopes in the oil sands pit wall. Such cases of ore “sterilization” would require special approval from the ERCB. The possibility of “ore sterilization” is addressed by the ERCB in ID 2001-7 Section 3.1. The key to such applications for planners is to ensure that all reasonable options that would achieve the desired environmental benefits have been investigated before the sterilization of resources is proposed to the ERCB. Option evaluations should be well-documented in anticipation of the need to submit supporting information to the ERCB.

2.7.2 Directive 074: Tailings Management

In February, 2009 the ERCB issued Directive 074, which establishes tailings performance criteria and requirements for oil sands mining schemes. While recognizing that other provincial regulators also have a role in regulating tailings related aspects of mine operations, the directive sets out performance criteria that will be used to ensure the ERCB's mandate of approving the need, location, design, and performance of discard sites is fulfilled.

Section 4 of Directive 074 requires oil sands mine operators to:

- Reduce fluid tailings through fines captured in dedicated disposal areas (DDAs);
- Form and manage DDAs; and
- Report on various tailings plan, monitoring, and performance aspects of the operations.

Directive 074 provides a strong driver for mine planning, and mine operators are developing plans to make the transition from previous tailings technologies and life-of-mine plans to achieving the performance requirements specified in the directive. The directive has the potential to affect ex-pit and in-pit landforms, including EPLs, in terms of chemical and physical characteristics. Additionally, due to the directive's focus on reducing FFT by incorporating fines into trafficable deposits, it is possible that FFT volumes contained in EPLs with water caps will be reduced compared to volumes planned prior to issuance of the directive.

In addition to modifying plans to meet the specific requirements outlined in Directive 074, planners wanting to develop robust mine plans (and EPL designs) that will stand the test of time should pay particular attention to statements in the directive indicating potential future regulatory trends. Section 1.1 of the directive lists several long-term objectives that would have implications for EPLs and states:

> *"recognizing that the above objectives will take time to accomplish, the EUB initiated a phased approach"*

This is a strong indicator that additional regulatory requirements that could affect mine plans and EPL designs in development. EPL planners should review the objectives highlighted in the directive and assess how their plans measure up against these objectives. Plans that achieve all objectives should be considered more timeless than those that achieve some of the objectives and plans that achieve some objectives could be more timeless than those that achieve none. Failure to anticipate future regulatory requirements could lead to large-scale regulatory surprises in the future with attendant cost implications.

Table 2-6: Selected documents contributing to oil sands mining regulatory framework.

Originator or Responsible Authority	Document
Alberta Environment	Surface Water Quality Guidelines for Use in Alberta (1999)
Alberta Environment/ Alberta Sustainable Resource Development	Fish Conservation Strategy for Alberta, 2006-2010 (2006)
Alberta Environment	Water Quality Based Effluent Limits Procedures Manual. (1995)
Alberta Environment	Environmental Protection and Enhancement Act
Alberta Environment	Conservation and Reclamation Regulation
Alberta Environment	Water Act
Alberta Environment	AENV Groundwater Management Framework for the Northern Athabasca Oil Sands Region
Alberta Environment	Athabasca River Phase I Water Management Plan
Alberta Environment	Athabasca River Phase II Water Management Framework
Alberta Environment	EPEA Approvals for Current Projects and Approved Projects not yet operating
Alberta Environment	Water Act Licenses and Approvals for Current Projects and Approved Projects not yet operating
Alberta Government	Lower Athabasca Regional Plan
Alberta Government	Alberta Land-use Framework
Alberta Government	Responsible Actions: A Plan for Alberta's Oil Sands
Alberta Energy	Provincial Energy Strategy
Alberta Environment	Guideline for Wetlands Re-establishment on Reclaimed Oil Sands Leases
Alberta Sustainable Resource Development	Public Lands Act
Alberta Sustainable Resource Development	Alberta Wildlife Act
Alberta Sustainable Resource Development	Fort McMurray-Athabasca Oil Sands Sub-regional Integrated Resource Plan
Alberta Government	Alberta Land Stewardship Act
Alberta Energy Resources Conservation Board (& Energy & Utilities Board) Oil Sands Mining Decision Reports. (Some are joint ERCB (or EUB)/Federal Decisions.)	Including Decisions Number 94-5, 1997-01, 1997-13, 1999-02, 1999-07, 2002-089, 2004-113, 2004-005, 2004-009, 2006-069, 2006-112, 2006-128, 2007-013, 2011-005
Alberta Energy Resources Conservation Board	Oil Sands Conservation Act
Alberta Energy Resources Conservation Board	Oil Sands Conservation Regulations
Alberta Energy Resources Conservation Board	Energy Resources Conservation Act
Alberta Energy Resources Conservation Board	Information Letter 96-7: EUB/AEP Memorandum of Understanding on the Regulation of Oil Sands Developments

Originator or Responsible Authority	Document
Alberta Energy Resources Conservation Board	Directive 074: Tailings Performance Criteria and Requirements for Oil Sands Mining Schemes
Alberta Energy Resources Conservation Board	Interim Directive, 2001-7: Operating Criteria: Resource Recovery Requirements for Oil Sands Mine and Processing Plant Sites
Alberta Energy Resources Conservation Board	Information Letter 94-19: Dam Safety Accord
Alberta Energy Resources Conservation Board	Directive 19: EUB Compliance Assurance-Enforcement
Alberta Energy Resources Conservation Board	Directive 73: Requirements for Inspection & Compliance of Oil Sands Mining and Processing Plant Operations in the Oil Sands Mining Area
Environment Canada	Canadian Environmental Assessment Act
Environment Canada	Canadian Environmental Protection Act
Alberta Environment	Climate Change and Emissions Management Act
Environment Canada	Migratory Bird Conventions Act
Environment Canada	Guidance for the Reporting of Tailings and Waste Rock to the National Pollution Release Inventory
Environment Canada and Health Canada	Priority Substances List Assessment Report. Ammonia in the Aquatic Environment. Canadian Environmental Protection Act, 1999
Environment Canada	Species at Risk Act
Fisheries and Oceans Canada	Canada Fisheries Act
Canadian Council of Ministers of the Environment, 1999	Canadian Environment Quality Guidelines
Canadian Council of Ministers of the Environment	CCME Water Quality Guidelines for the Protection of Aquatic Life
Cumulative Environmental Management Association	Landscape Design Checklist
Alberta Environment	Guidelines for Reclamation of Forest Vegetation in the Oil Sands Region
Alberta Environment Dam Safety Branch (primary provincial users)	Canadian Dam Safety Guidelines

2.8 Conclusion

End pit lakes pose unique challenges from a regulatory perspective. Given that lakes similar in dimension to the anticipated EPLs were not in existence prior to oil sands mining, most experts do not expect EPLs to represent the pre-disturbance landscape. Rather, they will be entirely new features. In the event that mining does displace a lake, it is highly unlikely that the resulting EPL would resemble a natural lake in many fundamental characteristics.

Government and industry have agreed to consider EPLs as a valid option to address legislative obligations to: control the quality of processed water returned to the greater Athabasca watershed; minimize the accumulation of compounds of concern through storage and degradation; and maximize the efficiency of oil sands resource extraction. This approval is contingent upon the successful demonstration of EPLs as a reclamation and/or bioremediation tool.

Due to their size and their effects on local geography, hydrology, and ecology, EPLs will be a permanent and significant feature of the post-mining landscape. Upon certification, they may also be expected to serve a variety of specified and potential long-term uses that have been identified by both government and other stakeholders, including wildlife habitat, traditional land use, human recreation, and economic development.

Through consultations with stakeholders, the ultimate objectives for each EPL will be determined on a case-by-case basis according to the specific characteristics of the lake and the surrounding watershed. However, while achievement of stakeholder objectives may be the goal for an EPL design team, it must be recognized that regulations and government policy may establish requirements counter to, consistent with, or extending beyond stakeholders' goals. It is critical that the EPL planning and design team keep abreast of regulatory requirements in force at the time when the EPL planning exercise is to be completed. Due to the extended timeline associated with EPL design, construction, and certification, the team should also examine regulatory trends to anticipate the future direction of policy and related requirements. This will ensure that appropriate risk considerations are factored into decisions regarding the EPL design, and that the necessary robustness of the design can be incorporated into EPL plans early to avoid costly retrofits.

2.9 Participation

2.9.1 Questionnaire

1. Are end pit lakes appropriate tools for oil-sands reclamation/remediation?
2. Should end pit lakes be a repository for tailings?
3. Should they be used as a bioreactor to eliminate toxins?
4. What should be the end uses of end pit lakes? Fish habitat? Human uses?
5. Should end pit lakes mimic natural lakes of the area in size and function?
6. Should end pit lakes mimic the shoreline slope and depths of natural lakes?
7. What constitutes "equivalent capability?" Is that the end pit lake objective?
8. Who should construct and who should monitor end pit lakes?
9. Is a "natural functioning ecosystem" a realistic objective for end pit lakes?
10. Is there an alternative to end pit lakes and if so, what?

2.9.2 Research Participants

The authors wish to thank the following for coordinating and/or supplying their respective employers' policies and perspectives on EPL objectives:

2.9.2.1 Government and industry consulted

Anderson, Bruce, Suncor. July, 2010
Chow, Geoff, Total E&P Canada Ltd. April 13, 2011
Hazewinkel, Rod, Alberta Environment. April 12, 2011
Kahn, Michael, Regional Municipality of Wood Buffalo. April 13, 2011
Mackoweki, Brian, Fisheries and Oceans Canada. May 6, 2011.
(views also applicable to Environment Canada position);
McEachern, Preston, Alberta Environment. April 27, 2011
Noble-Pattinson, Rachel, Imperial Oil Ltd. April 27, 2011
Payne, Fred, Syncrude Canada Ltd. May 5, 2011
Rogers, Tara, Alberta Energy Resources Conservation Board. April 19, 2011
Wilson, Vivienne, Shell Canada, Ltd. April 25, 2011

2.9.2.2 Fort McKay First Nation

A committee of the Fort McKay First Nation met with David Wylynko, the managing editor of the End Pit Lakes Guidance Document, and Theo Charette, the CEMA Technical Program Manager for the End Pit Lakes Guidance Task Group. David and Theo made a presentation on EPLs, which was following by questions and answers. During a half-day workshop, the Fort McKay views on EPLs were expressed, and David and Theo took notes in order to reflect these views in the present document.

2.9.2.3 CEMA Aboriginal Caucus and NGO Caucus

Details of the First Nations' perspectives were graciously provided by members of the CEMA Aboriginal Caucus: Peter Fortna, Jumbo Fraser, Elmer Herman, Bill Loutitt, Margeurite Punko, Lisa Schaldemose, and Glenn Tremblay. The CEMA NGO Caucus includes representation from the Alberta Biodiversity Monitoring Institute, the Alberta Fish and Game Association, the Canadian Parks and Wilderness Society, Ducks Unlimited Canada, the Fort McMurray Field Naturalists, the Fort McMurray Environmental Association, and the Oil Sands Research and Information Network (OSRIN). David Wylynko, the managing editor of the End Pit Lakes Guidance Document, and Theo Charette, the CEMA Technical Program Manager for the End Pit Lakes Guidance Task Group, met with each Caucus in a half-day workshop format. David and Theo made a presentation on EPLs, which was following by questions and answers.

2.9.2.4 CEMA Industry Caucus

Members of the CEMA Industry Caucus include:

Athabasca Oil Sands Corp.
Canadian Natural Resources Ltd.
Cenovus Energy Inc.
ConocoPhillips Canada
Devon Canada
Husky Energy Ltd.
Imperial Oil Resources
Ivanhoe Energy Inc.
Japan Canada Oilsands Ltd.
Nexen Inc.
Shell Canada
Suncor Energy Inc.
Syncrude Canada Inc.
Total E&P Canada

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3. EXPERIENCES FROM NON-OIL SANDS PIT LAKES

Devin Castendyk
State University of New York, College at Oneonta

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Chapter 3 Table of Contents

3.1 Introduction

This chapter provides direction on the closure of oil sands mine pits and the development of end pit lakes based on the experience of other surface mining industries. It begins with a review of the nature and distribution of non-oil sands pit lakes, with a special emphasis on existing northern latitude (i.e., above 40° North) pit lakes in North America. These lakes are exposed to similar climate conditions which are expected to influence the behavior of future oil sand EPLs, namely equivalent solar radiation, winter ice cover, and spring ice melt.

In addition, these lakes have developed under similar regulatory requirements and public expectations as future oil sands EPLs in Alberta. The bulk of the chapter discusses similarities and differences between non-oil sands EPLs and future oil sands EPLs, factors influencing the sustainable ecological development of future EPLs, and key information for pit lake policy makers and planners. The chapter then reviews seven case studies of existing pit lakes including four existing coal mine pits in Alberta that were designed to facilitate productive fisheries. It concludes with 14 “lessons learned” for designers and operators and with a list of questions to address prior to oil sands EPL design.

3.2 Global Distribution of Existing Pit Lakes

Globally, EPLs are common hydrologic features found in post-mining landscapes. McCullough and Van Etten (2011) noted the existence of 15 coal mine pit lakes in the Collie District of Western Australia. Shevenell et al. (1999) discussed 16 pit lakes resulting from precious-metal mining in Nevada, USA. Sánchez España et al. (2008) reported on 22 pit lakes in the Iberian Pyrite Belt, Spain. Brenner et al. (1987) studied the water quality of 60 coal mine pit lakes in Pennsylvania, USA. Yokom et al. (1997) noted the existence of hundreds of iron ore pit lakes in Minnesota, USA. Geller et al. (1998) and Friese et al. (1998) observed that lignite mining in Lusatia, Germany has resulted in roughly 500 pit lakes. Data are published for 18 northern climate pit lakes in North America situated above latitude 40º North that resulted from surface mining for coal, precious-metals, uranium, and iron (Figure 3-1). These northern climate pit lakes may provide the most insight into the likely behavior of future oil sands EPLs. Between 1982 and 2010, over 36 peer-reviewed journal articles and conference papers published limnological and geochemical observations from existing pit lakes mostly found in the United States and Canada (Table B-1, Appendix B).

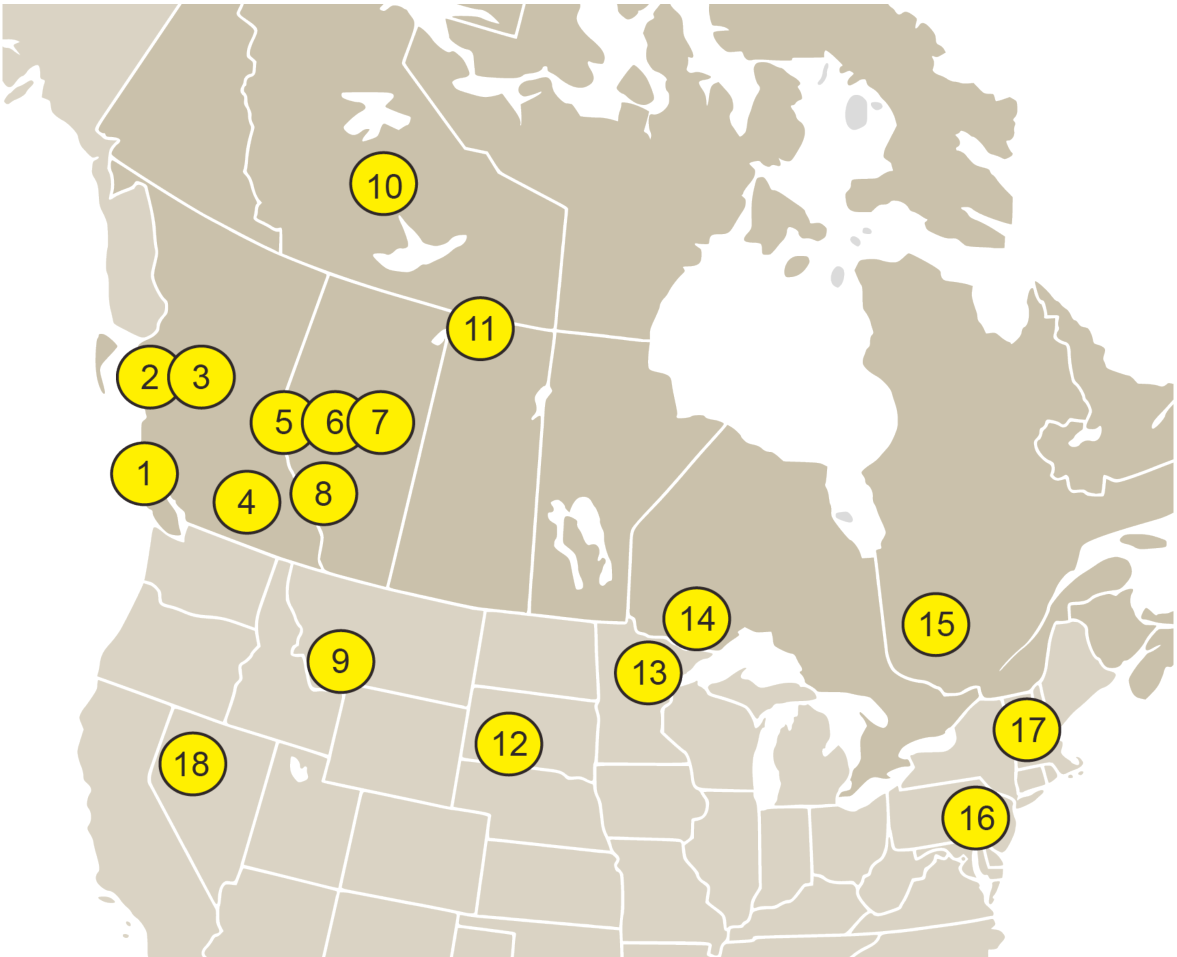

Figure 3-1. Map of North America showing the location of 18 northern climate pit lakes located above latitude 40° N. Lake names and literature references are listed below.

1. Island Copper (Copper), Port Hardy, British Columbia (Pelletier et al., 2009)
2. Waterline (Zinc), Houston, British Columbia (Martin et al., 2003)
3. Main Zone (Zinc), Houston, British Columbia (Martin et al., 2003)
4. Brenda (Molybdenum), Kelowna, British Columbia (Stevens and Lawrence, 1998)
5. Silkstone (Coal), Edson, Alberta (Luscar Ltd., 1991)
6. Lovett (Coal), Edson, Alberta (Luscar Ltd., 1991)
7. East (Coal), Wabamun Lake, Alberta (Sumer et al., 1995)
8. Lac Des Roches (Coal), Cadomin, Alberta (Luscar Ltd., 1991)
9. Berkeley (Copper), Butte, Montana (Gammons and Duaime, 2009a)
10. Colomac (Gold), Yellowknife, Northwest Territory (Chapman et al., 2007)
11. Gunnar (Uranium), Lake Athabaska, Saskatchewan (Tones, 1982)
12. Anchor Hill (Gold), Central City, South Dakota (Lewis et al., 2003)
13. Portsmouth (Iron), Crosby, Minnesota (Close et al., 2006)
14. Steep Rock (Iron), Atikokan, Ontario (Sowa, 2004)
15. East Sullivan Glory Holes (Copper), Val-d'Or, Quebec (Tassé, 2003)
16. Pond Creek (Coal), Freeland, Pennsylvania (Mase et al., 2008)
17. Elizabeth (Copper), Strafford, Vermont (Seal et al., 2003)
18. Sleeper (Gold), Humboldt, Nevada (Dowling et al., 2004)

3.3 Comparing Non-Oil Sands Pit Lakes with Oil Sands Pit Lakes

3.3.1 Geometry

Perhaps the simplest difference between non-oil sands pit lakes and oil sands EPLs is the orientation or geometry of the ore bodies. Precious metal ore bodies are often vertically oriented and open pits tend to have a circular or oval shape when viewed from the air. Pit mines are excavated into solid rock using blasting methods where the structural integrity of the host rock dictates the slope of the pit wall. The slope may range from 40 to 70 degrees. Pit walls may be prone to failure owing to the steepness of the wall, blast-generated fractures, and dewatering activities that increase the effective vertical stress on rocks. Pit walls typically exhibit horizontal benches and haul roads separated by 15 to 20 metres of sub-vertical wall, resulting in a steep, staircase geometry. In some cases, high-grade ore may continue to a depth underground. To extract this ore requires companies to first expand the width of the mine and then increase the depth of the mine floor such that the maximum slope of the pit walls in not exceeded. As such, the area and depth of the mine are not necessarily limited by the extent of the ore body but rather the market value of the ore, the costs of waste rock removal and disposal, and the permitted surface footprint of the mine. As a result, hard rock pit lakes in precious metal mine ore bodies tend to be very deep (20 to 380 m) with relatively small surface areas (0.01 to 1.9 km^2).

In contrast, oil sands mines and many coal mines tend to follow sub-horizontal ore bodies located near the land surface. Rocks may be loosely consolidated to unconsolidated, meaning truck and shovel-mining techniques may be used instead of blasting. These factors allow for shallow strip-mining excavations wide enough to extract most of the high-grade ore. Consequently, oil sands EPLs will tend to be shallow (6 to 55 m deep) with relatively large surface areas (0.6 to 13 km^2).

3.3.2 Water-rock Reactions

As with natural lakes, the water quality in a pit lake is strongly influenced by the chemistry of earth materials found within the surface and groundwater catchments of the lake, including wall rock exposed above and below the lake surface, backfill material, waste rock or tailings materials disposed of in the pit, and rocks exposed along the groundwater flow paths leading to the lake.

Precious metal mines and high-sulphur coal mines tend to have an abundance of iron sulphide minerals such as pyrite (FeS_2), marcasite (FeS_2), and pyrrhotite (FeS) associated with ore bodies. These sulphide minerals oxidize in the presence of oxygen and water to generate sulphuric acid and iron hydroxide (i.e., rust).

The solubility of trace metals generally increases as the pH of water decreases. As such, pit lakes that develop in high-sulphur coal mines, high-sulphur uranium mines, massive-sulphide mines, porphyry copper mines, and some precious metal mines can develop acidic surface water ($\leq$ pH 5) with high concentrations of dissolved metals (i.e., copper, lead, zinc, cadmium, chromium, antimony, etc.) that may exceed local water-quality guidelines. When associated with a mine site, these acidic waters are commonly referred to as acid mine drainage (AMD) or acid rock drainage (ARD). Because of low surface water pH, some pit lakes have been chemically treated *in situ* through the addition of lime and/or NaOH solutions, such as the Sleeper Pit Lake in Nevada (Dowling et al., 2004). Additional examples of acidic pit lakes are discussed by Sánchez España et al. (2008) and Schultze et al. (2009).

Pit lakes that develop in carbonate-rich ore deposits, such as Carlin-Type gold deposits, carbonate-hosted epithermal deposits, and limestone/marble quarries, will generally have high pH ($\geq$ pH 8) owing to the dissolution of carbonate minerals, such as calcite ($CaCO_3$), aragonite ($CaCO_3$), and dolomite ($CaMg(CO_3)_2$). The minerals raise the pH of lake water by neutralizing acid and increasing alkalinity.

Environmental concerns for these ore bodies include the development of neutral, basic, or saline drainage with elevated concentrations of metalloid species (i.e., arsenic, selenium, and molybdenum) and/or high salinity. Shevenell et al. (1999) review the water chemistry of 16 pit lakes in Nevada, USA, many of which exhibit high pH water owing to the presence of carbonate minerals.

Many pit lakes in low-sulphur coal deposits and gravel quarries contain low levels of sulphide or carbonate minerals and high concentrations of silicate minerals such as quartz (SiO_2) and feldspar ($KAlSi_3O_8$). These silicate minerals are relatively inert in water under surface conditions and pit lakes in these deposits commonly develop circum-neutral pH (pH 6 to 8) water with relatively low concentrations of dissolved solids and high water quality. These factors increase the potential for these pit lakes to be utilized as post-mining resources. Today, many lakes situated in former iron mines (Yokom et al., 1997), low-sulphur coal mines (Brenner et al., 1987; Luscar, 1991; Sumer et al., 1995), and aggregate quarries are used for recreational purposes or wildlife habitats.

For many pit lakes in aggregate quarries, the principle contaminants of concern (COC) are nutrients (i.e., nitrogen and phosphorous compounds) and road salts resulting from land use practices within the EPL watershed. Contaminant sources include agricultural activities, waste water treatment plants, and road de-icing salts (Antosch, 1982; Stern, 1991; Peckenham et al., 2009).

With respect to lake water pH, oil sands EPLs will be most similar to pit lakes found in iron deposits, low-sulphur coal deposits, and gravel quarries. Each of these deposits consists largely of quartz and feldspar minerals with low concentrations of sulphide and carbonate minerals. However, sulphide minerals have been identified in the overburden of some oil sands mines and the entire region is underlain by limestone. Although it is unlikely that oil sands EPLs will develop extreme pH waters found at some metal mines and high-sulphur coal mines, wall rocks and backfill materials should be tested for their net acid generation (NAG) potential prior to lake design to ensure that acidic or basic water are not added to the lake. Verburg and Bezuidenhout (2009) provide state-of-the-art, peer-reviewed methods for NAG tests online at: http://www.gardguide.com.

With respect to dissolved constituents and contaminants of concern (COCs), the water quality of oil sands EPLs may be very different from the water quality of other existing pit lakes. The marine sediments that host the oil sands impart elevated concentrations of sodium chloride to the local groundwater which may result in saline lake water with elevated concentrations of total dissolved solids and relatively high water density. Organic compounds such as residual bitumen, naphthenic acids, and polycyclic aromatic hydrocarbons (PAHs) may be found floating on the lake surface, dissolved within lake water, or adsorbed onto lake sediments or tailings. Elevated levels of some trace metals, such as vanadium, selenium, and arsenic (George Dixon, personal communication, 2010), may also occur in high concentrations in oil sands lake water. Process water typically exhibits basic pH (9.0-9.5), elevated NH_3, Fe, Al, Mn, Mo, Ca, and SO_4, and high Total Dissolved Solids (TDS). Collectively, bitumen, naphthenic acids, PAHs, select trace metals, nutrients, pH, and TDS (i.e. salinity) should be designated as potential Contaminants of Concern (COC) in oil sands EPLs. Leachate tests described by Verburg and Bezuidenhout (2009) should be performed on wall rock, backfill materials, and tailings materials prior to lake construction to identify the leachability of these COCs, and the concentrations of these COCs should be closely monitored over time once the lake develops. Mining companies should specify additional potential COCs as the knowledge of potential sources of dissolved contaminants becomes available. Oil sands EPLs may also exhibit high turbidity owing to the suspension of fine grained sediments in the water column, especially if fine-grained tailings are disposed of within the lake.

Long-term datasets of geochemical trends in existing pit lakes have rarely been published by mining companies because of concerns over potential liabilities. One of the best sources of long-term data for pit lakes is the International Network for Acid Prevention (INAP) Pit Lakes Database, a free, on-line resource containing geochemical data from over 370 water samples collected from over 70 metal- and coal-mine pit lakes (Johnson and Castendyk, 2012). The database generates time-series graphs for existing pit lakes containing acidic, neutral, and alkaline waters (see http://pitlakesdatabase.org). For example, the user can generate a nine-year graph of geochemical trends from the alkaline Summer Camp pit lake in Nevada.

Chapter 4 discusses the water chemistry of natural lakes in the Fort McMurray region. Data from these lakes provide the best guidance for the selection of appropriate water quality guidelines and action levels for potential COCs in oil sands EPLs. In addition to the COCs listed above, EPL planners should document nutrient and dissolved oxygen concentrations, salinity, and turbidity in natural lakes as these physicochemical parameters determine the aquatic ecosystem that will ultimately develop in EPLs. In the long run, it may be unreasonable to expect engineered EPLs to exceed the water quality of natural lakes in the region as natural processes will influence EPLs long after human manipulation of water quality has ceased.

3.3.3 Hydrogeology

The hydrogeology of a pit mine dictates the volume of various lake inputs (i.e., water balance), the time required to fill the lake, and the residence time of water in the final lake. The principle difference between the hydrogeology of oil sands EPLs and other pit lakes is the hydraulic conductivity, or ease of groundwater flow, of materials used in pit lake construction. Pit lakes that develop in hard rock mines may take 10s to 100s of years to achieve steady-state lake levels owing to the relatively low hydraulic conductivity of wall rocks and the associated low groundwater discharge rates. If tailings are not added to EPLs, they may be expected to fill faster ($\leq$ 20 years) than hard rock mines because sands and gravels typically have higher hydraulic conductivities than fractured bedrock. However, if tailings are added to oil sands EPLs, the low hydraulic conductivity of these materials combined with the compaction and reduced porosity of these materials over time may significantly lengthen filling times. It may be necessary to augment natural lake filling with surface water discharge to achieve steady-stead conditions over a reasonable period of time. For example, the Island Copper pit lake was flooded with sea water to a depth of 350 m in a matter of 30 days (see Section 3.6.2.3, below).

Apart from the composition of wall materials, pit lakes in both settings are likely to exhibit similar hydrogeological behavior. The daily pumping rate used to dewater a pit provides a first-order approximation of the daily groundwater discharge rate during lake filling. However, in practice this rate will not be constant over time. Darcy's Law dictates that the volume of groundwater discharge is equal to the hydraulic conductivity of the wall material multiplied by the discharge area and the hydraulic gradient.

Assuming that the shape of an EPL will resemble the geometry of a wide inverted cone, the groundwater input volume will initially increase over time as a function of the increase in discharge area as lake level rises (Gammons et al., 2009). At the same time, the hydraulic gradient steadily decreases as the lake elevation approaches the elevation of the surrounding water table. As a result, the daily groundwater discharge rate will peak at some point after the cessation of dewatering, and thereafter show an exponential decrease until steady-state conditions are achieved.

During filling, all pit lakes act as terminal sinks for local groundwater and surface water within the catchment area. In some cases, filling time has been accelerated by the diversion of stream water or ocean water into the open pit. This approach may be necessary if oil sands EPLs are used for tailings disposal, as the low hydraulic conductivity of the tailings will reduce groundwater discharge rates and increase the time until steady-state conditions are achieved.

Once steady-state conditions are achieved, the pit may continue to behave as a so-called "terminal pit lake" that only loses water by evaporation; alternatively it may behave as a so-called "flow-through pit lake" that discharges water to surface and/or groundwater (Figure 3-2). Terminal pit lakes can become increasingly saline over time due to evapoconcentration, whereby the progressive removal of fresh water by evaporation steadily increases concentrations of dissolved solids over time. Eventually, the concentration of specific dissolved species becomes controlled by the precipitation of minerals from the water column. At these concentrations, pit water may be too saline for use by endemic aquatic organisms, waterfowl, and other vertebrates. Eary (1998) discusses the impacts of evapoconcentration on the water chemistry of metal-mine pit lakes in the western United States.

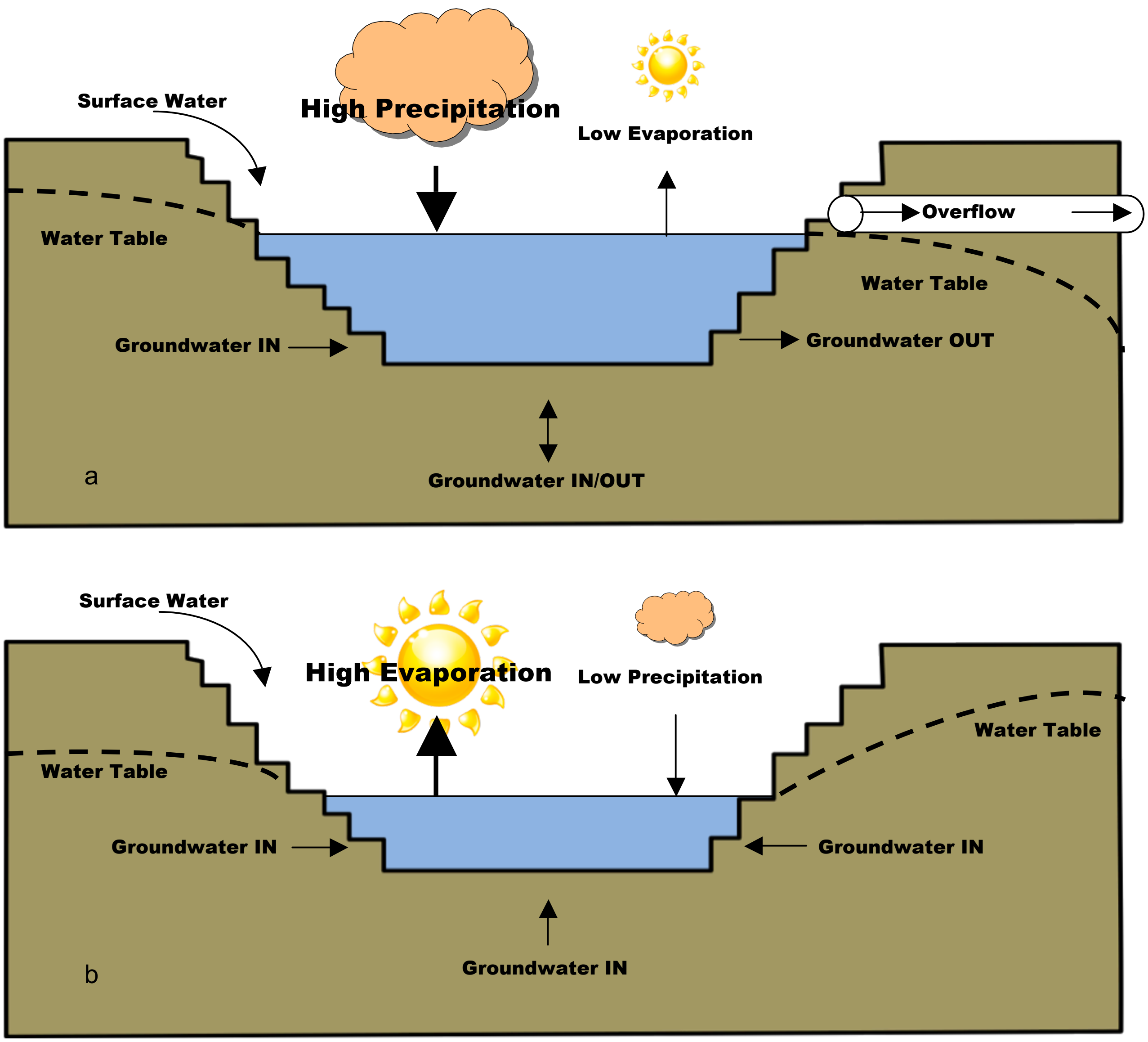

Figure 3-2. a) Conceptual model of a flow-through pit lake in a high-precipitation, net-rainfall climate. Both groundwater leakage and surface water overflow via a discharge pipe are illustrated. However, it is unlikely that both will be significant. Most surface water discharge from oil sands EPLs will occur through an engineered outlet instead of a pipe. b) Conceptual model for a terminal pit lake in a low-precipitation, net-evaporation climate (modified from Castendyk, 2009). Water is lost by evaporation alone.

Flow-through EPLs have the potential to discharge COCs to local groundwater and/or surface water which can affect present and future human populations and aquatic ecosystems. One example of the potential environmental impacts of flow-through lakes comes from the Harvard Pit Lake in California (Savage et al., 2000). Mining activity began during the California Gold Rush of the late 1800s. Subsequent groundwater discharge from the pit lake increased dissolved arsenic concentrations in local groundwater. The region surrounding the mine experienced rapid population growth in the decades following mine closure. This growth was affected by the limited availability of potable drinking water resources owing to high arsenic concentrations in local aquifers. This example of historic activity leading to contemporary liability underscores the importance of understanding both the ultimate fate of COCs originating from oil sands EPLs and the future water resource needs that will result from population growth and climate change.

Given the large watershed area of oil sands EPLs, the number of tributaries that will flow into these lakes, and the expansion of the watersheds over time as new mines close, it is expected that oil sands EPLs will be flow-through lakes once hydrologic steady-state conditions are achieved. As such, both groundwater and surface water resources will need to be monitored for potential COC's over time. Gammons et al., (2006) provides a robust method for quantifying surface water evaporation from lakes using stable isotopes. This method could be an accurate and inexpensive tool to validate water balance predictions once oil sands EPLs begin to develop.

Terminal EPLs generally form in flat-lying, closed basins, where evaporation rates equal or exceed the sum of all other lake hydrological inputs (i.e., surface water, groundwater, direct precipitation and pit-wall runoff). Flow-through pit lakes tend to form in regions of variable topography and where precipitation rates exceed evaporation rates. Hence, it is important to know the projected water balance of an EPL during the design phase. Average annual lake evaporation at Fort McMurray is 575 mm/year whereas average annual precipitation is 445 mm/year (Alberta Government, 2005). If the sum of all other lake inputs is less than 130 mm/year, some EPLs may exhibit terminal conditions whereby concentrations of dissolved solids slowly increase over time. Planners will need to decide whether to develop terminal EPLs that minimize risks associated with off-site impacts but are likely to develop high salinity, or flow-through pit lakes that are likely to have lower salinity but could potentially lead to off-site impacts. Chapter 4 discusses whether natural lakes in the Fort McMurray region exhibit terminal or flow-through conditions, and summarizes current and future climate conditions predicted for the region.

3.3.4 Limnology

Physical limnology describes the development of vertically stratified water layers within an EPL and distinct mixing events between those layers. Like hydrogeology, the physical processes that influence the limnology of oil sands EPLs will be similar to the processes that influence other existing pit lakes. Ultimately, the behavior of natural lakes near Fort McMurray may provide the best prediction of future EPLs (Chapter 4).

In general, natural lakes in temperate climates undergo summer and winter stratification periods where a shallow water layer (i.e., epilimnion) exhibiting comparatively low water density overlies a deep water layer (i.e., hypolimnion) with comparatively high water density. Water density is influenced by both the temperature and salinity of lake water. Natural lakes with low-salinity waters tend to mix from top to bottom during the spring and fall, when the water column temperature differential degrades and the water column has a uniform temperature and density. In addition to vertically homogenizing concentrations of dissolved solids, turnover events resupply hypolimnion water with dissolved oxygen and epilimnion water with nutrients, thereby strongly influencing aquatic ecosystems. Lakes that undergo complete turnover on an annual basis are called “holomictic” (Figure 3-3). Imberger and Patterson (1990) provide a sequential description of the seasonal development of lake stratification and the events leading to turnover.

Small changes in salinity have a greater impact on water density than small changes in temperature. As such, lakes that develop vertical changes in salinity will resist complete lake turnover more than low-salinity lakes of similar dimensions. Partial lake turnover of the upper water column results in a high density, stable bottom layer (i.e., monimolimnion). Permanently stratified lakes have monimolimnion layers and are called “meromictic” (Figure 3-3).

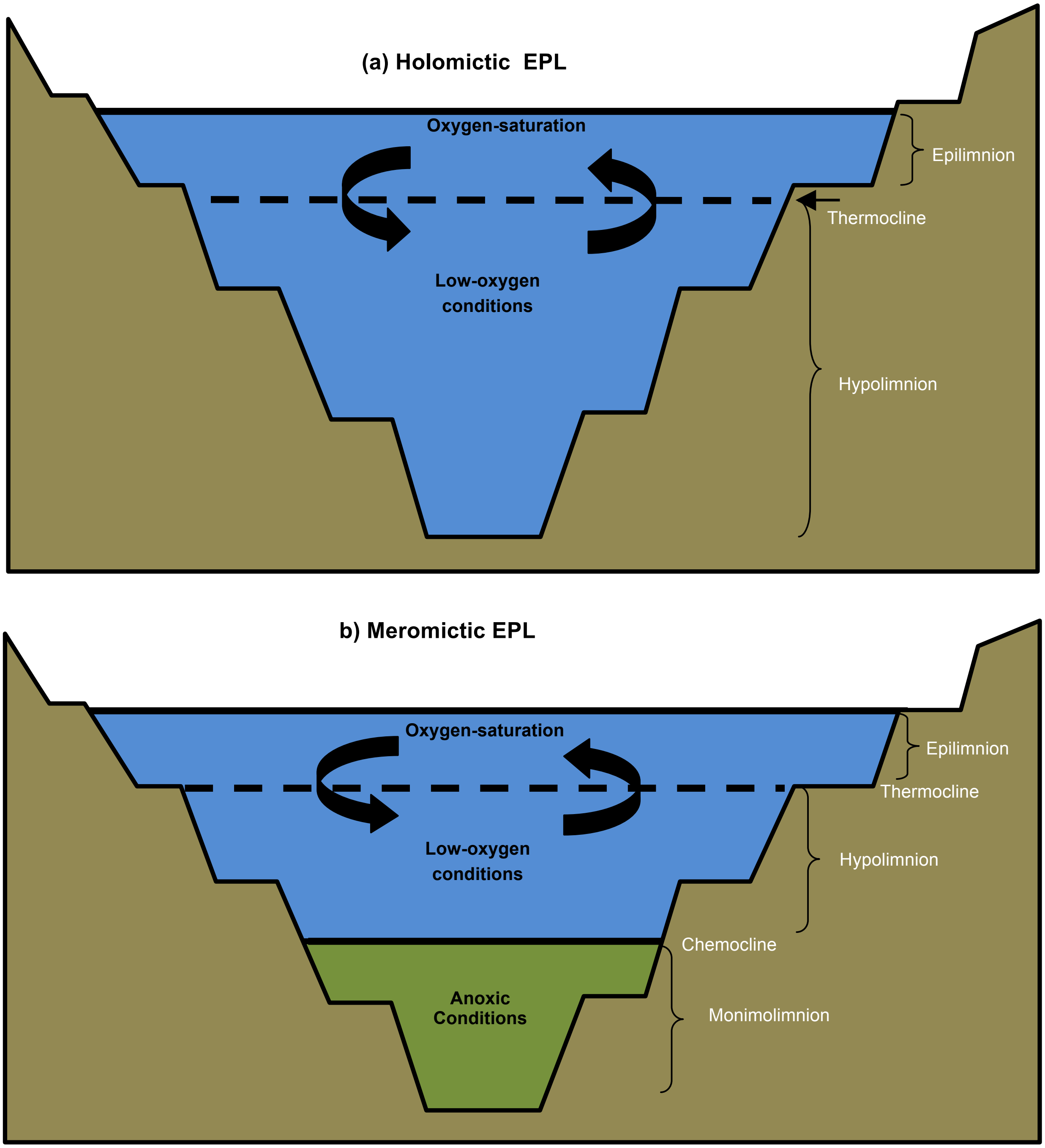

Figure 3-3: Conceptual models of holomictic (a) and meromictic (b) lakes with associated layer terminology (modified from Castendyk, 2009).

Several early papers in the literature emphasize the role of the geometry of the pit lakes in the establishment of meromictic conditions (Lyons et al., 1994; Doyle and Runnells, 1997). However, extensive comparisons between the geometry of existing pit lakes and limnology behavior have not identified a direct link between these variables and water column stability (Gammons and Duaime, 2006; Castendyk and Webster-Brown, 2007; Schultze and Boehrer, 2009). These findings have led contemporary EPL limnologists to conclude that meromictic conditions in pit lakes are more strongly influenced by the salinity of lake inputs than the shape of the pit lake basin.

Meromictic pit lakes provide both opportunities and additional risks for mining companies. Because the monimolimnion water is relatively isolated from surface conditions, it can be used as a repository for dissolved COCs from within the epilimnion and hypolimnion and can potentially be used for the disposal of liquid and solid mine wastes such as oil sands tailings. Martin et al. (2003) demonstrated how the addition of nutrients (i.e., nitrate and phosphate) to the surface water of the Main-Zone and Waterline pit lakes in British Columbia led to dissolved metal sequestration and the improvement of surface water quality. Nutrient additions stimulated the growth of algae which in turn provided a surface adsorption site for dissolved metals. When algae died in the winter, they sank into the monimolimnion, removing metals from surface water and permanently storing them in the monimolimnion. For this method to fully work, Kalin and Wheeler (2009) note that the mass of the settling plankton must be large enough to enable it to cross the density boundary separating the hypolimnion from the monimolimnion.

In some instances, meromictic pit lakes have been deliberately utilized as "bioreactors" for the *in situ* bioremediation of lake water. This procedure generally involves the addition of a labile (i.e., biologically reactive) organic carbon source such as manure, methanol, or molasses, which settles downward into the monimolimnion where it promotes the reduction of nitrate, iron, and sulphur, as well as fermentation and methanogenesis. The goal is to stimulate bacterial sulphate reduction (BSR), which raises pH, adds alkalinity, decreases sulphate concentrations, and promotes the precipitation of metal sulphides (Gammons et al., 2009). Under stronger reducing conditions, the accumulation of dissolved hydrogen gas in solution can lead to the production of methane gas.

BSR has been intentionally instigated at several coal-mine and metal-mine pit lakes to raise monimolimnion pH and to precipitate trace metals as sulphides. Examples include the Garrick East coal pit lake at Collinsville, North Queensland, Australia (McCullough et al., 2008), Island Copper Pit Lake, British Columbia (Pelletier et al., 2009), and the Anchor Hill Pit Lake, South Dakota (Lewis et al., 2003).

Sulphate reduction could potentially occur in some oil sands EPLs without organic amendment. In some oil sands operations, tailings have been stabilized using the addition of gypsum ($CaSO_4 \cdot 2H_2O$) or an aluminum sulphate (e.g., alum: $Al_2(SO_4)_3$). If sulphate-rich tailings are added to a meromictic pit lake in the presence of a labile organic carbon source (e.g., residual bitumen, naphthenic acid, PAH's, or decomposing algae), the potential exists for BSR to occur in monimolimnion water, resulting in the accumulation of dissolved hydrogen sulphide (H_2S). This raises some potential concerns. If the EPL is flow-through, acidic conditions may result down-gradient, where H_2S-rich lake water discharges to the surface environment and comes into contact with oxygen. Given the presence of naturally alkaline surface water, limestone bedrock, and basic tailings water, acid generated by H_2S oxidation will most likely become neutralized. Nevertheless, the pH of EPL groundwater discharge needs to be monitored to avoid off-site impacts; any water leaving the site with a pH < 6 or > 8 will require collection and treatment. In addition, H_2S gas dissolved in lake water is toxic to many forms of aquatic life as well as humans. If an EPL becomes meromictic and H_2S accumulates in anoxic monimolimnion waters, there would be a concern for human heath if the EPL rapidly degasses (see Section 3.6.2.2 below).

If sulphate is not present in the monimolimnion, it is possible that methanogenesis will occur, resulting in the accumulation of methane. It is important to note that some tailings ponds from oil sands operations presently produce significant quantities of methane, which indicates strongly reducing conditions. Methanogens and sulphate-reducing bacteria have been found in oil sands tailings (Holowenko et al., 2000).

If an EPL is designed to be a bioreactor at any point in time, EPL planners should specify mechanisms for the removal of COCs, demonstrate that these mechanisms will occur in the future EPL, and specify the types of organisms (e.g., sulphate-reducing bacteria, methanogens, etc.) participating in the biochemical reactions. To sustain these reactions, planners should also define the redox conditions and nutrient levels required for these organisms to thrive, as well as the chemistry of the reactants and products involved in these reactions. If oxidizing conditions are favored, planners may endeavor to design an EPL that will at least seasonally turn over or may consider the periodic addition of a chemical oxidant, such as hydrogen peroxide, to promote oxidizing conditions throughout the bioreactor phase. Judging from the conditions that promote the natural decomposition of hydrocarbon contamination in groundwater aquifers (Fetter, 2001), the oxidizing conditions found in the epilimnion and hypolimnion of an oil sands EPL will be favorable for the biodegradation of organic COCs. If the lake becomes meromictic, some decomposition of naphthenic acids may occur under anoxic conditions found in the monimolimnion. See Chapters 6 and 9 for more information on the decomposition of naphthenic acids.

Although meromictic conditions have facilitated measurable improvements in water quality at some existing EPLs (e.g., Island Copper), one potential risk associated with meromictic EPLs is the unexpected turnover of the lake water column, which could lead to the rapid degassing of lake water. Such events could be triggered by either an extreme weather event or a large landslide resulting from a pit wall failure (Murphy, 1997; Boehrer and Shultze, 2009). That said, at least one meromictic pit lake (Berkeley Lake, Montana) is thought to have undergone deep turnover without causing degassing issues (Gammons and Duamie, 2006). Nevertheless, companies that own or plan to own meromictic EPLs should attempt to determine the environmental conditions that would result in complete turnover, and the recurrence interval of these conditions. The results of this analysis should be incorporated into the lake risk management plan.

Given that oil sands EPLs will receive moderately saline surface and groundwater ranging from approximately 110 ppm to 527 ppm total dissolved solids (TDS), the potential exists for these lakes to become meromictic with chemoclines being formed if layers of different salinity develop. Lakes receiving higher TDS input waters, or high-TDS pore water from settling tailings, will be even more likely to develop meromictic conditions over time. Meromictic conditions will also be promoted by the freezing of the lake surface during winter months. Because lake ice is composed of low-salinity water, the freezing process will remove salt from shallow lake water and generate a dense plume of water that settles to the lake bottom. The melting of lake ice during the spring combined with snowmelt will add a layer of low-salinity water above the deeper salty water, creating the conditions for meromictic behavior. According to the Alberta Government (2005), daily average air temperatures in Fort McMurray drop below freezing between late October and early April, and daily minimum temperatures can be as low as -40ºC in January. As such, lake ice will form for a portion of the winter which will influence the limnological behavior of an EPL. The combination of freezing winter temperatures and high-salinity water inputs may similarly influence the physical limnology of future diamond mine pit lakes in the Northwest Territories (Gammons et al., 2009).

Industry supports the development of holomictic lakes in order to promote and accelerate the decomposition of organic COCs. Current hydrodynamic models suggest a very low probability of meromixis development at all planned and approved EPLs. Nevertheless, each company should have a monitoring plan designed to identify the development of meromictic conditions, and a contingency plan in place to manage meromictic EPLs if lakes should become meromictic over time.

Additional factors that could influence EPL limnology and water chemistry include the re-suspension of tailings during strong wind events and the vertical migration of residual bitumen from tailings. Both processes will influence the turbidity of lake water, light adsorption, and the temperature profile of the EPL, and thus strongly influence EPL limnology. Biofilms are expected to develop on submerged tailings, which will limit tailings re-suspension. However, in shallow EPLs with high surface areas and long fetchs, wind energy impinging on the lake surface may still be sufficient to re-suspend tailings into the water column. For this reason, it is recommended that the depth from the lake surface to the initial water-tailings interface be > 6 m in EPLs with tailings (see Chapter 6). Given that bitumen has a lower density than lake water, it is possible that residual bitumen in submerged tailings will slowly migrate towards the tailings-water interface and accumulate on the lake surface over time. This process may explain the sudden occurrence of bitumen slicks on Suncor's 20-year-old sustainability ponds after years of bitumen-free surface conditions.

Chapter 4 discusses the distribution of natural holomictic and meromictic lakes in the Fort McMurray region. These lakes provide valuable insight into the depth of the summer epilimnion, the timing and depth of lake turnover events, sub-ice dissolved oxygen levels, and the onset and melting of lake ice. Chapter 6 provides a detailed discussion of the limnological processes likely to occur within oil sands EPLs.

3.3.5 Chemical Reactions

Several geochemical processes have been observed in existing pit lakes that may or may not occur in oil sands EPLs. Tables B2 and B3 in Appendix B list a variety of processes observed within the epilimnion and hypolimnion, respectively, of existing non-oil sands pit lakes, and indicate the likelihood (low, medium, high) of each process occurring in oil sands EPLs. Most non-oil sands research has focused on metal mines and high-sulphur coal mines that store AMD (i.e., low pH lake water with high concentration of heavy metals and high TDS) or neutral/basic mine drainage (i.e., medium to high pH with high concentrations of metalloids and high TDS). Because oil sands EPLs will generally not contain sulphides or carbonate minerals, many of the processes described in the literature have low relevance. In this setting, it is possible that hitherto unstudied processes may develop. This data gap underscores the importance of future EPL water-quality monitoring programs that will inform future planning decisions and expand our understanding of closure risks.

3.3.6 Geotechnical Considerations

Two notable geotechnical differences between oil sands EPLs and non-oil sands pit lakes involve maximum lake depth and slope stability. If tailings are added to an EPL, the tailings will settle, compact, and dewater over time. As a result, the maximum depth of the water in the lake, defined by the distance from the lake surface to the tailings-water interface, will continue to increase over time after the EPL reaches a hydrologic steady state. This characteristic is uncommon in non-oil sands pit lakes. More often, pit wall slope failures lead to the accumulation of debris at the bottom of the lake and a slight reduction in lake depth. The wall rocks of metal and anthracite coal mines may be more likely to fail than the walls of oil sands EPLs because the former tend to have steep, fractured slopes. Van Zyl (2009) noted that pit wall failures present a risk to people accessing the lake, impact water quality by exposing and entraining fresh wall rock material, and enlarge the footprint of the pit over time. Similarly, the unconsolidated materials that make up the walls of oil sands EPLs may also be prone to slumping failure. Geotechnical considerations and risk evaluations for the slope stability of oil sands EPLs are addressed elsewhere in this document (see Chapter 8).

Like natural lakes, EPLs will experience annual variations in lake level in response to climate events, notably flood events. There is little published information available from existing pit lakes on the effects of lake level variation on slope stability, shoreline erosion, or lake outlet function/erosion. At least one future pit lake, at the Martha Gold Mine in New Zealand, will include a permanent passive treatment wetland designed to remove dissolved metals from lake water before lake water flows into an adjacent stream (Ingle, 2002). It is difficult to predict in advance how the performance of this wetland will be affected by high lake water levels, lateral erosion, or channel deepening, but the effect is likely to be detrimental. Long-term performance studies on geotechnical aspects of existing pit lakes are needed to provide proof-of-concept for design features for future EPLs.

3.4 Factors Influencing Sustainable Ecological Development

3.4.1 Ecosystem Selection and Colonization

Prior to EPL design, mine planners should decide on the type of long-term ecosystem desired for the pit lake. Regulators, community members, and mine managers will have different perceptions on the function of the post-mining lake and the type of species that should ultimately inhabit the lake. For rehabilitation to be considered successful by all stakeholders, a realistic, universally accepted aquatic ecosystem goal should be determined early on in the planning process.

Aquatic ecosystems in existing local natural lakes and compensation lakes probably provide the best indication of which species are likely to inhabit EPLs (see Chapter 4 for descriptions). As noted in Chapter 2, many stakeholders place a high value on the establishment of a viable fish population. However, ecosystem development should initially emphasize nutrients and phytoplankton production and build a more complex trophic structure over time. Ultimately, introduced fish species should be chosen based on habitat characteristics, zooplankton, and benthic productivity (Luscar, 1991).

The development of an aquatic ecosystem may be accelerated by deliberately introducing plants and animals from local ecosystems rather than allowing the lake to colonize naturally. In the development of Lovett and Silkstone coal mine EPLs in Alberta, Luscar (1991) introduced macrophytes from lakes located near the mine sites. At the time of writing this document (2012), no followup studies were available to judge the effectiveness of Luscar's efforts.

3.4.2 Physical Habitat and Littoral Zone

Based on Luscar's experience (1991) developing ecosystems in coal mine pit lakes in Alberta, the following list of habitat characteristics for the optimization of fishery habitat in pit lakes can apply to oil sands EPLs:

1. Lake area: A few small ponds are preferable over a single large lake. Increasing the surface area to lake volume ratio will promote ecological productivity.
2. Lake depth: The deepest part of the lake should range from 5 to 15 m. The mean depth should be about 3 m.
3. Bank slope: The vertical-to-horizontal ratio of shoreline slopes should range from 1:2 to 1:5. Topsoil should be replaced and slopes should be re-vegetated above and below the lake surface (i.e., submerged, emergent, and riparian zones). Runoff control berms, diversion channels, and sediment traps should be used to control slope erosion. Highwalls should be stabilized.
4. Shoreline: The shoreline should be long and irregular to provide habitat diversity and to minimize bank erosion resulting from wave action. Island development can increase habitat diversity and encourage utilization by waterfowl.
5. Littoral zone: The littoral zone may be defined as the bottom area of a lake that receives enough sunlight to support plant photosynthesis. To maximize ecological productivity, provide habitat diversity, and provide shelter, the littoral zone should ideally be 40% to 60% of the lake surface area.

6. Water fluctuations: Water fluctuations up to 1 m are beneficial for aquatic ecosystems.
7. Bottom configuration: The bottom of the lake should be irregular to provide habitat diversity.
8. Bottom substrate: The bottom substrate should vary in size and compaction to provide a variable benthic habitat. Organic soil placed in the littoral zone will promote vegetation establishment and growth.
9. Lake orientation: If possible, the long axis of the lake should be oriented parallel to the prevailing wind direction so as to promote mixing and oxygenation of the water column.

Overall, efforts should be made to maximize macrophyte productivity and to minimize algal productivity. Macrophytes will help stabilize bottom sediments and clarify lake water, whereas too much algal growth could lead to eutrophic conditions and anoxic bottom water. Careful planning should be exercised in fetch design as too large a fetch may lead to bank erosion and the re-suspension of submerged tailings, whereas too small a fetch might inhibit holomictic conditions.

3.4.3 Water Quality

The water quality of the lake is an overall reflection of dissolved concentrations of COCs, biological oxygen demand (BOD), chemical oxygen demand (COD), sediment oxygen demand (SOD), turbidity, dissolved oxygen, salinity, and nutrients levels. These variables should not impose limitations on the aquatic organisms desired for the lake.

Each aquatic ecosystem will have a different range of optimal water quality criteria required for maximum productivity. It is important to establish an appropriate nutrient (i.e., nitrate and phosphate) budget for the lake so that primary production can occur without the lake becoming eutrophic. Managers should compare predicted pit lake water quality to ecosystem requirements during the planning phase to increase the likelihood that the EPL will be able to support the desired ecosystem. If predicted water quality is below ecosystem requirements, managers can consider mitigation measures that will improve lake water quality and achieve the desired ecosystem. As a last resort, managers may need to change the ecosystem expectations for the lake by acknowledging that the lake may not sustain specific fish species by planning to perpetually stock the lake, or by planning to introduce heartier, less-sensitive species that will thrive under lower water quality conditions. Given that EPLs will be connected to surface water bodies, only native fish species should be introduced.

One water-quality problem that may limit fish populations is the depletion of oxygen as a result of algal blooms during the summer or ice cover during the winter (Gammons et al., 2009). Algal blooms are triggered by excessive nutrient (i.e., phosphorous and nitrogen) loading to the lake, and the subsequent decomposition of organic matter at depth, which removes oxygen from the hypolimnion. This phenomenon is called eutrophication and may occur in oil sands EPLs given the high nitrogen levels in process waters. EPLs can also be expected to freeze during winter conditions. In Fort McMurray, the daily average air temperature is often below freezing between late October and early April and can be as low as -40 ºC in January (Alberta Government, 2005). After the onset of ice cover, dissolved oxygen will not be added from the lake surface until the ice melts in the spring. Low sunlight levels during the northern winter may decrease sub-ice photosynthesis and oxygen production during winter months. Moreover, the high amount of organic carbon expected within EPLs, especially those with tailings added prior to flooding, will result in a high BOD and COD in lake water. The decay of organic carbon is likely to continue throughout the winter. Considering these factors, it is likely that dissolved oxygen concentrations in EPLs will steadily decrease during winter months, and could possibly drop below conditions required for fish respiration. If this occurs, fish mortalities may occur during the winter due to low oxygen levels; this is a phenomenon called "fish winterkill."

3.5 Legislation and Policies Regarding Pit Lakes in North America

In the United States, regulatory interest in the water quality of pit lakes began in the 1980s as a result of several factors: (1) New environmental legislation on surface water quality and coal mine reclamation (i.e., the Clean Water Act of 1972, and the Surface Mining Control and Reclamation Act of 1977); (2) The closure of several open pit metal mines in the western United States in the 1980s and the development of pit lakes on these properties; and (3) An increase in permit applications for new open-pit mines on state and federal lands corresponding to rising metal prices and improved efficiency in ore recovery from bulk rock. In 1989, Natural Resources Canada established the Mine Environment Neutral Drainage (MEND) Program to develop technologies to prevent and control acidic drainage resulting from metal, coal, and uranium mining, including open pit mining.

In endorsing the Minerals, Mining and Sustainable Development Report in 2002, members of the global mining industry formally established a precedent for attempting to engineer pit lakes into usable post-mining resources where possible (MMSD, 2002). Several pit lakes have now been designed to facilitate and enhance specific end uses, including the storage of mine waste, the storage of water supplies, recreation and tourism, ecological habitats, aquaculture, enhanced metal recovery, and scientific research (Gammons et al., 2009; McCullough et al., 2009).

3.6 Case Studies of Northern Climate Pit Lakes

3.6.1 Coal Mine Pit Lakes in Alberta

At least five coal-mine pit lakes in the Eastern Slope region of Alberta have been engineered into potential fisheries and recreational areas. In addition to the four lakes discussed below, Powter and Blako (1990) report on a coal-mine pit lake near Canmore that is extensively used for fishing and picnicking. These lakes provide additional design lessons for the development of sustainable EPLs in Alberta, and possibly illustrate the expectations of both regulators and the general public toward future EPLs. However, these case studies are over 16 years old and only discuss the "potential" for fisheries development. Contemporary evaluations of water quality, fish populations, and public recreational use are needed to provide proof-of-concept for the rehabilitation strategies, to quantify the success of rehabilitation efforts, and to conduct a cost-benefit analysis of various rehabilitation methods.

3.6.1.1 East Pit Lake (Sumer et al., 1995)

Strip mining near Wabamun Lake began in 1962 and concluded in 1982 (Fig. 3-1, #7). Because groundwater would be the principle water input to the filling lake, groundwater modelling was an important component of the closure planning. The lake was expected to reach steady-state conditions in 2004. The restoration goal was to establish and maintain a sport fishery, which required careful consideration of which species to introduce, stakeholder views, long-term enhancement costs, habitat limitations, and ecological requirements. Water-quality monitoring and habitat assessment between 1988 and 1994 demonstrated that East Pit Lake was suitable for establishing an arctic grayling recreational sport fishery. The mining company TransAlta received a reclamation certificate for the EPL from Alberta Environmental Protection in 1994. Activities are currently focused on fisheries management and planning day-use recreational activities including picnicking, cross-country skiing, and birdwatching.

3.6.1.2 Silkstone Lake (Luscar, 1991)

Silkstone Lake was developed 80 kilometres south of Edson with the intent of creating a fishery (Fig. 3-1, #5). A steady-state lake level was achieved in 1986. The lake inflow is dependent upon groundwater flow and runoff from the surrounding drainage basin. Silkstone Lake is a flow-through lake that discharges surface water to the Lovett River. A littoral zone less than 3 m deep was established for over 30% of the lake surface area. Shoreline and lake bottom configurations were left irregular to increase habitat diversity and minimize wave action. Macrophytes were transplanted from adjacent lakes into the EPL. In 1989, biannual water monitoring and limnologic and biological characterization concluded that the lake had the potential to support limited stocks of trout. However, growth rates would initially be poor due to low rates of primary productivity, low benthic invertebrate abundance and limited littoral habitat. Good fisheries potential was expected to develop over time as the continued colonization of macrophytes increased rates of primary production and invertebrate biomass.

3.6.1.3 Lovett Lake (Luscar, 1991)

Lovett Lake is also 80 km south of Edson, adjacent to Silkstone Lake, and was developed with the same fishery development goals and approaches described above (Fig. 3-1, #6). The lake achieved a steady-state lake level in 1985. The water level of this flow-through pit lake is maintained by the leakage of lake water to the surrounding groundwater system. The achievements and limitations discussed for Silkstone Lake in 1989 also apply to Lovett Lake.

3.6.1.4 Lac des Roches (Luscar, 1991)

The development of Lac des Roches, 40 km south of Hinton, began in 1985 and concluded in 1987 when the lake achieved steady-state, flow-through conditions (Fig. 3-1, #8). To accelerate lake filling, surface water was diverted from Luscar Lake and added to the pit. The pit lake discharges surface water to the adjacent Jarvis Creek West, and the littoral zone constitutes only about 5% of the lake surface area. As such, remedial work focused on shoreline accessibility and habitat enhancement. This included: placing tires in the lake to offer areas for periphyton attachment and fish cover; adding organic material to the littoral zone; transplanting macrophytes from an adjacent lake; seeding highwalls; and, constructing benches so that bighorn sheep and mule deer could utilize the lake area. To improve spawning potential immediately downstream of the lake, an extensive habitat improvement program of the lake outflow channel was undertaken which involved construction of a gabion mat and a plunge pool, plus a series of dams and pools. Chemical and biological studies between 1986 and 1989 concluded that although the lake was oligotrophic (low in nutrient concentrations and low productivity rates) with elevated nitrogen, sulphate, and sodium compared to local natural lakes, it appeared to be capable of sustainably supporting a fish population.

3.6.2 Precious Metal Mine Pit Lakes

As previously noted, existing precious metal mine pit lakes are significantly different from future oil sands EPLs, primarily because of the ultimate depth of open pits and the quantity of sulphide minerals present in waste rock and pit wall rocks. The following lakes have poor water quality characterized by low pH water and/or high concentrations of trace metals.

3.6.2.1 Berkeley Lake (Gammons and Duaime, 2006)

One of the "worst case" examples of an existing pit lake is the Berkeley Pit Lake at the Clark Fork Superfund Site, Butte, Montana (Fig. 3-1, #9). It is situated in a porphyry copper deposit (Gammons and Duaime, 2006). Mining began in 1955 and concluded in 1982. The lake began to fill in 1983. As of 25 May 2010, the lake was over 250 m deep, and the surface water had a pH of 2.49 and a dissolved copper concentration of 65.4 mg/L (GWIC, 2010). This value is 50 times greater than the US Environmental Protection Agency's (US EPA) maximum concentration limit for dissolved copper in drinking water (i.e., 1.3 mg/L; http://water.epa.gov/drink/contaminants/index.cfm). Concentrations of other trace metals are also remarkably high (e.g., zinc ~ 600 mg/L). In 1995, the lake caused fatal injuries to 342 migrating snow geese, which generated wide media attention (Hagler Baily Consulting, 1996; Woodbury, 1998).

As of 2006, the lake level continued to rise at a rate of approximately 10 million litres per day. The US EPA has mandated that the lake level in the pit is forbidden to reach an elevation of 1649 m. Above this level, lake water would discharge into a bedrock or alluvial aquifer and resurface in the nearby Silver Bow Creek. To maintain water below the critical level, lake water must be pumped and treated in perpetuity. Since 2003, copper has been economically recovered from monimolimnion water by sprinkling lake water onto scrap iron. After this process, the copper-depleted water is returned to the lake surface. This recovery system will continue until copper concentrations in lake water become too low to generate a profit. Recovery methods for other metals are not profitable at this time (Gammons and Duaime, 2006).

Although the lake was initially meromictic, the copper recovery process has generated holomictic conditions. At the time of writing, the lake is completely vertically mixed.

3.6.2.2 Anchor Lake (Lewis et al., 2003)

The Anchor Hill pit lake is a good example of an pit lake that was used as a "bioreactor" to improve water quality *in situ* (Fig. 3-1, #12). The Anchor Hill gold mine operated at what is now the Gilt Edge Superfund Site, in Lead, South Dakota, from 1986 to 1998. By 2001, the pit lake was 30 m deep with a pH of 3.0 and highly elevated concentrations of aluminum (223 mg/L), cadmium (0.6 mg/L), copper (43 mg/L), sulphate (3270 mg/L), and other trace metals. In 2001, the US EPA initiated a remediation project aimed at increasing the surface pH to 7.0 and lowering trace metals to acceptable levels. While successful, both goals proved more difficult to achieve than expected.

Initial lime additions only raised the pH to between 4.5 and 5.0. Methanol and animal feed-grade molasses were then added to stimulate both nitrate and sulphate reduction in order to increase alkalinity and pH. However, it was not until NaOH solution was added in September of 2002 that the pH reached the target of 7.0.

Metal concentrations were reduced by the precipitation of metal-sulphides in lake sediments. By the summer of 2003, denitrification was complete, sulphate reduction was established, and metal concentrations had dropped below regulator standards. However, organic amendments also caused elevated hydrogen sulphide (H_2S) concentrations in monimolimnion water. By 2004, hydrogen sulphide was 100 mg/L in deep lake water which presented a human health risk if turnover and degassing occurred. Consequently, organic amendments were terminated and hydrogen peroxide (H_2O_2) was added to the lake to oxidize H_2S to elemental sulphur and sulphate (Lewis et al., 2003). Remediation ended in 2006 when millions of gallons of acidic water from the nearby Sunday Pit were transferred into the Anchor Hill lake.

3.6.2.3 Island Copper Lake (Pelletier et al., 2009)

In 1996, BHP-Billiton flooded the Island Copper pit lake at Port Hardy, B.C., to a depth of 350 m in approximately 30 days using seawater (Fig. 3-1, #1; Pelletier et al., 2009). Under natural recharge conditions, lake filling would have taken 50 to 75 years. Mine managers deliberately engineered the pit lake to be meromictic by capping the final 16 m of the lake with fresh surface water. The density difference between the fresh water layer and the seawater layer prevents the lake from vertically mixing (Fisher and Lawrence, 2000).

Initially, AMD generated from adjacent waste rock dumps was injected into the monimolimnion at a depth of 220 m. However, the injected water had a lower density than the seawater it was injected into, and rose toward the top of the lake as a buoyant plume. The motion of this plume, combined with the redistribution of low-density water, threatened to destabilize lake stratification. This example underscores the need to fully understand lake limnology and monimolimnion stability before disposing of mine wastes into a pit lake. Once this risk was identified, the company replaced the injection system with a novel system that mixes alkaline water from a depth of 15 m with the AMD, and discharges this mixed fluid to shallow lake water. The new system treats AMD and maintains meromictic behavior in the lake (Pelletier et al., 2009).

Several million tons of reactive waste rock was intentionally stored in the pit prior to flooding. The rapid dissolution of oxidation products from the waste rock became the source of elevated zinc, copper, and cadmium concentrations observed in lake water today, each exceeding permitted water quality guidelines. To reduce dissolved concentrations of these metals, in 2001 the company began to disperse 1,700 L of liquid ammonium polyphosphate and urea and ammonium nitrate across the lake surface on a weekly basis to stimulate the growth of phytoplankton. Phytoplankton can improve water quality by directly incorporating trace metals into their biomass and by providing a surface adsorption site for trace metals. When phytoplankton die after 1 to 2 days, their bodies settle downward through the water column, removing COCs from the surface environment and accumulating these metals to the monimolimnion. Under reducing conditions in the monimolimnion, the organic carbon of the phytoplankton can fuel BSR. Ultimately, trace metals may be precipitated from the monimolimnion as sulphide minerals. BHP-Billiton will continue to add fertilizer to the lake surface on a weekly basis until the trace metals are depleted and surface water quality meets permitted levels. This is expected to take an extremely very long time (Pelletier et al., 2009).

3.6.3 Worst-case Scenarios

The six "worst-case scenario" environmental risks associated with pit lakes include the following:

(a) Degradation of human drinking water resources due to surface and/or groundwater discharge from a pit lake. This has occurred near Jamestown, California, where arsenic-rich groundwater discharging from the Harvard Pit Lake has degraded the water quality of local aquifers (Savage et al., 2000).

(b) Chronic and/or acute health injuries to terrestrial organisms utilizing a pit lake as a temporary or long-term habitat, including risks associated with bioaccumulation up the food chain. Hagler Bailly Consulting (1996) report on acute injuries to migratory waterfowl using the surface of the Berkeley Pit Lake in Butte, Montana.

(c) Chronic and/or acute impacts to aquatic ecosystems that receive surface water and/or groundwater originating from a pit lake. Above a specific lake surface elevation, water from the Berkeley Lake will flow into a shallow aquifer that discharges to a nearby stream. To avoid impacts to adjacent aquatic ecosystems, the US Environmental Protection Agency designed a "critical level" for Berkeley Lake that cannot be exceeded. The lake elevation will therefore have to be maintained by pumping and treating lake water in perpetuity.

(d) Acute impacts to terrestrial and aquatic organisms caused by the rapid degassing of H_2S, CO_2, or CH_4 resulting from the unexpected turnover of a meromictic pit lake. Murphy (1997) and Schultz and Boehrer (2009) question whether meromictic pit lakes could rapidly degas and cause impacts similar to the fatal 1986 limnic eruption of Lake Nyos, a volcanic crater lake in Cameroon (Halbwachs et al., 2004). Although this risk has not been reported at an existing pit lake, it influenced the remediation plan for the Anchor Hill Pit Lake in South Dakota, where unexpectedly high concentrations of dissolved H_2S in deep lake water required biochemical treatment activities to be curtailed (Lewis et al., 2003).

(e) Massive fish kills as a result of eutrophication or winterkills. This would be particularly tragic if significant funds and effort went into the design and construction of a self-sustaining fishery only to have that fishery wiped out. Fisheries must first be established for this to become a risk. However, it is important to keep this risk in mind if establishing a self-sustaining fishery is a specified goal for an EPL.

(f) Human fatalities resulting from drowning in a pit lake. The OSMRE (2007) report noted drowning accidents at abandoned coal-mine lakes in Virginia. Two deaths also occurred in pit lakes in Western Australia in the past 5 years and one in North Queensland in 2005 (McCullough, personal communication, 2011). McCullough and Lund (2006) list these as significant risks of pit lakes.

The first five risks involve geochemical, hydrological, and limnological processes within the EPL and may require advanced mitigation strategies. The last risk can be minimized by removing pit-high walls and establishing a gently sloping littoral zone.

3.7 Lessons Learned from Non-Oil Sands Pit Lakes

The global mining industry has over three decades of experience developing, remediating and restoring metal, coal, uranium, and aggregate pit lakes. From this wealth of knowledge, the following 14 key lessons relevant to the development of oil sands EPLs have been defined. These lessons should be considered during the planning phase of mining, or before mining begins, such that the results of each analysis can be integrated into mine planning, and the costs associated with closure and certification can be factored into initial profit estimates. In the following context, “closure” refers to the time when the EPL achieves a steady-state lake elevation, and “certification” refers to the time when regulators determine that the EPL has become a self-sufficient, functional component of the surrounding ecosystem.

(a) **Use a Risk Management approach to minimize potential environmental and social hazards instead of a Risk Response approach**. Companies using a Risk Management Approach identify hazards associated with EPLs *before* they occur and implement strategies to reduce the likelihood of occurrence and the severity of the impacts. Lee (1999) describes how to quantify risks for sulphur-rich metal-mines. Strategies to address risks are explicitly stated in a Risk Management Plan. This plan is updated regularly using information gained through monitoring and research programs that change the estimated likelihood and severity of known risks and identify new risks. By comparison, companies using a Risk Response Approach address risks *after* accidents occur, which often costs more money and undermines stakeholder confidence. Russell (2010), an environmental regulator for the U.S. Environmental Protection Agency, emphasizes the need for companies to quantify the risks associated with mining from a regulatory perspective. Risk workshops, now a common feature of mine closure planning, provide an ideal forum for operators to consider EPLs as a key feature for mine closure planning.

(b) **Characterize the mining environment in advance of mining, including local climate, hydrology, geology, water chemistry, ecology, economy and community/indigenous views**. Kuipers et al. (2006) identified a high percentage of error between geochemical predictions of water quality at hardrock mines in the United States and observed water quality. They concluded “the lack of adequate geochemical characterization is the single-most identifiable root cause of water quality prediction failures." Mines should collect environmental data throughout all stages of the mine life cycle, and use these data to forecast water quality and to validate and refine water quality predictions. Geochemical characterization of tailings, waste rock, and their leachates are not a common requirement for mine approval and closure plans worldwide.

(c) **Avoid over-simplification of complex processes; expect each lake to be unique**. Pit lakes are complex geochemical systems. Even adjacent lakes in similar bedrock receiving similar meteorological conditions can exhibit differences in water chemistry and limnology (see examples by Castendyk and Jewell, 2002; Schultze et al., 2010). To avoid unexpected outcomes, separate characterization and hydrological, limnological, and geochemical prediction studies are strongly recommended for each lake.

(d) **Know the site closure and certification expectations of all stakeholders, including corporate sustainability objectives, regulatory requirements, and local community expectations, before designing the EPL**. This information will help establish the targets for rehabilitation, and therefore the mitigation and rehabilitation efforts that may be needed. Planners should tabulate the concentrations of dissolved solids (especially COCs) and the aquatic and terrestrial ecosystem types required by regulators at closure and certification. To sustain positive public relations, it is equally important to ensure that any commitments made to community groups throughout the mine life, including promises made by previous mine operators, are acknowledged and upheld where possible. Russell (2010) further describes the need to understand the expectations of regulators, community members, and other stakeholders.

(e) **Budget for and perform decade-scale follow-up studies of post-closure EPLs to quantify, demonstrate, and support the effectiveness of rehabilitation techniques.** Such long-range studies, sometimes called "post-audits," are typically not performed due to a lack of funds or incentive, or if they are performed, the findings are poorly distributed such that the mining industry as a whole cannot learn from the experience. However, such studies are essential to validate the effectiveness of closure techniques proposed at new mine sites. Mining companies may wish to perform their own post-audit of another company's EPL if similar closure strategies are proposed, or if similar environmental conditions are expected to exist. A contemporary post-audit will demonstrate whether a given closure strategy "worked," thus reducing a company's reliance upon older, possibly outdated, information during the EPL planning process.

(f) **Invest time and other perspectives in developing a comprehensive conceptual model unique to each pit lake, and be prepared to update the conceptual model as needed over time.** In predictive modelling, errors between predicted values and observed values are most often associated with errors in the conceptualization of the processes involved, called the conceptual model (Anderson and Woessner, 1992). Companies should appreciate that the development and refinement of the conceptual model is one of the most time intensive components of predictive modelling (Bredehoft, 2005). Moreover, major changes to the mine plan after a prediction is generated typically require updates to both the conceptual model and the prediction (Castendyk and Webster-Brown, 2010).

(g) **In advance of mining, predict the likely pit lake water chemistry and evaluate closure costs based on these predictions.** Numerical models provide a useful tool to predict post closure water quality in advance of mining. For EPLs, this typically involves modelling groundwater hydrology, lake water balance, physical limnology, and geochemistry. Castendyk and Webster-Brown (2006) demonstrate how pit lake predictions can also be utilized to evaluate cost-effective remediation strategies that provide the "biggest bang for the buck." Their sensitivity analysis of a geochemical prediction for the Martha Pit Lake in New Zealand showed that covering acid generating wall rocks exposed above the lake surface caused a significant improvement in water quality. By knowing the post-mining water chemistry, mine managers can make realistic estimations of closure costs in advance of mining, and budget for these expenses accordingly.

(h) **Validate water quality predictions using direct observations, laboratory-based models, existing oil sands pit lakes, natural lakes, and other methods**. The standard approach used to validate a predictive model is to compare predicted data to observed data, and to adjust the model until it consistently reproduces observed data (Anderson and Woessner, 1992). Werner (2009) and Oldham et al. (2009) provide examples of this approach where predicted EPL water quality is directly compared to observations. Eary and Schafer (2009) describe several additional strategies to check the accuracy of prediction models. The modeler should use the validation procedure to quantify the degree of confidence in the model.

(i) **Have realistic expectations for the accuracy of long-range predictive models. Companies and mine planners should expect geochemical predictions to provide a probable range of dissolved concentrations that will exist in the future.** This information is useful in risk assessment and mitigation cost analysis. However, it is unrealistic to expect predictive models to provide the exact concentration of a given contaminant of concern decades after mine closure (Eary and Castendyk, 2009). Estimates of higher-concentration solutes will generally be more accurate than those for trace elements.

(j) **Develop an industry culture of technology transfer to share data and best-management practices and to minimize impacts industry-wide in an effort to reduce redundant research and improve the overall public image of the industry.** Multiple, collaborative, technology-transfer organizations have operated in the metal- and coal-mining industries over the past two decades, such as the Global Alliance (GA), the International Network for Acid Prevention (INAP), the International Mine Water Association (IMWA), the Mine Environment Neutral Drainage Program (MEND) in Canada, the Acid Drainage Technology Initiative, the Metal Mining Sector (ADTI-MMS) and the Coal Mining Sector (ADTI-CMS) in the United States, and the Australian Coal Association Research Program (ACARP). These organizations reduce industry costs by eliminating redundant research performed within the same mining sector and by collectively financing research into data gaps (Gallinger and Fleury, 2003). For the oil sands industry, the Cumulative Environmental Management Association (CEMA) currently functions in this capacity.

(k) **Recognize that hydrologic pit lake isolation from the surrounding environment is not a long-term management option: plan and prepare for off-site water quality effects**. The transportation of mine drainage away from mine sites into surrounding aquatic ecosystems via groundwater or surface water is widely recognized as the biggest environmental issue for the global mining industry (Savage et al., 2000; Younger, 2002; Kuipers, 2006). It is therefore important to characterize the surface and groundwater hydrology of the future EPL, to define flow paths leaving the EPL, and to identify aquifers and surface water bodies that will ultimately receive EPL discharge prior to lake development. It is equally important to predict the water quality of site drainage, and if necessary, develop active or passive treatment systems to mitigate water quality before the drainage enters the receiving environment and specific environmental receptors. The water quality of the receiving environment should be characterized prior to mining and routinely monitored during mining, closure, and post-closure phases.

(l) **Expect higher closure costs than initial estimates: in some cases, perpetual water treatment systems may be required to meet closure criterion**. In a recent presentation on modern mining practices, van Zyl (2010) noted that mining companies have a history of underestimating the full costs associated with mine closure during the planning phases of mine development. For example, to maintain lake elevation below the “critical level” specified by the US EPA, managers at Berkeley Lake, Montana, are required to pump and treat lake water in perpetuity. It is unlikely that the cost of this treatment was considered during mine planning.

(m) **Set internal benchmarks for water quality over time before lake development, monitor lake water over time, and be prepared to modify the lake closure plan if necessary**. Predictive models can be used to determine the likely trajectory, or trend, of water quality development in an EPL over time. Lakes that develop along a “healthy” trend are unlikely to exceed the closure guidelines, called maximum concentration limits (MCLs), for a given COC over time, whereas lakes developing along an “unhealthy” trend are likely to exceed MCLs for one or more COC’s at some point in the future. By defining these trends, companies can establish internal “benchmarks” for healthy lake development, and “action levels” for unhealthy lake development in advance of lake filling. During lake development, if monitoring data show the concentration of a COC exceeding an action level, the company can modify the closure plan to include a remediation measure(s) that will reduce the likelihood of the MCL being exceeded. These plans can be directly incorporated into the risk management plan for the EPL and assures stakeholders that a proactive plan for risk avoidance is in place. Using benchmarks requires a well-defined monitoring program with short time intervals between sampling events, predictive geochemical modelling during lake filling, and a flexible closure plan that can be modified if needed.

(n) **Seek sustainability by developing pit lakes into post-mining water resources valued by the public or future industries**. Ultimately, EPLs should become an integral part of the surrounding landscape. This is the goal of oil companies and the global mining industry (MMSD, 2002), as well as the expectation of regulators and community members. Moreover, the successful development of several coal mines into potential fishing areas has established a precedent for the post-mining use of EPLs within Alberta. Companies may be able to shorten the time required to establish a useful post-mining resource by designating a particular use for an EPL in advance of mine closure and designing the lake to support this use. McCullough et al. (2009) provide multiple examples where pit lakes with beneficial end uses have been established, particularly in low-sulphur coal, aggregate, and iron mines. It is important to note that not all have the potential to be useful post-mining resources on account of poor water quality, an example being lakes in porphyry copper deposits and massive sulphide deposits.

3.8 Questions to Address Prior to Oil Sands EPL Design

From the consideration of non-oil sands pit lake risks, lake processes, lessons learned, and existing examples in Alberta, a list of questions can be generated that should be answered before oil sands EPL are designed. Owing to the site-specific nature of existing pit lakes, it is important to answer these questions for each EPL individually even though some similarities will exist between many of these lakes. The answers to these questions will help design EPLs that meet company, regulatory, and public expectations, while minimizing the need for unexpected remediation efforts. These questions are explored in Chapters 6 (In-Lake Processes), 7 (Timelines and Drivers), 8 (Design Elements and Considerations) and 9 (Construction and Operation).

EPL end use

1. What are the expectations for EPL use(s), if any, held by the mining company, government, and local communities?
2. What potential EPL uses, if any, will be required by government for lake certification?
3. What are the projected water, soil, and land resource needs for the century following mine closure, taking into account the affects of climate change and population growth?

Water Quality

4. What is the likely annual chemistry of EPL surface water over a sufficiently long time period (at least 50 years) following lake closure?
5. What are the principle contaminants of concern (COCs)?
6. What are the maximum concentration levels (MCLs) for acute and chronic impacts, including bioaccumulation and biomagnification risks, on aquatic ecosystems for each COC?
7. What plants and animals are likely to bioaccumulate and/or biomagnify COCs and move the COC up the food chain?
8. What water quality criteria, including specific concentrations of COCs, will be required by government to certify an oil sands EPL and return it to public custody?

9. What is the monitoring program for EPL water chemistry (i.e., what parameters will be tested, how often, by whom, and from which lake depths)? Who will finance EPL monitoring? How many years will monitoring be conducted?
10. What are the “concentration action levels” for each COC that, if exceeded, will require prompt additional mitigation by the mining company to avoid exceeding chronic and acute MCLs?
11. What redox state best promotes the natural degradation of each organic COC over time, strongly oxidizing conditions or strongly reducing conditions?
12. If the EPL is designated a “bioreactor” for any period of time during or after lake filling, what specific chemical reactions/biological processes will these organisms facilitate?

Hydrology

13. How long will it take the lake to fill to steady-state surface water conditions?
14. What will be the final surface area and maximum depth of the lake under steady-state conditions?
15. Will the steady-state EPL be a terminal or a flow-through lake? If the lake is flow-through, how much water will annually discharge from the lake on average, and what local aquifers and/or surface water bodies will lake water discharge into?

Limnology

16. Will the EPL fully circulate on an annual basis or will it develop permanent or semi-permanent stratification?
17. What is the expected depth of the summer epilimnion? What is the expected depth of the hypolimnion? Are the epilimnion and hypolimnion expected to mix during both the fall and the spring prior to summer and winter stratification?
18. Will the lake surface freeze during winter months? If so, how many months of the year will the lake remain frozen?
19. If the lake is permanently stratified, what is the expected depth and volume of the monimolimnion? What dissolved gasses are likely to accumulate in the monimolimnion over time, such as CO_2, H_2S, and CH_4? What is the likely water quality of the monimolimnion?
20. If the lake is permanently stratified, what meteorological conditions (i.e., wind speed) would be required to fully mix the EPL, and how frequently do these conditions occur? What is the density and size of a debris flow needed to fully circulate the water column and how frequently are landslides of this magnitude expected to occur?
21. Does the mining company wish to induce permanent stratification with the intention of utilizing monimolimnion water for the disposal of oil sands tailings and/or other mine wastes? If so, what is the density of the waste to be added to the monimolimnion and is it denser than the monimolimnion water? How will the addition of the waste affect lake stratification and the depth of the hypolimnion/monimolimnion boundary over time?

Lake ecology

22. What aquatic ecosystem structure is desired for the EPL?
23. What is the monitoring program for EPL biology (i.e., what parameters will be tested, how often, by whom, and from which lake depths)? Who will finance EPL monitoring? For how many years will monitoring be conducted?
24. What percentage of the surface area of the lake will function as a littoral zone?
25. What slope grade and vegetation community will surround the lake? Will any constructed features be added to the lake to promote aquatic habitats?
26. What are the nutrient (nitrate and phosphate), temperature, salinity, and dissolved oxygen concentrations expected in the epilimnion and hypolimnion waters? What are the nutrient, temperature, salinity, and dissolved oxygen requirements of the desired organisms? Do any of these parameters need to be artificially manipulated to generate or sustain the desired ecosystem?
27. Will the turbidity of lake water be low enough to enable growth of photosynthetic algae and aquatic macrophytes?
28. Will the toxicity levels of any COCs impair ecosystem development?
29. If the lake is meromictic, the habitat for cold water fish will be restricted to water between the warm epilimnion layer and the anoxic monimolimnion layer. Will this hypolimnion layer be sufficiently large to sustain a population of cold water fish species?
30. During ice covered conditions, what is the potential that dissolved oxygen levels will drop below 2 mg/L resulting in "fish winterkill" of cold water fish species as discussed by Doudoroff and Shumway (1970) for fish in northern regions?
31. If the lake is intended to be used as a bioreactor during or after lake-filling, what organisms will participate in modifying water quality and what environmental conditions are needed for these organisms to effectively treat water quality (i.e., nutrient levels, salinity, turbidity, and redox conditions)?

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PART TWO

GEOGRAPHY OF END PIT LAKES

The validation of the EPL as a reclamation tool will largely depend on respect for the physical, chemical, biological, and ecological principles that govern pit lakes in a disturbed landscape. The science behind the planning, design, and construction of EPLs is incomplete, and always will be. But our understanding of the natural forces that shape an ecosystem has improved dramatically since the advent of oil sands mining 45 years ago. Chapter 4 surveys the geographical and ecological setting in which EPLs will evolve. It covers the watershed-scale climatological and geological elements over which mine planners have no control and then works down through the hydrology and morphology of lakes to the aquatic chemistry and ecology that will be determined largely by EPL design. Chapter 5 examines how those natural and artificial forces interact in a mining environment to shape the watershed. The chapter addresses design considerations involving tailings that may be present in EPLs, the fate and transport of surface and groundwater, and the physical limits imposed by geography. Chapter 6 reviews what is understood about the limnology of mined-out pit lakes and the implications of relevant physical, chemical and biological processes for water quality management in an EPL and the greater watershed.

4. REGIONAL GEOGRAPHY & ECOLOGY

Théo Charette
Charette Pell Poscente Environmental Corp.

+

Brent Mooder
BGC Engineering

Table of Contents

4.1 Introduction

Given the scale and scope of oil sands mining activity, reclamation will involve the construction of full ecosystems at the landscape scale (Johnson and Miyanishi, 2008). The return of ecosystem function, which is a key objective of reclamation activity, relies on a sustainable hydrological system. From a regulatory perspective, approvals issued under Alberta's *Environmental Protection and Enhancement Act* (EPEA) stipulate that "the reclaimed soils and landforms are [to be] capable of supporting a self-sustaining, locally-common boreal forest, regardless of the end land use." Thus, there is an expectation that these lakes will be integrated with the natural landscape and provide desirable ecosystem services (see Chapter 2).

This chapter describes the geography and ecology of the region in which EPLs will be built, with a particular focus on water flow and water quality. Landform design that considers upland and wetland topographic ratios and configurations is important for managing surface and groundwater interactions and long-term landscape sustainability. The balance between water transmission and storage dictates overall watershed characteristics. Well-defined water channels, uniformly sloping ground, and clay-rich materials promote runoff and rapid water transmission. Flat ground, hummocks, closed low areas, sandy soils, and wetlands promote water storage. Landscapes dominated by water transmission are characterized by rapid response to rainfall and snowmelt, high peak flows, and susceptibility to drought. In contrast, landscapes dominated by water storage are characterized by subdued response to rainfall events and snowmelt, moderate surface water flows, and drought resistance.

Past pit lake experience reveals mixed results in terms of achieving desirable end states (Chapter 3). This often reflects the narrow approach taken in some of these projects. For example, aquatic reclamation failures are often related to a misunderstanding of the hydrological setting. Also, much focus has been put on achieving acceptable water quality but biological quality objectives are often lacking. Despite their importance, food-web and whole-ecosystem approaches have not been readily applied in ecological restoration (Vander Zanden et al., 2006; Lund and McCullough, 2011; McCullough and Van Etten, 2011).

4.2 Regional Setting

4.2.1 Climate

The Oil Sands regional climate is characterized by strong seasonal variation with long, very cold winters and short, moderately warm summers. According to the Köppen Climate Classification System, which uses vegetation distribution, air temperature and precipitation trends, the oil sands regional climate is classified as hemiboreal (Dfb), or between temperate and subarctic zones. Based on records from the Environment Canada climate station at the Fort McMurray Airport, the coldest monthly average temperature occurs in January, measuring -19.3 °C. July is the warmest month, when temperatures average 16.7 °C. Only three months of the year have average temperatures greater than 10 °C. Long-term average annual precipitation is 437 mm, ranging from 242 mm to 676 mm (1944 to 2009).

Environment Canada maintains several climate stations in the oil sands region. Three climate monitoring sites are most relevant because of their long and/or current periods of record. These stations are Fort McMurray Airport (3062693/3062700 & 3062696), Mildred Lake (3064531 & 3064528) and Bitumont Lookout (3060705) climate stations.

EPL design and management will require detailed climate descriptions and parameters (see Figure 4-1; e.g., precipitation, temperature, wind speed and direction, etc.), which can then be used to anticipate evapotranspiration rates and other key variables associated with EPL water levels and watershed flow trends. These data can be downloaded from the Environment Canada website (www.climate.weatheroffice.gc.ca), while detailed and/or bulk data requests for some parameters not reported on the website (e.g., cloud cover, fog, hail, etc.) are available for purchase. Technical documentation describing bulk data structure, unit conversions, data flags and other information is available online at: climate.weatheroffice.gc.ca/ prods_servs/ documentation_index_e.html

Annual averages for selected climate data elements recorded at the Environment Canada Fort McMurray Airport climate station (3062693/3062700) are given in Table 4-1.

Table 4-1: Annual Averages for Selected Climate Data Recorded at Fort McMurray Airport.

Data Element	Annual Average	Period of Record
Air Temperature	0.3 °C	1944-2009
Wind Speed	9.6 km/h	1953-2009
Wind Direction	Southerly	1953-2009
Total Precipitation	437.0 mm	1944-2009
Rainfall	322.0 mm	1944-2009
Snowfall	143.1 mm	1944-2007
Potential Evapotranspiration*	591	1953-2009
Dew Point Temperature	-6.2 °C	1953-2009

* Potential evapotranspiration estimate is synthetic and was modelled as evaporation from a 1-m deep lake using Morton et al., 1985.

Potential evapotranspiration exceeds precipitation on a monthly basis from April through September, as well as on an annual basis (based on long-term average precipitation values). The fine balance between average precipitation and evapotranspiration means that small temporal variations in either may lead to anomalously wet or dry years.

Typical engineering design approaches assume a stable climate, typically using climate records from nearby stations for the past 30 years. More recently, modellers in the oil sands have been running the full 60-year data set from the Fort McMurray Airport climate station to look at the wet and dry cycles and better understand their impact on the local ecosystem. Designers have also started applying this approach to creation of mining landforms and reclaimed landscapes in the oil sands region.

Bjelkevik (2011) indicates that some mines in Europe are considering incorporation of long-term climate change in their closure plans and design of dams. Global circulation models are downscaled for local conditions, and produce estimates of temperature and precipitation patterns out to 100 years. There is insufficient confidence to extrapolate further into the future.

Taking a conservative or precautionary approach, EPL designers would typically account for the probable maximum flood (PMF) and ensure positive water balances to lakes so that there are significant annual outflows of EPLs even during drought cycles.

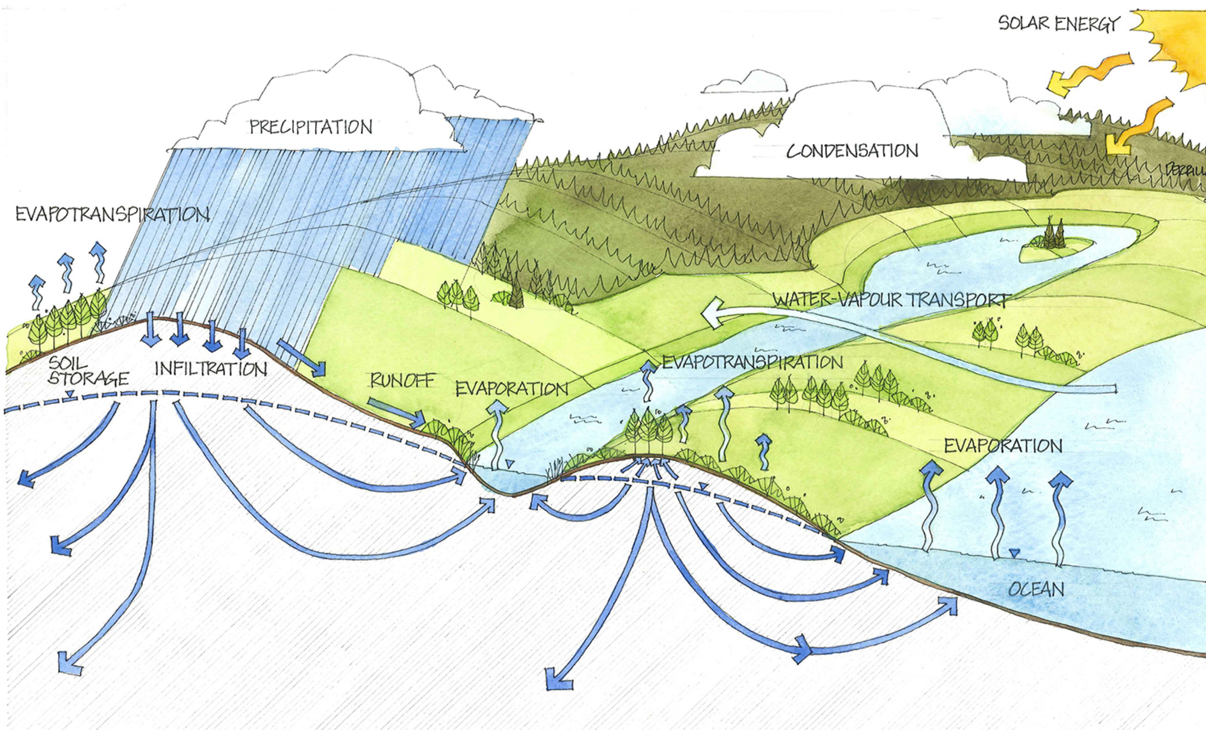

Figure 4-1. Hydrological cycle of a watershed surrounding a typical EPL. Modified from Devito et al. (2008).

4.2.2 Bedrock and Surficial Geology

The surface mineable and in-situ recoverable deposits of the Athabasca Oil Sands region are located within the Western Canadian sedimentary basin. Comprehensive information on regional scale geology of this area, which has been well characterized in numerous studies over the past 50 years, can be found in Carrigy (1959), Flach (1984), and Cotterill and Hamilton (1995). In addition, descriptions of the Quaternary sediments overlying the bedrock surface are also available (Andriashek and Atkinson. 2007; Andriashek, 2001; McPherson and Kathol, 1977).

Within the region, the subsurface distribution of bedrock geology is constrained by three major unconformities. A comprehensive review of geologic stratigraphics for the Athabasca Oil Sands Region can be found in Section 5.2.1.1 and in Table B-5, Appendix B. Of particular relevance are the Mesozoic and surficial Cenozoic deposits, which host the bitumen that is mined, and which comprise the overburden that must be moved in order to access the oil sands.

4.2.3 Topography and Vegetation

The topography of the Athabasca Oil Sands region is characterized by a broad central lowland, referred to as the Athabasca River lowland, containing the Athabasca River which is deeply incised into the McMurray Formation, and in some instances to the Devonian bedrock. The Athabasca River lowland floodplain is located at a surface elevation of approximately 220 metres above sea level (m asl), and is flanked by the prominent highland of the Birch Mountains to the northwest (850 m asl) and the less pronounced Muskeg Mountains to the east (650 m asl). Other notable physiographic features are the Fort Hills, south of McClelland Lake in the north-central part of the oil sands region, and the high-relief features of the Firebag Plains along the Alberta-Saskatchewan border (Andriashek and Atkinson, 2007).

Prior to mine development, the topography in the Athabasca Oil Sands region could be characterized as regionally subdued and locally variable, with flat to undulating relief and an abundance of small lakes, streams, marshes, bogs, and peatlands. The topography was poorly drained by a series of incised creeks and rivers that drain into the major rivers in the area and ultimately to the Athabasca River, which forms the base of drainage for the mineable oil sands region.

Vegetation in the region is characteristic of the Boreal Plains, where upland regions have mixed-wood stands of aspen poplar and white spruce. Lowland boreal forest or muskeg is dominated by black spruce and tamarack larch. Other typical species include balsam fir, balsam poplar, jack pine, and lodgepole pine (Gosselin et al., 2010). Upland vegetation is generally determined by the moisture gradient along a hillslope, which is a function of contributing area, slope angle, and substrate transmissivity. Poorly drained lowlands are usually covered by peat, while shrub fens are dominated by willows and sedges, and forest fens by tamarack and black spruce. Patterned fens are very common. Bogs, which occur mostly as islands in large fens or in small potholes, are dominated by short black spruce and sphagnum moss (Johnson and Miyanishi, 2008). Prior to logging activity in the region, the age of the forest and successional stage of the vegetation was largely determined by natural disturbances such as insect outbreaks and wildfire.

4.2.4 Wildlife

The Athabasca oil sands region supports a wide variety of animal types, many with large territorial ranges. Major mammals in the region include the American marten, beaver, black bear, Canada lynx, coyote, fisher, grey wolf, mink, moose, muskrat, mule deer, northern river otter, and white-tailed deer. Major water basins are important over-wintering, spawning, and rearing grounds for fish in the region, providing habitat for a mix of species. Species of fish common to lakes on the Boreal Plain include cool-water species such as walleye, yellow perch and northern pike. These species spawn in shallow, warm and productive littoral habitat in the spring. Fall-spawning coldwater sport and commercial species include lake whitefish, cisco and lake trout. Forage species include fathead minnow, brook and ninespine stickleback, longnose and white sucker, burbot, pearl, finescale, and longnose dace, slimy and spoonhead sculpin, and emerald and spottail shiner (Mitchell and Prepas, 1990; Government of Alberta, 2009). There is a wide range of game fowl in the region, including the American coot, Canada goose, various species of duck, the greater white-fronted goose, Ross's goose, snow goose, and Wilson's snipe. Populations of resident and migratory birds use habitat in the area as breeding grounds, staging areas during migration, and regional over-wintering grounds (Government of Alberta, 2009).

A species of particular significance for watersheds in the region is the beaver, *Castor canadensis*. Beavers are widely considered to be ecosystem engineers (Jones et al., 1994) – keystone species that create riparian and other habitat for a variety of other species through their damming activities. Beavers clear-cut trees, and dam creeks, rivers, and lake outlets to create ponds for protection from predators. They have the capacity to cause flooding in large areas, cause outburst flooding, redirect streams, attenuate peak runoffs, trap sediments, and change forests and habitats.

4.2.5 Current Use Activities

A large section of northeastern Alberta is captured by the Lower Athabasca land-use planning region (Government of Alberta, 2009). The most prominent and growing land use activity in this region is the development of the oil sands, with surface mining operations planned for much of the 3,500 km^2 of land covering the mineable oil sands, and in-situ operations extending farther (though with less surface disturbance impact).

Other economic activities in the Lower Athabasca include significant forestry and some agriculture and quarrying. Approximately 40% of the Lower Athabasca land-use area is covered by a Forest Management Agreement (FMA), a lease agreement between the crown and forest company that is generally 20 years in length. One of the requirements of the FMA is sustainable management of the resource, including reforestation.

There is also natural gas exploration and production, with associated land use needs including well sites and linear features such as seismic lines, roads, and pipeline rights-of-way. Some industrial mineral production occurs in the region, including the extraction of building stones (limestone, sandstone, granite), minerals (gypsum, salt, sulphur) and aggregate (sand, gravel, crushed stone, clay shale).

Non-industrial land-use in the region includes recreation and tourism activities such as camping, fishing, hiking, and other outdoor activities. Over 6,000 km^2 of the Lower Athabasca region is designated as parks, administered by Alberta Tourism, Parks and Recreation. There are a number of First Nations and Métis settlements within the area, with traditional land use activities including hunting and trapping, food and medicine gathering, and spiritual uses. Large industrial work caps dot the region.

The mix of land-use activities in a region has implications for the hydrology of the area, and as land use evolves in the Athabasca oil sands region – both with continued mining and in-situ extraction and with land reclamation – the water balance will evolve.

4.2.6 Surface Water Flow

Climate is the factor controlling hydrology on the sub-humid Boreal Plains. Major precipitation periods are synchronized with evapotranspiration, and the amount of water stored as snow is small, resulting in limited opportunity for overland flow (Devito et al., 2005).

The Water Survey of Canada (WSC) maintains several hydrometric stations in the region. Summaries of lake and river drainage area, average annual flow, mean winter low flow, and water level for the period of the record are provided in Tables 4-2 and 4-3.

Table 4-2: Summary of regional hydrometric stations and average annual streamflow statistics.

Rivers	WSC Station ID	Drainage Area (km^2)	Average Annual Statistics				Station Latitude	Station Longitude	Period of Record	Record Length
			Flow (m^3/s)	Peak Flow (m^3/s)	Minimum Flow (m^3/s)	Runoff Depth (mm)				
Athabasca	07DA001	132,585	626	2652	130	149	56° 46' 49.3" N	111° 24' 07.9" W	1957-2009	52
Beaver Creek	07DA018	165	0.6	11	0.02	121	56° 56' 43.2" N	111° 33' 58.5" W	1975-2009	34
Clearwater	07CD005	17,017	85	209	36	158	56° 39' 49.0" N	110° 55' 43.2" W	1966-2009	43
Firebag	07DC001	5,988	30	128	8	158	57° 39' 03.9" N	111° 12' 09.4" W	1971-2009	38
Hangingstone	07CD004	962	5	43	0.1	148	56° 42' 18.0" N	111° 21' 23.0" W	1965-2009	44
MacKay	07DB001	5,569	18	124	0.3	102	57° 12' 37.3" N	111° 41' 42.3" W	1972-2009	37
Muskeg	07DA008	1,457	5	28	0.2	110	57° 11' 28.3" N	111° 34' 12.5" W	1974-2009	35
Steepbank	07DA006	1,320	6	36	0.3	151	56° 59 '58.0" N	111° 24' 24.6" W	1972-2009	37

Table 4-3: Annual average minimum and maximum lake levels (RAMP, 2010).

Water Level Stations	Drainage Area (km^2)	Mean maximum level (masl)	Mean minimum level (masl)	Monitoring Period	Period of Record
McClelland Lake	28	294.61	294.39	Jan 1 - Dec 31	unknown
Kearl Lake	73	332.14	331.73	Jan 1 - Dec 31	unknown
Isadore`s Lake	191	233.92	233.69	Jan 1 - Dec 31	unknown

4.2.7 Groundwater Flow

Numerous regional-scale hydrogeological investigations have been carried out in the oil sands region, including those by Alberta Environment (2009), Bachu et al. (1991, 1992, 1993), Ozoray et al. (1980), and Hackbarth and Nastasa (1979).

The hydrostratigraphy of the bedrock units has been defined by the Alberta Research Council (Bachu et al., 1993) and Alberta Environment (2009), and follows a regional classification that was derived by identifying sequences of aquifers (geologic layers that transmit water readily) and aquitards (geologic layers that transmit water slowly or not at all). The following aquifers are considered to be of regional importance:

1. La Loche Formation
2. Methy Formation
3. Water-bearing sand at the base of the McMurray Formation (basal aquifer)
4. Clearwater Wabiskaw Member
5. Grand Rapids Formation
6. Quaternary Deposits (surficial aquifers)

Of particular interest for landscape reclamation activities such as EPL design are the aquifers located within and above the oil-bearing sands of the McMurray Formation, which are excavated during mining. Water bearing sands commonly referred to as the basal aquifer are found within the lower McMurray. The thickness and presence of the basal aquifer is largely controlled by the topography of the erosional surface of the Devonian, and is generally thickest and most continuous east of the Athabasca River. The basal aquifer is discontinuous and thin west of the Athabasca River.

Groundwater flow in the surficial aquifers of the region is complicated by the complex depositional history of the geologic materials; water moves more readily through permeable fluvial deposits than less permeable glacial till deposits. Andriashek and Atkinson (2007) identify a series of buried channels and valleys within the drift deposits throughout the region, which are not confined to topographic lows, have gradients that can trend opposite to topography, and typically lack regional continuity. Faults in the region may provide conduits for groundwater exchange between aquifers at different depths, and may enhance vertical components of flow.

Groundwater flow occurs at a variety of scales; in the Athabasca Oil Sands region, flow occurs predominantly at the local to intermediate scales, and is driven by low rates of recharge. In contrast to surface water, groundwater flows at much smaller velocities – 1 m/y in a permeable aquifer, compared with velocities of m/s in the Athabasca River. The timescale for groundwater processes is therefore much longer than for surface water processes, and residence times of water in the subsurface can range from years to centuries, or longer.

Ore recovery activity in oil sands mining operations disrupts natural groundwater flow systems. Depressurization, or reduction of the groundwater level in surficial and deeper aquifers, is necessary for open pit mine development. When mining operations and depressurization ceases, and pits are backfilled, the groundwater levels recover, eventually reaching a new dynamic equilibrium in the reclaimed landscape.

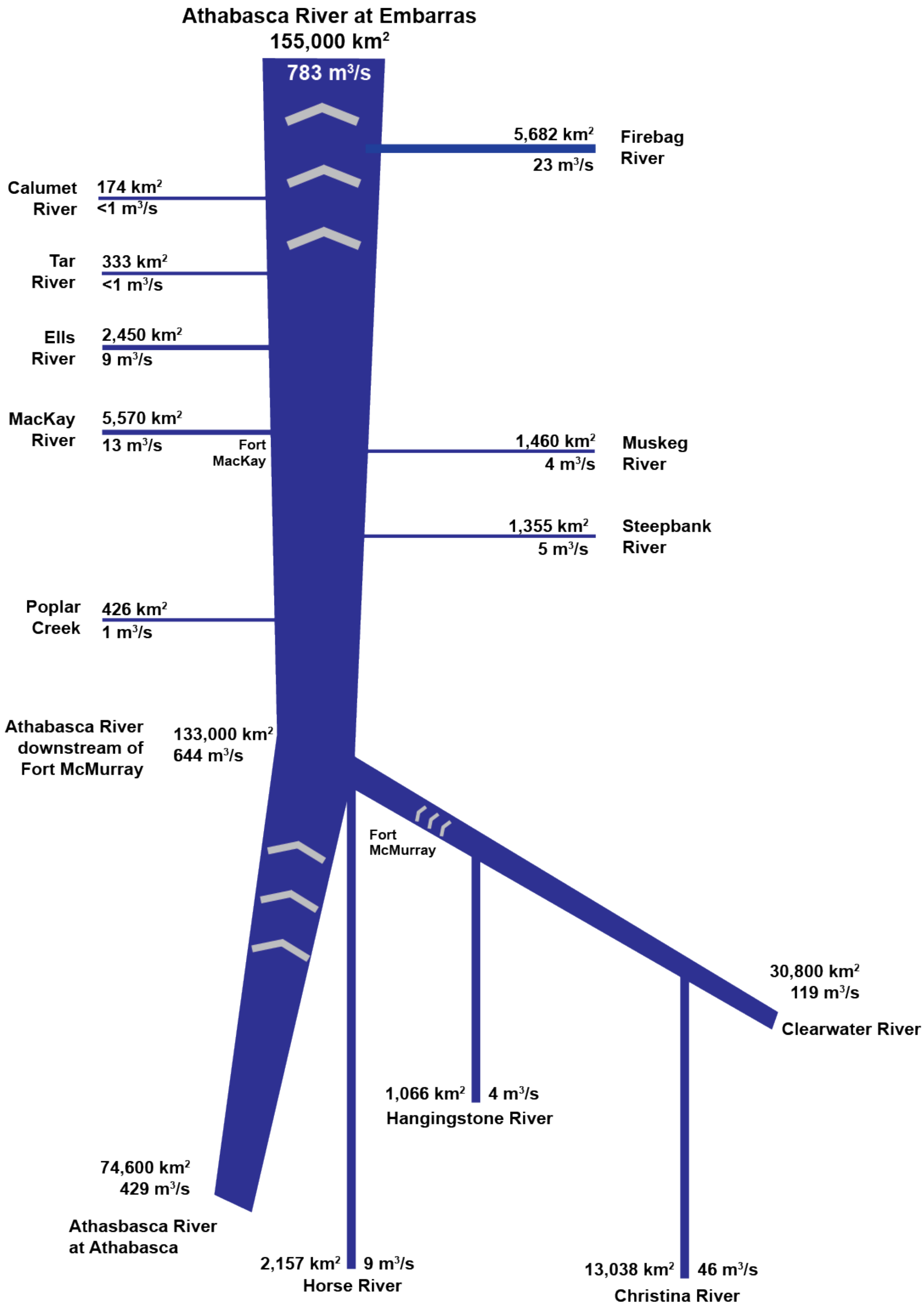

Figure 4-2: Flow rates of the Athabasca River and its tributaries. From RAMP, 2010.

4.3 Water Quality

4.3.1 Surface Water Quality

Surface water bodies in the Athabasca oil sands region may be exposed to naturally occurring bitumen deposits, resulting in the natural presence of several metals, hydrocarbons, and polycyclic aromatic hydrocarbons (PAHs) in the water and sediments of rivers and lakes (Government of Alberta, 2009). See Table B-6, Appendix B, for the water chemistry for four major tributaries to the Athabasca River: the Steepbank, Ells, Muskeg, and Firebag rivers. This characterization includes field-measured parameters, other conventional parameters, major ions, nutrients and chlorophyll *a*, biochemical oxygen demand, general organics, total metals, and dissolved metals.

Surface water quality monitoring is an ongoing activity in the Athabasca oil sands region. Water quality data are available from the following sources:

- Alberta Environment and Sustainable Resource Development (AESRD): Surface Water Quality Program. Data available include Lake Water Quality Data and River Network Station Water Quality Data. These data are readily available through a request to AENV or from the following website: http://environment.alberta.ca/01288.html.

- Regional Aquatics Monitoring Program (RAMP): Consortium of industry, government and other stakeholders in the region, mandated to monitor the aquatic environment. These data are readily available from the following website: http://www.ramp-alberta.org.

- Site-specific water quality information summarized in oil sands operators submissions to regulatory bodies, (e.g., EIAs), many available on operator websites.

4.3.2 Groundwater Quality

Commonly measured variables for groundwater quality include total dissolved solids (TDS, an indicator for major ion concentrations), ammonia, arsenic, naphthenic acids, and total phenols. Secondary indicators include other major ions (Ca, Mg, K, HCO_3), trace elements (including B, Ba, and Sr), and dissolved hydrocarbons (i.e., BTEX, THE, and LMW PAHs). Data were collected from 613 wells with chemistry data for the main aquifers in the oil sands region.

Notable observations on water quality conditions in the region include:

- TDS in the bedrock aquifers east of the Athabasca River tends to be lower compared to formations on the west side of the river, suggesting more active recharge to the groundwater systems in that portion of the study area.

- The presence of deep-seated structures (faults) resulting from bedrock movement following dissolution of the Devonian Prairie Evaporite bedrock and resulting collapse of the overlying formations (drop-down blocks) results in quite different quality conditions in certain overlying formations compared to other areas of the region.

- Differences in water quality between the shallower surficial sand aquifers and the deeper buried channels are minor compared to the differences between the bedrock aquifers and overburden deposits.

- Mixing of bedrock and surficial waters is likely based on the occurrence of otherwise anomalous readings of certain parameters (e.g., Na, Cl) within discrete intervals. The placement of screen in relation to bedrock is the suspected reason.

- The presence of naturally-occurring hydrocarbons is evident based on results obtained from monitoring wells established in areas yet to be developed, and well outside the influence of operations established in the area.

- Lack of sufficient spatial and temporal information is evident for certain water-bearing intervals, indicating a need for further assessment.

4.4 Temporal Scales

Important processes within the region operate at a variety of timescales, ranging from daily cycles, to episodic events, to the long term evolution of the landscape. Discussion in this section is limited to cycles and processes relevant to the hydrology and associated movement of solute through the landscape.

At the diurnal scale, evapotranspiration from vegetation, which is greatest during daylight hours, influences the fine hydrological balance in the subhumid climate of the Boreal Plain. For surface water systems in small catchments, response to individual rainfall events tends to occur within a few hours to days of the event.

At the seasonal level, spring snowmelt affects runoff and infiltration. Shallow groundwater flow systems tend to show a delayed, subdued response to snowmelt and summer and fall rainfall, followed by a gradual decline in groundwater levels throughout the winter. Seasonal changes in groundwater levels are more pronounced in upland (groundwater recharge) areas and tend to be subdued in lowland (groundwater discharge) areas.

Long-term patterns of wet and dry years will influence the variability in water balance. Shallow groundwater flow systems are expected to adjust to changes in topography over time scales of a few years. The long-range planning time horizon for oil sands operators and regulators is commonly on the scale of decades. Landscapes may evolve toward less runoff and more storage as soils and vegetation develop on time scales of decades. Groundwater recharge may decline as vegetation becomes established and water demand increases. Succession is expected to change the mix of plants and wildlife habitat as landscapes mature over the course of several decades.

Tailings consolidation and resulting water release may continue for decades in the reclaimed landscape. An EPL may change and evolve over the course of decades. The landscape may change due to landslides, subsidence, erosion, and changing patterns of drainage. Deeper groundwater flow systems could require decades to adjust to changes in the landscape due to excavation and backfilling associated with oil sands mining and reclamation and the end of dewatering activities.

The landscape is expected to continue to evolve over the course of centuries in response to potential changes in precipitation and temperature patterns, ongoing ecological succession, and human activities. Soil and muskeg development are slow processes that operate over centuries. Physical and chemical weathering of reclamation materials is a long-term process, with the resulting mobilization of salts and metals. Flushing of salts and other substances from tailings could take centuries.

4.5 Spatial Scales

The natural scale for an EPL is the watershed or catchment scale, which might typically be on the order of a few hundred square kilometres. Smaller-scale features within a catchment can be thought of as landforms (such as dumps, tailings facilities, and wetlands). An EPL watershed lies within a larger-scale regional drainage system, which commonly extends across lease boundaries to other mine sites or adjacent natural areas. The Athabasca River forms the regional base of drainage for oil sands groundwater and surface water flow systems and would be the largest scale of interest.

4.6 Natural Lake Characteristics

The Boreal Plain is generally flat and underlain by poorly drained soils due to the thick deposits of glacial till. As a result, wetlands are a predominant feature of the boreal landscape. The long contact time between water and the easily weathered glacial deposits and organic soils means that export of nutrients and mineral ions to surface waters is high relative to other regions of Canada. Furthermore, the shallow depths of the majority of lakes on the Boreal Plain mean that nutrient loading from bottom sediment (i.e., internal loading) is important and may account for 50% or more of the phosphorus budgets of lakes in this ecoregion. Consequently, lakes on the Boreal Plain are relatively alkaline (i.e., pH typically between 8 and 9) and nutrient-rich (Mitchell and Prepas 1991).

In Boreal Plain watersheds, the amount and type of wetland cover is one of the main drivers for lake water quality. Where wetlands typically dominate a lake's watershed, most of the variation in total phosphorus (a measure of fertility) and dissolved organic carbon concentrations (an indicator of lake colour) among lakes can be explained by the percentage of wetland cover. In upland watersheds (wetland cover less than 50%), water retention time, rather than percentage of wetland cover, can account for most of the variability in phosphorus concentration and algal biomass. In watersheds of the Boreal Plain, the type of wetland is related to lake-water nutrient concentrations with fens (peat-forming wetlands that are affected by mineral soil waters) retaining phosphorus and nitrogen and bogs (peat-forming wetlands that receive their water only from precipitation) exporting these nutrients to lakes (Prepas et al., 2001).

The hydrology of Boreal Plain lakes is not well-known. However, the enrichment signature for the naturally occurring isotopes of water (^{18}O, ^{2}H) in lakes from the Boreal Plain suggests that they can generally be high evaporation – low outflow systems. That is, most of the water lost is through evaporation (Gibson 2012). Because potential evapotranspiration exceeds precipitation, regional groundwater flow systems are thought to supply lake water budgets over areas that can far exceed topographic watershed boundaries (Devito and Mendoza, 2008).

Blue-green algae can dominate phytoplankton communities on the Boreal Plain in lakes affected and unaffected by human activities, particularly in August when elevated nutrient concentrations and water temperatures promote severe blooms. Relatively high concentrations of cyanotoxins (e.g., Microcystin-LR) have been measured in Alberta lakes that serve as municipal water sources (AENV, 2002) and every summer there are reports of poisoned domestic and wild animals. This concern led to several research projects that focused on reducing nutrient release from bottom sediments (see Case Study: Deep-water oxygenation of Amisk Lake). A high rate of accumulation of organic material (e.g., dead algae) in bottom waters of eutrophic systems can lead to high decomposition rates by bacteria. Dissolved oxygen consumption by decomposers, combined with a barrier to gas exchange (thermocline or ice cover), can reduce (hypoxia) or eliminate (anoxia) dissolved oxygen in bottom waters. Oxygen depletion is one of the most harmful side effects of eutrophication because it can cause winter fish kills, which are not uncommon in Alberta (Figure 4-10). Depletion of dissolved oxygen in deep water can lead to a loss or displacement of species intolerant of such conditions (Ludsin et al., 2001). In oxygen-stressed lakes of Alberta, characteristic fish types are surface-dwelling, warm-water fishes such as pike and perch, as compared to deep-dwelling, cold-water fishes like trout and cisco (Mitchell and Prepas, 1990).

Table 4-5: Minimum, mean and maximum values of lakes on the Boreal Plain in Alberta that are important in the design of EPLs.

Feature	Minimum	Mean	Maximum
Area (km^2)[1]	0.4	50	1160
Max depth (m)[1]	6.0	20	99
Slope to max depth (%)[1]	0.07	1.9	5.7
Shoreline complexity[1]	1.1	2.2	4.4
Max. depth of littoral zone (m)[2]	2.8	4.2	5.4
% littoral (of lake surface vegetated)[3]	10	28	48
% of shoreline vegetated [3]	5	61	100

Notes: [1] N = 65; data from Mitchell and Prepas (1990), Charette (2001) and Bennett (2005). [2] N = 42; calculated according to Chambers and Prepas (1988), [3] from Mitchell and Prepas (1990). [3] N = 22; from Mitchell and Prepas (1990). Only lakes comparable to planned EPLs are included.

Case study 1:
Deep-water oxygenation of Amisk Lake

Amisk Lake is a eutrophic (i.e., highly productive) lake located 175 kilometres northeast of the City of Edmonton. This level of productivity, and the corresponding decomposition of organic matter, is directly responsible for a substantial portion of the oxygen depletion in the deeper water and under ice. Low dissolved oxygen concentrations are correlated with high phosphorus release rates from the sediments, which is preferentially released during anoxic conditions. Deep-water oxygenation in Amisk Lake from 1988 to 1993 increased dissolved oxygen concentrations in deep water five-fold in the treated basin. As a result, total phosphorus concentrations were reduced such that a lake previously classified as eutrophic was reclassified as mesotrophic (i.e., moderately productive). The improvement in water quality was felt at higher trophic levels: the elevated oxygen concentrations and food abundance caused densities of the fish, cisco, to double due to the expansion of cold-water fisheries habitat (Prepas et al., 1997). Deep-water oxygenation is one of the many in-lake treatment options. The North American Lake Management Society (www.nalms.org) can be contacted for more information on these options.

4.7 Landscape/Watershed-level Principles

Water can be considered the common element that links terrestrial and aquatic processes as it moves through the landscape. The importance of water is particularly true in boreal Alberta, where there exists a potential water deficit (i.e., potential evapotranspiration exceeds precipitation; Fig. 4-3).

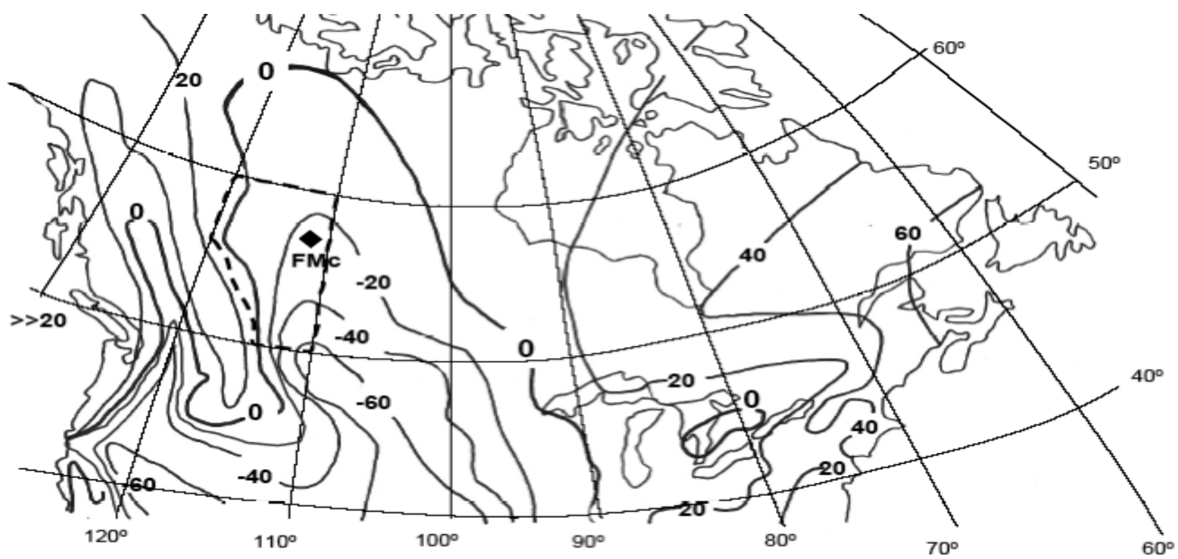

Figure 4-3: Map of Canada with contour lines representing precipitation – potential evapotranspiration. Note the diamond showing the City of Fort McMurray where there is a potential water deficit. Reproduced from Winter and Woo (1990) and Woo and Winter (1993).

The hydrology, chemistry, and biology of an aquatic ecosystem reflect the terrestrial and aquatic features that make up the landscape that contributes water to that receiving system. Thus, aquatic ecosystems must be regarded as "outcrops" of a complex surface-groundwater flow system that moves water through the landscape (Webster et al., 2006). In a landscape that is highly conducive to groundwater flow, a variety of lake hydrologic types exist (Figure 4-4).

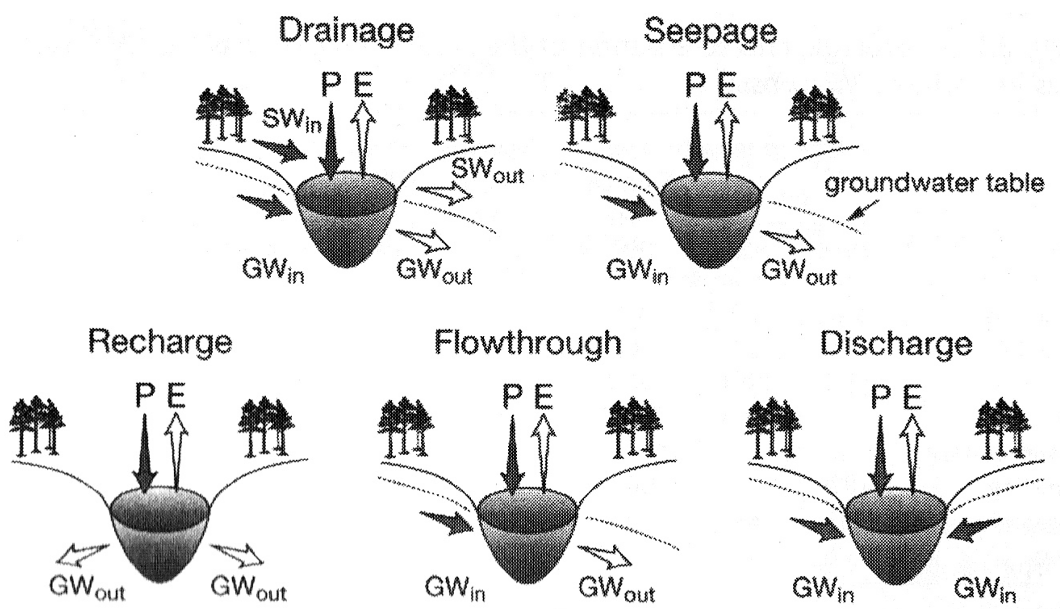

Figure 4-4: Hydrological lake types commonly found in Alberta. From Webster et al., 2006.

These lake types include "drainage lakes," which have surface water inlets and outlets, and "seepage lakes" that lack outlets and are dominated by groundwater flow. Seepage lakes can be further classified by the connections with the groundwater system: recharge lakes (do not receive groundwater inputs), flow-through lakes (both receive and contribute to groundwater), and discharge lakes (groundwater flow is to the lake only). The degree to which groundwater recharge and discharge influence a lake is a function of the landscape position of the lake (see Figure 4-5). The hydrology of lakes high in the landscape (near the hydrological divide) is dominated by precipitation, with local groundwater discharge. Lakes lower in the landscape (toward the regional discharge point) cross regional flow paths and have greater groundwater contributions in general (Figure 4-6). These lakes typically include contributions from up-gradient lakes and wetlands (groundwater flow-through seepage and drainage lakes and wetlands).

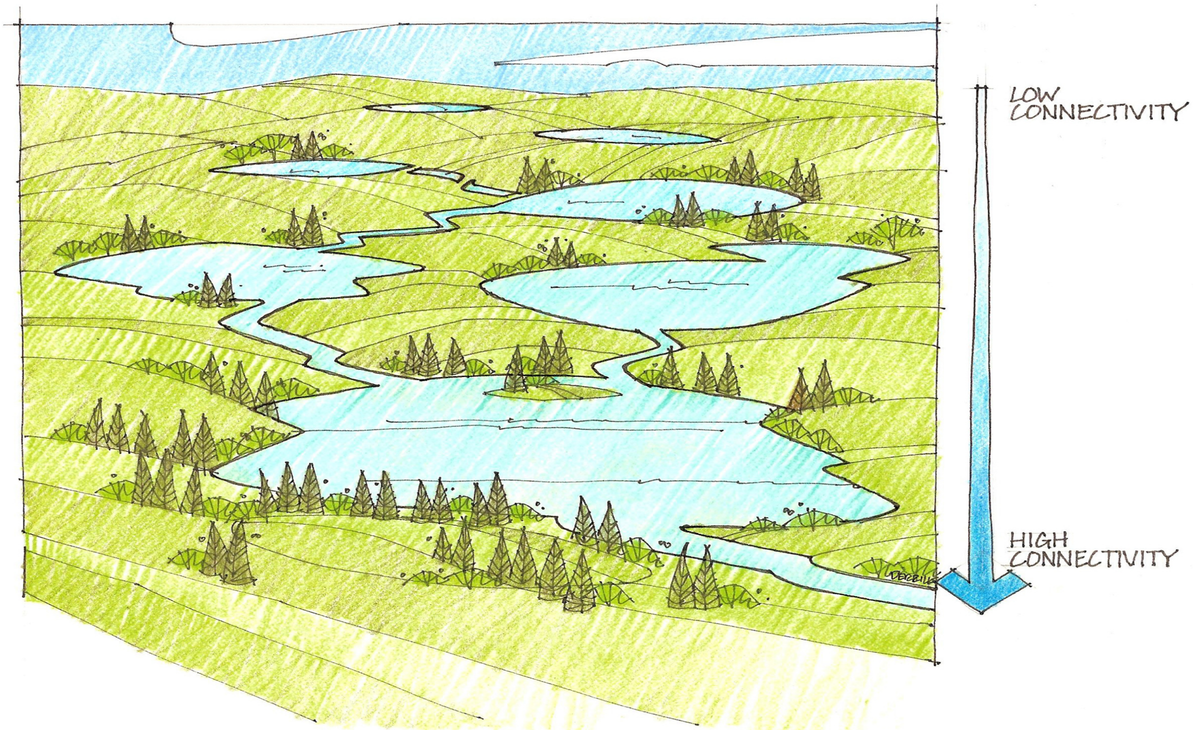

Figure 4-5: Topographic position of lakes in the landscape. Lakes that are low in the landscape tend to have increased stream connectivity and thus greater potential for fish diversity. Modified by Derrill Shuttleworth, from Kratz et al. 2006.

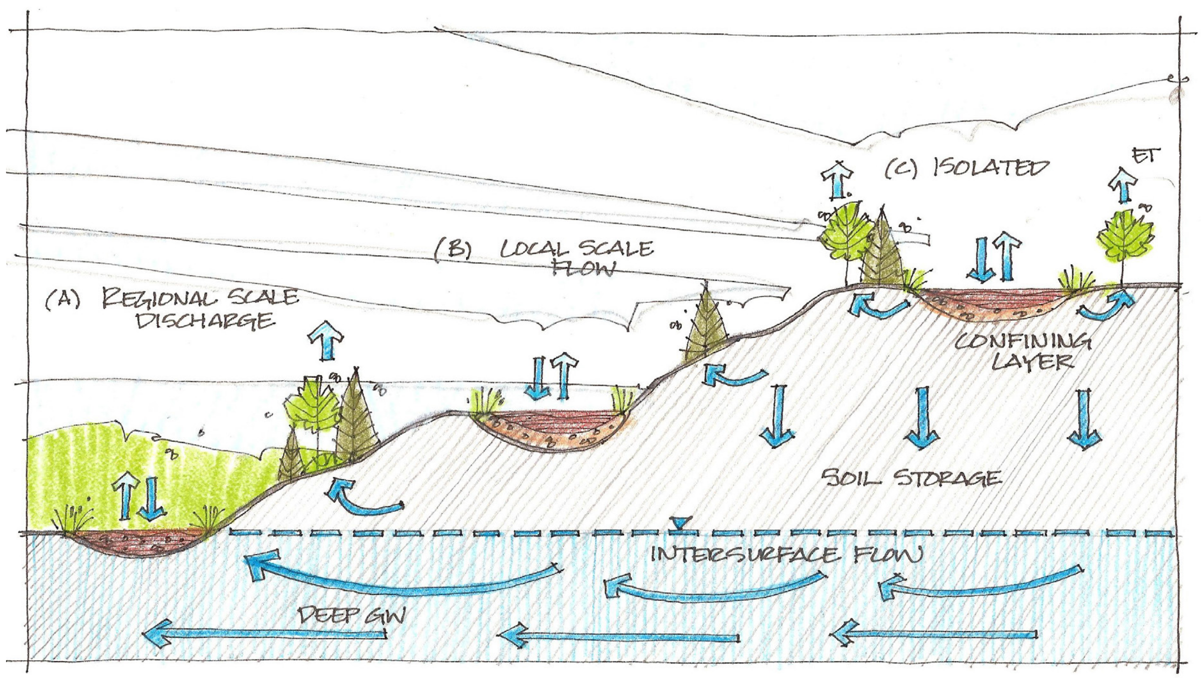

Figure 4-6: Conceptual model of dominant storage and water flow path for coarse-grained outwash within the sub-humid climate of the Boreal Plain.

Characteristics of down-gradient lakes, relative to up-gradient lakes, include:

- More inflows and outflows.
- More solutes are in the water because the relative contribution of “fresh” water from precipitation is less and intermediate and regional groundwater flow chemistry often has a higher solute content than local flow systems (Kratz et al., 2006; Toth 1999).

Higher fish richness tends to be found in these lakes. The “capacity” of down-gradient lakes to support multiple fish species is often greater because they tend to be better connected to streams and other lakes, which assists in recolonization following local extinction events (Figure 4-10; Kratz et al., 2006; Tonn 1990).

A lake’s watershed can consist of one or multiple landforms, each of which can have unique hydrogeological characteristics. This is particularly true of Alberta, where the geology consists of a thick layer of glacial drift that is vertically and horizontally variable in its hydrogeological properties. To cope with this complexity and “make sense of the landscape,” the concept of hydrologic landscapes was created (Winter 2001).

The hydrologic landscape framework considers the complete hydrologic system, or the movement of surface and groundwater and how they interact. The hydrologic-landscape framework recognizes that the movement of water through these hydrological compartments is controlled by common physical principles. Within a climatic region, these principles are a reflection of two components: the land surface form (shape, size, slopes of the earth’s surface) and the hydraulic properties of the geology. Under the framework, areas having homogeneous land-surface form and geology, relative to other areas, are regarded as a single hydrologic unit (similar characteristics of surface runoff, groundwater flow, interaction of groundwater and surface water, and climate), or fundamental hydrologic landscape units (FHLUs, Winter 2001; Devito et al., 2005). Thus, once individual FHLUs have been fully characterized and catalogued, they can be inserted spatially in a nested approach to characterize the landscape in an additive manner. This way, the hydrology of the landscape can be described using relatively simple and straightforward concepts. The hydrologic landscape framework is a useful tool particularly when a practitioner attempts to make sense of the hydrological behaviour of an area with numerous landform configurations.

Benefits of the hydrologic landscape framework include:

- being a useful tool through conceptual characterization of the hydrology of the landscape
- breaking down the landscape into manageable sections
- avoiding duplication in effort
- greater replicability in application
- greater capacity to predict the hydrology of a landscape

The greatest utility of FHLUs, from a pit lake perspective, is that they would allow greater predictability in water and solute loading from the watershed to pit lakes. Thus, development of

FHLUs would allow for better planning and management. For more information on FHLUs and the hydraulic properties of reclamation material, see Chapter 5.

Drought is the most significant climatic characteristic of the Prairies and generally has a return period of 30 to 50 years. Postglacial re-constructed climate data indicate that the prairies have experienced intervals of high temperatures and abnormally low precipitation over the past 1,000 years, conditions that were far more severe than during this century, including the drought of the 1930s (Herrington et al. 1997; Cook et al., 2004; Meko, 2006).

As components of a hydrological flow system, aquatic ecosystems can be highly responsive to drought. Physical (e.g., water column stratification, etc.), chemical (e.g., salinity, etc.) and biological (e.g., productivity, nutrient cycling, etc.) lake properties respond rapidly to climate-induced changes. During drought, an increase in salinity is apparent in some lakes in Alberta and Saskatchewan (Covich et al. 1997; Crowe 1993; Alberta Environment, 2006a). As salinity increases, aquatic species diversity tends to decrease (Swanson et al., 1988).

The magnitude of the response of aquatic ecosystems to drought is related to the water storage potential of watersheds. In general, aquatic ecosystems lower in landscape position (see Figures 4-5 and 4-6) and lakes with greater connection with groundwater tend to be more resistant to drought (Webster et al., 2000, Almendinger 1990). This is due to the greater availability of water through both surface and subsurface pathways. A prolonged drought in the 1980-90s caused the water levels of some lakes in Alberta to drop substantially (van der Kamp et al., 2008, Figure 4-7). Yet some lake levels showed little change (Kehewin Lake, Cold Lake, Marie Lake and Moose Lake). These drought-resistant lakes had relatively large watersheds and/or were highly connected to the local and regional groundwater system (Alberta Environment, 2006), which provided a buffer in the expression of the drought signal. In spite of these periods of drought and the potential water deficit that exists near Fort McMurray, surface water is abundant on the Boreal Plain (Vitt et al., 1996). This abundance of water has been attributed to water retention, specifically water stored in snow during periodic high snow years and water retention by frozen peatlands, which can remain frozen well into June (Mendoza 2011; Petrone et al., 2008). In general, lakes with watersheds that have relatively high water availability and storage potential (such as through large contributing areas, connectivity to groundwater, and retention mechanisms) are more resistant to drought-mediated effects. Because of the connectivity between groundwater and lakes, the impact of climatic variability should be viewed within the framework of a combined groundwater-lake system.

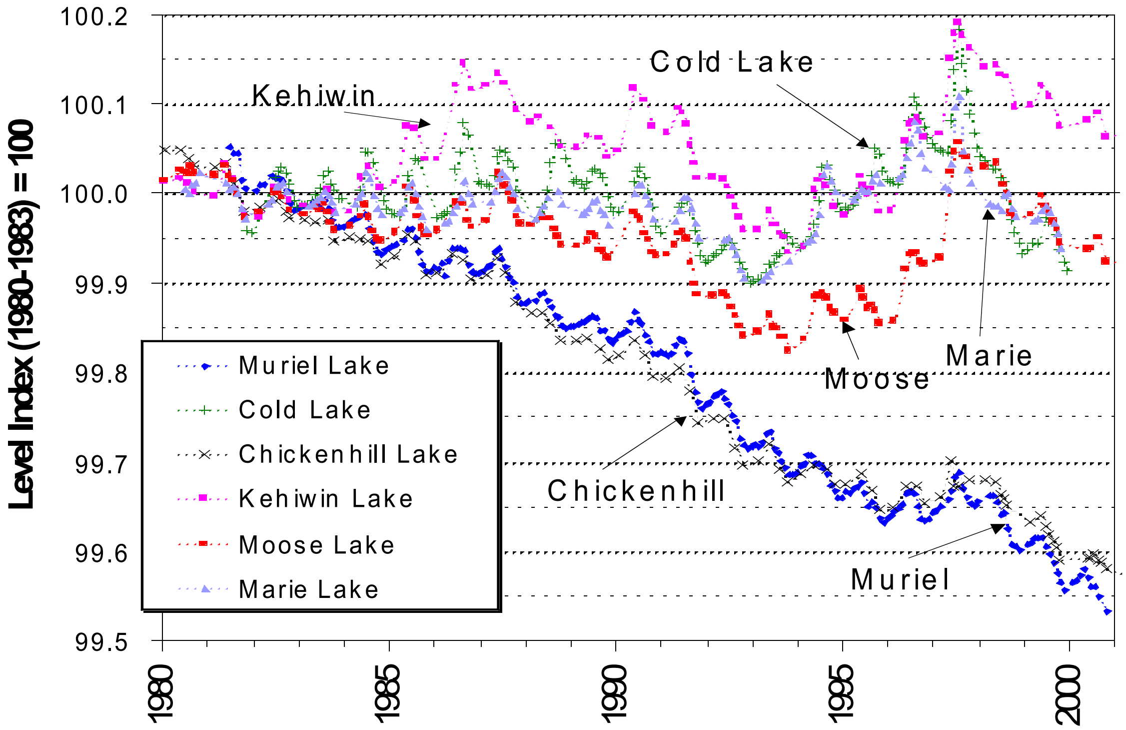

Figure 4-7: Response of selected lakes to a recent prolonged drought. From AENV (2006).

4.8 Lake Level Principles

4.8.1 Littoral Zones

The band from shoreline to the depth where aquatic plants disappear is often defined as the littoral zone. Littoral zones typically include three types of sub-zones (Figure 4-8), as defined by type of plant: the emergent plant zone, the floating plant zone and the submerged plant zone. Littoral zone aquatic plants contribute greatly to lake ecosystem diversity and perform many ecosystem services. Aquatic plants contribute to primary production and dissolved oxygen levels. They stabilize sediments, maintain water clarity, increase esthetics and provide fish and wildlife with food, spawning or nesting habitat, foraging substrates, and cover from sun and predators (Engel, 1990; Klessig, 1995; Anderson et al., 1999). Several species of fish, including some species common to northern environments, require aquatic vegetation directly for spawning whether for adherence of eggs, or the building of nests (e.g., northern pike, yellow perch and ninespine stickleback; Scott and Crossman, 1973). The littoral zone fish fauna plays an important role in freshwater lake ecosystems (Northcote, 1988). Abundance is typically greater than in other zones, and in many lakes, littoral species make up the bulk of the total fish community (Keast and Harker 1977; Werner et al., 1977). Littoral zone habitat and food resources are frequently important as prey to larger fish species (Lyons and Magnuson 1987). A naturally diverse fish prey base in the littoral zone, particularly the presence of large invertebrates, is critical for maintaining energy transfer to growing fish. An impoverished littoral benthic community can lead to stunting or a bioenergetic bottleneck – a failure to shift diets to larger-sized prey (shown in Figure 4-9 and demonstrated in Case Study 2; Sherwood et al., 2002, Rasmussen et al., 2008). In general, littoral zones are 10 times more biodiverse and productive than the open-water zone (Rasmussen, 2011).

4.8.2 Habitat Complexity

Simple ecosystems are less resilient and therefore more prone to destabilization and collapse. Diversity can be expected, on average, to enhance ecosystem stability (Yachi and Loreau, 1999; Post and Pimm, 1983; Robinson and Dickerson, 1987; Drake, 1991). Increasing diversity can increase functional redundancy, which means that the odds are greater that some species will be capable of functionally replacing important species. Essentially, ecosystem stability depends on the ability of communities to contain species, or functional groups that are capable of differential response. In addition, the diversity of many aquatic species, and thus ecosystem stability, is positively related to increased habitat complexity and heterogeneity. The goal of this section is to recommend approaches that will improve the ecological resiliency of EPLs.

4.8.2.1 Vegetation Diversity

Fish, bird and aquatic invertebrate diversity is often correlated to vegetation diversity (Tonn and Magnuson, 1982). In reclamation projects, the creation of temporary barren areas can allow invasive species to colonize, often in pure stands. Thus, vegetation should be managed so that monocultures are avoided and unwanted weedy species are managed (Ross 2011a).

4.8.2.2 Coarse Woody Debris

In natural lakes, coarse woody debris (CWD) falls from trees and branches into the water from the adjacent riparian zone. As such, CWD helps link water (the lake) and land (the riparian zone) and adds habitat complexity to lakes in forested regions. CWD is a critical component of aquatic ecosystems, serving as “breeding grounds” for benthic invertebrates, and supporting organisms higher in the food chain. In addition, CWD is important for fish by providing protection for nesting sites, a spawning substrate, and an area of greater food availability.

Experiments in which CWD was removed from entire basins of lakes have sometimes demonstrated drastic negative changes to fish assemblages (Sass et al., 2006; Helmus and Sass 2008). In general, CWD is positively related to fish species richness, abundance, and growth rates. Thus, the addition of CWD to lake restoration projects will support these processes.

The use of CWD, as well as the addition of other substrate features such as rock and gravel, to increase habitat diversity in EPLs, is further described in Gammons et al. (2009).

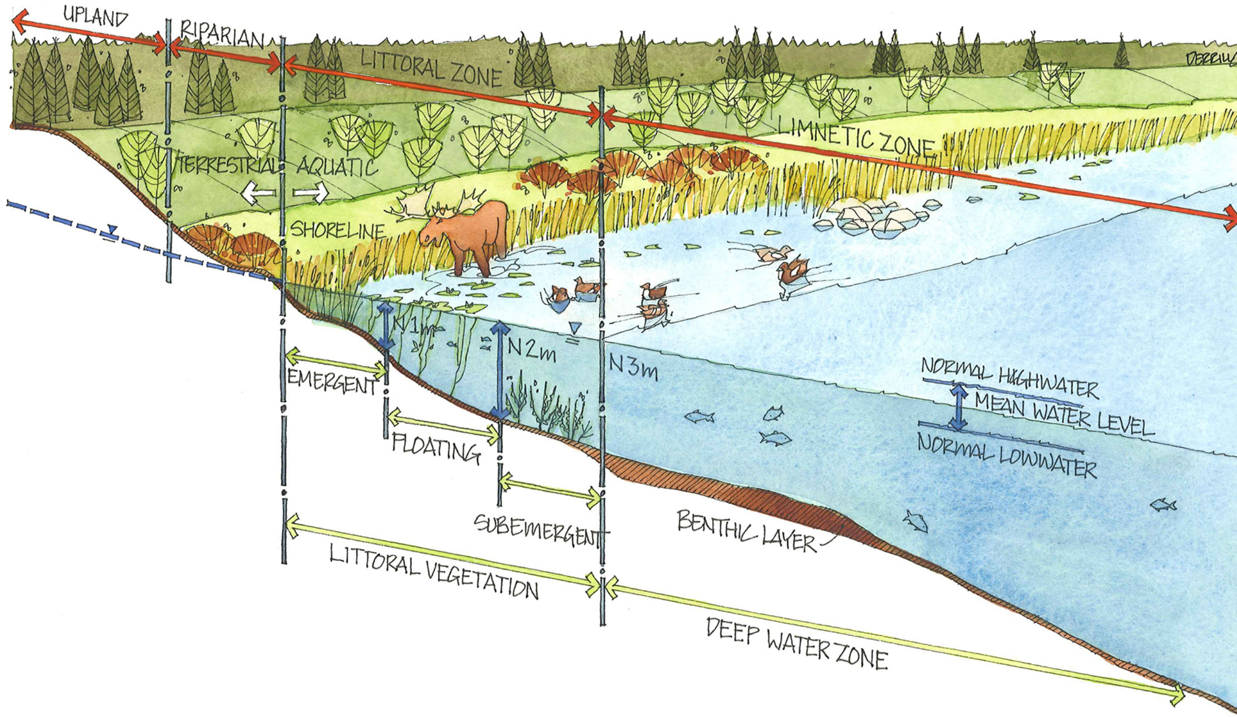

Figure 4-8: Lake zones from the terrestrial to littoral to open water zones.

4.8.2.3 Shoreline Complexity

Shoreline complexity (or shoreline development) indicates the degree of irregularity of a lake shoreline. It is measured as the shoreline development ratio, given as the length of the shoreline to the circumference of a circle whose area is equal to that of the lake. The closer this ratio is to 1, the more circular the lake. A larger ratio means the shoreline is more crenulated and hence the potential for littoral community development is greater. Shoreline development is calculated as

$$D_L = L / (2x \sqrt{\pi} \text{ x } A_o) \quad \text{(Equation 1)}$$

Where, L = shoreline length, A_o = lake surface area, and π = 3.1415

Table 4-5 includes shoreline complexity statistics for selected lakes on the boreal plain of Alberta, and can be used as design guidance.

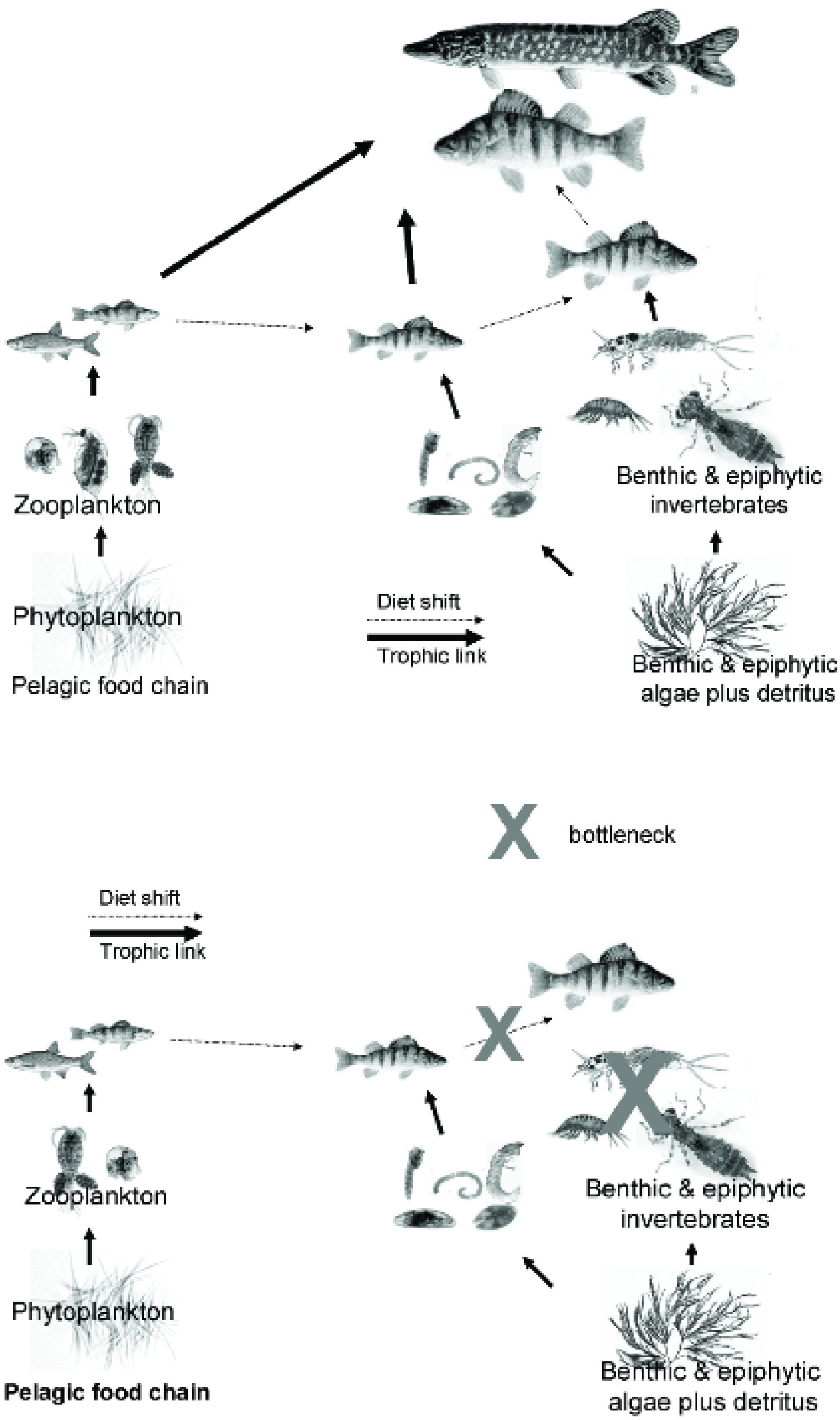

Figure 4-9: Comparison of fish production in (a) a lake with a diverse range of benthic prey, and (b) a lake where large benthic prey have been lost. Modified from Rasmussen et al. (2008).

Case study 2: A new Prairie irrigation reservoir in Southern Alberta (Brinkman and Rasmussen 2010)

The Twin Valley Reservoir is a new reservoir located approximately 45 km due south east of High River, Alberta. It was constructed as storage for irrigation purposes and to regulate peak flows in the Little Bow River. A study of this lake revealed a very simple food web where the reservoir almost completely lacked forage fish, which is a critical component of the food web. In spite of this, pike were present in the reservoir, being able to feed on a variety of foods. Although fish usually dominate pike's diets, invertebrates dominated their diets in the Twin Valley Reservoir. As a result, this food source was not adequate to sustain growth in large pike. With no larger prey to switch to (forage fish), the pike's growth was stunted.

4.8.3 Considerations for Littoral Zone Design

A suite of factors such as water clarity, substrate composition, and littoral morphometry (e.g., slope) and depth affects aquatic plants.

4.8.3.1 Area

The relationship between aquatic vegetation and fish is complex. Science, in itself, will perhaps never allow the determination of what is the ideal range for littoral zone surface area. However, the studies that have tackled this question directly show significant correlations between the occurrence of emergent and floating-leaf plant species and the biomass and size of fish (Radomski and Goeman, 2000; Valley et al., 2004). These studies show that, generally, conditions for game fish may deteriorate when the percentage of a basin that is covered with aquatic vegetation falls below 10% or exceeds 40% to 60% (Valley at al., 2004). At low plant abundances, prey is scarce because of a lack of refuges from predators. At high plant abundances, visual and swimming barriers created by dense vegetation may reduce the ability of predators to capture fish prey. Low feeding rates or poor growth by predators commonly result. A 10% lower threshold is consistent with the natural range of the percentage of a lake's surface area that is vegetated in Alberta (Table 4-5), as well as littoral areas proposed for planned EPLs. The coal mine End Pit Lake Working Group (EPLWG 2004) deems less than 10% of littoral zone as having a "low probability of success" and recommends about 30%, which has been the direction followed by coal mines in Alberta. In this chapter, 30% littoral zone is recommended with a minimum threshold of 10%.

4.8.3.2 Maximum Depth

The maximum depth of plant colonization (or littoral zone) is primarily related to light penetration. Secchi disk depth is the simplest measurement of light penetration and it typically yields the most robust results (Caffrey et al., 2006). Figure 8-10 describes the maximum depth of the littoral zone in relation to water clarity (as determined by Secchi disk depth). Designers can use this figure to determine the design depth for the littoral zone shelf, which will depend on site-specific predicted water clarity. On a case-by-case basis, water clarity will depend on the availability of nutrients and organic matter, phytoplankton and periphyton biomass, lake margin erosion and sediment resuspension, and salinity (through suppression of phytoplankton). Based on Figure 8-10, a littoral zone maximum depth of 3 m would be a conservative design target that would ensure the colonization of plants, regardless of productivity, whether the lake is oligotrophic (low productivity) or eutrophic (high productivity).

4.8.3.3 Slope

Slope can be a major factor controlling the physical characteristics of the sediments by affecting sediment stability and the deposition of fine nutrient-rich materials. Variation in slope can also modulate wave action in the littoral zone. A gently sloped littoral zone allows the deposition of fine materials, while steep slopes are mainly areas of erosion and sediment transport. Also, gentle slopes reduce the probability of slumping, with slumping by gravity alone having been reported for underwater slopes as low as 0.5% (Prior and Suhayda, 1979). In general, aquatic plant species richness (Forrest, 2010; Raab and Bayley, 2012) and biomass decreases where the slope nearshore is steep. Slopes less than a threshold of 2.5% do not appear to cause adverse effects for plant biomass (Duarte and Kalff, 1986). These slopes are consistent with slopes in natural lakes of Alberta (Table 4-5).

4.8.3.4 Substrate

Two factors commonly related to substrate composition are low nutrient levels and little or no organic matter. The lack of adequate attention to soil conditions can result in the total failure of vegetation to establish during reclamation. Sediment may act as an anchoring substrate and a source of nutrients for rooted plants. Some bottom types are inhospitable. Coarser sediment (sand and gravel) is unfavorable for aquatic plant growth. Coarse-textured cobble may provide few rooting microsites and sand is nutrient-poor. Excessively soft and flocculant substrates do not provide anchorage and may be eroded easily whereas clay is a more stable substrate. Low nutrient and organic matter levels will result in poor plant growth and high rates of plant mortality. In general, relatively favourable benthic substrates are composed of a mixture of inorganic particulates and are rich in humified organic matter (Lacould and Freedman, 2006).

There is little information available on optimal soil mixtures to support aquatic plant colonization and growth. Field trials are required to determine the optimal soil mix for plant colonization and resistance to wave action. In general, a good planting soil to the depth of the rooting zone has proven effective in wetland construction projects in western Canada (L. Ross, 2011b). The addition of organic matter (compost, peat) can result in higher nutrient and higher soil moisture levels, which can improve seed germination and seedling survival and growth rates (van der Valk, 2009). However, these additions do not appear to be critical (L. Ross, 2011b).

4.8.3.5 Wave Action

Littoral zones in large lakes, regardless of light availability, can be barren due to intense wave action caused by a large fetch. Habitats with intense exposure to wind and waves are suboptimal for aquatic plants because seedlings may be uprooted, mature plants damaged, or litter eroded (Wilson and Keddy 1986; Madsen et al., 2000). Wave action also washes away finer sediments such as silts and clays, leaving behind coarser, less fertile sediments such as sand and gravel. Since rooted plants obtain most of their needed nutrients from the sediments, wave action, through its effect on sediment particle size and organic content, has the potential to constrain plant growth. In addition, it may be difficult for plants to root firmly into coarse sediments.

The exposure of plants in the littoral zone is related to wave height and direction, which are affected by fetch and wind speed and duration (Lacoul and Freedman, 2006). On a site-specific basis, fetch is a critical consideration when selecting sites for aquatic plant colonization. Embayments are excellent options for creating low-sloped areas that offer protection from wave action. Shoreline complexity is the ratio of the length of the shoreline to the circumference of a circle of area equal to that of the lake. Shoreline complexity is of interest because it reflects the potential for greater development of littoral zone communities in proportion to the volume of the lake. Lakes with long shorelines compared to their area would be those with many bays, peninsulas and islands.

Establishing plant beds within the littoral zone of lakes, by designing for optimal conditions for plant colonization and growth, is an effective method of reducing wave energy and erosion, provided that intense wave action does not prohibit the plant establishment. There is a synergistic effect where wave energy and current velocity are reduced within beds in the littoral zone of lakes (Losee and Wetzel, 1988; 1993). Also, the occurrence of plants will aid water clarity through plant regulation of erosion and sediment resuspension, and by the preferential deposition of sediment in plant beds due to their capacity to reduce current velocities.

As highlighted above, fetch is an important consideration for the design of littoral zones. In contrast, a long fetch can be desirable for other in-lake processes (see Chapter 3). These considerations must be balanced by the design team.

4.8.4 Oxygen

In Alberta lakes, winter oxygen depletion (hypoxia) is a key natural disturbance that can affect fish assemblage composition. The severity of winter hypoxia is strongly related to lake productivity. Productive (or eutrophic) lakes have relatively higher sediment oxygen demand at the lake bottom due to bacterial decomposition of readily available carbon. During winter, oxygen becomes depleted due to this consumption and the barrier to oxygen replenishment caused by ice cover. This phenomenon would be particularly relevant to pit lakes with water-capped tailings because fluid fine tailings are high in bio-available carbon and have relatively high oxygen demand. Thus, water-capped oil sands pit lakes may be prone to winter hypoxia.

The lake's fish assemblage is related to oxygen concentrations in winter (Figure 4-10; Tonn and Magnuson, 1982). A stream or connecting lake may provide refuges from hypoxia in winter. Thus, lakes that are connected to other aquatic systems are more resistant to these natural disturbances and are better able to support multiple fish species. Such refugia should be included in EPL designs.

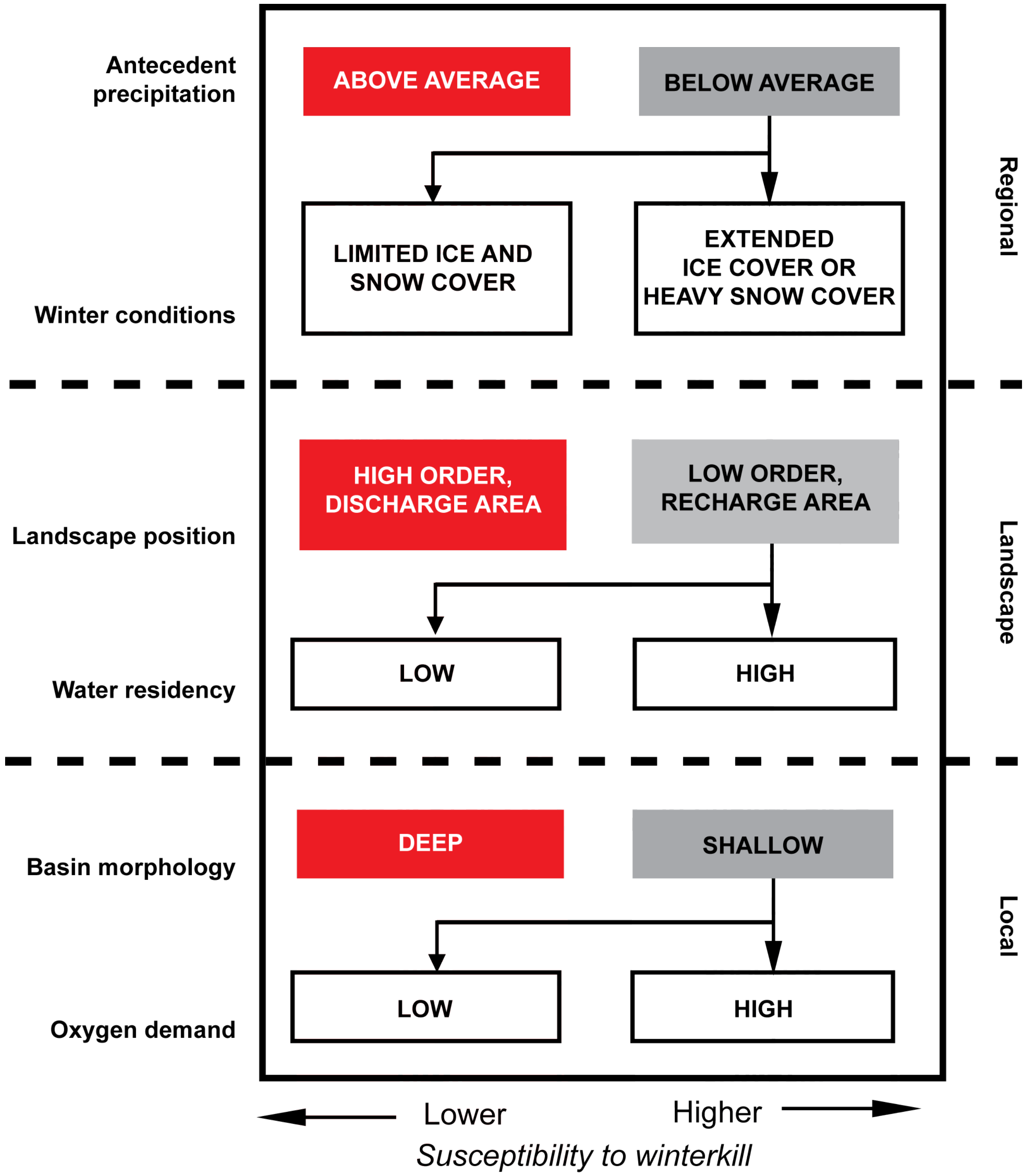

Figure 4-10: Conceptual model for the relative influence of local, landscape, and regional factors on the susceptibility of a lake in the Canadian Boreal Plains to experience winterkill of fish (modified from Danylchuk and Tonn, 2003).

4.8.5 Natural Meromictic Lakes

Naturally meromictic lakes are relatively rare, although they are widely distributed throughout the world. A meromictic lake has layers of water that do not intermix on an annual basis. As a result, the deeper layer of water (monimolimnion) receives little oxygen from the atmosphere and becomes depleted of oxygen. The upper stratum where mixing by wind occurs may behave like a typical lake and become seasonally stratified and/or mix completely. Meromictic conditions can last anywhere from one year to centuries. This type of lake may form naturally because:

- The lake basin is unusually deep and steep-sided compared to the lake's surface area, thereby creating a pre-disposition to meromixis; and
- The lower layer of the lake is highly saline and denser than the higher levels of water.

Two meromictic lakes were studied in Saskatchewan: Deadmoose and Waldsea lakes. These lakes receive saline groundwater and it is thought that these lakes became meromictic during the late 1960s, due to an influx of freshwater on top of the relatively saline inflow of groundwater at the lake bottom. Characteristics of these lakes include (Last and Slesak, 1986; Hammer, 1994):

- The deeper layer has salinity (dominated by sodium and magnesium sulphate) that is about twice the concentration of the surface layer (surface layer concentration is about 30 g/L).
- This deeper layer is strongly reducing and high in toxic hydrogen sulphide.
- Bottom waters become nutrient traps, thus the surface layers of these lakes have low productivity (oligotrophic).
- The stability of meromixis can vary, depending on climatic conditions. A surface input of freshwater strengthens meromixis, while drought tends to weaken it.
- The lower layer of the lake may exhibit low biodiversity. Benthic fauna are often impoverished or absent due to a lack of oxygen.

There is nothing inherently inappropriate with meromictic lakes – they are found naturally throughout the world. In general, they tend to have low productivity and few fish and they are often studied as ecological oddities. In the context of oil sands, however, what is relevant is that meromixis would reduce one of the main functions of a EPL during the "active treatment phase," that is, treatment efficiency (see Chapter 6). Low productivity in these types of systems may also be at odds with certain desired ecosystem functions, such as fish production.

4.9 Summary and Conclusions

EPLs will be integrated into the natural landscape and provide desirable ecosystem services. For this to occur, it is important to understand the characteristics and processes that make up a lake.

Lakes in the oil sands region are the result of complex interactions among terrestrial and aquatic features at multiple spatial and temporal scales. For example, regional-scale criteria control the distribution of fishes; that is, the regional species pool and the stream network controls the dispersal of fish across the landscape. At the other end of the spectrum, local-scale criteria, — structural complexity, water quality, and biotic interactions — control the maintenance of fish in an individual lake. Similarly, for a broad-scale classification of hydrologic response, the order in which factors are considered is important. The factors must be in order of decreasing spatial scale to determine their relative influence on hydrologic processes, scales of interaction, and water budgets (Devito et al., 2005). Accordingly, climate is the dominant control on regional hydrology, followed by bedrock and surficial geology, soil type and depth, topography, and drainage network. These features, as well as others, operate on a lake ecosystem in a hierarchical manner; regional features (e.g., regional species pool) both constrain and set the context for local features (e.g., biotic interactions).

Progressive reclamation of mines necessitates integration with the regional environment. To support regional reclamation objectives, design teams should consider the following regional processes:

1. Regional climate variation, as well as extreme events such as drought and floods/extreme rainfalls.
2. Lake “outcrops” of a complex surface-groundwater flow system that moves water through the landscape and region rather than as islands.
3. Multiple spatial scales, from the regional to local hydrological flow systems. As some EPLs are expected to intersect regional groundwater flow systems, an understanding of the quantity and quality of the systems of interest is required. In addition, the water quality of surface waters to be connected to EPLs must be carefully considered, both in terms of inflows to EPLs and outflows to natural waters.
4. Habitat capability for those species that are important to regional stakeholders. Because many of these species have regional spatial distributions, the design of habitat capability in oil sands EPLs must be considered at multiple spatial scales: from the regional to local. This is particularly relevant from the perspective of establishing and supporting fisheries in EPLs. Fish, in general, have been identified by regional stakeholders as being particularly important (Chapter 2). Considering the proposed morphometry of the planned EPLs (Table 1-2), fish (forage and/or game fish) will likely colonize these systems once the conditions are suitable. Connection of EPLs to the regional fish species pool will allow colonization of and passage through EPLs and greater potential for fish diversity. Although detailed habitat recommendations for specific species of interest is outside of the scope of this document, some work will be required by EPL design teams to generate design guidance for specific species of interest to local stakeholders.
5. The impact of beavers as engineers of landforms and landscapes. Design teams must determine how to accept and accommodate beaver activity.

The hydrology, chemistry, and biology of an aquatic ecosystem are reflections of the terrestrial and aquatic features that make up the landscape that contributes water to that receiving system, i.e., the watershed. Thus, watershed-level features should be explicitly recognized. Lake watersheds are comprised of a number of smaller units or landforms. Each landform can be characterized in terms of hydrological response, based on geological characteristics.

Essentially, hydrogeology of a watershed is a sum of its geologically defined landforms. By classifying types of landforms by geology and the corresponding hydrological response (i.e., Fundamental Hydrologic Landscape Units), oil sands reclamation practitioners will be able to additively predict the hydrological response of an EPL watershed, which will support progressive closure planning discussions and decisions. In turn, this will support the planning and design of landscapes that support desirable end land uses. A description of the hydrogeology of reclaimed landforms, as well as expected solute loadings, is included in Chapter 5.

A critical consideration when planning for and designing watershed landforms is water storage. Boreal Alberta is in a zone that, climatically, is under a potential water deficit. Water storage will shield watersheds from the effects of climate variability and increase water supply stability to support the multitude of critical watershed and lake functions (e.g., tree growth, wetland sustainability, littoral zone viability). To the extent possible, watersheds should be modelled after "storage-dominated watersheds" as described in this chapter.

In addition to regional and watershed-scale components, local processes, such as structural complexity, water quality, and biotic interactions, control the capability of EPLs to generate food webs characteristic of the Boreal Plain. Littoral zones feature the highest rates of primary productivity, and lakes with larger littoral zones are likely to support more biomass. Designs should incorporate littoral zones around EPL shorelines, according to the following specifications:

1. A minimum of 10% (30% to 40% is better) of in-lake littoral zone, as a portion of the lake's surface area, is recommended.
2. A stable littoral zone to support productivity and ecosystem development: ≤ 2.5% littoral slope
3. A water depth between 2 and 3 m
4. Vegetation consisting of locally common boreal forest plant communities.
5. Absence of monocultures.

In addition, including habitat complexity in design will increase diversity and ecosystem stability. Lakes that are connected to other aquatic ecosystems are more resistant to disturbance and are better able to support multiple fish species. At least one inflowing and outflowing watercourse, both of which are accessible to fish, are recommended. The shoreline should be long and irregular to provide habitat diversity and to minimize bank erosion resulting from wave action. Island development can increase habitat diversity and encourage utilization by waterfowl. Finally, the use of coarse woody debris, as well as the addition of other substrate features such as rock and gravel, is recommended to increase habitat diversity.

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5. WATERSHEDS IN THE MINING ENVIRONMENT

Brent Mooder
BGC Engineering

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5.1 The Geography of Disturbed Landscapes

Oil sands reclamation projects will be influenced by various landscape configurations. Watershed topography controls the closure surface water drainage system with creeks, wetlands, and lakes. Without drainage or topographic controls, large areas would become affected by excess salinity, resulting in sterilization of reclamation soils and mortality of vegetation. Watershed reconstruction and topography controls are linked. Contouring and relief structures are essential for promoting positive water drainage and trafficability on tailings sand deposits.

5.2 Landscape Elements

The reclaimed landscape will be constructed largely from overburden (material below the salvaged reclamation material layers that is removed to access the oil-rich McMurray sands and tailings. Soils and peat are generally stockpiled at mines for use during reclamation, while other mining byproducts, such as coke and sulphur, may be stored on the landscape for future recovery. The materials used in the construction of the reclaimed landscapes may change through time and as mining processes change. For example, the volume of solids, fines, and bitumen in oil sands tailings are influenced by variations in the ore from the mine, and operating and upset conditions within the extraction plant. In addition, regulatory requirements for soil salvage and replacement may change over time, resulting in a mosaic of reclaimed soil types on the landscape.

There are several types of oil sands tailings with various names such as composite tailings (CT), fine fluid tailings (FFT), tailings sand, cyclone sand (DT) and centrifuge fine tailings. As processing and dewatering technology continues to evolve (e.g., Suncor's Tailings Reduction Operation (TRO) or Albian's Atmospheric Fines Drying (AFD)), the composition and physical properties of the tailings may change, and could influence EPL water balance and water quality in the reclaimed landscape. Consolidation refers to the densification of fine-grained material by the release of excess pore-water pressure over time, typically in response to changes in applied stress. For oil sands tailings, this process often involves slow settlement over time in response to self-weight or vertical surcharge from a capping layer. The expelled water is referred to as release water. Many tailings materials remain soft even after full consolidation.

The hydraulic and chemical properties of the landscape materials are important factors to consider, because a functioning hydrologic system with a sufficient quantity and quality of water is necessary for overall ecosystem function. Hydraulic properties, such as hydraulic conductivity, will influence the manner in which water moves vertically and horizontally through the system. Chemical properties of the materials, such as salt content, organics content, and weathering behaviour are important to understand because these materials may act as sources of solute to the system, and their chemistry impacts the transport of solute in the subsurface. Ultimately, the physical and chemical properties of the reconstruction materials influence inputs to the hydrologic system within which end pit lakes are situated.

Oil sand mining disrupts the natural topography, vegetation, and surface and groundwater systems. The process of mine reclamation involves the construction of a new landscape, one which may evolve differently from the original landscape. Various configurations of landscape elements can be utilized to achieve different landscape goals with varying implications for end pit lakes.

5.2.1 Geological Materials

The following sections provide a description of the physical and chemical properties of the materials that will be used to construct the reclaimed landscape. Typical properties are summarized in Table 5-1, with materials broadly divided into three categories: in situ geologic material, stripped overburden, and tailings and mining materials. In situ refers to the geologic material in its natural context, while stripped overburden refers to the same geologic materials that have been modified by movement, with potential implications for hydraulic and chemical properties. Tailings and mining materials are mostly derived from natural geologic materials that have been physically and/or chemically modified during mining and processing. Tailings and byproduct properties vary depending on the original ore properties and the methods used to process the ore. Typical chemical properties of tailings are summarized in Table B-7.

Process-affected water is generally present wherever tailings deposits occur. Therefore, process-affected water quality exerts a key influence on long-term groundwater quality and groundwater discharge quality. If process-affected water quality were to be improved by treatment during operations, long term groundwater quality and groundwater discharge quality in the reclaimed landscape would also be improved. Improvements in groundwater discharge quality would lead to a reduction in ongoing solute loading to an EPL.

Table 5-1: Geologic and artificial materials involved in EPLs.

Material	Description	Comment
In-Situ Geologic Materials		
Holocene organic soils	Lowland peat and organic-rich upland soils	Upper portions of these overburden materials are typically used for reclamation material, lower portions for constructing dykes and dumps.
Quaternary / glacial deposits	Glacial tills, and glaciolacustrine and glaciofluvial sediments. Highly variable composition ranging from fine grained dense tills to loose coarse grained sands and gravels.	
Cretaceous Clearwater Formation bedrock	Clays and clay/shales, silts, and fine grained sands deposited in shallow seas. Dense, low moisture content, flat-lying with beds continuous over miles.	Often abbreviated Kc. The pore-waters are saline/sodic. These overburburden materials are typically used to construct dumps. This unit generally acts as an aquiclude. Clearwater-Wabiskaw (Kcw) incuded in this table.
Cretaceous McMurray Formation Oil Sands bedrock	Generally fining upward sequence of fluvial, estuarine, and marine sands, silts and clays. Lean oil sands has bitumen contents of 0-~7%. Ore-grade oil sands has bitumen contents ranging from about 7 to 18%, averaging about 10% Bitumen. Sandy McMurray Formation at the base of this unit is often referred to as "watersands."	These sands silts and clays are used to construct dumps and dykes. They are typically low permeability and have saline-sodic pore-waters. Except for the water sands, this unit generally acts as an aquiclude.

Material	Description	Comment
Devonian Carbonates / evaporates bedrock	A thick sequence of limestones, dolostones, and evaporites that underlie the oil sands.	Some limestone mined in quarries in the region.
Precambrian Shield	Metasedimentary rocks and granite.	Basement rock.
Surface water	Surface water from creeks and rivers, used to fill end pit lakes.	
Constructed landforms		
Sandy overburden dumps	Dumps constructed largely of sandy quaternary sediments. Loose to dense, medium to high permeability.	
Clearwater Formation dumps	Dumps largely constructed of Clearwater Formation, often with some glacial and lean oil sands. The deposits range from loose to dense, medium to low permeability, saline-sodic porewater, with some pyrite oxidation that produces even greater quantities of salts.	
McMurray Formation dumps	Dumps dominated by lean oil sands. Deposits range from loose to dense, medium to low permeability, saline-sodic porewater with bitumen signature. Some dumps have lean oil sands mixed with large quantities of Clearwater Formation and glacial materials.	
Overburden dykes	Dykes constructed largely of lean oil sands or oil sands / glacial material mixes. Very dense, low permeability.	
Tailings sand dykes	Dykes constructed of compacted tailings sand. Medium to high permeability, with tailings pore-waters.	
Coke piles	Dumps constructed of petroleum coke, which ranges from sandy gravel to gravelly sand, typically unsatured with high permeability.	Syncrude coke is a fine grained slurry and listed below. Coke is similar to coal, is predominantly carbon (>90%) with high levels of sulphur and metals.
Soil / reclamation stockpiles	Temporary dumps of organic reclamation material.	
Tailings deposits		
Tailings Sand (beach and dyke)	Extraction by-product comprised of sands, process water, and minor amounts of fines and residual bitumen. (Oil sands with the oil removed). Dykes are well compacted, beaches range from loose to dense. High permeability.	Texture: 5% clay, 80% sand, 15% silt.
Mature Fine Tailings (MFT) **Fine Fluid Tailings (FFT)**	Suspension of fine silts, clays, residual bitumen, and water with min. 30% solids (w/w). Settles very slowly, with fluid-like properties for decades or centuries. More recently, fluid MFT (30 to ~60% solids) has refererred to as FFT by some operators.	Low to very low permeability, high compressibility. These materials take decades to centuries to consolidate to soil/like material, some will remain fluid-like permanently.

Material	Description	Comment
Composite Tailings (CT) **Consolidated Tailings** **Non segregating tailings (NST)**	Non-segregating slurry of chemically amended fine (MFT or TT) and coarse tailings sand. Consolidates relatively quickly to form a semi-solid, loose, silty sand deposit. Gypsum is a typical amendment / coagulant (increasing calcium and sulphate levels in deposits). Polymers are also being employed. Dense, but low permeability and strength.	Typically consolidates over several years to decades. Unless unsaturated, requires permanent containment. Typically 80% sand, 20% fines. Offspec material consolidates much more slowly and is up to about 50% fines.
Thickened Tailings (TT)	Fine tailings flurry amended with a polymer flocculant in line or in a thickener veseels to promote rapid release of water and a soft clay-like consolidating deposit. Referred to as paste if no immediate water release.	Post-deposition consolidation rates similar to that of CT/NST.
Dried MFT/TT	Fine tailings that has been amended with a polymer flocculant and deposited in thin lifts to promote drying / freeze-thaw consolidation. Forms a semi-solid deposit if saturated, or a weak clay deposit if unsaturated due to drying.	Becoming commercial at several operations.
Froth tailings	Residual solids from bitumen froth clean up. High bitumen content sand and silt tailings with some residual hydrocarbon solvents.	Pyrite will oxidize to produce acid (pH3) drainage if stored above the water table. Concentration of naturally occurring ratioactive materials (NORMS) requires special handling.
Tailings water / process affected water	All waters that have had contact with tailings or the mined areas and included ponded water, and the pore-waters in the tailings deposits. The chemistry varies somewhat from material to material and with the age of the material. As there is typically just one water circuit for each site, the process affected waters mingle and have chemistry that is more similar than some people suppose.	Electrical conductivity 2 to 7 dS/m pH 8-8.5 Elevated levels of sodium, chloride, naphthenic acids, often sulphate. High SAR. These water chemistries apply to tailings sand, CT/NST, TT and Syncrude fluid-bed (Syncrude) coke.
Fluid-bed (Syncrude) Coke	Fine uniform sphrerical carbon sand slurried to form beaches. Upgrading by-product comprised of black, fine- to coarse-grained carbon particles. Highly permeable.	Coke is similar to coal, is predominantly carbon (>90%) with high levels of sulphur and metals.
Other byproducts	Other byproducts that may be in the reclaimed landscape (usually in landfills) include: Flue gas desulphurization (FGD) salts, water treatment salts, gypsum, fly ash, refinery wastes, construction and municipal wastes, elemental sulphur. There is much focused research on developing new tailings materials and desositional practices which may increase the number of different tailings materials in the watersheds and under end pit lakes.	

Notes: EC – electrical conductivity; SAR – sodium adsorption ratio; Sources: McKenna 2002; Qualizza 2000; (Kessler et al., 2010). McKenna and Qualizza references are in the database of OSRRN reclamation final draft project 0877

5.2.1.1 In Situ Geologic Materials

The in situ materials include Quaternary materials deposited by glacial and fluvial processes, Cretaceous units including the McMurray Formation, and Devonian units (Figure 5-1).

Quaternary Deposits

- *Peat and muskeg (Ho)* – Holocene organic soil consisting of decomposing plants, typically near the surface water table. Sponge-like in composition; capable of holding 15 to 30 times its own weight in water;
- *Lacustrine and glaciolacustrine clay (Hl, Pl)* – typically interbedded silt and clay with minor sand;
- *Fluvial and glaciofluvial sand (Hfs, Pfs)* – sand with minor gravel, cobbles, boulders, and minor lenses of silt and clay;
- *Sand and gravel (Hfg, Pfg)* – sand and gravel with minor cobbles, boulders, silt and clay;
- *Glacial till (Pg)* – composed of sand, silt, and clay, with gravel and boulders;
- *Pleistocene channel aquifers* – deep buried channel sediments; typically coarse sand and gravel.

Cretaceous Deposits

- *Grand Rapids Formation (Kg)* – characterized by salt and pepper texture of fine to coarse grained, uncemented quartz sand and heavy minerals (only present in a few mining areas);
- *Clearwater Formation (Kc)* – sequences of marine shales and siltstones with medium to high plasticity and low moisture content;
- *Clearwater Wabiskaw Member (Kcw)* – glauconitic sand and silt, saturated with bitumen in the eastern extensions of the Alberta oil sands deposit;
- *McMurray Formation Oil Sands (Km)* – bitumen saturated (up to 18% by mass) fine to coarse grained sand with interbeds of clay; hosts the mineable hydrocarbon reserves;
- *McMurray Formation Basal Clays (Km)* – continental pond and lake (lacustrine) clays within the lower McMurray Member; generally caps water sands where present;
- *McMurray Formation Water Sands (Km)* – water-bearing sands of the lower McMurray Member, thickness largely controlled by the topography of the erosional surface of the Devonian.

Devonian Deposits

- *Devonian Waterways Formation (Dw)* – alternating sequence of argillaceous limestone, calcareous shale, and clastic limestone;
- *Prairie Evaporite Formation (Dm)* – succession of evaporates (halite and anhydrite), carbonates, and shale;
- *Methy Formation (Dm)* – consists of three units: a basal, thin bedded dolomite and evaporite unit, a thick middle dolomite unit which is massive in places, and an upper, thin bedded evaporitic dolomite unit;
- *LaLoche Formation (Dm)* – pale brown, fine to medium grained, irregularly lenticular, thin bedded arkosic sandstone.

5.2.2 Mining Materials

The stripped overburden consists of materials below the salvaged reclamation materials that are removed to access the oil-bearing sands of the McMurray Formation. The materials are the same as the in situ geologic materials of the quaternary and cretaceous periods, but are altered by physical processes – that is, being dug up and reconfigured in dump formations. The hydraulic and chemical composition of these materials varies widely, and changes with exposure to atmospheric gases, in particular oxygen.

McMurray Formation oil sand is a mixture of bitumen, quartz sand, silt and clay, and water in varying proportions. Bitumen content ranges from 0% to 19%, with an average of 12% (by mass); water varies between 3% to 6% by mass, increasing as bitumen content decreases; mineral content, predominantly quartz sands, silts, and clay, varies between approximately 84% to 86% by total mass. Clays are present in the McMurray bitumen-containing deposits in thin, discontinuous clay layers (Chalaturnyk et al., 2002).

Overburden dumps consist of a variety of different materials: Kc, sands and lean oil sands. The hydraulic and chemical composition of these materials varies widely.

Reclamation materials are the surface soils salvaged prior to overburden removal. Peat mineral mix is coarsely mixed peat and mineral materials salvaged during the stripping process, in which peat is overstripped to a maximum depth of 3 m and includes 25% to 50% by volume of mineral materials. More recently, upland soils consisting of an LFH layer and the underlying mineral soils are separately salvaged for reclamation. Reclamation materials are either directly placed or put in stockpile for future use.

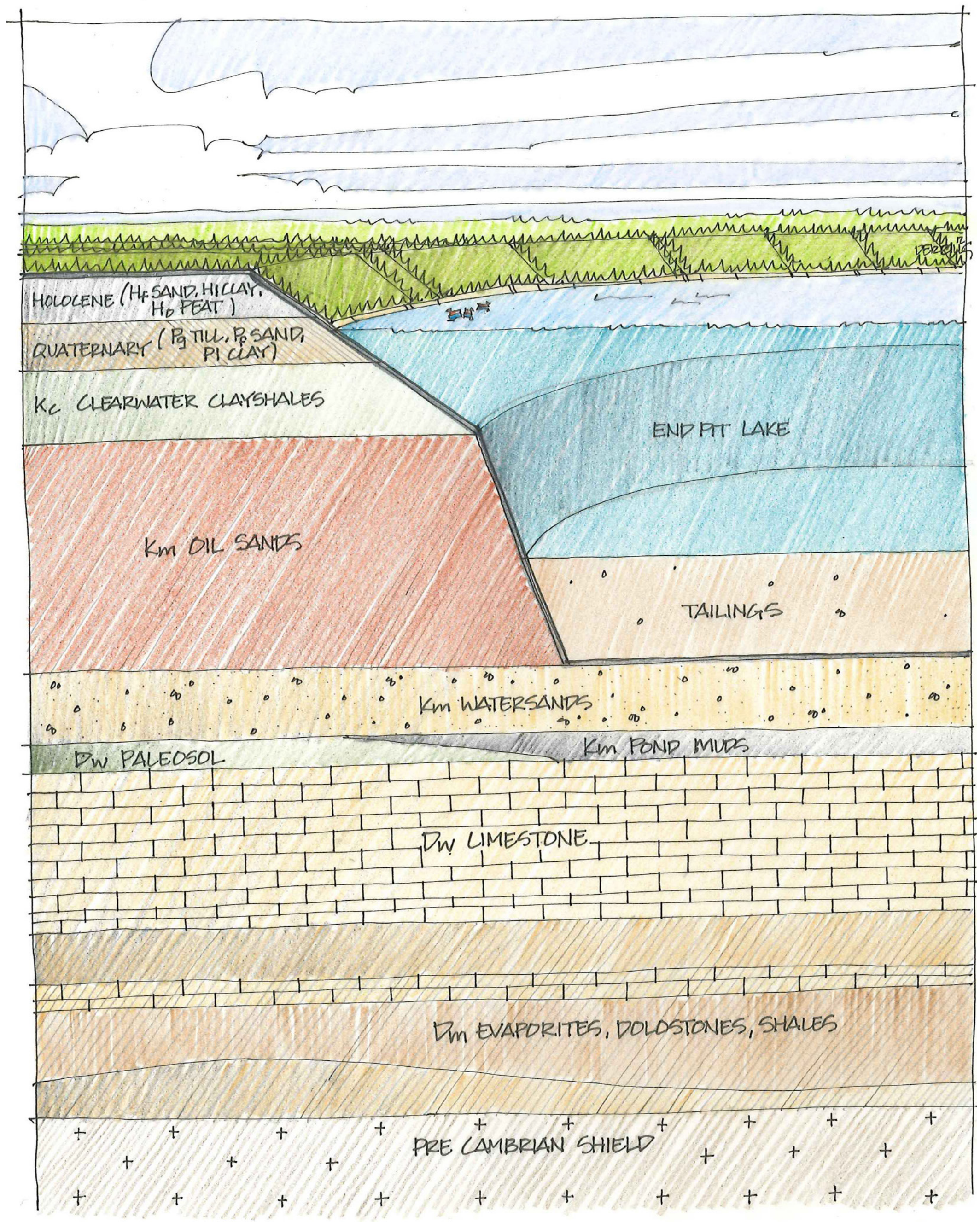

Figure 5-1: Typical geological stratigraphy of the Athabasca oil sands. More stratigraphy details can be found in Table B-5, Appendix B.

5.2.3 Tailings Materials

5.2.3.1 Solid and Fluid Tailings

Tailings are byproducts from oil sands processing, and include extraction tailings, treatment tailings, upgrading byproducts, etc. (Royal Society of Canada, 2010). Tailings typically comprise process water, sands, and clays, with minor amounts of residual bitumen. Sand tailings are coarse grained, while most other materials (e.g., MFT) are fine grained. CT falls between these two broad classifications (Devito and Mendoza, 2007), but is likely to exhibit properties closer to fine-grained materials. Fluid tailings include process water (predominantly water associated with caustic hot-water extraction used to separate the bitumen from the ore), soft fines that are a mix of slowly densifying tailings pond water (TPW) and MFT (containing TPW, un-recovered bitumen, silts, clays) and coarse tailings (predominantly sand saturated with TPW) (Fedora et al., 2003, and FTFC, 1995 cited in Farwell et al., 2009).

Fine tailings are a suspension of fine silts, clays, residual bitumen and water derived from the extraction of bitumen from oil sands, using the traditional hot water extraction process. The remainder from the extraction process is pumped to tailings facilities where coarse sand settles out. The overflow is directed to a settling pond where the fine grained portion slowly settles to yield a suspension of fine tailings. The fine tailings suspension is typically 85% water and 15% fines by volume. Further dewatering of fine tailings occurs very slowly. When first discharged, the very low density material is referred to as thin fine tailings (TFT). After a year or two, when the fine tailings have reached a solids content of about 30% by mass, they are referred to as mature fine tailings (MFT). Settling occurs much more slowly after this point, and MFT remains fluid-like for decades or centuries.

Cyclone tailings refers to tailings processed through hydrocyclones, which are used to classify (separate) oil sands slurry into a dense low fines sandy underflow (Cyclone Underflow Tailings) and a low density, fines-rich cyclone overflow (Cyclone Overflow Tailings). The underflow may be beached or used as a feedstock for co-disposal with fines; the overflow is typically pumped to a settling basin. Other tailings are:

- Mature fine tailings (MFT) – suspension of fine silts, clays, residual bitumen, and water (min 30% solids w/w). very slow settling and remains fluid-like for decades or centuries.
- Thickened Tailings (TT) – tailings with the addition of a flocculant to promote binding of the active minerals for rapid settlement.
- Composite Tailings (CT) – Non-segregating mixture of gypsum amended fine and coarse tailings that consolidates relatively quickly. The purpose of producing CT is to consume both legacy fines (MFT) and new fines (TFT thin fine tailings) to create a land surface reclaimable to upland or wetland vegetation. To this end, CT has a sand to fines ratio (SFR) that is greater than about 3:1 (to allow rapid consolidation) but less than about 5:1 (to permit useful levels of fines capture). CT starts as a slurry and ends as a semi-solid, loose, silty sand deposit that is dense enough and strong enough to support hydraulic sand capping.
- Tailings Sand – comprised of sands, process water, and minor amounts of fines and residual bitumen; by-product of oil sands extraction; oil sands with the bitumen removed.
- Dried MFT – many operators are moving to commercial scale environmental drying of fine tailings, and these materials may overlie large areas of future reclaimed leases. Water release rates from these materials are expected to be slow.

5.2.3.2 Tailings Materials and Consolidation

Those EPLs with tailings consist of two main functioning layers, the top water layer and the bottom tailings layer. It is important to understand how the different components might affect one another. In particular, it is critical to know how the process-affected water might be released from the tailings into the top water layer. In this section, compression mechanisms of the tailings layer in an EPL are explained and the rate and amount of compression is given.

Compression, or the water release process of tailings in EPL systems, is controlled by three main mechanisms, including sedimentation, consolidation and segregation. Sedimentation occurs when tailings slurry is deposited at low solids contents where a grain to grain contact between particles is not continuous to form a stress bearing structural network. Sedimentation of oil sands fine tailings generally occurs within a year after deposition from dilute slurry to solids content of approximately 25% (by weight). From this point forward, solid particles start to touch one another and stress may be transferred at the contact points. Typically, the oil sands fine tailings start to compress very slowly at solids content of about 30% when it is called mature fine tailings (MFT).

Once the sedimentation is over, a consolidation process commences. During consolidation, excess pore water pressure induced by self-weight or external applied stress dissipates, resulting in settlement and development of effective stress. For practical purposes, it can be assumed that consolidation governs the water release process of the MFT in an EPL system. The process of consolidation settlement of MFT is generally expected to take many decades to complete.

During sedimentation and consolidation, segregation can also occur whereby large particles fall toward the bottom of the water body, leaving high fines tailings at the top of the tailings layer. This particle sorting phenomenon has an implication on rate and amount of consolidation, since the hydraulic conductivity and compressibility of oil sands tailings is largely controlled by particle size distribution (Pollock 1988, Suthaker 1995, Jeeravipoolvarn et al. 2009). Other mechanisms can affect the rate of compression; for example, it can be affected by dynamic tailings mobilization, creep, thixotropy (strength gain with time), wave action and surface erosion, and resuspension. Currently, these mechanisms are not well understood and require further research.

The compression of the tailings in EPLs will release process-affected water into the surface water layer. In practice, the rate of water release can be approximated by theories of sedimentation and consolidation (Kynch 1952; Gibson et al. 1967; Pane and Schiffman, 1985). For tailings properties, compressibility and hydraulic conductivity of the tailings must be determined either by laboratory tests or historical matching analyses. Values for typical oil sands tailings compressibility and hydraulic conductivity can be found in Pollock (1988) and Suthaker (1995), respectively.

For EPL design, it is recommended that a water release rate from the tailings be initially estimated, with appropriate tailings characteristics and initial and boundary conditions. The rate of water release should be calibrated against known historical values once they become available.

The tailings rate of compression typically decreases rapidly with time. For oil sands fine tailings, during a short term period (within 25 years), one may expect to have a relatively large quantity of process-affected water released into the top water layer; during a longer term period, much smaller settlement and water release can be expected. This water release behavior of the tailings is directly related to various ions being carried with the process-affected water, which affects the operation of the EPL. Tailings compression therefore must be considered for EPL design. As well, other factors, including specifics of the design and tolerable risks and contingencies, should be included in any design effort.

5.2.4 Other mining materials

Petroleum coke is a byproduct of upgrading bitumen to synthetic oil. Syncrude coke consists of black, fine-grained carbon particles, with some sulphur and trace metals; the Suncor product has similar chemistry, but is sandy gravel in size. Some coke is used as fuel in processing plants, and the remainder is stored for use as a future energy source. Coke leaching is a concern. Recently, Suncor tested coke as a reclamation material to create a trafficable surface on treated tailings (Wells et al., 2011).

Sulphur blocks are large stockpiles of elemental sulphur, and are another byproduct of bitumen upgrading. They are built by pouring thin lifts, generally < 0.1 m of molten sulphur which solidify.

Other mining materials may also include unengineered dump fill, which is material that was not mechanically placed to control geotechnical and hydrogeologic properties, and engineered dam fill, which is material that has been constructed to control the geotechnical and hydrogeologic properties in order to meet a certain design specification.

5.2.5 Land Form and Function

The materials discussed in the previous section will be assembled into a variety of landforms to form the reclaimed landscape. Landscape types, their nature, characteristics, and functions are summarized in Table 5-2, and discussed in the sections below.

In general, landform design is constrained by mining requirements. Operators typically have limited storage space within their lease boundaries, and consequently, the locations and configurations of major landforms, such as dumps and tailings storage facilities, are largely controlled by mining needs. Therefore, landforms are constrained by what is required for ore extraction (mandated by ERCB) and mine waste storage. Within the landscape design constraints imposed by mining needs and overall reclaimed landscape performance objectives, EPL objectives introduce other landscape design considerations.

Mining disrupts the natural distribution and layering of geologic materials. Placed tailings, constructed dykes, and placement of other in-pit materials is expected to alter patterns of groundwater flow, and may change the surface water balance. Topography and drainage patterns are also altered by mining and reclamation activities.

Table 5-2: Landscape types, their nature, characteristics, and functions.

Landform	Mine Function Description	Watershed Function
Overburden Dumps	Used to store overburden.	Upland-like areas, tend to drain, supply water to the landscape, forest development. Kc overburden may leach salts.
Settling Basins	Used to store tailings, facilitate segregation, consolidation. Normally aboveground structures.	Upland areas (dykes), likely with a central lowland area draining to the external environment.
In-Pit	Tailings and overburden storage.	May alter groundwater flow patterns. Consolidation and settlement may result in development of closed topographic lows and the development of wetland areas.
Natural Areas/ Undisturbed areas	Uneconomic to develop – no mine function.	Integrate reclaimed areas with pre-mining environment, source of flora/fauna.
Streams/ Channels/ Swales	Drainage (ditches move water around the landscape; dyke ditches capture porewater release and recycle it to the tailings pond).	Move water through the reclaimed landscape and to the external environment. Recharge groundwater.
Wetlands		Flood attenuation, groundwater recharge, passive water treatment, carbon storage, wildlife habitat. General high ecological value.
EPLs	Potential disposal location for tailings.	Bottom of watershed, collection and treatment of process-affected water.

5.2.5.1 Overburden Dumps

Overburden dumps are large landforms, ranging up to tens of metres high and several kilometres long. In the context of an oil sands mine, the function of overburden dumps is to store overburden. In the reclaimed environment, these features typically act as upland-like areas, with the potential to drain water to the surrounding landscape, and support vegetation along hill slopes.

5.2.5.2 Settling Basins and Tailings Ponds

Tailings ponds are above-ground artificial impoundment structures containing tailings. Tailings ponds are enclosed by engineered dykes made with tailings and/or other mine waste materials. Their function is to store solids and water and to act as a settling basin to clarify process water so it may be reused in the processing plant. Tailings consolidation occurs during the operational life of a tailings impoundment and typically continues into the reclamation period. The softer tailings toward the centre of a pond generally consolidate more, and over a longer period, than the sandy beached tailings near the edges of a pond.

5.2.5.3 In-pits

Mine pits developed during oil sands mining are typically used to store tailings and other mine waste materials. Mine pits are generally divided into cells separated by dykes. In-pit dykes may be constructed from lean oil sands, tailings sand, or other mine waste materials. The pit floor may be exposed Devonian rock, McMurray Formation water-bearing sands, McMurray Formation clays or lean oil sands.

EPL functions may include:

- Flood attenuation
- Passive water treatment for runoff and seepage from reclaimed mine surfaces, and process-affected water
- Mixing of water from the undisturbed areas with runoff from the reclaimed mine surfaces
- Providing a water cap for MFT deposits, which are currently difficult to reclaim with sand or overburden due to extremely low settled dry densities.

5.2.5.4 Undisturbed Land / Natural Areas

Within the mining landscape, there will be portions of the original landscape to be incorporated into the end pit lake watershed. Undisturbed areas provide watershed and ecosystem functions, including water supply and storage to reclaimed portions of a watershed, vegetation and wildlife habitat, wildlife corridors, and recreational opportunities. However, it may be desirable to continue to divert some clean water from treatment wetlands and end pit lakes, at least initially in the reclamation process.

5.2.5.5 Streams and Channels

Streams and channels convey water across the landscape and provide the surface component of the EPL water balance from within the EPL watershed. Channel design may be complicated by such influences as topographic constraints, ongoing tailings consolidation, the use of erodible reclamation materials, consideration of solute transport and the accumulation of salts in the landscape, fish passage, and consideration of beaver activity. On tailings beaches, hummocks (typically 3 to 6 metres high and hundreds of metres across) need to be included in the engineering design to provide water table control and diversity.

5.2.5.6 Wetlands

Wetlands are a desirable feature of reclaimed landscapes in the mineable oil sands area, and design guidelines have been developed (Alberta Environment, 2007). They provide water storage, flow attenuation, vegetation, wildlife habitat, and other ecosystem functions. Managing salt accumulation in reclamation wetlands is a key design consideration. Wetlands may develop over time in depressions formed in the reclaimed landscape due to ongoing tailings consolidation and these wetlands should also be considered in mine reclamation design.

5.2.5.7 Roads and Infrastructure

Roads and other infrastructure associated with oil sands operations or landscape reclamation and monitoring activities will persist in the reclaimed landscape. Access to the reclaimed areas will generally need to be maintained, although roads and trails should be designed to be easily reclaimed at a future date.

Infrastructure that persists in the landscape may include pipelines and buried or surface power lines. The closure landscape must also accommodate landfills and store byproducts that require containment. Isolation and/or storage may be required for industrial landfills, flue-gas desulphurization solids, water treatment salts, and elemental sulphur.

Active mining areas may be present near reclaimed areas due to progressive reclamation and the presence of adjacent operators. The reclamation design and construction should account for activities in nearby watersheds, changes in those activities over time, and the reclamation plans of adjacent operators.

5.2.5.8 Dams and Hydraulic Controls

During oil sands operations, seepage water from the tailings facilities is managed with perimeter ditches, sumps, and seepage recovery wells. Collector drainage channels are required at the toe of the tailings sand storage areas to collect seepage, and monitoring wells are put in place to monitor potential releases of process-affected water off site. Under-drains are used for salinity control, in addition to increasing the trafficability of tailings deposits.

The Canadian Dam Association (CDA) definition of a dam is a structure that impounds 30,000 cubic metres or more and with a height of 2.5 metres or more. Fluid usually refers to water, but may also refer to other liquids and liquefiable materials such as tailings. To provide a maintenance-free landscape, no structures that require monitoring and maintenance under CDA guidelines may be left behind.

Long-term strategies for managing seepage zones are required for closure. These may include the creation of saline wetlands at the toes of tailings ponds and overburden dumps to bio-remediate saline process-affected seepage water, as well as streams and swales constructed to move water through the landscape in a prescribed manner.

5.3 Watershed Dynamics

The transmission and storage of water in a watershed are fundamental to watershed dynamics. Well-defined channels, uniform slopes, and low-permeability surface materials promote the runoff of precipitation. For an EPL watershed, runoff eventually collects in the EPL. Undulating topography, groundwater recharge, wetlands, depressions, ponds, and lakes store water. Water that is stored in a watershed upstream from an EPL may gradually percolate toward the EPL. However, a portion of the stored water (potentially all the water in some years), may be consumed by evaporation and plant transpiration without reaching an EPL. A runoff-dominated reclaimed EPL watershed would tend to maximize water supply to the EPL at the cost of reducing water supply to wetlands and upland vegetation in the watershed. A storage-dominated watershed would tend to support wetlands and vegetation growth at the cost of providing a smaller water supply to the EPL.

This section describes some of the hydrologic concepts that may be considered in water management in the reclaimed landscape. The overall focus of the EPL design guidelines is to provide tools to an EPL designer. However, the EPL will exist in a reclaimed landscape with its own water demands. Therefore, the following discussion takes a somewhat broad approach to describing hydrologic processes.

Much of our understanding of the watershed hydrology came from Moran et. al (1990) and has subsequently been expanded through the use of instrumented watersheds in the oil sands and the HEAD project at the Utikuma Lakes region of Alberta.

5.3.1 Hydrologic Landscapes

The concept of hydrologic landscapes (Winter, 2001) can be used to develop conceptual models of water movement through various types of terrain, formed on the basis of land-surface form, geology, and climate. This movement of water encompasses: surface water, which is controlled by slopes and permeability, groundwater, which is controlled by the hydraulic characteristics of the geologic framework, and atmospheric water, which is controlled by climate.

Atmospheric water, which moves as precipitation (snow and rain), evaporation, and evapotranspiration, affects the distribution, timing, and magnitude of surface runoff and groundwater recharge throughout landscape hydrologic units. Shorelines, the periphery of wetlands, and anywhere else where the water table intersects the land surface are areas of particular interest. Focused recharge at these boundaries can result in the creation of highly transient water table mounds. Transpiration by nearshore plants has the opposite effect of focused recharge, drawing down the water table in daily and seasonal cycles (Winter, 2001).

Steeper slopes yield faster runoff responses than flatter slopes, and rates of runoff versus infiltration depend on the permeability of the substrate. Flatter slopes with longer runoff times provide greater opportunities for infiltration if permeable, and for the formation of wetlands if less permeable. Geologic characteristics, including hydraulic conductivity, influence the configurations and lengths of groundwater flow paths, affecting rates of water movement and geochemical interactions.

Groundwater flow systems occur across a variety of scales, and are generally referred to as local, intermediate, or regional. Local flow systems have contiguous recharge and discharge areas, intermediate systems are separated by one or more local systems, and regional flow systems hydraulically link a basin’s principal divide and its thalweg (lowest point) (Toth, 2009). The depth of penetration of the flow system is a function of the relative magnitude of local relief and regional slope, and regional flow patterns are sensitive to two principal aspects of a basin’s geometry: the configuration of the water table and the relative depth of the basin (i.e., the depth-to-width ratio) (Toth, 1963; 2009).

Natural landscapes can be conceptualized as multiple nested hydrologic landscape units, with complex groundwater and surface water flow systems resulting from small-scale local flow systems superimposed on larger, more regional flow systems. These patterns of multiple flow systems, as anticipated in hummocky terrain, are characterized by alternating regions of recharge and discharge, and stagnation zones in the subsurface.

5.3.2 Controls on Hydrologic Response

For a broad-scale classification of hydrologic response, the order in which factors are considered is important. They must be in order of decreasing spatial scale to determine their relative influence in controlling hydrologic processes, scales of interaction, and water budgets (Devito et al., 2005). Accordingly, climate is the dominant control on regional hydrology, followed by bedrock and surficial geology, soil type and depth, topography, and drainage network.

5.3.2.1 Climate

Climate, with its controls on temperature, precipitation patterns, evaporation, and evapotranspiration, is a dominant factor in determining the hydrologic response of a landscape. It essentially determines the amount of water available to move throughout the hydrologic landscape. The climate of the Athabasca oil sands region is considered sub-humid, with a climatic water deficit.

Despite this hydrologic constraint, the natural landscape features many streams, lakes and wetlands. Mechanisms that may maintain them include (Devito and Mendoza, 2007):

- An external water source such as surface water occurring via overland flow or groundwater flow systems which may originate beyond a watershed defined by topography;
- Water storage mechanisms due to the natural geologic materials, the morphology of the basin, or potentially the presence of ice; and
- Decreased evapotranspiration, with actual evapotranspiration in wetlands with peat and emergent vegetation being potentially less than the evapotranspiration of uplands with trees and shrubs (Petrone et al., 2007).

5.3.2.2 Bedrock and Surficial Geology

The Athabasca oil sands region bedrock is sedimentary with significant amounts of carbonates. It is generally encountered at significant depths, though it may be considerably shallower in the mineable region. In places, Cretaceous or Devonian rocks outcrop at the surface. Very long-term groundwater flow processes, such as those that occur at the regional scale, and geochemical processes may be influenced by bedrock. However, most significant hydrologic processes are constrained to surficial deposits (Devito and Mendoza, 2007).

The surficial geology in the mineable oil sands region is 0 to 50 m thick and of variable glacial origin. Deep glaciated substrates result in complex surface and groundwater interactions (Devito et al., 2005; Winter, 2001); this is partly due to the heterogeneity of the geologic materials, which ranges from sand-rich outwash to moraine deposits to lacustrine clay deposits.

Generally, coarse-grained geologic materials, such as sand and gravel, have high hydraulic conductivity and high specific yield, which is a measure of the water released with the lowering of the water table. Coarse deposits enhance both infiltration and subsurface flow, and in sub-humid climates result in a water table that mirrors the underlying confining layer rather than the surface topography (Smerdon et al., 2005).

Fine-grained geologic materials like stiff silt and clay are the opposite, with low hydraulic conductivities and specific yields. In combination with the sub-humid climate, fine-grained deposits restrict the infiltration of precipitation through the vadose zone, retaining water near the surface where it is subsequently taken up by the high vegetative water demand (Rodriguez-Iturbe, 2000; Devito et al., 2005). Fine-grained deposits permit the development of perched wetlands that are not connected to the surrounding groundwater system.

Not only is surficial geology important for the hydrologic response of a landscape in terms of infiltration dynamics and subsurface flow; it is also a direct point of contact with water features in the landscape. Lakes, with their wave-washed littoral zones, may allow relatively unrestricted exchange between surface water and groundwater, while isolated wetlands may be underlain across their entire bed by poorly permeable sediments, restricting exchange (Winter and LaBaugh, 2003). The material that underlies rivers, lakes, and wetlands directly influences groundwater-surface water interactions in the landscape.

5.3.2.3 Soil and Vegetation

At a finer geologic scale, edaphic variables like soil organic content, depth and permeability influence the arrangement of vegetation, with direct hydrologic implications.

Vegetation has a physical effect on the hydrologic response of a landscape, providing roughness to flow hydraulics, slope stabilization via root reinforcement, shear strength to resist erosion by overland flow, and protection against rainsplash erosion (Marston, 2010). In addition, surface vegetation exercises controls on evapotranspiration, bounded by the climatic constraints of a region. Within the moisture-deficit regime of the Western Boreal Plain, evapotranspiration is the dominant hydrologic flux (Brown et al., 2010).

Vegetation in the riparian zone — the margin of vegetation including trees, shrubs, and grasses extending from the waterline of rivers and streams — plays a critical and complex role in filtering and slowing runoff, capturing sediments during flooding, and building the storage capacity for the groundwater that maintains stream flow in dry periods. It also provides shelter and forage area for a wide variety of waterfowl and mammals (Alberta Environment, 2011). In the short term, vegetation can be considered a design tool, critical to the functioning of hydrologic systems that will ultimately determine the success of a reclaimed landscape.

Creating wetlands that can accumulate organic matter (and eventually peat) will be important for the reclaimed oil sands mining environment, because of their ability to retain water and release it during periods of drought, as well as their lower rates of evapotranspiration, which allows the landscape to retain water despite the sub-humid climate. Accumulation of organic material requires relatively high primary production (plant growth) and slow decomposition; decomposition may be slowed by the initially saline reclamation environment (Trites and Bayley, 2009).

In the long term, vegetation and landforms co-evolve via a complex web of disturbances and feedbacks through time (Marston, 2010). Landscape and substrate elements determining flows of water and salt balances will determine vegetation, which in turn will influence the hydrology of the landscape. As vegetation undergoes primary succession, temporal changes in evapotranspiration will occur, affecting the water balance of the region. In particular, fire plays an important role in the boreal forest hydrology, restarting the ecological succession of burnt patches.

5.3.2.4 Topography and Drainage Network

In many cases, hydrology is thought to reflect regional topography, such that the water table mirrors the surface elevation and surface water flow is determined by permeability and land slope. This is not the case, however, in the boreal plain, where the complex hydrology does not conform easily to the concept of simple topographic control (Smerdon et al., 2005). Glacial terrain, as is found in the oil sands region, is perhaps the most complex hydrologic landscape to describe (Winter, 2001). In some cases, water catchment areas extend beyond topographic watershed boundaries (Devito and Mendoza, 2007), and complex topography coupled with varying types and distributions of unconsolidated geologic materials results in multiple nested hydrologic landscapes, from very small scales to entire morainal complexes.

In general, well-developed drainage networks within a region will tend to shed water from the landscape, whereas poorly defined drainage networks will result in water retention on the landscape. In areas with a sub-humid climate and low relief like the oil sands region, research shows that unsaturated zone storage, vegetation water demand, and vertical flow dominate over lateral flow in hillslope water balances (Rodriguez-Iturbe, 2000; Winter, 2001; Smerdon et al., 2005). This suggests that drainage over the surface of the natural landscape is not a major factor in average water balances, though episodic high-precipitation events may generate overland flow.

5.3.3 Characteristic Watersheds

As conceptual models, watersheds can be broadly categorized by their dominant processes. As presented in this chapter, watersheds can be either *runoff-dominated* (Section 5.3.3.1) or *storage-dominated* (Section 5.3.3.2); these are simplified versions of true hydrologic systems, but are useful for visualizing the kind of watersheds that can be constructed or which may develop naturally from certain constructed landforms. In reality, landscapes are composites, with certain elements promoting runoff and others favoring storage.

In the sub-humid climate within which oil sands development and subsequent reclamation occurs, soil storage and groundwater flow play significant roles in the water budget. The vertical movement of water dominates in the subsurface (except in regional groundwater systems), while the development and maintenance of perched wetlands is governed by local geology, morphology, and vegetation (Devito and Mendoza, 2007).

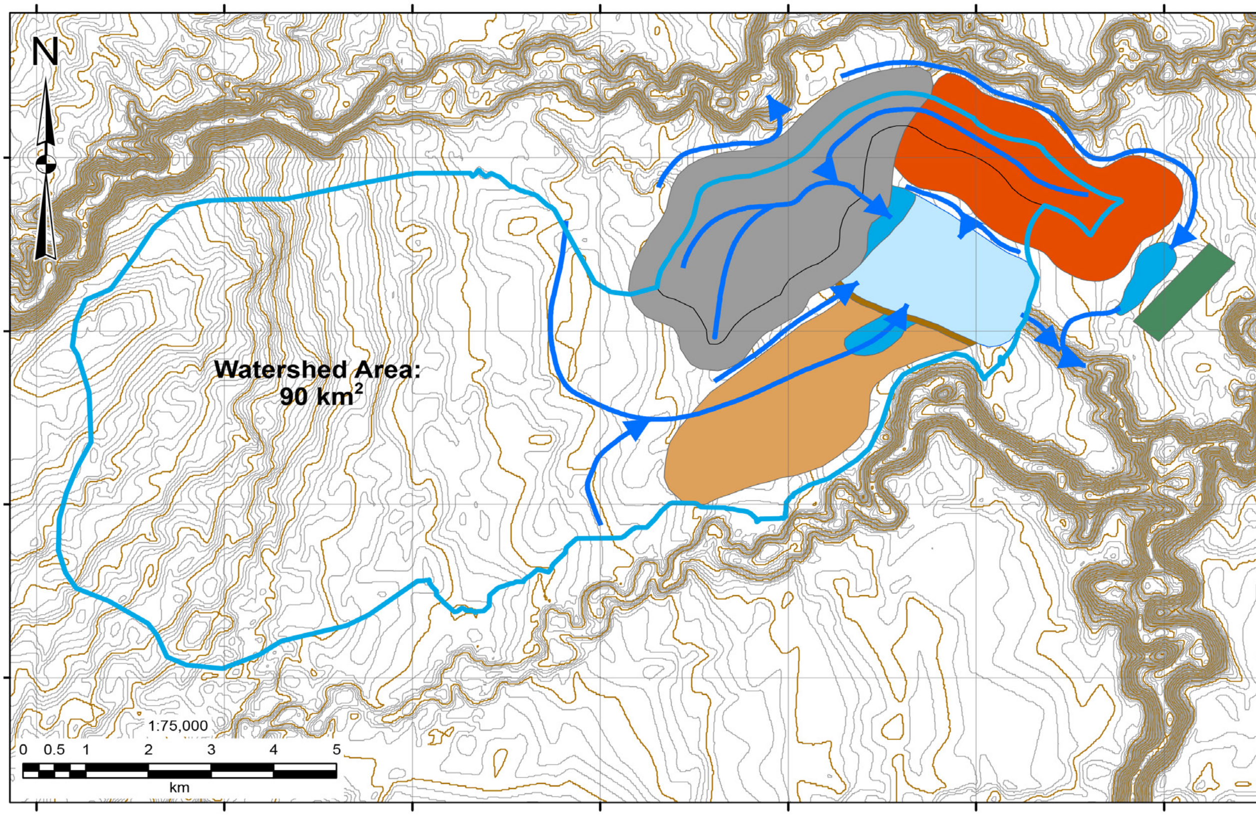

Figure 5-2: An EPL within a mining watershed.

5.3.3.1 Runoff-Dominated Watersheds

Runoff-dominated watersheds are characterized by sloped landscapes with limited plant growth, incised with armoured channels and swales. The combination of low permeability substrate and mechanisms for overland flow supports runoff from the landscape. Runoff water will supply whichever feature lies at the bottom of the drainage basin — in the case of a closed system this will likely be an end pit lake, whereas in an open system water ultimately drains to the Athabasca River.

Runoff-dominated systems may prove advantageous in terms of providing a more regular supply of water to receiving bodies, such as an end pit lake. This is because a reasonably predictable fraction of precipitation will move as overland flow, though water supply will vary with annual precipitation. Runoff-dominated watersheds do not experience much in terms of hysteretic effects; wet years will look similar regardless of the conditions in prior years.

Watershed landscapes that support runoff by their very nature have lower potential for water storage. These systems support limited groundwater recharge, and may tend to desiccate the landscape, limiting the potential for plant establishment and growth. Runoff-dominated water systems also increase the potential for flash floods and greater erosion due to the abundance of slopes, better defined channels, and limited plant growth.

5.3.3.2 Storage-Dominated Watersheds

Storage-dominated watersheds are characterized by an abundance of wetlands, flat areas, closed depressions, and poorly defined drainage channels. These systems will tend to support vegetation.

The high storage capacity of storage-dominated systems implies many years of low yield to a receiving body such as a pit lake, with a few years of high runoff. This will depend on multi-year precipitation patterns, which determine the degree of water storage deficit built up over the course of several years. These systems may experience pronounced hysteretic effects, with a wet year following a dry year or series of dry years behaving quite differently than a wet year following prior wet years.

Three conceptual models for the hydrologic behavior of storage dominated systems, and the existence and maintenance of wetlands in the sub-humid climate of the oil sands region, are illustrated in Figures 5-3, 4-4, and 5-4.

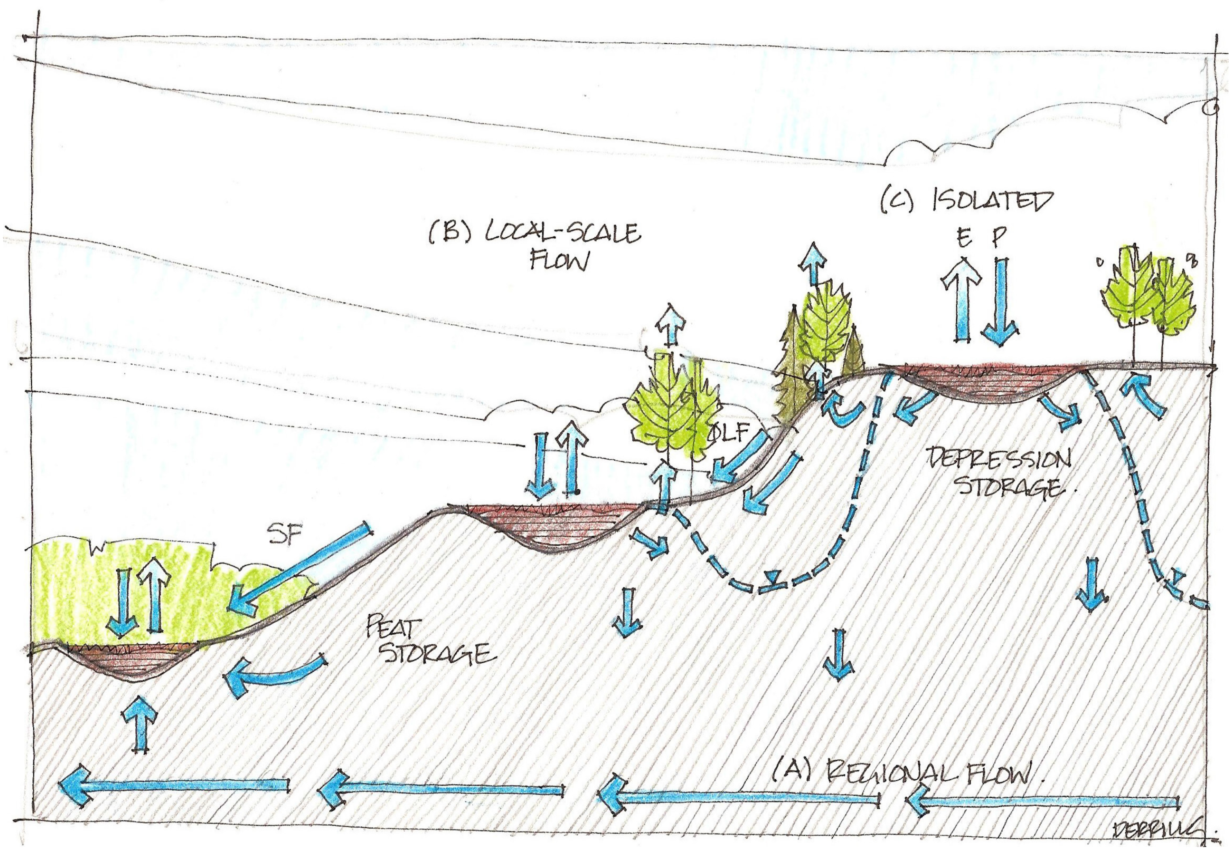

Figure 5-3: Conceptual model of dominant storage and water flow path for fine-grained moraine and low-lying plain within the sub-humid climate of the Boreal Plain.

The first conceptual model, Figure 5-3, is based on fine-grained deposits such as Clearwater Formation, till, and mature fine tailings. Most depressions with low permeability material have the potential to saturate, creating wetlands. There will tend to be limited regional connectivity, in that these wetlands will be isolated or have only local-scale flow systems. Wetlands will largely be perched, and may act as recharge areas for adjacent hillslopes. A design consideration for landscapes constructed entirely of low permeability material is the provision of adequate basin storage or peatland storage for resilience to periods of drought. Wetlands on very flat terrain require peat to retain water on the landscape.

The second conceptual model (Figure 4-4 in the previous chapter) is a landscape composed entirely of coarse-grained deposits, such as tailings sand or sandy overburden. In this case, topographically low areas will tend to connect to larger-scale regional flow systems; water features at the bottom of the landscape – such as an EPL – will act as discharge areas with relatively constant water levels coming from a consistent groundwater supply.

The effective catchment area of the EPL, including both surface water and groundwater sources, may be very large depending on the connectivity of the surficial materials. In uplands, wetlands will only exist on fine-grained confining layers, which will be somewhat isolated, perched above the regional hydrogeologic system.

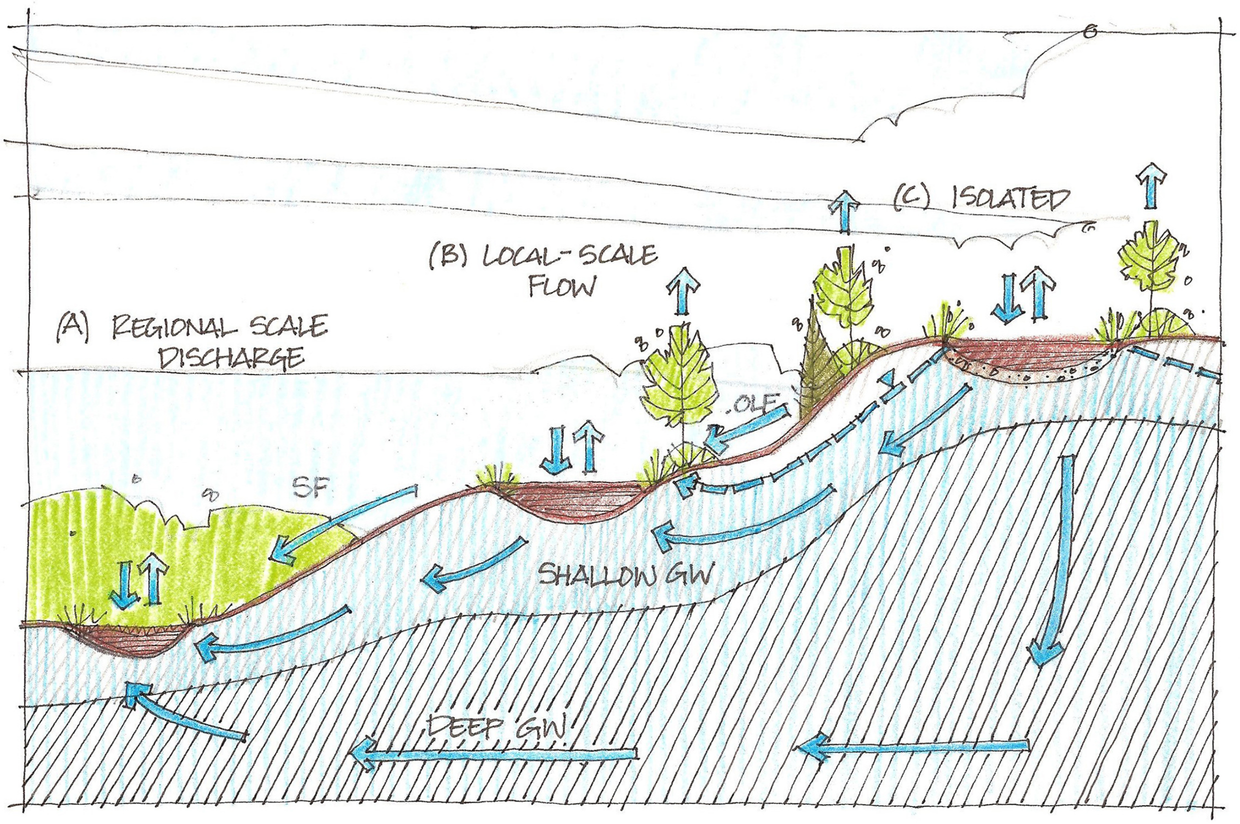

Figure 5-4: Conceptual model of dominant storage and water flow path for layered systems with high permeability material overlying less permeable material within the sub-humid climate of the Boreal Plain (adapted from Devito and Mendoza, 2007).

The final conceptual model, illustrated in Figure 5-4, consists of a coarse veneer overlying fine-grained deposits. In the presence of a permeable veneer, groundwater flow systems will tend to be shallow, implying that responses to climate will be accentuated, and that there will be enhanced connections between wetlands relative to a more homogeneous landscape.

5.4 Solute and Sediment Transport

Chemical compounds in the environment can be broadly categorized as organic, such as hydrocarbons, or inorganic, such as metals and salts. The behaviour and environmental fate of these compounds is determined by the physical and chemical properties of the specific element or compound, and the conditions of the surrounding environment.

There are a number of physical, chemical, and biological processes that govern the fate and transport of elements and compounds in the environment, including partitioning and degradation processes, as well as interactions with vegetation.

The transport of solute in the environment is strongly influenced by partitioning between different phases, such as in the distribution between aqueous and particulate solid phases. Equilibrium expressions are often used to describe these processes, using distribution, partition, or sorption coefficients. Partitioning can either attenuate solute, or facilitate its movement.

Degradation is another process acting to attenuate solute, and organic compounds undergo a variety of degradation processes in the natural environment, usually involving oxidation or hydrolysis. These may occur as abiotic reactions, but are often biologically mediated. The decay products formed during degradation may be toxic and, therefore, degradation mechanisms and pathways should be understood.

Attenuation may also occur through interaction with vegetation, such as through the selective uptake of metals by certain plant species. But attenuation may be short-lived; after senescence, decomposition releases any compounds sequestered in plant tissue back to the environment. Interaction with vegetation is key to understanding the fate of nutrients in the landscape.

Ultimately, substances may reach the end pit lake through direct deposition (atmospheric processes, discharge of process water, tailings consolidation), or indirect deposition, moving as dissolved or solid phases with groundwater and surface waters. The contribution of water and solute from tailings consolidation is considered in Section 5.5, while the remainder of Section 5.4 focuses on the indirect deposition pathways that are influenced by the geography of the watershed within which the end pit lake is situated.

5.4.1 Substances of Interest in the Closure Landscape

Broadly, substances of interest in the closure landscape comprise salts, metals, nutrients, and organic compounds, some of which occur naturally in the geologic materials of the region, and some of which are produced or concentrated by processing and other mining activities. At least initially, surface water runoff will tend to be fresh, and groundwater will tend to be saline in the reclaimed landscape. Excessive salts entering the reclaimed landscape from mine or tailings substrates will pose a major challenge for landscape reclamation.

The substances of interest in the reclaimed landscapes may change as processing and treatment technologies continue to evolve. Some recent innovations in water treatment, for example, include: chemical modification of membranes and adsorbents to reduce fouling problems and enhance pollutant removal rates, advances in photocatalytic oxidation processes for the degradation of recalcitrant organic compounds, improved performance of granular activated carbon-fluidized bed reactors on toxic feedwaters, and application of large-scale treatment wetlands to remediate hydrocarbon-contaminated wastewaters (Allen, 2008).

Substances of interest will also evolve as the landscape matures. For example, salts, which initially may prove to be problematic, will eventually be flushed from the landscape, and organic compounds will undergo biodegradation processes. Inputs to the end pit lake will evolve as the landscape continues to evolve.

It has been debated whether salts or organic compounds are the greater threat. For reclaimed marshes in the oil sands, Ciborowski (2010) indicates that the *combination* of salts and organics has negative effects on benthic invertebrates. Many of the strategies for watershed and lake design deal with all elements of water quality, while others are tailored to particular types of constituents.

5.4.1.1 Salt Species

The total salinity of a solution is primarily generated by eight key ions: calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^{+}), potassium (K^{+}), bicarbonate (HCO_3^{-}), carbonate (CO_3^{2-}), sulphate (SO_4^{2-}), and chloride (Cl^{-}). Concentrations of ionized components of other elements such as nitrogen (N), phosphorus (P), and iron (Fe) may also contribute to total salinity, in addition to their biological importance (Wetzel, 2001). Oil sands process affected water is dominated by sodium, chloride, bicarbonate, and in some cases sulphate ions.

Salinity in natural waters is generated by the weathering of soils and rocks and atmospheric deposition, and is influenced by environmental factors such as climate and drainage. The composition of soils and rock and their ion-exchange capacities influence both rates of weathering and ion supply to surface runoff and percolating water. Climate affects salinity via its control on precipitation and evaporation, with a general increase in ionic concentration as water levels decline. The salt content of lake waters in closed drainage basins is governed by surface water and groundwater inputs, and by the fate of these materials upon evaporation, whereas in open drainage basins outflow of solute is also a governing factor.

5.4.1.2 Organic Compounds

Organic compounds can originate from natural or anthropogenic sources, and exhibit a wide range of chemical and physical properties that affect their fate and toxicity. In the context of the reclaimed oil sands environment, organics of particular interest include naphthenic acids (NAs), polycyclic aromatic hydrocarbons (PAHs), BTEX constituents (benzene, toluene, ethylbenzene, xylenes), and their alcohol derivatives such as phenol.

Naphthenic acids are a diverse family of saturated, polycyclic and acyclic carboxylic acids that occur naturally in petroleum deposits. This family of chemicals partitions to the soluble fraction of waste material during bitumen processing, and may be concentrated in process-affected water found on reclaimed landscapes. Some types of naphthenic acids are acutely toxic to aquatic organisms. Though this fraction tends to undergo some microbial degradation, the more recalcitrant NA compounds that are left behind could still exhibit chronic toxicity.

Polycyclic aromatic hydrocarbons are a family of compounds (see Table B-8, Appendix B) that are produced by the incomplete combustion of organic matter, in addition to occurring naturally in hydrocarbon deposits like the oil sands. The volatility and solubility of PAHs decreases with increasing molecule size; PAHs tend to partition to soil, sediment, or non-aqueous fluid phases.

BTEX compounds, a subset of volatile organic compounds (VOCs), and their derivatives are also natural constituents in crude oil, and may be released or concentrated through bitumen processing.

5.4.1.3 Metals

Metals and metalloids are naturally occurring elements whose concentrations in the environment can be altered through human activities. Unlike organic compounds, metals do not undergo degradation processes. They exist in solution as free cations or as inorganic or organic complexes. Many metals have the potential for bioaccumulation, or accumulation in living organisms, and concentrate through successive trophic levels in an ecosystem. They may also be taken up by vegetation in a process of phytoextraction from the surrounding soil.

5.4.1.4 Nutrients

Nutrients are chemicals required for the life and growth of many organisms, including aquatic plants and microorganisms. They are present naturally in the environment; however, human activity has increased the supply of biologically reactive forms of nutrients, particularly nitrogen and phosphorus (Chambers et al., 2001). Nitrogen occurs in freshwaters in numerous forms, including molecular nitrogen (N_2), ammonia (NH_4^+), nitrite (NO_2^-), and nitrate (NO_3^-); anthropogenic inputs of nitrogen to the environment often take the form of nitrates found in sewage and fertilizers. Phosphorus commonly limits biological productivity in freshwaters, and occurs most commonly in organic forms and as inorganic orthophosphate (PO_4^{3-}) (Wetzel, 2001). Anthropogenic sources of phosphorus to the environment include detergents and fertilizers.

Large inputs of nutrients can stimulate primary production in aquatic ecosystems, ultimately leading to a decrease in the dissolved oxygen available in the water. This process, which is known as eutrophication, is often associated with changes in biodiversity. As well, ammonia, nitrate, and nitrite are toxic to aquatic and terrestrial organisms at high concentrations (Chambers et al., 2001; Newman and Unger, 2003).

5.4.2 Sources and Mechanisms of Mass Loading

Within the reclaimed landscape there are a variety of sources of the compounds of interest. The potential sources of aqueous and solid matter presented in this section should not be considered a comprehensive list – actual sources will vary by mine site with geology, geochemistry, site infrastructure and processing technique.

The mechanisms of mass loading covered in this section are mechanisms of loading to groundwater and surface water. Loading to the EPL is covered in the sections on fate and transport in surface water (Section 5.4.3) and groundwater (Section 5.4.4).

5.4.2.1 Natural Sources

Natural sources include landscapes undisturbed by mining activity that feed surface water and/or groundwater into the reclaimed landscape. Natural sources may be exposed to processes by excavation. Natural mechanisms of mass loading to surface and groundwater include physical weathering processes such as sedimentation, and chemical weathering processes such as oxidation and dissolution.

5.4.2.2 Overburden

Mining overburden, which consists of the material removed to access the oil sands, is used as backfill in open pits or is placed in large upland structures referred to as overburden dumps. These dumps will act as sources of solute to the surrounding environment according to the geologic nature of the material they contain, with salts and other compounds dissolving or suspending and moving by advection and dispersion with groundwater and surface waters.

Many overburden dumps in oil sands mining environments have a component of Clearwater Formation, pyritic shales overlying the McMurray oil sands. Upon exposure to atmospheric oxygen, this material undergoes pyrite oxidation and acid sulphate weathering, wherein sulphuric acid reacts with carbonate minerals to release calcium ions, which then exchange with sodium ions bound to the shale (Kessler et al., 2010). The result is circumneutral pH saline-sodic pore water chemistry that reflects the complex interaction of the initial marine salts and the newly produced pyrite oxidation salts.

Upon reclamation, overburden dumps are covered with a soil layer to support revegetation (deeper soil layers are required over Clearwater Formation overburden). In experimental plots, salts have been found to accumulate in the cover soils (15 to 20 cm above the overburden) beyond acceptable values for vegetation growth. Salt redistribution was not related to slope position or cover thickness. It is hypothesized that diffusion is the primary mechanism driving salt migration upwards from the overburden into the soils because of the pattern of salt ingress (Kessler et al., 2010).

In addition to dissolution and movement via advection, mass loading may occur to surface waters via erosional mechanisms. Erosion of soils contributes to the load of suspended sediment and colloidal mass in waterways, bringing along any chemical species contained within or adsorbed to sediments.

5.4.2.3 Tailings Facilities

Oil sands tailings consist of the material left behind during the bitumen extraction process, ranging from sands to fine tails to process-affected water. The facilities used to store oil sands tailings can be broadly categorized as in-pit, such as settling basins and tailings ponds, and out-of-pit, such as dykes and dams. Some of these landforms are termed dedicated disposal areas (DDAs) under the new ERCB Directive 074. The term process-affected water refers to water that has come in contact with oil sands material during extraction or processing.

Out-of-pit facilities generally contain and are constructed of coarser materials, such as tailings sand. These materials may contain residual hydrocarbons, salts, and other chemicals commonly found in process-affected water.

In-pit tailings ponds and facilities contain tailings that are composed of water, dissolved salts, organics, minerals, and bitumen. Tables B-9 and B-10 in Appendix B compare inorganic and organic water chemistry of oil sands process waters with regional river and lake waters; dissolved solids are more concentrated in tailings pond water than local surface water.

Specific chemicals of environmental concern in oil sands process water include naphthenic acids, bitumen, ammonia, sulphate, chloride, aromatic hydrocarbons, and trace metals (Allen, 2008). These compounds contribute to the acute and chronic toxicity of water in reclaimed aquatic environments.

The composition and chemistry of the material contained in tailings ponds and facilities varies with ore quality, source, extraction processes, and age (Allen, 2008). The age of tailings is a factor for consideration due to tailings consolidation processes, and in-situ biodegradation processes (e.g., the natural degradation of the acutely toxic fraction of naphthenic acids over time).

Compounds from in-pit and out-of-pit tailings facilities may enter the surrounding waters via diffusion, dissolution, or suspension-related processes. Seepage of process-affected water from tailings facilities may result in solute loading to groundwater, and surficial erosion of tailings facilities may result in dissolved or suspended loading of solute in surface water. Additionally, consolidation of fluid tailings within tailings deposits releases process-affected water and its chemical constituents to overlying water or geologic materials.

5.4.2.4 Other Sources

Additional sources of solute within the closure landscape may include coke, landfills, flue gas desulphurization waste, sulphur piles, the plant site itself, and water treatment salts. These will be site-specific considerations.

5.4.3 Fate and Transport in Surface Water

5.4.3.1 Transport Processes and Timescales

Surface water moves both dissolved solute and suspended or colloidal mass resulting from erosional and other processes.

Erosion of exposed oil sands deposits has distributed hydrocarbons throughout the region's river systems. Heavy metals and major ions co-occur with elevated levels of naturally occurring petroleum hydrocarbons and complex NA mixtures. Mixed contaminants of inorganic chemicals and hydrocarbons may thus enter surface water systems through natural weathering processes including erosion of riverbank oil sands deposits (Headley et al., 2005).

Transport processes in surface water can occur over a variety of timescales. For example, solute moving via overland flow-through wetland complexes will move at a much slower pace than solute dissolved in the waters of a major river.

5.4.3.2 Attenuation Mechanisms

Concentrations of most metals in bed sediments were well correlated with the percentages of clay in the sediment. Clay particles have a much larger surface area than clay-and-sand mixtures, and the correlations indicate that adsorption of metals to sediment surfaces is an important determinant of metal concentration (Conly et al., 2007).

5.4.3.3 Surface Water Loading to EPLs

Surface water loading into end pit lakes will largely be a function of the surface water connections that are engineered into the reclaimed landscapes (i.e., the number of streams connected to the lake). Actual loading will depend on the sources that surface water has come into contact with, the amount of time from source to receptor, and any attenuation that occurs along the way.

Lateral flow generated by rainfall on Western Boreal Plains hillslopes is uncommon, thanks to the generally available soil moisture storage capacity and the low probability of rainfall events of sufficient magnitude and intensity (Redding and Devito, 2010).

5.4.4 Fate and Transport in Groundwater

5.4.4.1 Transport Processes and Timescales

Once solute has entered the groundwater system, it is transported by advection, dispersion, and diffusion through the geologic material, governed by the hydraulic conductivity and hydraulic gradient of the system.

In the unsaturated zone, subsurface flow exerts significant control on the distribution of soil moisture and salts within reclaimed landscapes. Salt redistribution occurs along slopes (Kessler et al., 2010). Generally, increases have been observed in soluble salts in the cover material immediately over the spoil (overburden). The increase has been attributed to: upward salt movement driven by diffusion due to the sharp salinity gradient between the spoil and overlying soil, advective transport due to upward water movement in response to evapotranspiration, and the restriction to downward flushing created by the presence of the underlying low hydraulic conductivity saline-sodic material.

Subsurface flow exerts a significant control on the distribution of soil moisture and salts within reclaimed landscapes. Increased downslope water movement in the form of surface runoff and subsequent infiltration as well as interflow along the cover/overburden interface (Kelln et al., 2009) may lead to salt redistribution along the slope.

Timescales for groundwater processes are generally much longer than surface water processes. Depending on the hydrogeological context, it can take decades for substances in groundwater to migrate from a source to a receptor, such as an end pit lake. Consequently, groundwater monitoring will likely be necessary for years or decades after specific operations cease, especially if the sources of solute are still present within the landscape and continue to release solute to the environment (Royal Society of Canada, 2010).

5.4.4.2 Groundwater Loading to EPLs

Groundwater loading to the EPL will depend on the sources of solute in the landscape, the material with which the landscape is reconstructed (i.e., permeability), the path length from source to receptor, and the chemical nature of the solute and geologic material, which will influence attenuation.

5.5 Design Considerations

5.5.1 Integration with Overall Closure Design

Constraints imposed on the reclamation design by mining needs and reclamation landscape function needs are fundamental considerations in EPL design. An EPL will typically be designed to be placed at the base of a reclaimed watershed. The watershed morphology and size may be largely determined by mining needs, particularly tailings and overburden storage. Water storage in the watershed for consumptive use to support wetland function and vegetation may be required, depending on overall reclamation objectives. The EPL design process should be integrated with mine planning and overall reclamation design to support successful reclamation.

5.5.2 Water Quality

In the filling and initial EPL operational stages, the operator will have considerable control over water quality and salinity within the EPL. Runoff, groundwater seepage, and tailings consolidation (in cases where tailings are in contact with the EPL) may contribute water with high concentrations of salts and organic compounds. Concentrations of organic compounds might be expected to decline over the course of years to decades. Concentrations of salts may remain high for a period of decades to centuries. Strategies to maintain or develop acceptable EPL water quality might include:

- Promoting rapid flushing within a shallow sandy aquifer zone across the reclaimed landscape to dilute salts released from deeper zones;

- Designing the landscape to concentrate salts in well defined areas by groundwater flow path design and topography;
- Providing large EPL storage capacity, relative to water contributions from the reclaimed landscape to increase the time required for watershed contributions to change EPL concentrations; and
- Incorporating water treatment into initial EPL filling and operational stages to provide good water quality.

5.5.3 Designing for Beaver Activity

Beavers are widely considered to be ecosystem engineers (Jones et al., 1994) – keystone species that create riparian and other habitat for a variety of other species through their damming activities. They clearcut trees, and dam creeks, rivers, and lake outlets to create ponds for protection from predators. They can cause flooding in large areas, cause outburst flooding, redirect streams, attenuate peak runoffs, trap sediments, and change forests and habitats. Water balances of EPLs may be influenced by beaver activity in the contributing watershed, and may also change the area of contributing watershed. The design of EPLs should accommodate a range of water balance conditions as beavers modify the landscape in ways that are difficult to predict. The effects of potential outburst floods due to beaver dam failure in the contributing watershed should be evaluated as part of the long-term EPL operation. The consequences of beaver activity on outlet channels will be an important design consideration, with a high potential to block flow, raise water levels, and create outburst flooding downstream.

5.5.4 Mine Waste Materials Locations

Mine wastes are typically stored in dumps, above-ground storage facilities, or mined-out pits. Materials stored in-pit may be in direct contact with an EPL if the pit is only partially filled with mining waste materials. Mine planning and material placement is subject to many constraints and considerations, such as geotechnical stability, ore sterilization, mine footprint, environmental impact, etc.

Designers have some ability to design the relative location of end pit lakes and various other artificial landforms:

- Temporary soil stockpiles should be located close to where the reclamation material will ultimately be placed. Large volumes of reclamation material will be needed for the EPL littoral zones and adjacent slopes.
- Overburden dumps may be located below the ultimate water levels in EPLs, adjacent to EPLs forming containment, elsewhere in the EPL watershed, and outside the EPL watershed. Except for the last case, there will be solute and sediment loading to the EPL deserving of special consideration in design. The dispersive nature of Clearwater Formation fills means it is desirable to avoid creating lakeshore from these materials, given their likely high rates of slope retreat due to wave erosion if unprotected by riprap.
- Tailings deposits will seep process-affected waters, so generally must be located within an EPL watershed to allow dilution and bioremediation of seepage waters. Given the

high erodibility of tailings sand, its use in steep slopes at the EPL lake level would require extensive riprap slope protection. Tailings sand beaches provide an opportunity for creation of extensive littoral zones. There are advantages and limitations to using soft tailings as substrates for EPLs.

- Coke is highly erodible but may be suitable as a lake substrate or as a cap for soft tailings in an EPL.

5.5.5 Lake Elevation Fluctuation

Seasonal lake level fluctuations and response to prolonged drought are key considerations for EPL design. Chapter 4 discusses the influence of watershed scale, water storage and runoff characteristics on lake level fluctuations. Lakes with watersheds that have relatively high water availability and storage potential (such as through large contributing areas, connectivity to groundwater, and retention mechanisms) are more resistant to drought-mediated effects. Because of the connectivity between groundwater and lakes, the impact of climatic variability should be viewed within the framework of a combined groundwater-lake system. Hydrologic modelling, using multi-decade climate records, can be used to evaluate EPL water balance and corresponding range of lake level fluctuation. An understanding of the range of lake level fluctuation is needed to design an appropriate littoral zone, and to understand the ecosystem response to climate variations.

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6. IN-LAKE PROCESSES

Jerry Vandenberg
Golder Associates

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6.1 Introduction

The behaviour, characteristics and ultimate success or failure of EPLs will be determined by the physical, chemical, and biological processes that occur in the lakes. As there are no existing oil sands end pit lakes, a literature review of the most similar and relevant systems was completed for each process. For physical processes, the review focuses primarily on studies of other pit lakes and oil sands tailings facilities. For chemical and biological processes, the review focuses on oil sands experimental and reclamation wetlands that will contain similar chemicals and materials. This information is intended to inform pit lake designers of the processes that should be considered and accounted for in the design of EPLs.

This chapter presents an overview of limnological processes, a description of limitations to achieving an aquatic system, and some modelling considerations. More extensive details on modelling are provided in Chapter 9, along with a section on monitoring. The modelling section (9.5) gives advice for predictive modelling of EPL hydrodynamics and water quality, and the monitoring section (9.6) gives general monitoring recommendations for EPLs.

6.1.1 Unique Challenges Posed by EPLs

Generally, oil sands EPLs will pose challenges similar to those faced by pit lakes formed by other mining industries. For example, the quality of mine-impacted water is regarded as the single largest environmental impact of the global mining industry, including metal, coal, and uranium mines (Castendyk and Eary, 2009). Additionally, managers and mine closure planners of all pit lakes need to consider fundamental design aspects, such as pit wall stability, hydrologic balance, and self-sustaining closure drainage. Broad management issues such as public safety, ecological protection and corporate liability are common to all mining companies. With respect to these issues, oil sands mining operators have the advantage of many case studies from other mining industries on which to draw lessons (Chapter 3).

The principal and overarching issue related to EPL water quality will be degradation of oil sands process waters (OSPW) toxicity. Whereas in hard rock mine pit lakes, water quality is generally controlled by geochemical processes such as oxidation/reduction reactions, metal leaching and acid rock drainage, these processes are of secondary concern in EPLs. Instead, EPL water quality will be driven primarily by dissolved organics and salinity. As a result, nearly all information regarding the toxicity and fate of OSPW constituents has been gained through studies that were conducted specifically on OSPW.

Related to the issue of OSPW is the potential presence of fluid tailings under the water cap of EPLs. These tailings, through densification with time, will add OSPW from the bottom sediment into the water cap layer. Consequently, a continuous, but decreasing flux of OSPW will be released into the deeper parts of the lake over a number of years. The rate and quality of this release water may play an important role in lake development. Additionally, the densification of tailings will result in EPLs with increasing water depths over the initial decades, which must be accounted for in EPL design and planning.

6.2 Limnological Processes

6.2.1 Littoral Zone Processes

The importance of littoral zones has been recognized in oil sands mining applications, and the commitment in applications has been to create pit lakes with littoral zones that are similar to natural lakes. A common commitment is to create pit lakes with 10% to 30% littoral zone by surface area (Shell, 2007). Recommendations in other documents range from 20% to 40% of area (Herricks, 1982; Hildebrand et al., 1982, respectively, as quoted in Luscar, 1991). The End Pit Lake Working Group predicts a medium probability of success in sustaining salmonid populations in coal mine pit lakes in Alberta with littoral zones of 10% to 20% of area, and a high probability of success with littoral zones of 20% to 40% of area, although it is uncertain how these probabilities and percentages were derived (EPLWG, 2004).

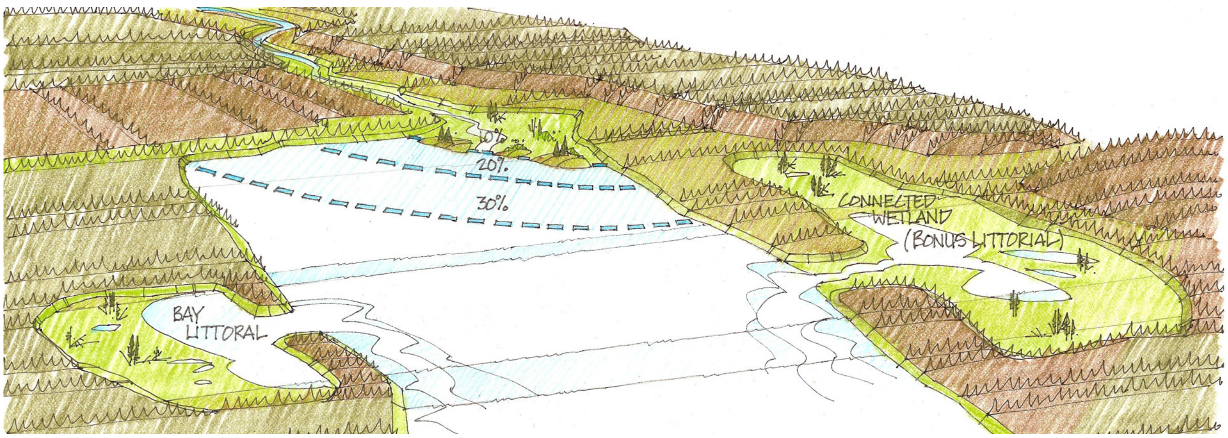

Figure 6-1: Littoral zones in an EPL.

Given the importance of establishing and maintaining littoral zones once constructed, closure drainage plans specify that breakwaters will be constructed around littoral zones to protect these areas from wave erosion. The breakwaters are designed to allow sufficient circulation of water between the pelagic and littoral zones. Engineered structures are mainly required in the early stages of pit lake development, before rooted vegetation that will provide additional erosion control can become established.

An alternative method for creating littoral zones would be to construct embayments at one or more locations around the EPL. If considered as part of mine plan design, embayments could be developed by backfilling surrounding areas to a few metres below the anticipated water level. If this is done, consolidation of the backfilled materials would need to be accounted for so that the embayments do not become too deep with time. If added at the later stages, embayments could be developed by removing a few metres of material from lands adjacent to the EPL. Either way, the connection between the EPL and embayments must be wide enough to allow for sufficient circulation to avoid stagnation within the embayments.

6.2.2 Stratification and Meromixis

Vertical mixing is a key process that must be considered in designing and operating a pit lake (Boehrer and Schultze, 2006; Gammons et al., 2009). In pit lakes, as in natural lakes, the frequency and extent of vertical mixing will affect many other variables. Vertical mixing is a particularly important process in EPLs that contain water-capped tailings, which will release oxygen-demanding substances to the water at the sediment-water interface. Other constituents released from water-capped tailings will also be transported advectively during periods of vertical mixing. Vertical mixing transports oxygen to the lower portion of the lake, which in turn affects other processes. Degradation of naphthenic acids, for example, is much more rapid under aerobic conditions compared to anaerobic conditions (Herman et al., 1994; Scott et at., 2005). The oxidation state also influences the mobilization of metals (Stumm and Morgan, 1996) and cycling of nutrients (Wetzel, 2001) in sediment as a key driver of sediment processes. Given the influence of vertical mixing on these processes, the anticipated mixing behaviour of an EPL should be understood as early as possible in the design stage.

Previous hydrodynamic modelling for CEMA (Golder, 2007) examined vertical mixing in 486 hypothetical pit lakes that covered a range of lake geometries, meteorological inputs, inflow salinities and initial lake salinities. This modelling used CE-QUAL-W2 with source code modified to include the salt-exclusion process. The range of salinities and lake geometries were based on all planned EPLs up to 2006. It was predicted that under nearly all conditions, the EPLs would be holomictic. Since the development of the CEMA model, all oil sands mine applications have evaluated the potential for meromixis in planned EPLs on a site-specific basis (Shell, 2007; Suncor, 2007; Total, 2010). So far, all EPLs evaluated for these projects were expected to be holomictic.

To date, no oil sands operator has proposed an EPL with induced or promoted meromixis within the water column. Instead, EPLs would be designed to promote aerobic degradation of organic substances. However, it should be noted that EPLs with water-capped tailings will be stratified systems, but with a water zone overlying a high-density fluid tailings zone. In such systems, the pycnocline must be great enough to prevent mixing of fluid tailings across the water-sediment interface and to prevent resuspension of tailings (Section 6.2.4).

6.2.2.1 Modes of Stratification

Thermal Stratification

In most lakes, whether natural or man-made, thermal stratification occurs on a seasonal basis due to temperature-driven changes in water density (see Chapter 4). Typically, surface waters warm in the summer and become less dense than the cooler, underlying water. This temperature difference causes two distinct strata to form: the epilimnion near the surface and the hypolimnion at depth. In the fall, epilimnion temperatures decline. When the lake becomes isothermal, the density gradient breaks down and vertical mixing requires relatively little energy. In the winter, surface temperatures cool below 4ºC, making the surface water less dense than the underlying water. This causes inverse stratification, in which a cool epilimnion overlies a relatively warmer hypolimnion. Because ice cover prevents any wind-driven mixing, stratification generally persists until the ice melts in the spring, at which time the lake may become isothermal. Although variations exist within this category, this is the general pattern exhibited by dimictic lakes (Wetzel, 2001), which are typical in the region.

Meromixis

In meromictic lakes, the deepest portion of the lake, the monimolimnion, is permanently isolated from the upper layers, typically by a salinity-driven density gradient. Meromixis may occur in nature due to a variety of causes, such as saline spring inflows, biogenic accumulation of salts and tidal intrusions (Wetzel, 2001). In EPLs, the intrusion of saline groundwater from the Basal Aquifer, or the release of OSPW from water-capped tailings, can potentially induce meromixis. In a meromictic lake, thermal stratification may cause seasonal formation of an epilimnion and hypolimnion above the monimolimnion (see Figure 3-3 in Chapter 3).

Cryogenic Meromixis

In relatively cold environments, such as northern Alberta, all natural lakes form ice covers annually. As the ice forms, dissolved ions are expressed from the freezing water, elevating the salinity just below the ice-water interface. This surface water, with its elevated salinity and density, can plunge to the lake bottom and accumulate, thereby inducing meromixis. This type of meromixis is termed cryogenic meromixis (Gammons et al., 2009; Wetzel, 2001). In these northern lakes, vertical mixing can be further inhibited by the replacement of a low-density freshwater cap over the lake when the ice cover and surrounding snowpack melt. This process has been documented on a number of Antarctic lakes (Gibson, 1999) and on Tailings Lake, a gold mine pit lake in the Northwest Territories (Pieters and Lawrence, 2009). In Tailings Lake, the low-density water cap was thought to prevent a spring turnover that would otherwise occur, changing a lake that would normally be dimictic to monomictic (Pieters and Lawrence, 2009).

Although cryogenic meromixis has not been documented in natural lakes in the oil sands region (Chapter 4), it may occur in EPLs, which are predicted to have higher salinities compared to natural lakes. Temporary stratification was observed in experimental ponds containing OSPW, where stratification persisted in a 6-m-deep pond until fall turnover (MacKinnon, personal communication). The conductivity of waters in this pond were high (> 4,500 µS/cm), but it did demonstrate a potential for cryogenic meromixis.

The range of Total Dissolved Solids (TDS) in planned pit lakes is similar to the TDS of 1000 mg/L in Tailings Lake, where salt rejection did influence lake turnover (Pieters and Lawrence, 2009). The ice thickness of planned pit lakes is also expected to be similar to the 60 to 80 cm reported for Tailings Lake, which is located nearly 900 km north of Fort McMurray. A survey of field data from baseline studies (CNRL, 2002, 2006; Imperial Oil, 2005; Shell, 2007; Suncor, 2007) over the past 10 years indicates that a typical maximum ice thickness of regional lakes is about 55 cm. The mean ice thicknesses of two large, natural lakes located within 250 km of the mineable oil sands region, Cold Lake and Lake Athabasca, were 83 and 99 cm respectively. This is based on four decades of measurements (CCIN, 1999).

Cryogenic meromixis was recognized as a process that could affect stratification in EPLs during Phase II Pit Lake Modelling completed for CEMA (Golder, 2007). As part of that work, the source code of numerical models was modified to account for salt rejection. This process should be included in all modelling completed for EPLs (Section 9.5).

6.2.2.2 Case Studies on Meromixis

In other mining industries, pit lakes have been managed to promote meromixis as a strategy to isolate the lower stratum from the receiving environment. This has been accomplished by partially flooding a mined out pit with saline water, then capping it with freshwater (Pelletier et al., 2009). This strategy has not been proposed for EPLs, but the case study illustrates the process of stratification. In other pit lakes, meromixis has occurred due to the characteristics of the inflow sources. A few case studies are provided below to illustrate different vertical mixing in pit lakes:

Meromixis by Design: Island Copper Mine Pit

In 1996, the Island Copper Mine pit on Vancouver Island was flooded up to 90% with seawater and capped with freshwater as a tailings containment strategy and a mitigation against in-pit development of acid rock drainage. The objective in inducing meromixis was to induce anoxia in the monimolimnion to promote the removal of trace metals through reductive sulphide precipitation and to inhibit geochemical and biochemical reactions that oxidize sulphide minerals exposed in submerged wallrock. Sulphide mineral oxidation, if unmitigated, could lead to acid generation and metal mobilization in the water column.

By 2000, the pit lake had developed three distinct strata. The lower layer had become anoxic but the intermediate layer had not. Therefore, anoxia was further promoted by fertilizing the epilimnion with liquid ammonium polyphosphate and urea ammonium nitrate to increase primary production. The accelerated primary production was intended to increase autochthonous biochemical oxygen demand and uptake and settling of metals. As of 2002, the fertilization was proving successful, although time frames to become a fully passive system were not yet established. Further details regarding Island Copper Mine pit are provided in several publications (Fisher, 2002; Fisher and Lawrence, 2006; Pelletier et al., 2009; Poling et al., 2002, 2003). See also the discussion on limnology in Section 3.3.4 and case studies in Section 3.6.

Unintentional Meromixis: Brenda Mine Pit

In 1990, molybdenum mining ceased at Brenda Mines, near Kelowna, B.C., and the remaining pit was filled over the following five years. Several sources were used to fill the lake, including precipitation, mine waters, groundwater and surface runoff. Over time, the saline groundwater built up in the lower portion of the pit and formed a monimolimnion.

Stevens and Lawrence (1998) studied the stratification of Brenda Mines Pit Lake. They found that complete turnover did not occur in the spring or fall, but the lake may not be permanently stratified because the ambient temperature and salinity were conducive to double diffusion. Double diffusion occurs when cold water with low salinity sits atop water with warmer temperature and higher salinity. Because thermal diffusion is much faster than chemical diffusion, the overlying water absorbs heat from below, causing it to rise, while the lower water becomes cooler and denser, causing it to plunge. The movement of water leads to near-field mixing near the pycnocline and a characteristic “staircase” profile (Gammons et al., 2009). Stevens and Lawrence (1998) stated that “Conditions were found to be suitable for double diffusion, but only weak evidence of its effect was found.” Subsequently, one-dimensional modelling suggested that double diffusion was present in the monimolimnion and was the dominant mixing process in that layer (Hamblin et al., 1999).

Meromixis Induced by Changing Water Diversions: Mono Lake

While not a pit lake, the story of Mono Lake, California, illustrates the effects of manipulating inflows on lake stratification. In 1941, inflows to Mono Lake were diverted for domestic use in Los Angeles. Consequently, Mono Lake water volume declined by half and salinity doubled throughout the following decades. In 1994, water diversions were restored to Mono Lake in response to public outcry and legal action. Because the inflow salinities were now much lower than lake salinities, the inflows remained buoyant at the surface, and meromixis was expected to establish permanently. Meromixis was, in turn, predicted to cause anoxia and biogenic gas production in the monimolimnion and lower productivity in the epilimnion (Jellison et al., 1998). Presently, the lake is intensively managed with lake level targets aimed at restoring ecological functions. As of 2003, the lake remained meromictic but was expected to mix in the coming years as the saline water became flushed from the lake.

6.2.2.3 Summary

In summary, meromixis has not been proposed as a containment strategy in EPLs, and hydrodynamic modelling of recently proposed EPLs indicated that these lakes would not be meromictic. Unlike pit lakes from other mining industries, EPLs are expected to have much larger surface areas and be much shallower. Nevertheless, because meromixis has the potential to affect a number of key processes, vertical mixing should be modelled for all planned EPLs, as early in the design process as possible. Numerical modelling (Section 9.5) should be used to determine whether pit lakes are likely to become meromictic, and to evaluate mitigation strategies to avoid meromixis where necessary.

6.2.3 Sediment Processes

Sediment processes are key drivers of water quality in lakes (Section 4.3). Biochemical and geochemical processes that occur in sediments can affect the cycling and availability of oxygen, organics, metals and nutrients in the water column and benthos (DiToro, 2001). As discussed in Chapter 1 and Chapter 9, EPLs may or may not contain fluid tailings, depending on the tailings strategy of each particular operation. In lakes that do not contain tailings, the lake beds will initially be barren, and the main challenge with respect to sediments will be to establish a substrate that will support vegetation and benthic invertebrates. Sediments may be placed as part of reclamation, or they may accumulate through deposition from inflow sources. Regardless of the composition of the sediments, they may ultimately become anaerobic due to biochemical or geochemical oxygen demand, as they commonly do in natural systems (Wetzel, 2001).

However, tailings-free lakes will be affected to a lesser extent by the processes discussed in this section; the sediment processes below refer mainly to lakes with fluid tailings.

6.2.3.1 Tailings Consolidation Pore Water Release

As described in Section 5.2.3, tailings will consolidate with time. A clay-dominated fluid fine tails (FFT) or thickened tails will densify at rates dependent on water quality, clay mineralogy and rheological properties of the deposit. The flux of water release from consolidating tailings is inversely related to the deposit density and viscosity, so consolidation rates decline with time after placement. The rate of this drop will depend on initial fines contents, as well as the placed volume and depth. The time for complete settling of FFT has been estimated at 125 to 150 years (Eckert et al., 1996), although methanogenesis may reduce this settling time considerably (Fedorak et al., 2003; Foght et al., 2010). The impact on the water zone must factor this in, since the flux for each cubic metre of FFT can vary from 50 L/m^3/year in the initial 3 years to <5 L/m^3/year by year 25 (Mike Mackinnon, personal communication).

The tailings consolidation has two direct effects on EPLs. First, as the tailings consolidate, water will be expressed from the tailings into the water column. This represents a source of OSPW (Section 6.3.1) and oxygen demand that will have to be assimilated and degraded. Second, the consolidating tailings can create a water column that is several metres deeper. The additional water volume will have the beneficial effect of increasing the residence time of EPLs, thereby increasing time available for degradation of toxic constituents. However, both the increased depth and the release of higher-salinity pore water increase the potential risk of meromixis (Section 6.2.2). Consequently, the time-varying depth must be accounted for in predictive modelling for any EPLs that will contain tailings.

6.2.3.2 Biogenic Gas Production

Biogenic gases such as methane, sulphide, and ammonia are the by-products of anaerobic respiration. Observations from tailings ponds suggest that these gases will be produced during the filling stage, but it is uncertain how long this process will take. Studies have indicated that labile carbon sources in the tailings will be consumed initially, and the potential contributions from the refractory sources will be small (Holowenko et al., 2001). A brief summary of observations from oil sands tailings facilities is provided below.

Prior to the early 1990s, methanogenesis in oil sands tailings facilities was limited to the ongoing gas efflux observed at Suncor Energy's Pond 1 and 1A that had started in the early 1970s. It wasn't until Syncrude's main settling basin, Mildred Lake Settling Basin (MLSB), began to also show methane release that formal studies of source, fate and impact of the biogenic gas production were initiated. Although methanogens and sulphate-reducing bacteria (SRB) had been observed in tailings samples, laboratory analyses suggested that methanogens were not active at ambient conditions in these facilities (Foght et al., 1985; Sobolewski, 1992). In subsequent years, concentrations of methanogens showed a rapid and significant increase (>1,000 times those seen previously) which corresponded to levels of methanogenesis at MLSB that was evident from gas escaping from the pond. The reason for the time lag and onset of methanogenesis at this pond is not clear. It may have been due to the depletion of sulphate by

SRB, which allowed carbon (CO_2) to overtake sulphur as the dominant electron acceptor. Alternatively, it may have been due to input of fresh tailings that contained naphtha compounds.

Since the onset of methanogenesis, the MLSB has produced significant amounts of gases. Primarily, carbon dioxide has been produced, which dissolves in the pore waters to form carbonic acid. Methane has also been produced, which has a low solubility and remains in gaseous form. It was estimated that 2% to 5% (v/v) of Mildred Lake was comprised of trapped and dissolved gases, with the gas phase comprised predominantly of methane. The methane that agglomerated and mobilized was buoyant enough to escape the FFT, and generated methane fluxes of >10 g CH_4/m^2/day (Holowenko, 2000). Holowenko (2000) also experimented with sulphate addition, and found that at elevated levels, methanogens were outcompeted by SRB, and suggested that an anticipated shift to gypsum-amended tailings might result in higher concentrations of sulphate in the tailings and a concomitant decrease in methanogenesis. Sulfate inhibition of methane production was confirmed by subsequent work, in which methanogenesis was found to occur when sulphate was consumed to levels below 20 mg/L (Fedorak et al., 2002). Sulfate levels in tailings may be an important control on gas production, because several operators use gypsum as a tailings amendment. However, the downside to sulphate addition is the potential for sulphide production, which under the proper pH conditions could shift the sulphide equilibrium toward the gaseous H_2S form. In laboratory studies, gypsum-amended tailings were found to inhibit methanogenesis (Salloum et al., 2002). Methanogenesis may also be inhibited by salinity (Daly, 2007), but it does proceed at salinity levels present in oil sands tailings.

Studies conducted to determine the carbon source in methane-producing tailings have generally ruled out large organic molecules that are the main hydrocarbon source associated with bitumen and the dissolved organic acids such as naphthenic acids. Holowenko et al. (2001) examined methanogenesis rates in the presence of various concentrations of naphthenic acids, and concluded that naphthenic acids were not likely an important carbon source of methane in tailings ponds. Furthermore, naphthenic acids did not inhibit methanogenesis due to toxicity at concentrations likely to be found in tailings ponds. Holowenko (2000) amended tailings with bitumen and also observed no significant increase in methanogenesis, indicating that bitumen was not the primary source of carbon in methanogenesis. Haveroen et al. (2005) found that polyacrylamide may contribute to methanogenesis by providing a source of nitrogen, but the carbon was not utilized.

The main carbon source in methanogenesis is likely the lighter-end solvents (naphtha, alkanes) used by oil sands operations as diluents for froth treatment and bitumen preparation for upgrading. Studies have documented the microbial conversion of short chain n-alkanes (Siddique et al., 2006) and BTEX compounds (Siddique et al., 2007) to methane. Degradation was found to occur more rapidly in n-alkanes in the sequence C10 > C8 > C7 > C6 and in BTEX compounds in the sequence toluene > xylene > ethylbenzene > benzene. Other naphtha compounds were found to be more recalcitrant within the 46-week incubation period. Subsequent work (Siddique et al., 2008) led to first- and second-order models to predict methane production in the MLSB. This model, in its present form, is likely not applicable to

EPLs, because it relies on a fresh input of labile BTEX or alkanes, which will not be deposited in pit lakes after mining operations cease or after a water cap has been placed.

The majority of research on methanogenesis in oil sands tailings, and all of the studies discussed above, were conducted at Syncrude's facility, which uses a naphtha solvent. At operations that transport the bitumen offsite for upgrading, in this case Shell's Muskeg River Mine, paraffinic diluents (C6 to C9 alkanes) are used to adjust viscosity for pipelining as well as to precipitate asphaltenes. It is known that the alkanes are useful methanogenic substrates, but it is unknown what the potential impact is of higher relative amounts of the more polar hydrocarbon fractions. In operations where sodium citrate is used as a process aid in extraction in place of caustic soda, loading of such low molecular weight carboxylate into produced FFT could affect microbial activity. While this carbon source was more refractory than naphtha, degradation did occur under ideal laboratory conditions within two to three years (Li, 2010).

While the studies summarized above provide information on the nature of biogenic gas production in fresh tailings, this process can continue only as long as microbes have available and suitable substrates. As labile sources are consumed and tailings are covered with allochthonous and autochthonous sediments, biogenic gas production can be expected to approach levels observed in natural lakes (Chapter 4). In the long term, tailings in the lake bottom will serve both as a source of recalcitrant organics and also as a source of microbial inoculums.

6.2.3.3 Water Quality Implications

The sediment processes described above will result in the release of water, solutes and gases to the water column. The primary source of liquid from tailings will be the pore water released as the tailings consolidate. The quality of this water will be similar in character to OSPW (Section 6.3.1), with additionally elevated levels of the by-products described in Section 6.3.1.2. In the water column, excessive gas production could lead to oxygen depletion if the produced bubbles have sufficient contact time to diffuse oxygen-demanding gases before reaching the surface.

Other chemical transformations (diagenesis) that occur in anaerobic sediments may also influence EPL water quality. In anaerobic sediments, iron and manganese become reduced and soluble, releasing phosphorus otherwise bound to these metals (Wetzel, 2001). The released phosphorus can then enter the water column, where it can promote nutrient enrichment (Wetzel, 2001). The redox status of sediments also influences the cycling of nitrogen, sulphur, silica and other metals (DiToro, 2001). A potential benefit to sulphide production in alkaline conditions is the binding of metals to sulphide, which can extract these metals from the water column (Stumm and Morgan, 1996). Given the importance of these constituents on overall water quality, their fate should be considered as part of design and evaluation.

In addition to chemically releasing these constituents, biogenic gas production may have the additional effect of enhancing transport by creating preferential pathways in the sediment (van Kesteren and van Kessel, 2002).

6.2.3.4 Other Environmental Implications of Gas Release

In addition to the water quality issues highlighted above, there are other potential environmental implications to gases that could be released from an EPL. For example, there is a potential for release of volatile organic compounds (VOCs) from EPLs, which can affect ambient air quality. These compounds are presently released from tailings ponds (Simpson et al., 2010). If present in fluid tailings, VOCs could be entrained in bubbles formed during biogenic gas production and released to the atmosphere.

The primary gases produced in the process of methanogenesis are methane and carbon dioxide. While these gases are significant contributors to greenhouse gas emissions, they are likely to be relatively small compared to overall greenhouse emissions from oil sands extraction. Nevertheless, the release of these gases should be considered as part of the greenhouse gas accounting by the owners of EPLs.

Hydrogen sulphide is a known toxin that may be produced in anaerobic sediments or tailings. Hydrogen sulphide production may be increased in tailings that have been influenced by gypsum amendments due to elevated sulphate in the tailings. At a pH of about 8, which is likely to be present in EPLs based on the pH of filling sources, hydrogen sulphide will be predominantly in the form of HS^-, as opposed to the more toxic form of H_2S. However, EPLs will be dynamic systems, and the pH could drop due to changing inputs or internal processes, so H_2S monitoring should be completed at EPLs until a negligible health risk has been demonstrated.

Finally, in the case of a meromictic pit lake, there is a potential for limnetic eruption of trapped gases, as famously occured in Lake Nyos, Cameroon. While the likelihood of such an occurrence is remote, it can only be ruled out by monitoring, as described in Section 9.6.

6.2.4 Sediment Resuspension and Light Limitation

The potential for sediment resuspension should be considered as part of EPL design, because re-suspended sediment could influence pit lake water quality. The process of sediment resuspension is an important consideration, whether the sediment bed is comprised of tailings or natural materials. The resuspension of sediment could increase Total Suspended Solids (TSS) concentrations and increase turbidity, thereby limiting light availability and causing adverse effects on aquatic organisms. The entrainment of particulate material from a fluid tailings bed into the water column could elevate concentrations of constituents that are associated with the tailings.

Fresh OSPW in active settling basins will generally have elevated TSS and turbidity. If this water is placed during the filling stage, high TSS and light limitation can be expected. In a newly-developed EPL, the near-shore (littoral and riparian) substrate will not be protected from erosion by vegetation, and reworking this sediment will also add to the lake turbidity. Native overburden can contain swelling clays (montmorillonites) and silicates that could be re-worked by wave action. While these clays are not toxic, this period of resuspension will favour species that colonize the epipelagic zones and can tolerate high TSS. Within two years, this limiting factor should be minimized and turbidity cycles will mirror natural lakes (Mike Mackinnon, personal communication).

The potential for wind-driven resuspension of tailings has been examined in an oil sands tailings pond that is similar in dimension to proposed EPLs. In a tailings pond with a fetch of approximately 5 km, Lawrence et al. (1991) calculated that a depth of just over 6 m would be necessary to reduce the likelihood of tailings resuspension given the fetch and wind velocity of 17 m/s for one hour. In studies of tailings ponds for other mining industries, depths of 2.5 m were recommended due to the smaller surface areas of those ponds (Samad and Yanful, 2005). While studies such as Lawrence et al. (1991) and Samad and Yanful (2005) indicate potential approaches to determining appropriate water cap depths, the depth necessary to avoid or minimize sediment resuspension will depend on site-specific factors such as length and orientation of fetch, degree of wind sheltering and the particle size and chemical properties of substrate. For lakes with larger surface areas, deeper water columns are likely necessary to ensure tailings are not re-suspended by wind-wave action.

Fine tailings should never be placed in littoral zones, which are nominally less than 3 m in depth. In addition to being the most important zone of the lake ecologically (see Section 6.2.1), the littoral zone is the part of the lake that is most sensitive to wind and wave action.

As documented by Huber et al. (2008), the wind sheltering is an important variable that will affect the depth to which wind-driven turbulence will penetrate. Initially, the landscapes surrounding EPLs could have little vegetation, depending on the timing of terrestrial reclamation. A lack of forest cover will reduce the wind sheltering, which will increase the effective depth of wind-driven turbulence. As the surrounding forest is reclaimed, the wind sheltering will tend to increase with time.

In addition to wind-driven mixing, there are other factors that should be considered as part of EPL design. If tailings are placed subaqueously, the tailings must be sufficiently viscous and dense relative to the water cap to minimize resuspension. The disposal of low-density waste under a high-density water cap led to tailings resuspension at Island Copper pit lake (Chapter 3). Bubble-facilitated transport may also be a source of tailings resuspension if biogenic gas production is active. The resuspension of solids due to ebullition has been observed in two separate static laboratory studies (J. Foght, personal communication; Yuan et al., 2007). The reconnection of upstream tributaries to a mature EPL could also lead to tailings resuspension if the inflows maintain enough velocity at the sediment-water interface to reach the tailings. The velocity along the sediment-water interface could be higher than expected if the inflows follow density currents, such as when colder inflows plunge to the bottom.

Given the number of variables determining sediment resuspension and the potential effects on water quality, the potential for sediment resuspension should be examined on a site-specific basis for each EPL. Sediment resuspension is thought to be primarily an issue during the early years of development, but there is a possibility that initial conditions may set up longer-term issues. Lake design should consider ways to minimize sediment resuspension, and adaptive management approaches should be considered if sediment resuspension persists. Sediment transport can be predicted using a variety of numerical models, such as those described in Section 9.5. Ideally, the modelling should incorporate any of the variables and processes described above that are relevant to the specific EPL being designed.

6.2.5 Sloughing of Pit Walls

As discussed in Gammons et al. (2009), landslides or sloughing of pit walls is a potential concern. The likelihood of slope failure may increase in the post-closure landscape as the groundwater table rebounds and stability decreases. In the event of non-catastrophic failures or erosion, some of which will be inevitable, the freshly-exposed material may be lean oil sands. Though naturally occurring, exposure to oil sands has been shown to cause acute and chronic toxicity to fish (Colavecchia et al., 2004). This issue has been examined through modelling exercises and field observations, both of which suggest that chemical diffusion from pit walls will contribute very minor loads. In the case of larger slumps or failures, water-capped tailings or accumulated sediment could be resuspended, potentially creating the water quality issues described in Section 6.2.4. A large slump would also have the potential to cause overturn in a stratified lake, and this scenario should be evaluated for any EPL that is likely to be meromictic. In any case, through design efforts, the sloughing of pit walls and exposure to bitumen should be minimized to the extent possible.

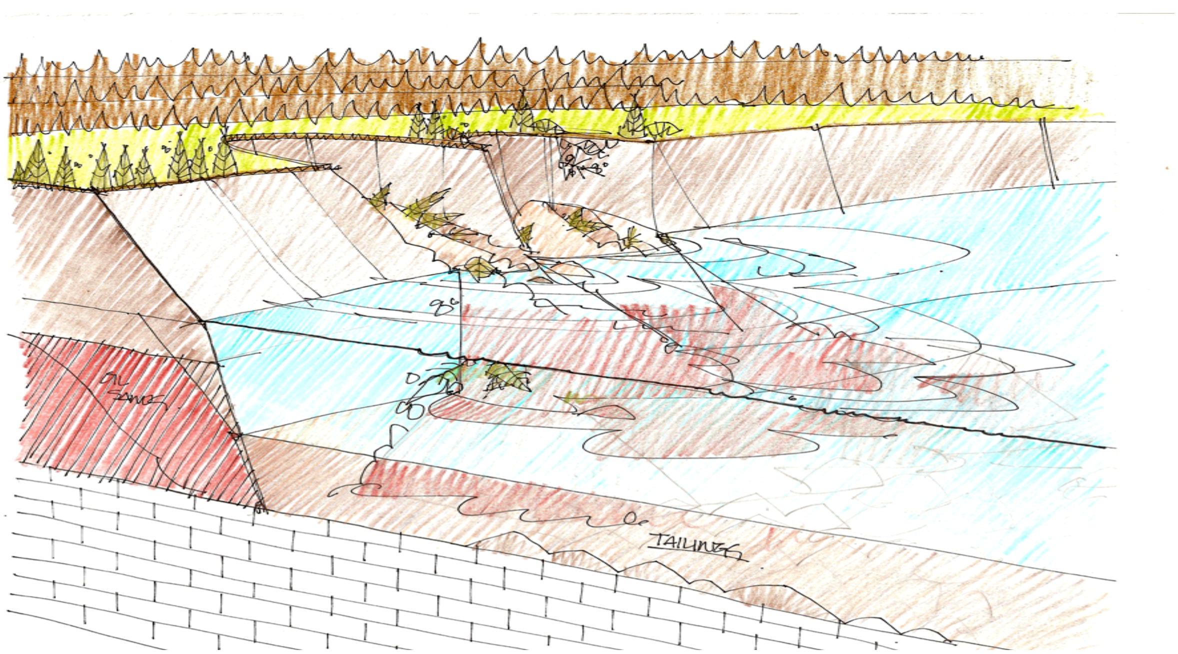

Figure 6-2: The likelihood of slope failure may increase in the post-closure landscape.

6.3 Limitations to Achieving an Aquatic System

As discussed in Section 2.5, EPLs will be required to progress from actively managed waterbodies to self-sustaining lake ecosystems to obtain regulatory certification. This section describes the limitations to achieving such a system. It begins with a discussion of OSPW, including its chemical makeup, toxicity and degradation, followed by a summary of field trials conducted in ponds containing OSPW, and a discussion of nutrients and trophic status.

6.3.1 Oil Sands Process Water

Oil sands process water will be a major component of nearly all planned EPLs in terms of water volume, solute mass and toxicity (CNRL, 2002; Imperial, 2005; Shell, 2007; Suncor, 2007; Total, 2010). Oil sands process water will enter EPLs through direct discharge at the end of mining operations, as release water from submerged tailings, and as a component of runoff that contacts tailings stored in the reclaimed landscape. A description of other inflow sources is provided in Chapter 5.

A chemical profile of OSPW, based on a regional data compilation of tailings pond water completed for Shell (2007), is provided in Table 6-1, and additional data are provided in Appendix B. Notably, OSPW contains elevated levels of major ions, ammonia, trace metals and organic compounds such as naphthenic acids, phenolics and polycyclic aromatic hydrocarbons (PAHs) (Miskimmin et al., 2010). Total suspended solids will also be elevated in waters that contain fluid tailings, as discussed in Section 6.2.4. In addition to these main sources of toxicity, OSPW contains numerous low molecular weight hydrocarbons (e.g., iso- and cyclo-alkane components of fugitive extraction solvents) that partition across membranes but are recalcitrant to biodegradation (Sikkema et al., 1995).

Table 6-1: Chemistry of Oil Sands Process Water (μg/L)

Parameter	Median	n
dissolved organic carbon	56,000	78
total dissolved solids	1,159,000	135
bicarbonate	565,000	190
calcium	18,000	320
chloride	139,000	327
potassium	12,000	184
sodium	405,000	321
sulphate	96,000	321
sulphide	870	24
ammonia	6,400	218
nitrate + nitrite	28	109
total Kjeldahl nitrogen	11,000	21
total phosphorus	55	53
biochemical oxygen demand	13,500	22
naphthenic acids	53,000	125
total phenolics	94	38

total recoverable hydrocarbons	13,600	27
benzene	< 0.4	15
ethylbenzene	< 0.4	15
toluene	6.3	15
m&p-xylenes	< 0.8	6
o-xylene	< 0.4	6
aluminum	470	47
antimony	1.4	17
arsenic	2.2	75
barium	130	46
beryllium	2.4	29
boron	2,300	252
cadmium	1.6	45
chromium	4.4	56
cobalt	4.7	47
copper	2.5	50
iron	76	309
lead	1.2	34
magnesium	10,000	319
manganese	63	124
mercury	0. 047	23
molybdenum	69	82
nickel	120	56
selenium	1	52
silver	0.17	4
strontium	520	224
vanadium	3.1	50
zinc	20	53
Target PAHs and alkylated PAHs*		
naphthalene	< 0.075	14
methyl naphthalenes	< 0.5	6
c2 subst'd naphthalenes	< 0.5	6
c3 subst'd naphthalenes	< 0.5	6
c4 subst'd naphthalenes	< 0.5	6
acenaphthene	< 0.11	13
acenaphthylene	< 0.1	14
anthracene	< 0.05	14
dibenzo(a,h)anthracene	< 0.008	13
benzo(a)anthracene/chrysene	< 0.05	14
methyl benzo(a)anthracene/chrysene	< 0.5	12
c2 subst'd benzo(a)anthracene/chrysene	< 0.5	6
benzo(a)pyrene	< 0.029	14
methyl benzo(b&k) fluoranthene/methyl benzo(a)pyrene	< 0.5	7

c2 subst'd benzo(b&k) fluoranthene/benzo(a)pyrene	< 0.5	6
benzo(b&k)fluoranthene	< 0.075	14
benzo(g,h,i)perylene	< 0.030	14
biphenyl	< 0.05	6
methyl biphenyl	< 0.5	6
c2 subst'd biphenyl	< 0.5	6
dibenzothiophene	< 0.05	6
methyl dibenzothiophene	< 0.5	6
c2 subst'd dibenzothiophene	< 0.5	6
c3 subst'd dibenzothiophene	< 0.5	6
c4 subst'd dibenzothiophene	< 0.5	6
fluoranthene	< 0.045	14
methyl fluoranthene/pyrene	< 0.5	6
fluorene	< 0.05	14
methyl fluorene	< 0.5	6
c2 subst'd fluorene	0.08	6
indeno(c,d-123)pyrene	< 0.055	14
phenanthrene	< 0.055	14
methyl phenanthrene/anthracene	< 0.5	6
c2 subst'd phenanthrene/anthracene	< 0.5	6
c3 subst'd phenanthrene/anthracene	< 0.5	6
c4 subst'd phenanthrene/anthracene	< 0.5	6
pyrene	< 0.035	14

NOTES:
< = below method detection
n = number of samples* Compounds in this category were at or below the technological detection threshold at the time of survey.

The toxicity of OSPW is complex, and is covered comprehensively in other publications (e.g., Allen, 2008; Eickhoff et al., 2010; Miskimmin et al., 2010; Quagraine et al., 2005). An overview of OSPW toxicity is provided below that includes the most relevant information for predicting and managing OSPW toxicity. The overview is organized as follows:

- Naphthenic acids and their role in toxicity of OSPW
- Identifying specific compounds causing toxicity
- Variable toxicity and biodegradation potential of groups of naphthenic acids
- Other OSPW properties known to affect toxicity

6.3.1.1 Naphthenic Acids and their Role in Toxicity of OSPW

When considering the toxicity of OSPW in the context of EPLs, it is important to recognize the provenance of the samples. In assessing toxicology, the use of fresh or undiluted OSPW provides an indication of how such waters will perform before entering an EPL. All OSPW will be subject to a period of years to decades of in-situ degradation of constituents, as well as dilution with some proportion of fresh water, prior to connection with the receiving environment.

In the 1980s and 1990s, it was established that the toxicity of OSPW is due primarily to organic acids (Mackinnon and Retallack 1982; MacKinnon and Boerger, 1986; Mackay and Verbeek, 1993; Verbeek et al., 1993). Since then, many studies have been conducted to evaluate the effects of OSPW on a variety of organisms representing a range of predicted EPL biota (Miskimmin et al., 2010). These studies have confirmed and refined the original hypothesis that OSPW toxicity is due primarily to freshly released naphthenic acids (MacKinnon and Boerger, 1986).

Naphthenic acids are a complex mixture of alkyl-substituted acyclic and cycloaliphatic carboxylic acids, represented by the empirical formula, $C_nH_{2n+z}O_2$, where n = number of carbons and z = number of ring structures. They exist naturally in bitumen and are thought to be the result of partial degradation of petroleum. During the oil sand extraction process, they are released into the process waters as their carboxylate anion. Under the alkaline conditions of oil sands processing, they are very soluble and act as surfactants, which explains their mode of toxicity (Clemente and Fedorak, 2005; Headley and McMartin, 2004). Other compounds present in tailings and OSPW, such as ammonia, phenolics, PAHs and metals must be considered as part of EPL planning, modelling and monitoring. As well, actions taken to reduce organic acids and salinity to acceptable levels will likely mitigate any toxicity associated with these constituents.

6.3.1.2 Identifying Apecific Compounds Causing Toxicity

Due to the complexity of the mixture of naphthenic acids in OSPW, historical studies that examined the toxicity or degradation of individual components in the naphthenic acids group are limited. In many studies, commercial naphthenic acids rather than OSPW naphthenic acids were used to predict toxicity, rates of detoxification and rates of microbial decay. The relative composition and properties of the commercial naphthenic acids show they are more toxic and more labile than those prepared from OSPW (Scott et al., 2005). Additionally, OSPW naphthenic acids measured in nearly all historical studies were, strictly speaking, not naphthenic acids, but rather were similar acid-extractable organic compounds that were detected by Fourier transform infrared (FTIR) spectroscopy (Grewer et al., 2010). These acid-extractable organics do not fit the technical naphthenic acids empirical formula, but were included in quantitation based on the FTIR method of detection, which uses the response of the carboxylic acid functional group in analysis. Therefore, the historical database of naphthenic acids includes compounds with multiple carboxylic acids, heteroatoms and other functional groups (Barrow et al., 2010; Frank et al., 2008; Grewer et al., 2010). However, for fate and pathway studies, this modified naphthenic acids group should be considered, particularly since their relative importance to total naphthenic acids increases with ageing and biodegradation, processes that will be occurring in the EPLs.

While it is recognized that historical studies include other acid-extractable organics in their reported naphthenic acids concentrations, the term "naphthenic acids" is used throughout this chapter by convention. Research into naphthenic acids characterization, toxicity and decay is evolving rapidly (Miskimmin et al., 2010).

6.3.1.3 Variable Toxicity and Biodegradation Potential of Groups of Naphthenic Acids

Most acute toxicity in OSPW has been associated with the naphthenic acids group of compounds, but it appears that within this group, relative toxicity and rates of degradation vary. Although no distinctive feature has been identified to classify individual compounds as either labile or refractory, they have been differentiated in aggregate based on:

1. molecular weight (Biryukova et al., 2007; Clemente et al., 2004; Clemente and Fedorak, 2005)
2. number of carbon atoms in molecule (Han et al., 2008; Holowenko et al., 2002)
3. number of rings in molecular structure (Han et al., 2008; Lo et al., 2006)
4. degree of alkyl side branching (Han et al., 2008; Johnson et al., 2011; Lo et al., 2006; Smith et al., 2008)
5. boiling point (Frank et al., 2008)
6. carboxylic acid content, and therefore hydrophilic nature (Frank et al., 2009; Whitby, 2010).

Studies have shown that both acute toxicity and degradation potential of naphthenic acids vary with molecule size and ring structure (i.e., the more labile and toxic fraction of naphthenic acids in OSPW appears to be the lower molecular weight, non-cyclic fraction of naphthenic acids). Labile naphthenic acids are found at the highest levels in freshly-produced process waters in extraction tailings (Scott et al., 2005). Their initially elevated toxicity declines relatively rapidly when they are selectively degraded from mixtures of naphthenic acids during aerobic biodegradation (Holowenko et al., 2002; Clemente et al., 2004; Han et al., 2009). Refractory naphthenic acids are generally larger and less toxic, and recent work (Han et al., 2008, 2009; Grewer et al., 2010) shows that aged OSPW, comparable to what will be found in EPLs, will be dominated by higher-molecular-weight naphthenic acids with greater cyclic character and increasing evidences of degradation processes. Although larger naphthenic acids are less polar (and therefore have higher potential for toxicity through the narcotic mode of action), the higher proportion of dicarboxylic acids within this group seems to reduce its overall toxicity (Frank et al., 2008). The differences in degradation rates have implications for predicting naphthenic acids concentrations through modelling, as described in Section 9.5.

6.3.1.4 Other OSPW Properties Known to Affect Toxicity

Oil sands process water has elevated salinity resulting from liberation of connate water during extraction, chemical aids, ions associated with import waters and by-products of site operations. Sensitivity to salinity varies by species and depends on both the absolute concentration of all ions in solution (i.e., the absolute TDS concentration) and their relative abundance of individual ions. In general, water containing higher proportions of multiple ions tends to be less toxic than solutions dominated by two ions (Mount et al., 1997).

The toxic effects of salinity in OSPW are mainly exerted on higher plants and algae. For example, salinity was found to have additive toxicity with naphthenic acids on phytoplankton in experimental wetlands with salinities up to 3,000 mg/L (Leung et al., 2003). In macrophytes planted in reclamation wetlands, osmotic stresses led to decreased rates of germination and growth in several plants (Crowe et al., 2002). At least one study has shown additive toxic effects of salinity with naphthenic acids on fish. Nero et al. (2006) added up to 1,000 mg/L of sodium sulphate to mixtures of naphthenic acids, and found that these additions increased damage to gills of yellow perch (*Perca flavescens*).

Since salinity does not degrade with time, an adequate supply of fresh water is required for filling and as a permanent source of recharge after the lake is hydraulically connected to the receiving environment. All planned EPLs will be filled partially with fresh water from the Athabasca River, and will subsequently receive recharge from local watercourses. The range of salinity in these lakes is generally predicted to be in the range of 500 to 1,000 mg/L, owing to the low concentration (~175 mg/L) of TDS in the Athabasca River. This range of salinity exceeds that of regional lakes, but receptor-based risk assessments have consistently found this salinity to pose minimal risk to aquatic, wildlife and human health (CNRL, 2002; Imperial Oil, 2005; Shell, 2007; Suncor, 2007; Total, 2010).

Other general properties of OSPW may affect species diversity and their success in EPLs. For example, TSS will be initially high in OSPW, as discussed in Section 6.2.4. Another limiting factor to lake evolution involving higher trophic levels during the early stages will be the oxygen demand of OSPW and its impact on dissolved oxygen (DO). In the first few years of filling, it can be expected that DO will be consumed to the point of anoxia during the ice-cover period. After the initial load of oxygen demand is consumed, EPLs are expected to remain oxygenated throughout most of the water column, at levels dependent on the balance of OSPW, tailings and fresh water present (Golder, 2007). Due to the fundamental importance of DO in establishing an aquatic ecosystem, site-specific DO modelling should be incorporated into the design of all EPLs (Section 9.5).

6.3.2 Field Trials in Establishing Aquatic Ecosystems on Oil Sands Leases

As part of the oil sands reclamation landscape, research and development have evolved over the last three decades. In the early 1980s, the conceptual development of wet landscapes for reclamation was evaluated through laboratory testing and field testing using experimental ponds. Early evaluations indicated that EPLs would be technologically and economically viable and would result in a biologically productive lake ecosystem (Nix and Power, 1988; Hunter et al. 1989; Gulley and MacKinnon, 1993).

Since research on the water-capping approach began, a series of experimental ponds at the Syncrude site were constructed. These ponds, containing FFT, with both OSPW and fresh water capping layers, were constructed in clays that acted as a liner. Syncrude's wet landscape field research facilities include experimental ponds constructed to examine various aspects of water capping of soft tails (seven small experimental pits, two large experimental pits, a demonstration pond, several pits with composite tailings release waters) as well as site water bodies that acted as control or impact study sites (Mildred Lake Reservoir, South Bison Pond, seepage water pond and ditches, active settling basins). Researchers at Syncrude and the University of Waterloo conducted studies on the biota (phytoplankton, zooplankton, macrophytes, benthic invertebrates and fish communities) within Syncrude's experimental ponds in comparison with regional lakes (Harris, 2001). Experimental ponds were also constructed at the Suncor facility to capture runoff from tailings and dyke seepage (Cooper, 2004). The results of these studies are summarized in the following subsections.

6.3.2.1 Benthic Invertebrates

In studies that examined benthic invertebrates in reclamation wetlands, both density and diversity were reduced compared to reference systems in all species except stress-tolerant chironomids (Bendell-Young et al., 2000; Whelly, 1999). In subsequent studies, benthic invertebrate communities differed in species composition compared to regional lakes, but were found at similar densities (Barr, 2009; Leonhardt, 2003). These studies suggested that, initially, benthic invertebrate communities were slow to establish in the experimental ponds that contained FFT and unamended clay substrates, but over time appeared to be following a trajectory to diversity similar to natural systems of the region (Leonhardt, 2003). As a main food source for many fish, the development of benthic invertebrate communities will be essential for long-term success of an EPL. Indications from previous studies is that given sufficient time, a benthic community will become established, and will play an important role in supporting higher trophic species such as fish and waterfowl.

In establishing both benthic and higher trophic orders, the introduction of "seed" populations from surrounding areas should be considered. With the import of non-OSPW from surrounding water bodies, natural biota will also be transported to the EPL. One strategy might be to initially stock EPLs with smaller forage fish (fathead minnows, lake chub, sticklebacks) until their populations are sustained at levels that will support higher game fish (perch, whitefish, walleye). If introduction of these higher trophic levels is too accelerated, food supply or over predation may result in both poor fish production as well as benthic community suppression. The goal in the evolution of a successful EPL will be the development of a viable, diverse benthic community (Harris, 2001).

6.3.2.2 Phytoplankton

Studies on experimental ponds showed that even when water caps were mainly OSPW, the high nutrient levels and non-limiting aspects of light allow rapid establishment of phytoplankton populations (Hayes, 2005). In some cases, algal blooms were observed. With higher proportions of OSPW in the water cap, salinity and high naphthenic acid levels could result in dominance of the more tolerant species (Hayes, 2005). The presence of FFT below the water cap, whether capped with OSPW or fresh water, had no influence on phytoplankton. Initial high turbidity of OSPW was quickly reduced by settling, and light limitations did not persist. In fact, cap waters in experimental ponds were able to support a primary productivity comparable to natural systems, but with differences noted in phytoplankton diversity and species composition. In two experimental pits containing aged FFT (four to eight years old), phytoplankton communities were similar to those in a reference system (Harris, 2001). In similar studies, thresholds for ecological effects, such as variation in phytoplankton taxonomic composition, were estimated at 6 to 19 mg/L of naphthenic acids (Leung et al., 2001; 2003).

6.3.2.3 Zooplankton

The University of Waterloo studies showed that fresh OSPW poses a threat to zooplankton communities, depending on the life cycle of the species (McCormick, 2000). They indicated that OSPW properties, such as high concentrations of TSS, TDS and naphthenic acids, would affect species success and bias a population toward the more tolerant species. In experimental ponds, generally lower abundance and diversity were found compared to regional lakes.

6.3.2.4 Amphibians

In many aquatic systems, amphibians are considered a sentinel species because of their sensitivity to pollution and habitat stress (Wyman, 1990). However, their potential success in the proposed EPLs is not clear, and conclusions drawn about their chances have been mixed, particularly since these large open-water reclamation waterbodies are not physically optimum habitats for amphibians. Pollet and Bendell-Young (2000) studied western toad and wood frog tadpoles in reclamation wetlands, and concluded that EPLs would not support amphibian populations. However, they were working in a constructed wetlands habitat that was being constantly impacted by fresh OSPW, which is a much more highly impacted environment than an EPL containing aged OSPW and freshwater. In a follow-up by Gupta (2009), field and laboratory studies on wood frog tadpoles living in OSPW and oil sands substrates indicated that tadpole growth was similar to that in natural systems, but the laboratory studies indicated that both growth and survival would be reduced. Subsequent studies by Hersikorn (2009), Hersikorn et al. (2010) and Hersikorn and Smits (2011) showed that wood frog tadpole survival and metamorphosis in reclamation wetlands older than 7 years of age was similar to that in reference wetlands. They concluded that wetlands containing aged tailings could support native amphibian populations. For amphibians to be successful in the EPLs, sufficiently shallow, wetland-type habitats will be required. While such habitats are planned for EPLs, the presence of fish as predators of the early life stages of the amphibians could prevent them from being successful in this lake habitat. These research findings support the general observations of other studies on species in oil sands reclamation and experimental wetlands: namely, acute toxicity is limiting in new EPLs but is reduced to at or near reference conditions with time.

6.3.2.5 Macrophytes

Studies on experimental ponds found that macrophyte growth was limited in tailings compared with natural substrates which were predominantly un-amended clays. These studies indicated that macrophyte productivity could be accelerated through the addition of good reclamation soils and organic materials, such as peat (Harris, 2001). Growth was inhibited by salinity only at levels well above those in the experimental ponds, which are higher yet than anticipated salinities of pit lakes.

Osmotic stresses led to decreased rates of germination and growth in several plants in reclamation wetlands on the Suncor lease (Crowe et al., 2002). However, a wetland that formed primarily from dyke seepage waters, which are similar in character to OSPW, was able to support and sustain a diverse population and abundance of macrophytes (Crowe et al., 2002).

The potential use of macrophytes in phytoremediation of OSPW was studied in a laboratory setting (Armstrong et al., 2009). In hydroponic systems with various concentrations of naphthenic acids, plant growth was shown to reduce the whole effluent acute toxicity to *Daphnia magna*, a species native to the region. This study indicated that once macrophytes are able to establish in an EPL, they may contribute to detoxification through phytoremediation.

6.3.2.6 Avian Shorebirds

Potential effects of oil sands reclamation sites on shorebirds representative of those that could be relevant in reclaimed riparian zones adjacent to such EPLs were examined in five studies involving health, survival and immune suppression of tree swallows (*Tachycineta bicolor*) inhabiting reclaimed wetlands. The reclaimed wetlands included the Demonstration Pond as an analogue to a water-capped FFT waterbody and constructed wetlands that received fresh OSPW. Tree swallows were also observed at nearby reference wetlands throughout the studies. Tree swallows were considered reflective of avian species that could bioaccumulate oil sands by-products, because over 80% of their diet was based on aquatic invertebrates (Smits et al., 2000).

The first study, conducted in 1997 and 1998, found few differences in reproductive, immune and physiological end points between tree swallows from the reclaimed and reference sites (Smits et al., 2000). After a harsh winter in 2003, the researchers observed that tree swallows inhabiting the reclaimed wetlands had higher mortality rates compared to those at reference wetlands (Gentes et al., 2006). The researchers concluded that these swallows would have lower success because of their decreased ability to withstand environmental stressors.

In 2004, the researchers conducted three studies on the tree swallows. First, they examined the tree swallows and found that those nesting near reclaimed wetlands were highly parasitized compared with those at reference sites (Gentes et al., 2007a). They speculated that the higher mortality observed during the preceding winter might have been related to these parasites. However, they noted that the parasitism might have resulted from factors unrelated to the reclamation wetlands, and that parasitism did not result in mortality or reproductive success. Subsequently, researchers dosed nestling tree swallows by injection for one week with naphthenic acids at concentrations 10 times higher than they would be exposed to through routine contact with the reclaimed wetlands. The nestlings showed little or no response, suggesting that naphthenic acids would have no acute toxicity on these species at relevant concentrations (Gentes et al., 2007b). Researchers also euthanized nestling tree swallows at reclaimed and reference sites and analyzed their thyroidal hormone content. The results indicated increased hormone synthesis, which could negatively affect several physiological processes in the swallows (Gentes et al., 2007c). Again, it was suspected that the reclaimed wetlands were a contributing factor to the hormonal activity, but the cause was not apparent.

6.3.2.7 Fish

EPLs are not likely to be considered successful by stakeholders unless they are capable of supporting large-bodied fish. This should be an objective of EPL design because demonstrating that they can support fish populations, or that they some day will, is likely to be a criterion for certification. Since constituents of fresh OSPW, such as naphthenic acids, ammonia and salinity may be toxic or limiting to fish, fish community development is more suited to the certification phase.

Studies of fish exposure to OSPW in experimental ponds that involved penned and free-roaming studies using rainbow trout (*Oncorhynchus mykiss,* a popular sportfish in Alberta but not native to the oil sands region) and fathead minnows (*Pimephales promelas*, a species native to the region) as the test organisms have shown that the initial toxic character of OSPW is quickly dissipated under natural ageing. However, effects such as stress on reproduction and tainting potential (the potential for substances to affect flavour or odour in fish flesh) may persist in the long term (ETL, 1995; Rogers et al, 2007; Young et al., 2007, 2008, 2011).

In a large set of trials conducted in the field and laboratory, Siwik et al. (2000) conducted chronic whole effluent toxicity tests using fathead minnows on water from experimental ponds containing various mixtures of FFT and OSPW, aged from four to eight years. Water was collected from several ponds for laboratory bioassays, and field bioassays were conducted in three ponds. In the laboratory tests, a seven-day growth and survival assay resulted in no significant differences among water from five ponds compared with control samples, despite naphthenic acids concentrations of up to 45 mg/L in the ponds, which are 5 to 10 times higher than typical EPL projections. In a second assay, survival of fish in two of three ponds with naphthenic acids concentrations of 22 and 59 mg/L were significantly lower than fish in control samples, although growth was not significantly different in any of the three ponds. In the 56-day test, there were differences in endpoints at various times throughout the test, but fathead minnow larvae exposed to oil sands FFT and OSPW exhibited similar growth and survival over 56 days compared with control samples. In the field tests, survival after 21 days did not differ among the control and two test sites, but growth was significantly higher in the control site. Both field test sites contained FFT and were aged for four years; a freshwater-capped site had naphthenic acids concentrations of 6.8 mg/L and an OSPW-capped site had naphthenic acids concentrations of 59 mg/L.

To evaluate the capacity of FFT-cap water to support fish, yellow perch (*Perca flavescens*, a species native to the region) were transplanted from Mildred Lake to the experimental ponds containing water-capped FFT and OSPW (van den Heuvel et al., 1999a, b). The perch successfully reproduced, which allowed studies to be conducted on perch at all life stages. The transplanted perch and their offspring showed physiological stresses, such as reduced immune function, but had improved nutrition relative to fish in a reference lake because of the abundance of prey and lack of competition.

In a laboratory study, using OSPW from experimental ponds, Kavanagh et al. (2011) found that aged OSPW negatively affected the reproductive physiology of fathead minnows. They suggested an effects threshold for impairment of 25 mg/L for aged naphthenic acids, which is about two to four times as high as a typical projection for an EPL.

The following learnings are based on three decades of research into aquatic reclamation of water capped FFT and OSPW (Mike Mackinnon, personal communication): “It is important that the introduction and establishment of sustainable fish populations extend over a number of years, with the time of success being a function of the rates of chemical modification, dilution effects, substrate sorting and detrital accumulation, and presence of suitable food sources and spawning habitats. At this stage, long-term acute or chronic impacts are not expected to be limiting to eventual fish species colonization, survival and reproduction, but this will not occur until the EPL has matured to a point suitable to each species. By the certification stage, the goal will be to have a viable fish community as part of the lake ecosystem, but because of physical and chemical differences relative to natural lakes in the region, fish populations will be different as well. While you can build it and they will come, the community structure will be part of the natural selection and interspecies competition.”

6.3.3 Nutrients and Trophic Status

An important consideration in establishing an aquatic ecosystem is the availability of nutrients. A shortage of nutrients could hinder the development of a productive aquatic ecosystem, whereas an excess of nutrients could lead to eutrophication. Eutrophication is commonly characterized by the proliferation of algae and higher aquatic plants, their accumulation in the water body in excessive quantities, reduced biodiversity, and reduced dissolved oxygen (Chambers et al., 2001). Thus, while an increase in nutrients may be beneficial in some waterbodies, it could be problematic in others. In Alberta, nutrients are seldom limiting in lakes, except those located in mountain headwaters. Of 151 lakes surveyed (AENV, 2011), six lakes were oligotrophic (all six were in the Rockies or foothills), 62 lake were mesotrophic, 47 lakes were eutrophic and 36 lakes were hyper-eutrophic based on total phosphorus rating (CCME, 2004).

Similarly, nutrients are unlikely to limit EPL productivity, because the main inflow sources are relatively high in nutrients. The main inflow source during filling, the Athabasca River, is relatively high in both nitrogen and phosphorus, with both nutrients exceeding surface water guidelines of 1 mg/L total nitrogen and 0.05 mg/L total phosphorus (AENV, 1999). Occurrences of the upper range of nutrient concentrations are usually associated with periods of high flow (i.e., spring melt, storm flows) when TSS concentrations are also high (Hebben, 2009; RAMP, 2010); in these conditions, a high proportion of the nutrients would be in particulate phase. The original conditions of EPLs with high OSPW content will include the relatively high nitrogen and phosphorus associated with OSPW constituents (Table 6-1), and these have been shown to support robust primary production in experimental ponds (Zyla and Prepas, 1995). Additionally, the natural tributaries in the region that are expected to provide long-term inflows are generally high in nutrients (RAMP, 2010). This observation is noted in numerous baseline studies conducted in support of Environmental Impact Assessments (EIAs). Other nutrient sources to EPLs to consider include groundwater inflows and release from sediment.

During filling, operators may have some ability to control nutrient loading to the lake by selectively pumping high or low nutrient concentrations from the Athabasca River. In particular, total and dissolved phosphorus concentrations follow regular seasonal cycles (Hebben, 2009).

Note that pumping rates and times will be constrained by water licence limits, In-stream Flow Needs restrictions (AENV and DFO, 2007), pumping to fill the lakes of other operators, and plant requirements, if the project is still operating when the EPL begins filling.

Ultimately, the nutrient status, whether limiting or eutrophic, will need to be considered on a lake-by-lake basis, along with the projected aquatic ecosystem that may be desired within the pit lake. Nutrient levels vary from tributary to tributary, and EPL planners will need to evaluate long-term conditions in the specific watersheds that will provide inflows. Site-specific data on total and dissolved forms of carbon, nitrogen and phosphorus for these sources is freely available in several sources, including the baseline reports for each project, the AENV water quality database and annual RAMP reports and RAMP's online database. Long-term nutrient status, including sediment nutrient diagenesis, can be evaluated through the development of a demonstration EPL and by reviewing the outcomes of surrogate systems such as reservoirs that have been constructed in the region. Predictive modelling (Section 9.5) can be used to support such studies, and the reliability of such modelling will be increased if the models can be calibrated to these proxy systems.

6.4 Considerations for Water Quality Management

As discussed in Sections 6.2 and 6.3, EPLs are complex systems in terms of hydrodynamics and water quality. While these lakes will differ from natural lakes and pit lakes of other mining industries, there will also be much variation within the range of EPLs. On one end of the spectrum will be EPLs that contain significant quantities of tailings and OSPW and smaller quantities of fresh water. Conversely, some EPLs will be tailings-free and filled almost exclusively with fresh water. The position of each EPL on this spectrum should be evaluated to provide context for the considerations listed below.

6.4.1 Modelling Considerations

Please see Section 9.5 for a more comprehensive list of modelling considerations. Above all, modelling should be driven by a robust monitoring program, as described in Section 9.6. Although models are very important in the design of EPLs, the ultimate measure of the success or failure of an EPL will be determined through a robust and long-lived monitoring program.

Understand the System. The first step in designing an EPL is to understand the system being designed. This means building a conceptual model, which should be done regardless of whether a numerical model will be applied to it. A conceptual model is a description or schematic of the relevant processes and interactions that control the behaviour of a physical system. It is a tool used to illustrate and understand the individual components of a complex system. The conceptual model should include the most important inputs and processes that will influence the system. As a guide to developing the conceptual model, each input listed in Chapter 5 and each process listed in Sections 6.2 and 6.3 should be evaluated to see if it applies to the EPL in question.

Understand the Inputs. To the extent possible, the biological, chemical and physical inputs of all EPL inflow sources should be quantified. As discussed in Chapter 5, the chemical makeup of different inflow sources will vary considerably. As mining progresses and knowledge of inflow characteristics becomes more detailed and accurate, confidence in water quality predictions will increase and management scenarios can be refined.

Use models appropriately. At each stage of development, consider the general and specific recommendations for modelling EPLs listed in Section 9.5. As information changes regarding inputs to the pit lake, update the conceptual model and numerical model inputs accordingly. At major milestones in mine development, the model platforms and approach may need to be updated to meet the objectives of the modelling.

Keep contingency measures available. As the mine develops and information becomes more reliable, confidence in predictions will increase. However, as time goes on, management options to improve water quality will also become more limited. At each stage of development, planners should evaluate whether adaptive management options (Appendix D) that may have been applied at one stage are still applicable.

6.5 Summary and Conclusions

The incorporation of OSPW into end pit lakes poses reclamation challenges, including the management of naphthenic acids and other toxic organic compounds, the potential for meromixis, and constantly evolving water quality. Most EPLs will not be constructed until decades after the initial design stage, and numerical modelling can be used to forecast hydrodynamic and water quality conditions. The objectives associated with each stage should guide modelling efforts. At every stage, the numerical model should reflect an initial conceptual model to the degree that the input data allow. In the absence of well-defined inputs, modelling should be based on conservative assumptions and commitments by operators to implement mitigation. The key to predicting water quality is through continual monitoring. In addition, studies of OSPW toxicity thresholds and degradation rates can be used to improve ecological predictive capabilities. The level of uncertainty must be quantified and communicated as part of the predictions. Confidence levels can be assessed with Monte Carlo simulations or other statistical tools.

Field, laboratory, and modelling studies completed to date indicate that EPLs will meet the objectives of isolating fluid tailings, allowing degradation of OSPW constituents and providing conditions suitable for development of lake habitats with self-sustaining biota. In addition, EPLs are attractive to operators because they offer a safe and efficient option for managing tailings as well as providing a path toward eventual certification within their lease-closure landscapes. Studies indicate that, initially, EPLs will likely function as bioreactors and reduce the toxicity of OSPW and materials placed in the lakes. Water quality should be acceptable by the time of initial release if the screening criteria are based on a combination of levels observed in natural lakes and aquatic health thresholds. Organisms at a variety of trophic levels may be sustainable in EPLs, although not necessarily at the abundance and breadth of biodiversity observed in natural lakes in the region. What is uncertain is the rate of progression and the degree to which these pit lakes will replicate natural systems, and the degree to which they will be expected by regulators to do so.

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Personal Communications

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Mackinnon, Michael. OSPM Solutions Ltd. Hamilton, ON.

PART THREE

DESIGN OF END PIT LAKES

While mining reclamation was once treated as an afterthought in some sectors, modern strategies embrace a planning schedule that begins before the onset of mining. EPLs are no exception. Chapter 7 lays out a 100-year timeline for the planning, design, construction and certification of EPLs, from pre-mining lease development through to abandonment. The timeline includes not only those activities associated directly with EPL construction, but the modelling, maintenance, and monitoring that will be required to put a project on an acceptable trajectory. The chapter also reviews the planning drivers, such as ore body geometry and site topography, that will determine the schedule and specifics of every EPL plan. Chapter 8 is devoted to the technical considerations and criteria that engineers and designers must address as part of any permit-level EPL design. Included are discussions of site geology, tailings, containment, hydrology, lake contents, and shoreline stability, among others. Chapter 9 addresses a similar list of issues in the context of construction and operation, along with sections on modelling, monitoring, and adaptive management, all of which will be necessary to ensure successful certification and transfer of custody of EPLs to the Crown.

7. TIMELINES AND DRIVERS

Aaron Sellick
Norwest Corporation

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Chapter 7 Table of Contents

7.1 Timelines: Conceptualization to Certification

The successful planning, design, construction, and commissioning of oil sands EPLs pose significant project management challenges. Among them are technical knowledge gaps, decades-long project execution time, wholesale changes in individuals and group involvement over time, uncertain objectives and performance requirements, advancing technology, changing societal expectations and regulatory regimes, and an unpredictable economic climate. To complicate matters further, these challenges must sometimes be managed along with other, more immediate and/or overwhelming challenges associated with day-to-day oil sands mining operations. Examples include challenges related to cost control (discussed in Section 7.2.12), safety, technical feasibility, and competing environmental performance objectives.

This section provides guidance on project management issues and strategies for EPLs. By highlighting activities related to EPLs at various stages of an example oil sands mine development and closure schedule, it is hoped that readers involved in EPL projects, be they planners, designers, builders, regulators, or stakeholders, will be in a better position to manage their own activities to contribute to a successful conclusion of the project.

Oil sands mining projects are typically long-lived, with ore production periods for current operations ranging from about 20 years to over 50 years (Table 7-1). The average production period for the projects shown in the figure is about 42 years (this assumes the Suncor Lease 86/17 Mine and Steepbank/Millennium Mine are considered as two mines). However, long lead times prior to commencement of oil production ("first oil") coupled with potentially extended post-mining reclamation activities can extend the development-operations-reclamation timeline for a project significantly. It is possible that the total time required between project conceptualization and certification could be 100 or more years.

Table 7-2 shows a conceptual high-level project schedule spanning 100 years that focuses on activities related to a single, typical EPL. This schedule is provided as an example to illustrate the complexity and extended time horizons associated with the planning, development, construction, and certification of oil sands EPLs. However, the reader should note that the specific tasks shown on the schedule, the sequencing of those tasks, and the time required for the tasks will vary from EPL to EPL to account for variations in site-specific factors and development strategies. For instance, the example presented is based on a true "end" pit lake that would be formed in the area last mined. In some cases, proposed EPLs would be established earlier in the mine life with additional lakes established in the traditional end pit location when mining is completed. In these and possibly other instances it may be possible to significantly shorten the timelines presented for EPL closure and certification. It is expected that regulatory authorities will require operators to demonstrate timely progress in EPL development and closure processes. For more information about project-specific timelines, the reader can consult the respective applications for EUB/ERCB approval for individual mines and the associated environmental impact assessments.[1]

In Table 7-2, ore production would start approximately 10 years after the start of pre-mining activities and last for 42 years. It has been assumed for this example that the area ultimately used for the EPL would be

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[1] See https://external.sp.environment.gov.ab.ca/DocArc/EIA/Pages/default.aspx

mined in two discrete periods, as indicated by the “L” (Lake) in the schedule. A pattern sometimes occurs wherein a portion of the pit that would ultimately form a part of the EPL landform would be mined in the early to middle years of operation while the larger portion of the future EPL would be mined in the final years.

Table 7-1: Approximate ore production schedule for approved oil sands mines

Mine	Year																																																				
	1968	1970	1972	1974	1976	1978	1980	1982	1984	1986	1988	1990	1992	1994	1996	1998	2000	2002	2004	2006	2008	2010	2012	2014	2016	2018	2020	2022	2024	2026	2028	2030	2032	2034	2036	2038	2040	2042	2044	2046	2048	2050	2052	2054	2056	2058	2060	2062	2064	2066	2068	2070	2072
Suncor Lease 86/17, Steepbank, & Millennium[1]	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																				
Suncor Fort Hills[2]																								■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■								
Syncrude Mildred Lake & North Mine[1]						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																									
Syncrude Aurora North[1]																	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■																	
Syncrude Aurora South[1]																									■	■	■	■	■	■	■	■	■	■	■	■	■	■	■														
Shell Muskeg River[1]																		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■						
Shell Jackpine[2]																						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■									
CNRL Horizon[2]																						■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■											
Imperial Kearl[1]																							■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■		
Total Joslyn North Mine[3]																									■	■	■	■	■	■	■	■	■	■	■																		

Notes:
1. Schedules from 2010 Directive 74 Tailings Plan submission.
2. Schedule from 2009 Directive 74 Tailings Plan submission.
3. Schedule from Total JNM ERCB Decision 2001-005.

Filling the EPL with a combination of process-affected and fresh water would occur when mining operations cease and, in this example, would last about 10 years such that the EPL would be filled to the design water level about 52 years after first oil. Water release to the external environment would commence the following year, after treatment if required to meet the release water quality requirements in force at the time. It has been assumed for this example schedule that the EPL outlet water would meet water quality requirements without treatment after about 18 years, 70 years after first oil. After a further period of about 6 years, during which time outlet water would not be treated, the operator would commence the process of applying for abandonment and certification approvals from the ERCB and AENV respectively. These applications would be supported by extensive monitoring data of both EPL and receiving stream performance collected over the life of the project as shown in the “Monitoring” portion of the schedule.

The example schedule shown in Table 7-2 assumes that a reclamation certificate for the EPL would be granted in the 82nd year after first oil. However, the reader should recall that this date, as with all dates shown in the figure, could vary significantly depending on a number of factors. This example schedule is included only to show, at a high level, approximate relationships in time between activities related to EPL planning, design, construction, monitoring, and certification.

Additionally, while this section has been written primarily with new “greenfield” mining projects in mind, that does not mean existing operations have been designed and operated in a vacuum with respect to EPLs prior to the issuance of this guidance document. Rather, it is the author’s view that this section is in large part simply a description of existing practices in the oil sands industry. Current operators can simply find their current location in the timeline to see how this section may apply to their circumstances. The activities listed in the Table 7-2 schedule and some of their potential impacts on the EPL planning, design, and construction process are described in the following sections.

Table 7-2: Conceptual development and reclamation schedule for a typical oil sands mine.

Activity		Approximate Year of Project Timeline																																																		
		-10	-8	-6	-4	-2	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90
Pre-mining lease development	Resource exploration & preliminary mine waste characterization	•	•	•	•																																															
	Scoping level project development plan & EIA baseline information collection	•	•																																																	
	Pre-feasibility planning and EIA compilation		•	•																																																
	Regulatory review & approval process			•	•																																															
	Feasibility Study phase			•	•																																															
	Detailed Engineering, Procurement, & Construction phase				•	•																																														
EPL Planning, Design, & Construction Teams	Project approval team (scoping, pre-feasibility, & feasibility plans; ERCB approval)	•	•	•	•																																															
	Development range planning (life of mine plans; technology evaluations, etc)						•	•	•	•	•	•	•	•	•	•					•					•																										
	Long range planning (10-year plans)																•	•	•	•	•	•	•	•	•	•																										
	Short range planning & construction management (1-2 year plans)																			•	•	•	•	•	•	•	•																									
	Closure team commissioning, monitoring & adaptive management																								•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					
EPL Design Stages	EPL conceptual integrated design			•	•																																															
	Preliminary integrated engineering design including EPL FMEA										•					•					•																															
	Permit level integrated design including FMEA																									•																										
	Landform element construction quality designs													•	•	•					•	•	•	•	•	•	•																									
Mine Operations	Infill resource & mine waste drilling & geological model updates						•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•																										
	Geotechnical drilling							•		•		•		•		•		•		•		•		•																												
	Overburden & ore mining (EPL area indicated by "L")					•	•	•	•	•	•	•	•	•	L	L	L	L	•	•	•	•	L	L	L	L	L	L																								
	Watershed dyke and dump construction and reclamation					•	•	•	•	•	•	•	•	•	•	•	•				•	•	•	•																												
	In-pit dyke and/or dump construction including EPL elements (indicated by "L")									•	•	•	•	•	•	•	L	L	L	L	•	•	•	L	L	L	L	L																								
	Creation of specialized EPL landforms for stability, erosion protection, diversity, etc																	•	•	•					•	•	•																									
EPL Commissioning	Collection & analysis of EPL as-builts & design/planning of final EPL construction																								•																											
	Landform re-grading (pit walls, dumps, etc)																									•	•	•																								
	Tailings placement in the EPL (if applicable)																									•	•	•	•																							
	Shoreline & littoral zone finishing (contouring, soil capping, revegetation, erosion protection)																			•						•	•	•	•																							
	Construction of surface water inlets and outlets																											•	•			•																				
	Connection of undisturbed and reclaimed landscape surface water flows into EPL																												•																							
	Water filling (process affected + fresh water) & terminal bioreactor stage																												•	•	•	•	•																			
	Operational infrastructure construction																												•	•																						
EPL Operations, Maintenance, & Certification	Water treatment plant design & construction (if required)																															•	•																			
	Control of access, water levels, and inlet water quality (if needed)																														•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•					
	Maintanance of shorelines, littoral zones, inlets, & outlets																												•	•	•	•	•	•	•	•																
	Added solute from reclaimed landscape groundwater sources																												•	•					•					•					•					•		
	Re-establishment of regional long-term groundwater levels and movement																													•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Initial water release phase (active management; water treatment if needed)																																	•	•	•	•	•	•	•	•	•										
	Construction of final land use infrastructure																																			•	•															
	Certification qualification phase (water release without treatment)																																										•	•	•	•	•					
	Abandonment and certification approval processes																																													•	•					
	CERTIFIED: Long-term maintenance free / land use phase																																															•	•	•	•	•
EPL Modelling	Gather modelling input data	•	•	•																																																
	Refine modelling input data from additional testing & monitoring								•	•	•				•					•					•		•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•								
	Preliminary stage; high-level model, only key variables evaluated	•																																																		
	EIA stage; 1D, 2D, & 3D hydrodynamic models; many variables evaluated		•	•																																																
	Operational stage; Like EIA stage but with project specific inputs (e.g. OSPW)										•					•					•					•																										
	Filling, Initial Release & Certification stages; calibrated using EPL observations																											•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•							
Monitoring	Regional aquatics monitoring (RAMP or similar updated program)	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•
	Aquatic baseline information collection for project	•	•																																																	
	Operational stage; verify inputs, feedback to planners						•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•																								
	Filling stage; EPL water and sediment quality, gases, pH, biota, etc																												•	•	•	•	•																			
	Initial release stage; Like filling stage but added downstream receptor monitoring																																	•	•	•	•	•	•	•	•	•	•	•	•	•	•					
	Certification stage (by government or research organizations?)																																															•	•	•	•	•

7.1.1 Pre-mining Lease Development Activities

Pre-production lease development activities can range for many years, depending on when the lease to be developed was acquired in relation to the production of first oil. In some cases significant resource evaluation work, primarily in the form of resource drilling, will have been undertaken well in advance of the timeframes indicated in Table 7-2. In a few cases, previous development plans and applications to regulators for approval of mining schemes on the site in question may even have been filed before current project development efforts. However, to be more representative of a critical-path development schedule, a timeframe for pre-production activities has been shown to be approximately 10 years in duration, culminating with production of first oil in year 0 (T0) of the conceptual project schedule.

Major data collection and planning activities that occur during the 10 years leading up to production of first oil and some of the expected impacts of the activities on EPL planning and design are summarized in Table 7-3. There are four primary categories of activities during this period:

- Data collection regarding the resource base, mine waste characterization, and environmental setting for the project;
- Plant design, technology selection, mine design, development sequence selection, and environmental assessment;
- Stakeholder consultation and regulatory processes; and
- Project construction.

As a project progresses through the pre-production activities, key decisions are sometimes made that involve commitments to a course of action that could be irreversible, or reversible only at high cost, especially for those decisions that affect construction and operations in the early years of the project. Given the uncertainty and level of EPL design work typically completed during pre-production years, the degree to which commitments and predictions made regarding EPL design details and performance in pre-production years are reversible, whether by project proponents or regulators, is debatable. Nevertheless, while EPL construction activities are generally focused in the mid-late years of mine operation, it is important to recognize that many decisions are made during the pre-production period that may significantly influence the ultimate performance of the EPL as a closure and reclamation feature. Examples of such decisions include selection of the mine opening location and development sequence, tailings technology, and EPL site.

Table 7-3: Example of pre-production lease development activities for EPLs

Activity (Example Timing)	Description of EPL Impacts
Resource exploration and preliminary mine waste characterization (T-10 to T-2)	Initially little consideration for EPL in early exploration work. Increasing (but limited) effort with time to design drill programs to identify any potentially problematic geological structure and identify minable resource limits (and therefore EPL limits) in time for EIA completion.
Scoping level project development plan (T-8)	Purpose is primarily to determine whether there is a reasonable likelihood that a successful project could be developed such that investigations should continue. Data needed for EPL design are generally limited and the primary efforts are aimed at determination of whether the EPL options identified in planning exercises lead to viable closure scenarios. Insight is gained into potential EPL site, size, depths, elevations, contents, outlet locations, and timing. A base-case EPL configuration may be chosen as the basis for further evaluations.
EIA baseline information collection (T-10 to T-7)	The objective of baseline data collection is to characterize the environment within which the project will be located. The baseline data collected typically includes many aspects of the aquatic environment as described in Section 9.6. In particular, the quantity and quality of water in the project area will influence the viability of the pit lake because these waters may one day flow into the EPL. Also, baseline information will be used to determine the condition of the receiving environment. Project specific baseline data are typically combined with available regional baseline datasets to form a basis for the project EIA.
Pre-feasibility planning and EIA compilation (T-7 to T-6)	A pre-feasibility level project development plan, complete with preliminary technology selections, typically forms the basis for a greenfield project application and EIA. One key goal of the pre-feasibility study is to ensure that the project is technically feasible. Preliminary decisions are typically made regarding processing plant, tailings, and mining technology and several life-of-mine (LOM) planning scenarios are developed and evaluated with respect to feasibility, economics, and environmental performance. Several potential EPL configurations are considered, including the conceptual integration of those EPLs into closure drainage patterns. Major project design elements are selected and the LOM plans for the selected option are developed in detail to form the basis of the application for project approval and the associated EIA. As part of the EIA, EPL performance is modelled using a combination of 1D, 2D, and 3D models as needed and the required baseline data is collected for that purpose. Since no process water for the project exists at this stage of a greenfield project the models must be based on assumed characteristics, usually based on a similar operation, for this important model input. An appropriately conservative set of assumptions should be used to mitigate the resulting uncertainty. See Section 9.5 for a more detailed description of EPL modelling and assessment activities during EIA preparation.

Activity (Example Timing)	Description of EPL Impacts
Regulatory review and approval process (T-5 to T-3)	Through a coordinated application review process the proponent for a new (or significantly amended) mining project applies to obtain the necessary approvals to construct and operate the project from the ERCB, AESRD, and other regulatory agencies as appropriate for the project at hand. Currently, the review and decision process can take from about 12 to 36 months depending on the complexity of and impacts expected from the project. If major changes are made to the project description during the review process then the timeline can be extended. The application and EIA contains a complete mine development, closure, and reclamation plan that would describe any EPLs to be included in the closure plan. Designs for individual landform elements that together make up the integrated EPL designs (e.g., dumps, temporary dykes, pit walls, etc.) typically would be completed at a conceptual level at this time. Similarly, the closure drainage plan and EPL outlet design would be done at a conceptual level. Prior to making decisions regarding the project application, the regulators solicit input from stakeholders who believe they could be affected by the project. On the basis of that input and the technical and economic merits of the development and reclamation plans proposed, the regulators issue approvals if deemed appropriate, attaching whatever conditions they believe necessary. Diligence is needed by the EPL planning team during the application review process to ensure that proposals and expectations regarding EPL performance are realistic. EPL planning teams at this stage use the best information available to understand and present expected EPL performance. Any proposed changes to the project resulting from feedback received during the review process should be tested against this technical basis to ensure that any conceptual design changes are made only after evaluation of the impacts of those changes on EPL design feasibility and performance and project economics.
Feasibility Study phase. (T-4 to T-3)	A pre-feasibility study often results in identification of areas that should be studied further to optimize development plans. During the feasibility study the results of such additional studies are sometimes incorporated into project development plans (sometimes with no major changes). Otherwise, the feasibility study tends to re-examine the same aspects of the development plans that were evaluated at the pre-feasibility stage, but in greater detail (especially with respect to costs). It is possible that desirable changes to the project that affect the EPL(s) could be identified in feasibility level plans. However, in many cases the scale of changes contemplated from pre-feasibility plans are such that no significant conceptual EPL design changes result. In the event that major changes do result, it is possible that additional regulatory review could be required before project approvals can be granted.
Detailed Engineering, Procurement, and Construction (EPC) phase (T-4 to T0)	The detailed EPC phase of a project is a very busy period during which the conceptual design of the EPL should be taken into consideration when designing other facilities. However, design of the EPL is generally not done during this stage of project development as the focus is on project construction and start-up.

7.1.2 EPL planning, design, construction teams & activities

Over the life of oil sands mining projects the teams responsible for EPL planning, design, and construction are expected to change to keep pace with organizational structure changes and the changing nature of the work to be completed by the EPL team. During pre-production the EPL planning and design duties are often assumed by a project approval team. This team is often comprised of project owner staff with significant technical contributions from consulting engineers and scientists.

After regulatory and internal approvals for the project are obtained, the responsibilities for project construction and operation typically transition from the project approval team to the project staff that will be responsible for operation of the project. Responsibilities for EPL planning typically pass to the operational planning groups and at any time reside with the planning group that has primary responsibility for the time horizon in which significant EPL work is expected to occur. Assuming the timing of EPL excavation/construction activities occurs in the mid-late mining years then the transition between super-long-range (a.k.a. “development-range”), long-range, and short-range planning may follow the example schedule shown in Table 7-2. As mining nears completion, the mine closure team focuses on sculpting final EPL landform, and commissioning, monitoring, and managing the EPL until it receives a reclamation certificate. Table 7-4 summarizes the EPL planning focus of the planning groups that could be responsible for EPLs throughout project life.

It is noteworthy that overlapping periods of responsibility for EPL activities are expected as shown in Table 7-2. For example, in the middle mining years it is expected that integrated EPL planning would be done by a long-range planning group whereas detailed design and construction of individual EPL landform elements would be handled by the short-range planning group.

Table 7-4: Example of evolution of EPL planning teams over time

Activity **(Example Timing)**	**Planning Focus and EPL Impacts**
Project approval team (T-10 to T0)	Completes scoping, pre-feasibility, and feasibility plans and manages ERCB, EPEA, and *Water Act* application processes. Obtains owner approvals and establishes plans for transition of project management responsibilities to the construction and operations team. All aspects of conceptual EPL planning fall within the duties of this team during pre-production stage of a greenfield project.
Development-range planning (T0 to T19; T28 and T38)	Searches out and eliminates potentially infeasible situations in lease development plans, evaluates new technologies, and re-aligns the life-of-mine plans (including closure plans) to seize opportunities if warranted. Makes required changes to all aspects of operations in the mine plan; plant, mining, and tailings technology; and ensures EPL configuration is possible to the extent that regulatory applications for approval amendments could be triggered. Intermittent responsibility for EPL planning is shown in later years to represent ongoing involvement to ensure alignment of EPL plans with other development range project plans.

Activity (Example Timing)	Planning Focus and EPL Impacts
Long-range planning (T20 – 39)	Primarily responsible for creation of long range (~years 2 to 10 of a 10-year plan) bitumen production plans annually. Includes optimization of plans, changes to production rates, lay-out of landform elements of EPLs, etc. Preliminary and detailed designs of integrated EPLs are developed by this group. Detailed designs for individual EPL landform elements may also be done by this group (or by the short-range planning group). Major changes to project layout and integrated EPL configuration may be beyond the scope of this group. However, significant changes to EPL landform elements, and lake dimensions, could comprise part of updated long-range mine plans.
Short-range planning (T26 – T41)	Primarily responsible for final optimization of plans and for providing operational support for execution of the plans. Large-scale changes to EPLs are generally not possible with the short-range planning horizon (1 to 2 years). Implementation of large-scale structural aspects (i.e., landform construction management) of the detailed design of EPL is typically managed by this group.
Closure team (T36 – T81)	Primarily responsible for final re-grading of EPL landforms, and all aspects of EPL activities in the post-production period including EPL commissioning, monitoring, adaptive management, and abandonment and certification.

Just as the organizational group responsible for EPL planning evolves over time, so too does the composition of an EPL planning team. During some periods of the development-operations-closure timeline, very little effort may be expended on EPL planning and design and the expertise of the staff involved may encompass only a small sub-set of the complete interdisciplinary suite of skills needed over the life of the project. At other times, large teams of specialists will need to be assembled to complete the required EPL focused activities.

Table 7-5 shows conceptual EPL planning team compositions at various stages of a project and the approximate level of effort or impact expected from each of the disciplines (High, Medium, Low). It is expected that the teams would consult stakeholder advisers (including Aboriginal and government representatives), and be composed of geoscientists and mine planners early in the pre-development phase, shifting to environmental scientists as mining nears completion and activities shift toward commissioning the EPL. Peak team size and breadth of specialists' disciplines would be expected during the pre-feasibility study/EIA phase and during periods when *Environmental Protection and Enhancement Act* (EPEA) approval renewal applications are being prepared.

Table 7-5: Conceptual planning/design team composition at various stages of EPL development and level of impact/effort.

Discipline	Pre-Mining Exploration		Pre-Mining Planning and Design			Operational Geology Delineation		Operational Planning, Design, and Construction			Mine Closure EPL Stages		
	Initial	Continuity Delineation	Scoping	Pre-Feasibility and EIA/App.	Feasibility	Resource Infill	Structural Delineation	Develop-ment Range	Long Range	Short Range	Commission, Filling, and Bioreactor	Initial Release	Pre-Certifi-cation
Geologist	H	H	H	H	M	H	H	M	M	L	-	-	-
Geophysicist	H	M	H	L	L	L	L - M	L	L	L	-	-	-
Hydro-geologist	L	M	M	H	L	L	M	L - M	L - M	L	L	M	L
Mining Engineer	L	H	H	H	L	H	M	M - H	M	H	L	L	-
Tailings Engineer	-	L	H	H	L	L	L	M - H	M - H	L	L	L	-
Geotechnical Engineer	L	H	M	M	L	-	H	L - M	M	H	L	M	M
Closure Designer	-	M	L	H	L	-	L	H	L	L	L	M	M
Reclamation Specialist	-	L	L	H	L	-	-	L	M	H	H	L	L
Vegetation Ecologist	-	-	L	M	L	-	-	L	L	H	H	L	L
Process Engineer	-	-	L	M	L	-	-	L	-	-	L	-	-
Hydrologist	-	-	M	H	L	-	-	L	L	L - M	L	M	M
Geochemist	L	L - M	L	M	-	L	L	L	-	-	M	L	L
Limnologist	-	-	L	H	L	-	-	L	L	L	H	H	H
Aquatic Biologist	-	-	-	H	L	-	-	L	L	-	L	H	H
Toxicologist	-	-	-	H	L	-	-	L	L	-	H	H	H
Wildlife Biologist	-	-	-	H	L	-	-	L	L	-	L	L	M

7.1.3 EPL Design Stages

While some smaller EPLs are expected in oil sands closure schemes, many are expected to have relatively large water surface areas, in the order of several square kilometres. Additionally, when landforms forming the boundaries of the EPLs are included the "footprint" of the overall integrated lake design can be significantly larger than the water surface area due to the width of the base of those landforms. "Integrated EPL design" in the context of this chapter refers to the entirety of the EPL water body, bottom of the lake, and bounding landforms as opposed to the smaller scale EPL landform element design, which focuses on individual landform components of an EPL.

Mine operations covering the large footprint area of the integrated EPL are expected to occur over a span of several years, exceeding the timeframe typically considered by short-range planning groups who will be the construction managers for most of the lake landforms. However, the successful development of an EPL requires that the integrated lake design be considered as a whole. Therefore, it is necessary to complete bigger-picture, integrated EPL designs which then form the context for more detailed design and construction of individual component landform elements. In essence, integrated EPL designs are created by zooming out so that the EPL, and the EPL watershed, can be considered as a whole. This level of design work is typically done conceptually during pre-production activities as part of the ERCB Application/EIA and periodically thereafter in more detail to test new approaches, incorporate new findings, or prepare regulatory submissions.

In the example schedule shown in Table 7-2, integrated EPL design work is shown for years T-6/7, T8, T18, T28, and T38 to represent EPL designs completed for initial project application, EPEA approval renewal applications, and the final design to support EPL commissioning activities. Throughout this progression, it is expected that the amount of information available to support the design work and the level of detail incorporated into the design would increase.

While the integrated design described above is needed to ensure that the EPL and supporting watershed will achieve the required performance, that level of design does not provide adequate levels of detail to support construction of individual EPL landforms. For that purpose more detailed designs are typically completed as part of the mandate of long-range and short-range planning and design teams. Designs for individual mine waste dumps, temporary in-pit dams, pit walls, and other landforms that would ultimately form a part of the EPL are normally done to support construction activities scheduled to occur in the relative near term. For example, detailed designs might be done to support construction activity planned for the next 1 to 3 years.

It is noteworthy that landforms may have a different function and design purpose during the operating life of the mine than they assume in the closure landscape. For example, temporary in-pit dams may be constructed to contain in-pit tailings while enabling mine operations to continue in the same pit as shown in Figure 7-1. For the geotechnical designers and construction managers these structures are "dams" during the operating life of the mine and must be designed and constructed as such. However, in the closure landscape, because these same landforms are contained wholly within the pit and because hydraulic gradients across the structures have been negated, they are no longer considered to be dams. Rather, they simply become a part of the integrated EPL landform.

Some examples of EPL design activities are provided in Table 7-6.

Table 7-6: Example of EPL design activities.

Activity (Timing)	Impacts
EPL conceptual design (T-7 to T-6)	ERCB Application and EIA level of design. See the Pre-feasibility and EIA complication entry in Table 7-3 for details.
Preliminary engineering design (T8, T18, T28)	Similar in scope to EIA level of design but includes updated inputs for EPL modelling such as project specific process water characteristics and solute decay rates. Also includes updated input data from ongoing regional and site specific monitoring programs. Inclusion of a failure modes and effects analysis (FMEA) is recommended. Typically would be completed and/or updated each time an EPEA approval renewal application is prepared or to assess major project changes that are contemplated. See Section 9.5 for additional details.
Permit level design (T38)	Scope expanded from Preliminary Engineering Design stage. Includes detailed integrated EPL design, land use goals, site investigations, detailed analyses, performance predictions, and commissioning schedules and budgets. Discussions of adaptive management plans/possibilities and FMEA are also recommended. See Appendix D for additional details.
EPL landform element construction design (T14 to T19 and T28 to T41)	The example schedule shown in Table 7-2 includes EPL landform design in the middle and later years of mine production. This reflects the common need for detailed designs for in-pit dumps, dykes, and/or pit walls that may form one or more sides of the final EPL landform relatively early in the mine production period. Then, after mining in non-EPL areas for a number of years (shown as T26 to T33) mining returns to the EPL area at which time detailed designs for new EPL landform elements are needed. Detailed designs would typically be based on detailed site investigations and would include construction drawings to guide day to day construction activities. See Chapter 8 for more details regarding design issues and practices for the landform elements.

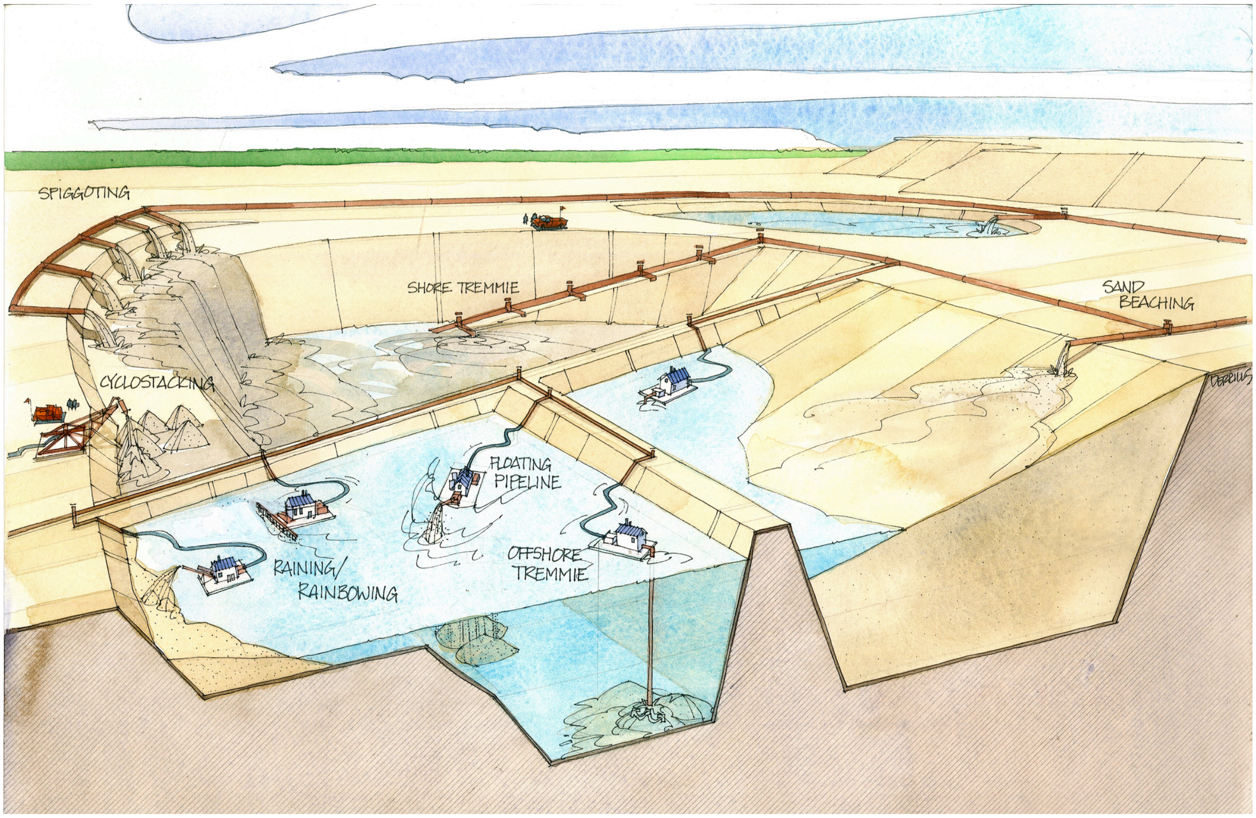

Figure 7-1: Temporary in-pit dams may be constructed while enabling mine operations to continue.

7.1.4 Mine Operations

The preceding sections described some planning and design activities that are expected to influence and be influenced by EPL design and performance. Table 7-7 describes example mine operations activities that exert or are subject to similar influences. This includes activities such as drilling, mining, and landform construction. Environmental monitoring activities that would be done in parallel with mining activities are covered separately in Section 9.6.

The commencement of construction activities is where the "rubber hits the road," literally. New geological, geotechnical, and geochemical data acquired from annual/periodic drilling programs and process-water monitoring programs feed into mine plan and EPL design refinements. Mining activities commence and new groups of people including mine, tailings, and extraction operations staff get involved, creating an engineering/science-operations interface that must be managed successfully as part of the EPL project. Landforms, first in the ex-pit areas and then in in-pit areas, are created as part of mine waste and tailings disposal operations. Large-scale specialized EPL earthworks such as future islands in the EPL that would not typically be constructed as part of mine operations are also constructed during mine operations.

Throughout the operations portion of the EPL project timeline, satisfying EPL objectives and requirements — while dealing with an ongoing barrage of new information, misinformation, and operational pressures — is indeed challenging. Clarity regarding objectives and requirements and a good understanding of integrated design requirements and options are required to equip the various teams to navigate the active mining period to successful EPL project conclusion.

Table 7-7: Example of mine operations activities.

Activity	Impacts
Infill resource and mine waste drilling and geological model updates (T1 to T39)	From the first year until almost the last year of mine production annual drilling programs and geological model updates are normally completed. Geological model updates refine the interpretation of the oil sands resource, mine waste characteristics, and geological structure within the project development area. If needed, geochemical testing of the mine waste materials can be completed to confirm attributes with respect to presence and mobility of materials that may add to the solute loading expected for the EPL. Also, the addition of infill drilling can result in re-interpretation and change of ultimate mining limits in a way that may affect the EPL configuration.
Geotechnical drilling (Periodically from T2 to T35)	In addition to the resource and mine waste drilling described above, mine operators periodically conduct geotechnical drilling programs and other site investigations to refine the interpretation of geological structure, vertical and lateral distribution of geotechnically sensitive materials, and material properties with respect to geotechnical analysis and design practices. These programs typically occur on an as-needed basis rather than on an annual basis. Updates to interpretations regarding distribution and performance of geotechnically sensitive materials can result in changes to EPL landform design in terms of slopes, final elevations, erosion resistance, etc. Larger scale changes could occur if updated information leads to shortages in construction material and significant re-designs of the integrated EPL.
Overburden and ore mining (T-2 to T42)	Typically, overburden excavation commences 2 to 4 years ahead of “first oil” to enable construction of pre-production earthworks and exposure of the ore. At the end of mining the overburden is typically exhausted a year or two before the ore. At that time the only available mine waste from the mining operations comes from oil sands interburden and the quantities available are often relatively small. This reduction in material supply may come at a critical time for EPL landform construction and final commissioning activities. Careful scheduling of mine waste placement in the final years of operations may be required to maximize littoral and riparian zone effectiveness and to ensure EPL landform stability. See Chapter 8 (Design) and 9 (Construction) for more detailed guidance regarding final EPL landform construction. An ore production life of 42 years is assumed in the example schedule shown in Table 7-2. There is typically a ramp-up period of increasing annual ore production rates in the first 3 to 6 years of a mine and a corresponding ramp down in production rate toward the end of a mine life. When ore is produced so too is process-affected water and tailings. These can be important details when considering the ultimate contents of EPLs and how to complete construction of the EPL landforms. Significant scheduling issues can arise at the end-of-mine life related to disposal of final tailings production volumes, transfer and/or treatment of fluid tailings inventories, placement of capping material on tailings deposits, placement of reclamation materials, and commissioning of the EPLs.
Watershed dyke and dump construction and reclamation (T-2 to T21 and T28 to T35)	During the initial years of mining at a greenfield site, mine waste and tailings must be placed in ex-pit storage areas. This practice is often discontinued or diminished in scale once sufficient in-pit space becomes available to allow placement of those material in-pit. However, ex-pit waste placement can continue for the life of the mine or can resume for some future period, as represented in Table 7-2, due to site specific conditions and development strategies. Ex-pit landforms often form a significant part of the EPL watershed and run-off and seepage waters from those landforms may contribute significant solute loads to the EPL.

Activity	Impacts
In-pit dyke and/or dump construction including EPL elements (T6 to T42)	It takes a number of years at a greenfield site for a pit bottom to be exposed over sufficient area to allow in-pit placement of mine waste or tailings. Once commenced, in-pit placement may continue for the remainder of the mine life but interruptions sometimes occur due to site specific factors and development strategies. Construction of pit walls, dumps, and/or temporary dams that end up within or bordering the EPL can occur at any time during in-pit waste placement activities. However, EPL landforms tend to be created in the mid-late mining years. In the example schedule shown in Table 7-2, the bulk of shoreline landforms would be created in year T26, when an in-pit mine waste dump might reach final elevation and in the final years of mining, years T38 to T42. Note that this activity refers to the construction of the bulk of the landform that will ultimately be incorporated into the EPL. Fine-tuning of this landform is expected to occur later as described for EPL commissioning below and in Chapter 9. Construction of EPL landform elements is indicated by an “L” in Table 7-2.
Creation of specialized EPL landforms (T 22 to T27 and T36 to T41)	Some of the large-scale landforms that may be included in EPL designs for erosion control, seepage reduction, shoreline diversity, etc., would not typically be built as a part of “normal” mining operations. However, the scale of such features (islands, breakwaters, seepage blankets, etc.) may dictate that they be constructed as part of the mining operations in the affected area rather than leaving them to be constructed as retrofits during EPL commissioning. See Chapters 8 and 9 for more discussion of specialized EPL landforms and commissioning activities.

7.1.5 EPL Commissioning

As mining operations draw to a close and the footprint of the planned EPL becomes available for the final earthworks required by the EPL design, it is expected that responsibility for EPL work would pass to the Closure Team and focus would shift to construction-EPL-specific design elements and establishment of lake management systems.

Construction of the EPL earthworks could be viewed as analogous to construction of a house. The rough-in earthworks constructed as part of mining operations would correspond to the framing of a house. Regrading of the EPL landforms to establish the slopes and shoreline elevations required for reclamation and establishment of the inlets and outlets would be similar to cladding, roofing, wiring, and plumbing the house. EPL shoreline finishing, including establishing littoral zone micro-contours and placement of specialized materials in littoral and riparian areas to enhance biological function of the lake would be akin to the finish carpentry in a house. While the framing of the EPL during mining operations is certainly necessary (without it there could be no lake), it is the attention to detail in the finishing stages that makes the house (or lake) attractive to the inhabitants and liveable. Design, selection of materials, and quality of construction are all critical to award-winning construction of a dream house and so it is expected to be with construction of oil sands EPLs.

At the EPL commissioning stage the final earthworks would be completed, infrastructure necessary for operation and monitoring of lake would be installed, and the lake would be filled with water. It is expected that the quality of the work undertaken at this stage of EPL development will be the most critical to the long-term success of the EPL as it will set the initial chemical and biological conditions in the lake and establish the foundations necessary to achieve the required development trajectories for the in-lake processes described in Chapter 6. Table 7-8 provides some examples of EPL commissioning activities (See also Chapter 9).

Table 7-8: Example of EPL commissioning activities.

Activity	Impacts
Collection and analysis of EPL as-built and planning/design of final EPL construction (T37)	Near the end-of-mining operations the responsibility for planning, design, and construction of the EPL passes to the Closure Team as described previously. This team will need to collect as-built information for the EPL and for any landforms constructed along planned inlets and outlets to enable design and planning of any work that remains to be done to construct the EPL. The as-built information will also be needed to support regulatory applications for the permit level EPL design as well as abandonment and certification approvals. Operators should note that collection of survey information during mine operations to support this work may exceed that required for normal mining operations. However, collection of the survey information will ultimately be less costly than such activities as drilling to determine the locations of boundaries between in-situ pit walls and dumps that may have been placed against the pit walls.
EPL landform re-grading (T38 to T43)	The bulk of landforms comprising the ultimate integrated EPL would be constructed as part of normal mining operations with consideration for integrated EPL design requirements but not focused solely on EPL construction. These landforms would include pit walls, dumps, and temporary dams. However, it is likely that the slopes and elevations of these landforms will not meet EPL design requirements exactly as they will be built before the permit-level EPL design is completed. Therefore, a significant amount of landform regrading will likely be required to trim slopes, establish contours that support closure drainage patterns, and set elevations of such critical features as littoral zones. Because deposition of materials trimmed by dozers into fluids could create unstable landforms and because operational safety could be compromised in such situations it is recommended that such work occur before filling of the lake commences. See Chapter 9 for additional details regarding EPL landform regrading.
Tailings placement in EPL (T38 to T45)	Several EPLs that have been proposed by oil sands mining project proponents and operators have been envisioned as final repositories for mature fine tailings (MFT) or other tailings in the reclaimed landscape. Generally this concept has involved storage of MFT in operational tailings ponds during mine operations and transfer of the final MFT inventory into the bottom of the EPL prior to placement of water cap. As an alternative, it is possible that an in-pit area could be used as part of the active tailings disposal and water recycle system during mine operations with the result that MFT inventory may already be in place in the EPL area and water capping could take place without MFT transfer. It has been assumed for the example schedule shown in Table 7-2 that MFT would be placed in the EPL and that transfer of MFT is shown from T38 to T45. This could occur earlier in some cases, depending on the timing for exposure of the pit floor and walls in the planned EPL area. However, mine planning considerations tend to drive the transfer of MFT in the final years of mining and beyond (as discussed in Section 7.2 on Drivers).
EPL shoreline and littoral zone finishing (T26 and T38 to T42)	After EPL landforms are "roughed-in" as part of mining operations and re-graded to the slopes and elevations required by the Permit level design, commissioning efforts should be focused on final EPL shoreline construction. This will include final contouring of EPL shoreline elements to create the foundation for littoral and riparian zones and placement of reclamation materials as required for these zones. Erosion protection, dressing of EPL shorelines with material beneficial to aquatic and riparian organisms (e.g., gravels, cobbles), placement of woody debris, etc will occur during the indicated period. If possible, completion of some of this work earlier in the mine life may be beneficial. For example, establishment of riparian vegetation early may provide benefits in terms of erosion resistance and could avoid issues associated with establishment of riparian vegetation at a potentially high energy lake boundary. Early completion of work may also enable the operator to take advantage of readily available waste material during mine operations versus re-handling options after mining has been completed. See Chapter 9 for additional information regarding EPL shoreline finishing issues and activities.
Construction of surface water inlets and outlets	As described in Chapters 8 and 9, outlet design and construction will be critical to the success of the EPL both in terms of its geotechnical integrity and ecological function. Soon after mining

Activity	Impacts
(T42 to T45 and T50)	operations conclude it is expected that EPL inlets and outlets will be constructed so that surface water from the EPL watershed can be directed to the EPL to assist in filling and to facilitate maturation of the inlets in terms of vegetation growth and geomorphology (T42 to T45). The outlet must also be constructed prior to the completion of filling of the EPL to ready the lake for water release. Construction of the outlet is shown to occur at T50 in the example schedule provided in Table 7-2. However, it may be beneficial to construct the outlet earlier to enable establishment of vegetation on outlet slopes. See Chapters 8 and 9 for additional information about issues and design requirements for inlets and outlets.
Connection of undisturbed and reclaimed landscape surface water flows into EPL (T44 to T45)	Inflow of surface water to the EPL is expected to provide some of the water required for filling the EPL in many cases. In the example schedule shown in Table 7-2 the connection of surface water inlets to the EPL has been shown to occur in years T44/45. Selection of surface water sources to be connected to the EPL and the timing for that connection would form a part of the closure drainage plan for the site. For streams containing significant solute loads, an operator may wish to consider water treatment prior to discharge into the EPL to minimize the volume of water that must be treated in the lake.
EPL water filling (T44 to T53)	After re-grading of the EPL landforms and transfer of any MFT planned for the bottom of the EPL, filling of the remaining lake volume would take place. The water used for lake filling could be from several sources including process affected water inventory (some of which could be transferred with MFT), water pumped from the Athabasca River, and surface and groundwater sources within the EPL watershed. During this stage the EPL is expected to function as a bioreactor. The length of time required for filling the lake would be based on considerations such as lake volume, available raw water supply volumes, and the trajectory of the EPL water quality. Ideally, by the time the lake was filled the water would be suitable for release to the receiving environment.
Operational infrastructure construction (T44 to T47)	During re-grading and reclamation operations and as filling of the EPL nears completion it will be necessary to install the infrastructure necessary for active use of the EPL. This could include roads, boat launches, electricity sources, etc. Establishment of EPL monitoring systems would be one of the critical operational management activities at this time. See Section 9.4 for details regarding operational infrastructure requirements.

7.1.6 EPL Operations, Maintenance, and Certification

After the EPL is commissioned it is expected that a period of active lake management will occur that will last several years to several decades. During this period access to the lake will be controlled, water quality will be actively manipulated if necessary, earthworks will be maintained, initial water release will commence, and regulatory certification will occur. The lake shoreline, inflows to the lake, and in-lake processes are expected to undergo changes during this period and a wealth of monitoring data will be collected and interpreted. If necessary, changes will be made to adjust earthworks and in-lake processes to ensure the lake continues to proceed along the desired physical, chemical, and biological development trajectories.

Table 7-9 provides some examples of EPL operations, maintenance, and certification activities. Chapter 9 discusses EPL operations in greater detail.

Table 7-9: Example of EPL operations activities

Activity	Impacts
Water treatment plant design and construction (T50 to T53)	It is possible that passive water treatment processes established during the filling period will be adequate to enable water release without actively treating the water first. However, active water treatment may be required. It is expected that both the need for and type(s) of treatment needed would be highly project specific. Additionally, operators may have options regarding the selection of streams to be treated including EPL inlet streams, the EPL water body itself, or outlet streams. See Chapter 9 for discussion of water treatment issues and options.
Control of access, water levels, and inlet water quality (T48 to T81)	Once the EPL is commissioned it will likely be necessary to manage it for a significant period of time. This management will include controlling access to the lake (including lake inlets and outlets), potential treatment of inlet streams, and potential manipulation of lake water levels if maintenance on lake or outlet earthworks are required.
Maintenance of shorelines, littoral zones, inlets, and outlets (T44 to T49)	Reclaimed landforms often require some form of small scale maintenance for a period of time after initial reclamation to repair gullies, patches bare of vegetation, beaver disturbances, etc. The same is expected to be true of EPL landforms after the final grading, placement of reclamation materials and any specialized littoral-riparian area substrate materials that may be required. See Chapter 9 for more detailed discussion of landform issues and potential repairs that may be required for EPL landforms.
Added solute from reclaimed landscape groundwater sources (periodically T44 until after certification granted)	As mining operations wind down it is expected that groundwater levels and flow regimes would begin to re-establish as dewatering effort was reduced. Groundwater inflows to the EPL may commence soon after mining is completed; some groundwater sources may not appear for many years due to slow groundwater movement rates as described in Chapter 5. While groundwater inflows to EPLs may be relatively minor on a total volume basis, the potentially high solute concentrations in some groundwater inflows may contribute significantly to total EPL loading. In the example schedule shown in Table 7-2, the addition of groundwater sources to the EPL are shown to start in about year 44 and to occur periodically thereafter. Due to the long time frames expected before regional groundwater regimes stabilize, it may be desirable in some cases to consider EPL certification prior to the addition of all long-term groundwater inflow streams to the EPL. However, such scenarios should be assessed on a case-by-case basis to determine potential impacts of future groundwater inflows to the EPL and a precautionary approach is advisable.
Re-establishment of regional long-term groundwater (T46 onward)	Groundwater levels and flow patterns within the oil sands surface mining area are affected by individual operators dewatering programs for their mines. However, dewatering activities by other operators may also affect groundwater levels and flow patterns within the region, potentially extending the time required before post mining groundwater levels and patterns reach natural levels. The state of groundwater and expected trajectories for groundwater system recovery should be considered when assessing EPL performance trajectories and any certification efforts.
Initial water release phase (T54 to T71)	Long-term operation of a “terminal EPL” is thought to be undesirable due to potential build-up of chemical constituents in the lake caused by lake evaporation. Therefore, establishment of outlets and outflow from the lake relatively soon after commissioning is desirable, after treatment of the outflow if necessary. In the example schedule shown in Table 7-2 initial water release is shown to be occur from T54 to T71. However, the appropriate timing of initial release would have to be established for each case based on filling schedule and EPL water quality monitoring results.

Activity	Impacts
Construction of final land use infrastructure (T58 to T61)	The end land uses targeted for the EPL will form a part of the permit-level design of the EPL and ultimately will be a significant part of the application for certification of the EPL. If the planned/approved end-land uses for the EPL require infrastructure such as access roads, pathways, or boat launches, then they would be constructed either during commissioning (as part of efforts to establish operational infrastructure) or later in project life as indicated in the example schedule shown in Table 7-2. See Chapter 9 for additional information regarding final land use infrastructure.
Certification qualification phase (T72 to T81)	It is expected that a significant monitoring record will have to be established for the EPL and the outflow receiving environment to form the basis for an application for certification. A part of this record should be based on outflows without water treatment to confirm that long-term active maintenance of water quality in the EPL is not required. The intent would be to allow water release without active treatment so that water and sediment quality and any effects on aquatic life in the receiving watercourses could be monitored. Note that if unacceptable effects were evident then active water treatment operations could be resumed and certification deferred until water quality improved.
EPL abandonment and certification approval processes (T78 to T81)	Regulatory processes to obtain EPL abandonment approval (ERCB) and reclamation certificate (AENV). See Chapter 9 for discussion of Abandonment and Certification processes.
CERTIFIED (T82)	Long-term maintenance-free EPL with self-sustaining ecosystem. Land returned to Crown and land uses managed by AESRD as the provincial manager of Crown lands.

7.1.7 EPL Modelling Activities

To be considered "feasible," an EPL design and associated mine and closure plan must pass at least four fundamental tests. It must:

- Be feasible to construct within the constraints imposed by the mine and tailings planning drivers;
- Be based on sound geotechnical engineering practices and ecological principles;
- Have a basin water yield that generates sustainable flows through the lake;
- Lead to acceptable EPL performance in terms of water quality and biological productivity.

Testing EPL schemes can therefore be considered a cyclical and interdisciplinary process. This process often starts with mine planners completing life-of-mine plans and initial evaluations of feasibility based on rules of thumb regarding conceptual landform designs and EPL-watershed relationships. Once the planning options have been reduced to a manageable number on the basis of feasibility from the perspective of mining drivers, the plans can be tested for geotechnical soundness. The options that pass on both a mine planning and a geotechnical basis can then be tested from the feasibility of closure drainage design perspective. Options that appear feasible on all three fronts can then be evaluated based on whatever selection criteria the operator chooses. If no options are feasible, or if infeasible options could be made feasible by adjusting mine planning or geotechnical design details, then the process could be repeated until acceptable options are identified and passed on to selection/decision processes. This design-planning-evaluation-repeat cyclical process is standard practice in many oil sands design processes and is described in more detail in Chapter 9 and Appendix D.

A challenge associated with EPLs is that the ability to evaluate results of planning, design and construction activities through monitoring will often not be possible until long after those activities have been completed. Therefore, a different form of evaluation of the closure drainage component of the testing described above is required. Numerical modelling as described in Section 9.5 typically fills this gap. Hydrological and EPL modelling early in the project development timeline, when input data may be scarce in some regards, can be accomplished using appropriately conservative parameters. Then, as mine development proceeds and additional data are acquired, the numerical models can be refined. If at any time EPL models predict unacceptable performance from EPLs, that information can be used to re-initiate the EPL planning-design-evaluation process to remedy the indicated problem. The key is diligent pursuit of the required data through monitoring (including monitoring of other operator's EPLs, fisheries compensation lakes, and the local and regional external environment), research, and frequent modelling to ensure early identification of any unacceptable EPL performance predictions. That will enable EPL design adjustments to be incorporated into plans as early as possible. Due to uncertainties related to model input parameters and current inability to calibrate models as described in Section 9.5, a precautionary approach is recommended for model creation and for interpretation of modelling results.

In the example schedule shown in Table 7-2, EPL modelling occurs during pre-production years, intermittently throughout the mine production life, and annually during the filling stage and water release stages until certification. Modelling on a more frequent basis may be warranted in specific cases.

Table 7-10 describes some modelling activities that are expected over the course of the project life. Section 9.5 provides additional details regarding modelling.

Table 7-10: Example of EPL modelling activities

Activity	Impacts
Gather modelling input data (T-10 to T-6)	Most data are collected during this stage as part of baseline data collection for the EIA. Baseline data are collected for the flows and chemistry of natural lakes and streams near the project area. Other EPL model input data consist of anticipated process affected water chemistry and runoff from reclaimed areas. These data are generally derived from similar operations. Although this entry in the example schedule is largely a component of the EIA baseline data collection described in the Pre-Production Activities section, it is included in the modelling section of the schedule to collect all modelling activities into one easy to reference location.
Refine modelling input data from additional testing and monitoring (periodically T4 to T74)	Initially, EPL models completed for mining projects would be based on available input data. Then, as mine operations start, data regarding the project specific process water characteristics would be acquired and added to model inputs. Other model updates would also be completed when warranted by the addition of significant data. It is expected that new data could be acquired from research activities, site specific studies, monitoring activities, or learnings from other mine operator's EPL experiences. The example schedule shown in Table 7-2 shows updates to model input data occurring periodically from T4 to T74. It is envisioned that significant updates to input data could be

Activity	Impacts
	warranted in the early years of operations (~T4-T8) after the new mine and plant reaches stable operation and produces representative tailings and other waste streams. This updated input data could then be used for EPL modelling in support of EPEA licence renewal applications in about year 9 to 10 or 19 to 20 of the operations. Periods of initial EPL filling and initial water release would also be expected to produce significant monitoring results that should be incorporated into EPL modelling input data.
Preliminary stage modelling (T-9)	Typically based on limited project specific information regarding EPL inflow volumes and chemistry with use of surrogate information from other operations. Only key variables can be evaluated at this stage and only at a high level. Key questions related to EPL feasibility can be answered as described in Section 9.5 but EPL design optimization at this stage is generally not warranted due to scarcity of data and level of detail of models.
EIA stage (T-6 to T-4)	The objective of EPL modelling at EIA stage is to predict concentrations of constituents to enable completion of aquatic, wildlife, and human health risk assessments as described in Section 9.5. Modelling may be done using 1D, 2D, and 3D hydrodynamic models and many variables are typically evaluated. A significant source of uncertainty in models done at the EIA stage arises from the lack of information about project-specific EPL inflow water volume and chemistry. This uncertainty is often managed by using conservative model input parameters or through operator commitments to mitigate negative impacts from EPLs.
Operational stage (periodically T8 to T38)	EPL modelling during the operation of the mine would benefit from the addition of information about the project process water chemistry. Models would typically be created that are similar to those used during the EIA stage evaluations but updated to incorporate information about process water chemistry and other updated regional or site-specific input data. The primary goals of modelling during operations would be to confirm expected EPL trajectories and to feed back required changes to the EPL planning and design teams if necessary as described in Section 9.5.
Filling, Initial Release and Certification stages (T42 to T77)	The example schedule shown in Table 7-2 shows EPL filling and initial release of water occurring from T42 to T77. During this period, models would be calibrated to observed behavior in the EPL as described in Section 9.5.2. Modelling in this period should commence as soon as a water column develops and should continue at least until a reclamation certificate is obtained.

7.1.8 EPL, Watershed, and Aquatic Receptors Monitoring Activities

Monitoring of the natural watercourses in the oil sands region, coupled with site-specific EPL related monitoring, are expected to provide significant feedback to inform EPL planning, design, and certification processes. Monitoring activities are expected to occur each year over the life of the project as shown in the schedule in Table 7-2. Table 7-11 provides a brief summary of EPL-related monitoring activities with indicated timing consistent with the example schedule. Monitoring activities are described in more detail in Section 9.6.

Table 7-11: Examples of EPL-related monitoring activities

Activity	Impacts
Regional aquatics monitoring program (T-10 to post-certification)	Long-term regional monitoring programs typically provide some of the data required to establish pre-project baseline conditions during the pre-production period of a project. Continuation of such regional monitoring programs as RAMP and Alberta Environment's Long Term Monitoring Network through the life of the oil sands mining industry is expected and ongoing contributions of monitoring results from this important data source is expected to beneficially supplement project specific EPL monitoring programs.
Aquatic baseline information collection for project (T-10 to T-8)	Site-specific aquatic baseline information collection is generally done as part of the EIA baseline data collection program. This data collection forms some of the earliest "monitoring" related to the environment within which EPLs will be set.
Operational stage (T0 to T42)	As described in Section 9.6, the primary focus of monitoring during the operational life of the mine should be to confirm the inputs to the lake will be similar to what was predicted in the EIA, to refine model inputs and assumptions where conditions deviate from expectations, and to evaluate the suitability of various water sources as inputs to the EPL. Monitoring during operations and feedback of observations to EPL modelling and EPL and closure design teams is an important feedback cycle that enables adjustment of mine and closure plans if necessary to optimize EPL design.
Filling stage (T44 to T53)	The primary objectives of monitoring during EPL filling are to confirm that EPL waters are following a desired trajectory. Additional information regarding recommended monitoring approaches is described in that section.
Initial release stage (T54 to T81)	The release of water from the EPL is expected to bring increased focus on monitoring of the receiving environment to confirm acceptable response to release of the EPL water. The length of time required to establish whether there are any significant impacts to the receiving environment and to demonstrate that the EPL is functioning as a self-sustaining system is not certain. The example schedule in Table 7-2 shows this period as a relatively long one, from T54 to T81. However, it is possible that the period could be significantly shorter or longer, depending on site specific factors. See Section 9.6.1 for additional details regarding monitoring during the initial release stage.
Certification stage (post-certification)	It is not known whether monitoring will continue beyond certification of EPLs. It is understood that certification of an EPL removes both the responsibility and the authority of the mining company with respect to the EPL. Therefore, it is likely that decisions as to whether monitoring programs related to EPLs would continue beyond certification, and the funding obligations for any such programs, would fall to the responsible government authorities.

7.2 Planning Drivers

Many issues must be managed effectively as part of planning an oil sands mining project. These include considerations for technical mining issues, economics, environmental issues, and regulatory issues. Issues related to process plant design and operation will not be discussed as they do not involve EPL design and performance. The following sections first provide an overview of mine planning tasks and then describe some issues that tend to act as drivers for mine plans, at times exerting strong influences that can be either consistent with or contrary to optimum EPL design and construction strategies. Trade-offs and compromises are often necessary to manage conflicting goals.

7.2.1 Overview of Oil Sands Mine Planning Tasks

Oil sands mine planning areas of focus typically vary according to the stage of the project. In the pre-approval stage, the focus is generally on establishing the overall layout of the mine and required ex-pit facilities, general approach to mining, the technology selections, and the technical feasibility of the project. Specific tasks include evaluation and selection of:

- Mine opening location
- Plant site location
- Annual production rates
- Mining sequence
- Ex-pit and in-pit tailings area locations and conceptual design
- Ex-pit and in-pit mine waste dump locations and conceptual design
- Mine waste and tailings annual disposal schedules (material balance)
- Mining technology
- Tailings technology
- Crusher and ore processing plant (OPP) locations and relocation strategy
- Final landform configuration to accommodate required closure drainage patterns (including EPLs and the plans of adjacent operators)

In the post-approval, but pre-production stage, tasks include optimization of the work done in the pre-approval stage while incorporating any requirements imposed on the project by regulatory approvals. Refinement of cost estimates to confirm economic feasibility of the project is a key task performed at this stage. If the economic feasibility is confirmed and the operator decides to proceed with the project, then detailed design work on plant facilities and early earthworks (e.g., ex-pit tailings area) is done during this stage of the project. Construction project management then becomes the focus to ensure completion of the early earthworks required to support production of first oil.

During mine operations, the focus of planning changes from evaluation of major project components and project feasibility to mine plan optimization and operational support. Plan optimization includes annual re-evaluation of:

- Annual production rates
- Mining sequence
- Ex-pit and in-pit tailings area conceptual and/or preliminary engineering designs

- Ex-pit and in-pit mine waste dump locations and conceptual and/or preliminary engineering designs
- Mine waste and tailings annual disposal schedules (material balance)

Operational support includes:

- Preparation of short-range production plans (daily, weekly, and monthly as needed). Detailed engineering designs complete with construction drawings for tailings areas and/or waste dumps to be constructed within the short range planning time horizon
- Interface with operational staff to ensure adequate engineering support for field activities
- Budget preparation
- Many other varied tasks as required to complete final optimization of plans and operating procedures

In addition to the consistently repeating tasks described above, major project components may be re-evaluated periodically to test new technologies, respond to changes in geological interpretations, and to increasing knowledge from operations, scientific/engineering studies, monitoring programs, and other data sources. For example, design changes for tailings impoundments or mine waste dumps may have to be incorporated into plans in accordance with the observational approach commonly used in oil sands geotechnical practice (see Chapter 8 for discussion of the observational approach). Changing stakeholder perspectives and regulatory requirements can also cause re-evaluations of project components. These re-evaluations could include such project components as:

- Mining technology
- Tailings technology
- Crusher and ore processing plant (OPP) relocation strategy
- Final landform configuration to accommodate required closure drainage patterns (including EPLs)

Throughout the course of the planning work described above, the level of detail of the evaluations tends to follow a pattern that includes evaluation of a large number of options at the conceptual level, a smaller number of options at the preliminary engineering design level, and one option at the detailed design level. Conceptual designs/plans in this context are those that can be done by an experienced mining generalist using rules of thumb that may be taken from a number of areas of specialization (e.g., geotechnical engineering, economics, environmental sciences, etc). Similarly, preliminary engineering designs in this context refer to designs/plans that are typically done by individuals with formal training in their respective disciplines on the basis of experience and regionally representative design parameters. Detailed designs/plans would be based on site-specific conditions and would typically be completed and reviewed by qualified individuals from the respective disciplines.

7.2.2 Technical Mine and Tailings Plan Drivers

Similar to many large-scale mining projects around the world, oil sands mines are relatively complex projects of long duration requiring integration of many technical disciplines for planning, design, and execution phases of the project. However, while many of the issues faced by other parts of the industry are common with those faced by oil sands miners, the degree to which those issues drive the mine and tailings plans in oil sands mining tend to be more common and predictable across the oil sands industry than across the mining industry in general. Because of the similar climate, geographical setting, geological setting, and assemblage of stakeholders, one oil sands mine is likely to have much more in common with another oil sands mine than with, for example, large copper mines in the mountains of South America, gold mines in Africa, or coal mines in Australia. Therefore, the following discussion of technical mine and tailings plan drivers is focused on oil sands mining to provide some insights into some technical mining issues that may affect oil sands mine EPL design and construction. Nevertheless, readers should recognize that there is much to be learned from the experience gained at non-oil sands mining operations in terms of potential application to oil sands mining and EPL construction. Chapter 3 provides some insights into issues, successes, and failures in EPL design and construction in other parts of the mining industry.

Over the life of the project, the teams responsible for EPLs will be forced to complete their work within the context of pressures exerted by other mine and tailings planning drivers. At many times, those drivers may cause operations staff to consider a course of action that could be detrimental to the long-term success of the EPL(s) planned for the site. For example, the creation of significant littoral areas for EPLs will typically require the placement of large volumes of mine waste or tailings sand at relatively precise elevations and perhaps to a higher specification (in terms of compaction, etc.) than would normally be done. It would be a rare coincidence indeed if a waste placement plan required for creation of littoral zones (or other EPL landforms) was identical to the most economically attractive waste placement plan. Therefore, during the construction of EPL landforms such as littoral areas, mine planners and operations staff will face conflicting priorities: minimize costs in the short term or follow EPL designs to meet long-term mine closure objectives. EPL planning teams will need to understand such drivers to work effectively with mine planners and operations staff and achieve the right balance between responses to mine plan drivers and EPL drivers.

The following sections provide examples of how some important mining and tailings technical planning drivers may affect activities related to EPLs, and suggest strategies that EPL planning teams may wish to employ to ensure continued viability of the targeted EPL scenarios. Readers should remember that the impacts of the drivers described can vary significantly from site to site. It is often the interplay of unique combinations of these drivers that creates the most challenging situations for both mine planning and for EPL planning. Due to the integrated nature of mine and tailings plans for oil sands mines, they will be collectively referred to simply as “mine plans.”

7.2.2.1 Site Geology

The geological setting within which the project is set is important for both integrated EPL design and for the design of individual EPL landform components. However, perhaps of equal importance is the degree of confidence that planners have in the geological interpretation current at the time that major project decisions are made. In most cases a problematic geological setting can be accommodated within mine plans in a manner that leads to a solid foundation for EPL design as long as those problematic conditions are known relatively early in the project life. However, the discovery of large-scale geological “surprises” later in a project life can lead to large scale changes to mining and closure plans. Depending on their exact nature, such changes have the potential to either impair or enhance EPL schedules and expected performance.

A key requirement for development of robust mine plans is that the mine planning team know the geology of the site, with a relatively high degree of confidence, at a scale suitable for the level of planning and design work to be undertaken. For an oil sands mine this knowledge should typically include:

- Ex-pit and in-pit foundation conditions
- Mine waste quality and potential for use as construction material
- Ore body characteristics such as continuity, oil sands grade, fines content, water content, and particle size distribution
- McMurray Formation facies (ore and waste grades) and the processability of the ore facies; and
- Ex-pit and in-pit aquifer conditions

7.2.2.2 Ex-pit foundation geology

External-to-the-pit (ex-pit) geology varies from site to site, from relatively impermeable and geotechnically weak material to relatively strong material with highly permeable zones and all combinations in between. An example of a relatively impermeable geological feature would be the widespread presence of Clearwater Clay formation across the sites. This scenario can sometimes offer benefits from a hydrogeological perspective because the relatively low permeability of this formation reduces the number of potential groundwater flow paths. However, geotechnically the presence of this material in ex-pit areas is challenging because of the relatively low shear strength and high pore-pressure response exhibited by this material when it is loaded. As a result, for example, an ex-pit tailings impoundment area or mine waste dump may require comparatively flat slopes, approaching 20H:1V (horizontal to vertical) in some cases, whereas the slopes may be much steeper on a more favourable foundation material, perhaps 5H:1V or even steeper. An in-between condition may exist if a significant portion of the ex-pit area is underlain by surficial clay deposits. In such conditions, slopes may range from about 8H:1V to 12:1V.

Weak ex-pit foundations tend to drive mine plans as follows:

- increased ex-pit footprint is typically required for mine waste dumps and tailings impoundments due to flat slopes and maximum height limitations;
- increased demand for construction material to accommodate wider cross-sections required for containment structures;
- increased demand for in-pit tailings and mine waste disposal capacity early in the mine life to reduce ex-pit storage requirements and the requirement to engineer above ground landforms at closure;
- increased offsets between pit crest and ex-pit tailings or mine waste storage areas;
- flatter pit slopes where the weak foundation material daylights in the excavated overburden face;

- increased use of tailings sand for dyke construction with a resulting reduction in sand available for consumption of fines using such agglomerating tailings technologies as composite tailings;
- increased capital and operating costs.

From an EPL perspective, planners should recognize that the above tendencies may result in a larger proportion of upstream watershed being comprised of mine waste and tailings deposits versus undisturbed terrain due to the increase in ex-pit footprint. Additionally, increased pressure on the construction material balance (i.e., the need to use a higher proportion of available good material) for the site may mean that it is not possible to use higher-quality mine waste to create features that may be beneficial to the planned EPL. With respect to the EPL landform itself, use of designs that maximize in-pit waste placement early in the mine life can lead to high and steep in-pit structures not suitable as EPL shorelines, and potentially challenging closure drainage patterns due to the combination of relatively steep topography and erosion-prone materials. Finally, increased use of sand to manage construction material imbalances can lead to an increased final inventory of fluid fine tailings (FFT). This may lead to an increase in FFT volume to be placed in an EPL in a water-capped FFT closure scheme.

7.2.2.3 In-pit foundation geology

As with ex-pit geology, in-pit foundation geology can vary significantly in both strength and permeability. Pit bottoms may be founded on highly competent limestone, in which case slopes for in-pit mine waste and tailings containment dykes may be steep. Alternatively, the presence of weak Paleosols (weathered limestone) or basal McMurray clays, or highly permeable watersands in the in-pit foundations, can result in the need for flatter slopes for waste structures (potentially reaching about 12H:1V) and/or seepage barriers such as cut-off walls or low permeability “seepage blankets.”

Weak or highly permeable in-pit foundations tend to drive mine plans as follows:

- increased volumes of mine waste and/or tailings in ex-pit structures leading to increased ex-pit disturbance footprint
- increased demand for construction material to accommodate wider cross-sections required for in-pit containment structures or seepage barriers
- increase in size of the EPL (both surface area and volume)
- increased use of tailings sand for dyke construction with a resulting reduction in sand available for consumption of fines using such agglomerating tailings technologies as composite tailings
- increased capital and operating costs

Several of the impacts listed above repeat those listed for weak ex-pit foundations. However, where weak ex-pit foundations might lead to a smaller EPL due to a drive to maximize in-pit waste disposal, weak in-pit foundations would tend to result in larger EPLs. This is largely due to scheduling issues related to the time when EPL footprint is exposed in the pit, the slope of in-pit landforms bordering the EPL, and the rate at which those landforms can be constructed.

Figure 7-2 shows an example of the effects of shallower in-pit structure slopes on EPL design. In this example, mine operations would progress toward the final pit wall in the final years of mining, establishing the final in-pit dump toe about 1 km from the final pit wall toe. If the EPL final depth is assumed to be 70 m, then the EPL effects of a dump slope change from 5H:1V (for good foundation) to 12H:1V for weak foundation would be a significant increase in EPL water cross-sectional area (19%) and water surface length (31%). These effects would be exaggerated if mine waste ran out before the dump was constructed to at least the EPL water level. This is one reason that the toe of the dump is offset significantly from the final pit wall, to ensure that the dump can be constructed to the required elevation before the mine waste runs out (another reason is to leave adequate space for operation of in-pit equipment fleets).

A larger EPL in terms of volume and/or surface area may be desirable depending on the requirements of the site-specific closure drainage plans. However, even if expansion of the EPL is undesirable, then EPL planning teams typically have few tools at their disposal to mitigate the effects of weak in-pit foundation materials on EPL design. Some strategies that could be considered in such cases include:

- reducing the design final water level in the EPL by constructing a deeper outlet channel or connecting to the receiving watercourse in a different (lower) location;
- avoiding placement of in-pit ore processing facilities in areas that will become part of the EPL. Offsets required from such equipment to dump or dyke toes can result in increases in the effects shown in Figure 7-2 for weak in-pit foundations; and
- examining potential EPL landform geometry carefully when planning the final mining sequences. Concave dump toes (concave toward the EPL when viewed from above) will tend to reduce the flat slope effects shown in Figure 7-2 whereas convex dump toes will tend to increase the effects.

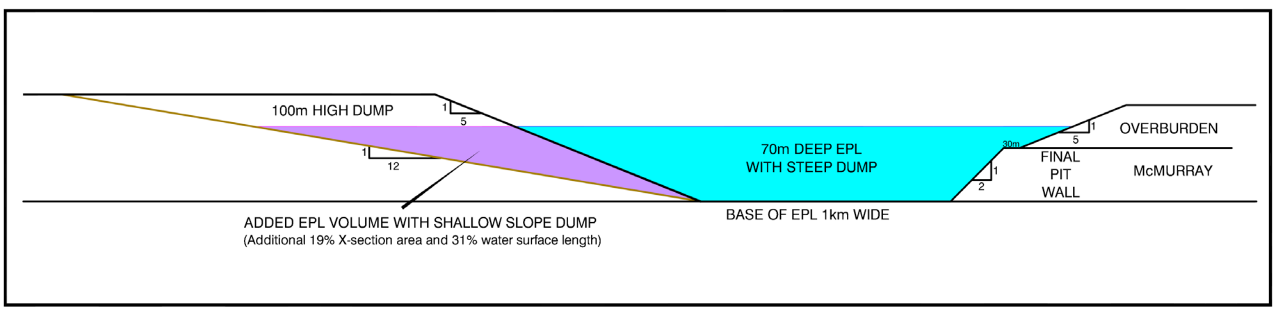

Figure 7-2: Example of in-pit foundation effects on EPL design (nts)

7.2.2.4 Mine waste quality

Oil sands mine waste includes Quaternary deposits, Clearwater Formation, top McMurray reject and center McMurray reject. Quaternary, Clearwater, and top reject materials are often referred to together as "overburden" and center reject as "interburden." Quaternary mine waste varies widely from site to site in both quality and thickness. At some oil sands mine sites little Quaternary waste can be used for construction, usually because of a combination of unfavorable lithology, grain size distribution, and moisture content. In some cases, this is true to the extent that higher-quality McMurray rejects must be used to cap quaternary dump lifts to ensure trafficability for mine trucks. In other cases, Quaternary waste may provide significant volumes of construction quality material and the need for capping of dump lifts can be almost completely avoided.

Qualities of McMurray rejects are typically less variable than those of Quaternary waste and these rejects typically comprise a large proportion of the higher specification mine waste that is used for dyke construction. However, some McMurray waste facies do not compact well and while those materials would often be expected to form trafficable dump surfaces, they cannot be used for dyke zones requiring a high degree of compaction.

The presence of extensive, poor-quality mine waste tends to drive mine plans as follows:

- increased volumes of ex-pit tailings disposal to maximize containment efficiency for the limited available construction material;
- increased ex-pit mine waste storage resulting from an effort to maximize in-pit disposal of tailings so as to maximize use of exposed final pit walls for containment;
- small increase in size of the EPL (both surface area and volume) due to use of shallower dump slopes for poor quality mine waste;
- potential scarcity of competent material for use in building stable and erosion resistant EPL shoreline landforms;
- increased use of tailings sand for dyke construction with a resulting reduction in sand available for consumption of fines using such agglomerating tailings technologies as composite tailings. This could lead to an increased final inventory of FFT which could add to the FFT to be transferred to the EPL in an FFT water-capping closure scheme; and
- the potential effects on EPL design resulting from poor mine waste quality are similar to several of those described above for poor ex-pit and in-pit foundation conditions.

7.2.2.5 Hydrogeology

During mining operations, groundwater levels must be reduced to prevent uncontrolled flow into active mining areas from surficial aquifers and to depressurize the base of the pit to ensure trafficability. However, when mining is completed and pumping from dewatering wells and sumps around the perimeter of the mine is discontinued it is expected that the groundwater levels and flow patterns will re-establish to pre-disturbance conditions, modified somewhat by the changes imposed on the closure landscape. Hydrogeological processes associated with oil sands mines are described in Chapter 5 and those processes and their effects on EPL design are highly site-specific.

Groundwater inflows to EPLs from the landscape after closure must be accounted for in EPL water quantity and quality models as described in Chapter 9. Potential groundwater pathways from the EPL to the receiving environment must also be considered as part of the integrated EPL and EPL landform element design processes. Early identification of large-scale hydrogeological patterns and potential seepage pathways in proximity to planned EPLs (whether flows are toward or away from the EPLs) is beneficial to ensure appropriate mitigation of expected seepage (if required) is accounted for in EPL designs. In some cases mitigating seepage-related issues may be relatively easy and small-scale. In others, relatively large earthworks may be required. In those cases, early identification of the issues is critical to ensure that feasible mitigation plans can be developed. Some techniques that may be employed for seepage mitigation are described in Chapter 8.

7.2.3 Ore Body Geometry

Ore-body geometry can have wide-ranging effects on the entire mine plan, including mine opening location, mining sequence, ex-pit and in-pit dump/dyke designs, tailings technology selection, and surface facilities placement. The feasibility of mine plans for a given ore-body geometry are often highly sensitive to site geology, topography, and availability of ex-pit areas for facilities and waste disposal. Typically, several life-of-mine plans must be developed and compared before the preferred strategy can be identified with confidence. EPL and closure drainage system design are important components of this work and, in some cases, can be determining factors in the strategy that is ultimately selected. For example, a mining sequence and waste placement scenario that resulted in many very positive project attributes would still be discarded if it resulted in an unsustainable closure drainage plan.

In general, ore bodies for a given oil sands mine may be comprised of two or more discrete pits, semi-discrete pits connected by relatively narrow mining corridors, or single large continuous pits. While it is difficult to speculate on EPL impacts related to ore body geometry due to the importance of other site factors in determining the appropriate mining strategy, some tendencies that may affect EPL designs related to each ore body geometry scenario are described below.

7.2.3.1 Multiple Discrete Pits

One of the basic premises regarding the need for EPLs is that they are “end” pit lakes, that is, they are formed by the excavation that is left when mining stops and there is no waste left to backfill the final excavation area. In the case of project areas comprised of multiple discrete pits, the number of EPLs ultimately formed may depend on whether multiple pits are mined sequentially (i.e., one after the other) or simultaneously. If the pits at a mine property that was comprised of more than one pit were mined sequentially, then it is possible that a single EPL could be left, since the waste from the pit(s) mined later in the project life could be used to backfill the final excavation in the preceding pit. However, for a number of reasons mining may occur in multiple pits simultaneously at the end of mine life, resulting in multiple EPLs.

For example, as mining nears completion and in-pit ore processing facilities are relocated to facilitate in-pit waste disposal, mine planners may be driven to consider mining from two or more pits during the final years of operations to avoid mobile equipment fleet congestion and over capitalization of production systems in relatively small pits. This tendency can lead to EPL challenges as multiple EPLs could be formed, one in each active pit. In some cases this can be beneficial as the extra flexibility afforded by multiple EPLs may optimize the closure drainage plans. However, in other cases it may be difficult to integrate multiple EPLs into sustainable closure drainage schemes.

For example, one or more of the EPLs may be in a location that must discharge water to a watercourse that is more sensitive to potential EPL release water quality than alternative preferred receptors. Careful allocation of mine and tailings waste streams to different available storage locations may be required in such a scenario to reduce poor water quality loading to the EPL that then discharges to the more sensitive watercourse.

7.2.3.2 Semi-Discrete Pits

Mines comprised of semi-discrete pits can provide very efficient in-pit containment of mine waste and tailings if the mining and waste disposal schedule can be manipulated to allow use of final pit walls to provide in-pit waste containment. In such a scenario, the demands on the construction material balance can be reduced and large scale in-pit tailings and mine waste placement might be accelerated. This could result in a reduction in ex-pit waste storage and a corresponding reduction in the proportion of EPL watershed area comprised of mine waste or tailings. Semi-discrete pits may also enable more efficient use of on-line fine tailings consumption processes such as composite tailings because more sand can be allocated to such processes.

In some cases, ore bodies comprised of semi-discrete pits can result in project layouts that lead to multiple EPLs similar to projects mining discrete pits. This can lead to similar EPL outcomes to those described above for discrete pits, though the reduced distances expected between semi-discrete pits compared to discrete pits should enable better integration of EPLs in the closure drainage plan.

7.2.3.3 Large Continuous Pits

Large (long and wide) continuous pits can pose challenges from the tailings containment and closure drainage planning perspectives. Such pits tend to provide the least efficient layout possibilities for tailings containment because a significant length of dyke must be constructed to contain any tailings. This tends to put pressure on the construction material balance and may lead to use of sand to supplement high quality mine waste as construction material. Use of sand for this purpose can lead to the storage of larger FFT volumes and increased FFT volume in water-capped FFT scenarios. Similarly, the potential need to wait longer before placement of in-pit tailings (due to longer in-pit dykes) tends to increase the amount of waste stored ex-pit, which increases the amount of the EPL watershed area comprised of mine waste and/or tailings. This effect can be significantly increased if the in-pit foundation of a large continuous pit is comprised of weak material.

7.2.4 Ore Quality

The term “ore quality” can be used to refer to several aspects of oil sands ore bodies. In some cases, it refers to the qualities of the ore that is sent to the extraction plant, including bitumen content, water content, fines content (fines are solid particles less than 44 μm in size), mineralogy, or connate water chemistry. In other cases, ore processability is the key attribute described in terms of ore quality, though processability is largely determined by the physical and chemical parameters referred to above and the extraction technology used at a mine. Alternatively, ore quality may refer to overall ore body quality in which case it may refer to the degree of inter-bedding of ore and waste layers or to the distribution and average waste-to-ore ratio (WOR) or total-volume to bitumen-in-place (TVBIP) ratio.

Ore quality can affect EPLs. The larger effects are associated with ore properties that strongly influence the mining sequence because the sequence greatly influences the closure landscape and EPL geometry. Secondary effects can arise from fines content, mineralogy, and chemical composition of the ore-body due to potential effects on volume of FFT to be reclaimed in water-capped EPL schemes and on process-water chemistry (both free water and water draining from tailings sand dykes). Examples of potential ore quality implications for EPLs are described below.

7.2.4.1 "Problem ore" Distribution

"Problem ores" are ores that negatively affect bitumen recovery in the extraction plant. The negative effects can include failure to recover bitumen from the ore in question at the targeted efficiency. Additionally, relatively small amounts of problem ore can "poison" the extraction process, potentially suppressing bitumen recovery from a larger mass of ore.

Two approaches used to reduce the impact of problem ores are ore blending and addition of chemical process aids. Ore blending requirements can be quite onerous to the extent that the mining sequence can be dictated by blending considerations over significant portions of the pit. This can significantly influence the closure landscape and EPL location and geometry. Use of chemical process aids to reduce the impacts of problem ores and increase extraction recovery efficiency can change process water (and tailings pore water) chemistry which could change solute loading to EPLs and affect the in-lake processes discussed in Chapter 6.

7.2.4.2 Total Volume to Bitumen in Place Ratio

The TVBIP ratio (units are m^3/m^3) is defined as the total volume of ore and waste that must be mined to recover ore divided by the total volume of bitumen in the recovered ore. This ratio is often used as an indicator of ore-body quality for oil sands mining and a cut-off value for TVBIP is often used to determine pit limits. An industry standard cut-off used to establish minimum pit crest limits was set by the Alberta Energy and Utilities Board (now ERCB) in 2001, when it indicated that it expected pit limits would be based on a TVBIP of 12 (with some flexibility possible depending on cut-off grade, selectivity, and extraction recovery performance) (EUB 2001: Interim Directive 2001-7).

An ideal pit, all other things being equal, would have the lowest TVBIP ratio early in the mine life with higher ratios left until the latter part of the mine life so that mining costs would be lowest in early years. The mine opening would typically be in the lowest TVBIP and highest grade area of the mine. However, a number of other site specific factors could interfere with that ideal mining sequence, one of which is the need to develop a feasible closure drainage plan including any EPLs required for the site in question.

7.2.4.3 Plant Feed Quality

Ore that is mined and sent to the extraction plant is referred to as "plant feed." Plant feed quality parameters typically include bitumen grade, particle size distribution, mineralogy, and chemistry. Plant feed quality can influence the mine opening location and mining sequence due to cost considerations in a manner similar to the distribution of TVBIP ratios as described above. For example, achieving plant feed grade of 11 wt% bitumen in a given year versus 10 wt% means that about 10% less ore and waste would have to be mined in that year to produce about the same amount of bitumen. It would be most advantageous from a net present cost reduction perspective to achieve this reduction as early as possible. Therefore, ore grade considerations are significant drivers of the mining sequence, and can influence the location and design of the EPL. This influence on EPL location and design arises simply because the final mining location, which is generally also the location of the EPL, and the mine waste and tailings disposal area designs are highly dependent on mine opening location and mining sequence.

Secondary impacts on EPL design and performance can arise due to plant feed fines content and chemistry, as those characteristics can influence the contents of the EPL and solute inflows. Plant feed with higher fines content, for example, may result in a larger final inventory of FFT to be placed in the EPL as part of the closure scheme. Plant feed mineralogy and chemistry, together with any chemicals added to the extraction process to aid in bitumen recovery, can result in unique combinations of solute loading to an EPL which may in turn affect in-lake processes (Chapter 6).

7.2.4.4 Ore-waste Inter-bedding

Areas of the ore body that have highly inter-bedded ore waste zones can influence the mining sequence and therefore the location and design of an EPL. Plant feed quality from highly inter-bedded areas is often somewhat poorer than feed from other areas of the pit and mine planners may wish to delay mining in the inter-bedded area for that reason. However, mine planners may also try to take advantage of the waste zones from highly inter-bedded areas to increase the available construction material during critical periods of high demand. Finally, mining costs in highly inter-bedded areas of the ore body can be higher than in other areas of the mine due to the need to separate ore and waste more frequently. Separation of ore and waste at the mine face requires longer loading time for trucks, which means more shovel and truck hours and costs to mine a given plant feed volume. These cost impacts affect the selection of mine opening location and mining sequence, which in turn can significantly influence the EPL location and design as described above.

7.2.5 Site Topography

Site topography can strongly influence ex-pit tailings site selection, plant site selection, ex-pit mine waste dump layouts, closure drainage patterns and therefore pit lake size and location. Because of its importance when selecting ex-pit tailings sites, topography can sometimes indirectly affect the mine opening location and mining sequence. This indirect impact is due to a desire to locate the mine opening reasonably close to the plant site and ex-pit tailings area to reduce the cost of early earthworks.

Topography can greatly affect the pre-production cost and overall tailings storage efficiency in an ex-pit tailings area. Ideally, the ex-pit tailings storage can be located such that a small overburden starter dyke can be used for ponds constructed using traditional upstream sand cell construction. A small pond area bounded by a short, sharp rise in topography on the interior side of the pond can enable storage of the required start-up water using a relatively small three-sided starter dyke. However, if the topographic slope above that short, sharp rise is relatively shallow, then the overall storage capacity is normally greater than that of a steeper sloped area covering the same pond footprint. Similarly, if suitable mine waste is available to construct ex-pit tailings storage impoundments, then a different ideal topography could be described for a given mine site. The schematic in Figure 7-3 shows an example of the effects of topography on volumetrics of a 60-m-high ex-pit pond with a base 3,000 m wide, 6H:1V downstream slopes, and a 3% sand beach slope. Note the variations in cross-sectional area indicated on the figure for fluid, beach, dyke cell, and starter dyke due simply to the change in slope of the foundation. Note also that due to the assumed limitation of maximum dyke height equal to 60 m, the pond does not use the full footprint width of 3,000 m in the case of the 3% topographic slope.

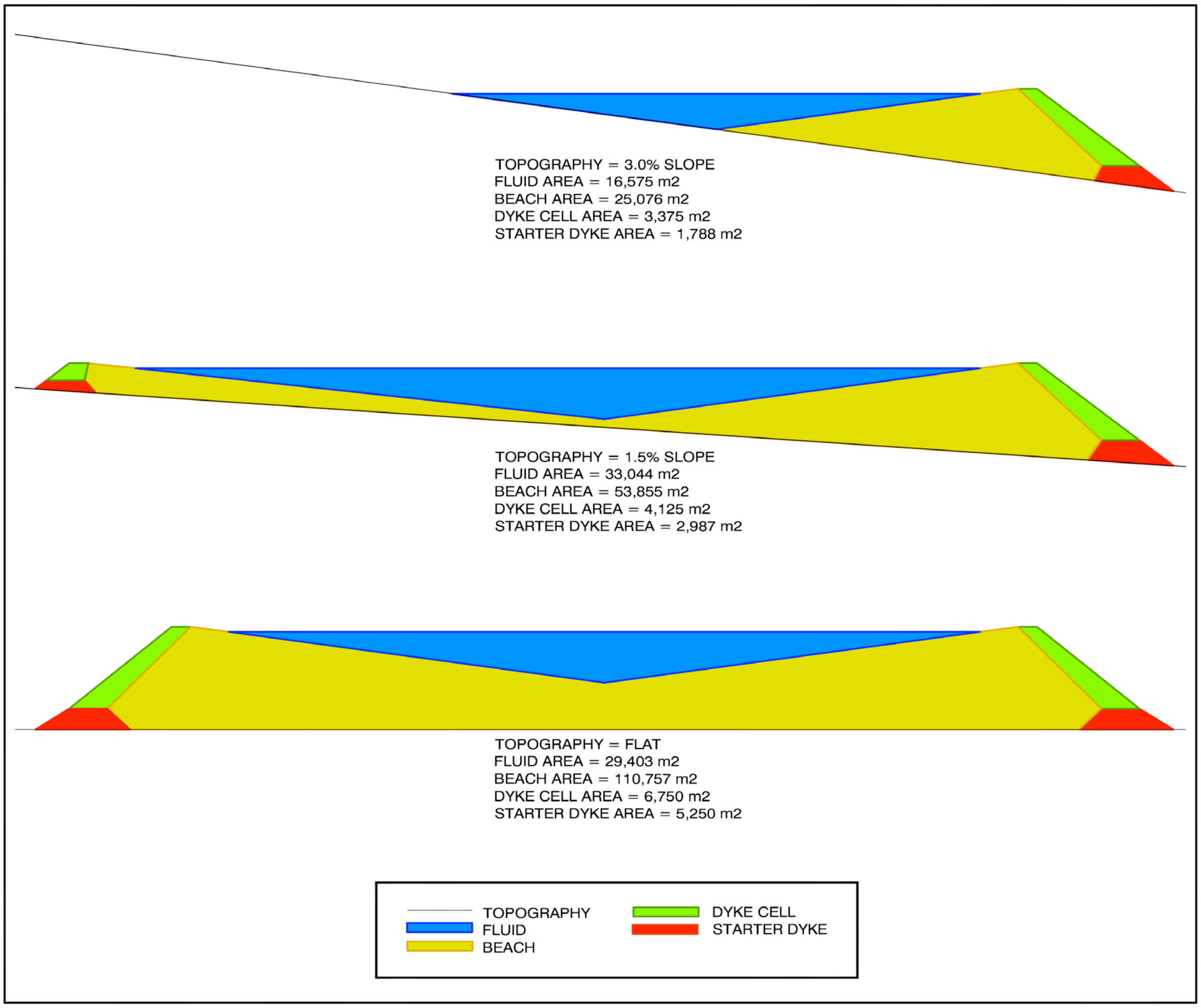

Figure 7-3: Example of topography effects on ex-pit tailings pond (nts)

Finding the best location and conceptual design for ex-pit tailings areas is a key part of the early planning work done for a project, because this part of the plan is a key driver of start-up costs and construction material balance feasibility. Additionally, plant site selection is often strongly influenced by the location selected for the ex-pit tailings area due to a desire to minimize tailings pumping distances. The combination of ex-pit tailings area and plant site selections in turn influence selection of the mine opening location.

In addition to being an important driver for mine planning, topography can be an important consideration when locating and designing EPLs because the EPLs must be integrated into a sustainable closure drainage pattern. Portions of the watershed involved in feeding the EPL are expected to come from areas disturbed by mining operations, with the remainder coming from the natural topography. However, in some cases the drainage from the natural topography could be cut off from the EPL by constructed waste dumps or tailings storage areas. Ensuring that mining landforms fit within the closure drainage design plan can be challenging and costly due to the potential need to haul or pump waste material farther or higher so that drainage corridors to the EPL can be maintained.

7.2.6 Mapped Constraints

It would be ideal to plan and operate an oil sands mine, or indeed any mine, without constraints on the use of the landscape. However, in reality all oil sands mines are constrained by landscape features. These features can include lease boundaries, other industrial operations (including mines), waterways such as creeks and rivers, fens, high-value wildlife habitat or movement corridors, Aboriginal or other historical sites, and regional infrastructure. Restrictions or extra requirements may be imposed when planning pit excavations or mine waste or tailings disposal sites in proximity to such constraints. These may include increased geotechnical factors of safety, limitations on available operational and/or closure drainage paths, limitations on allowable visual effects, requirements for seepage mitigation measures, or restrictions on placement of different types of mine waste or tailings near to constraining features.

Avoiding multiple constraints near the planned pit areas can be difficult and in some cases impossible due to lack of alternative space for surface facilities. The presence of multiple constraints in combination with weak ex-pit foundation materials can be particularly problematic because of the potential need to break up ex-pit tailings and mine waste storage areas into multiple facilities to avoid constraints. In such cases, the need to leave offsets from constraints and shallow slopes imposed by the weak foundation materials can result in failure to achieve feasible waste material balances. An example of the potential impacts on ex-pit waste dumps is shown in Figure 7-4, which shows the impact of leaving a 200-m-wide corridor, perhaps for a creek, through an area that could be used for a waste dump in an area with a weak dump foundation. In the case shown, a modest reduction of dump footprint width of 200 m (7%) results in a significant reduction in dump cross-sectional area from 96,000 m^2 to about 65,000 m^2 (-32%). Therefore, it is critical that the planning team understand the landscape use constraints for their project area, the value of the areas earmarked for avoidance, the circumstances under which the constraints can be eliminated, and mitigation possibilities. In some cases trade-offs may be required if the project is to proceed.

The most important mapped constraints for EPLs are those that limit options for closure drainage patterns. These include existing watercourses and watershed divides, and may include artificial constraints such as lease boundaries. Cooperation between adjacent lease holders to establish integrated closure drainage systems may be beneficial in some cases to provide the most sustainable and productive EPLs possible.

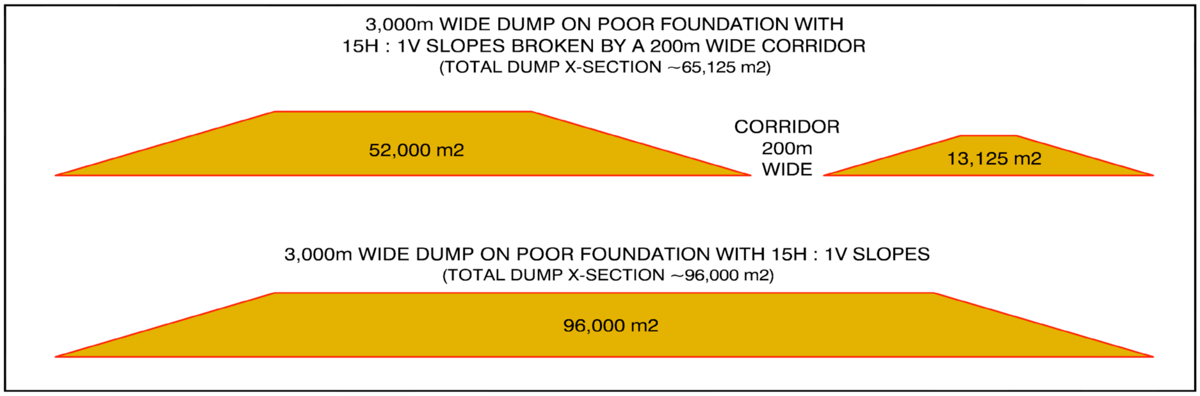

Figure 7-4: Example of physical constraint effects on ex-pit waste dump (nts).

7.2.7 Legacy FFT Deposits

Much of the preceding discussion has focused on issues related to greenfield projects with the intent that operators could pick up the discussion at the point appropriate for their respective positions in the project timeline. However, existing operators may also have significant legacy issues to manage in addition to those issues described for a greenfield site. One important legacy issue is the existence of inventories of FFT at a mine site.

All commercial oil sands processing technologies result in the formation of some FFT. The conventional extraction and tailings technologies used for the first oil sands mining operations resulted in higher rates of FFT formation than is expected for some of the newer tailings technologies. However, there are no commercial on-line processes that completely avoid FFT formation. As a result, a significant amount of current industry research and development is aimed at off-line processes that would attack the FFT inventory directly through some form of treatment technology. In almost all cases, a working inventory of FFT is needed to enable consolidation of the FFT to a solids concentration that is suitable for treatment. While the appropriate working inventory varies according to production rates, ore body fines content, pond geometry, and the FFT management strategy, for this discussion it is assumed that a working inventory of about 80 Mm^3 +/-20 Mcm is required for efficient operation.

In operations where the FFT inventory builds to a greater volume than the minimum working inventory, the need to store the extra fluid can become a strong driver of the mine plans. At some legacy volume it often becomes necessary to store FFT in more than one tailings pond. This is often accompanied by a buildup of process water inventory which forms as a water cap on each pond as the contained FFT consolidates. Additionally, the increased fluid storage requirements lead to increased dyke construction, which may lead to problems with the construction material balance for the site. This may cause an operator to use tailings sand to supplement available construction material from mine waste, which may in turn cause an increase in FFT formation compared to the planned rates (especially if that sand was intended for use in on-line fines consumption processes like CT). The greater the inventory of FFT, the greater the potential influence of the containment needs on the mine plan becomes.

The transfer of FFT to EPLs and capping with water is an important part of the closure plans described in several oil sands mining project regulatory applications. It is widely believed that water-capping FFT can be more cost-effective than some other FFT reclamation approaches currently under investigation by industry. However, planners should recognize that buildup of large legacy FFT volumes may result in exceedance of the capacity of EPLs in water capping schemes, and that the cost of managing large legacy volumes throughout the life of the mine may become excessive. One of the challenges associated with understanding the true costs of FFT storage is that assessments must often be done on a life of mine basis. This necessarily introduces uncertainty due to the conceptual nature of containment designs for structures that would not be used until some time in the future. Therefore, a significant component of any assessment of the cost of legacy FFT containment should be a risk assessment.

7.2.8 Production Facility Placement and Relocation Strategies

Bitumen production facilities at oil sands mines typically involve several key components including:

- Ore excavators, typically large cable or hydraulic shovels;
- Ore transportation to a crushing facility;
- Ore crushing;
- Crushed ore transportation to a conditioning facility;
- Ore conditioning;
- Primary separation of bitumen from solids;
- Secondary separation; and
- Froth treatment.

Ore hydro-transport systems are commonly used today and combine crushed ore transportation and conditioning into one component. In other cases, conveyors are used to transfer ore to conditioning facilities.

In current oil sands mine operations, ore is transported from the mine face to the crushers using trucks which, together with the mining shovels and mining support equipment (graders, dozers, etc.), make up the mobile mining fleet. To reduce ore haulage costs and mobile fleet air emissions, and to increase the reliability of ore feed to the crushers, it is desirable to minimize the distance and elevation gains from the active ore mining areas to the crushers. To achieve these objectives, crushers may be moved periodically to be closer to the mine face. Crushers may also be placed at the floor of the pit or on an exposed mining bench somewhere between the original topography and the pit floor to reduce uphill haulage versus scenarios where crushers are placed on topography. While beneficial in terms of meeting ore transportation objectives, in-pit placement of crushers can create significant constraints on in-pit waste placement. Maintaining the open in-pit footprint space required for crusher, dump pocket, offsets to dumps or tailings dykes, and potential multiple haul routes to the crusher can require delays in in-pit waste placement, constraints on closure landform design, and subsequent crusher relocations. In-pit crusher placement in the later years of mining tends to increase the size of EPLs because it requires an increase in minimum working space at the bottom of the pit. Additionally, if EPLs are planned for the final in-pit crusher location, then the footprint used for the crusher may form the deepest part of the EPL.

If a hydro-transport system is used for transport and conditioning of the ore, then an ore preparation plant (OPP) is required to create the slurry needed to feed the hydro-transport pipeline. This can be located in close proximity to crushers or more remotely, in which case conveyors are typically used to transport crushed ore to the OPP. Typically, slurry pipeline capital and operating costs are lower than conveyors and so there are potential cost benefits if OPPs are placed close to the crushers. Additionally, slurry pipelines can provide greater flexibility in terms of corridor alignment because they can be curved, whereas conveyors must be maintained in reasonably straight lines. However, if OPPs are placed in-pit with crushers, then the footprint required for the combined facilities can be significantly larger than for crushers alone. Additionally, the cost to relocate crusher/OPP combinations far exceeds the cost of relocation of crushers alone so the facilities should be moved less frequently in the combined case if possible. The greater footprint required and the potentially greater time that the in-pit footprint would be used for facilities has the same potential effects on in-pit waste placement and EPLs as described above for crushers, but to a greater extent.

Facilities for primary and secondary extraction and froth treatment require significant footprint area in locations that last for the life of the operation. All ore must pass through the extraction plant prior to discharges of tailings to the various tailings disposal areas used over the life of a mine. To minimize mass transportation distances, the extraction plant site should be located close to the ore source and tailings disposal areas if possible. Additionally, constructed foundation costs for such facilities can vary significantly depending on the geology of the site with costs in poor geological foundation areas (such as thick and shallow Clearwater Formation) potentially exceeding those in good condition by hundreds of millions of dollars. Extraction and froth treatment facilities would ideally be placed in an ex-pit location with good geological foundation that is close to the mine (especially in the early years of mining) and the ex-pit tailings areas. Incorporation of extraction plant areas into the closure drainage plan can be difficult because the area must be maintained at near original topography levels until after mining is completed, while almost all other disturbed areas can be engineered to achieve the elevation and slope required for the integrated closure drainage plan.

7.2.9 Closure Drainage Setting

Creeks may have to be temporarily or permanently diverted around the active mining area during mine operations, in accordance with an approved operational water management plan. After mining operations are completed, closure drainage patterns must be designed to direct reclamation waters to appropriate receptors, be they wetlands, pit lakes, or the surrounding environment. Generally, all of the reclamation waters normally require some level of passive treatment in wetlands or pit lakes prior to release to the surrounding environment. Achieving the required watershed dynamics, as described in Section 4.7, and non-erosive drainage patterns, can be a very challenging part of the mine planning process and may affect mine sequencing and waste storage layout for the project. Additionally, the layout and design of waste storage areas can significantly impact the solute loading to EPLs as described in Section 4.3. Planners should consider options for placement of materials in the closure landscape from this perspective.

Some closure drainage oriented questions that planning teams should consider when planning for an EPL for their project include:

- Where does the final drainage need to go to meet hydrological requirements at closure?
- What is the elevation of the design EPL water level corresponding to the identified outlet location(s)? Is there flexibility in choice of EPL outlet and therefore in the design of EPL water level? How would variation in EPL design water level affect EPL surface area, residence time, ability to create littoral and riparian zones, etc?
- What final drainage gradients can be used for the types of materials that will comprise the closure landscape? How will the performance of the materials be affected by placement methodology?
- What are the acceptable approaches to creation of walk-away containment for fluids and potentially liquefiable tailings materials that may comprise part of the closure landscape?
- How do choices regarding tailings technologies potentially affect the EPL and closure plan overall? For example:
    - How might chemical additions such as sulfate in the coagulants required for CT or flocculants for new fines tails management techniques affect EPLs?
    - Should all drainage be directed to one EPL or should run-off and seepage be dispersed to engage a broader assimilative capacity in the receiving environment?
    - Are in-pit tailings better/worse than ex-pit placement with respect to salinity loading to the EPL and rates of chemical of concern degradation over time?
    - Should impoundments be constructed of mine waste instead of tailings sand in some areas to reduce seepage rates and resulting rate of salinity contribution to the EPL?
    - Should waste storage areas be zoned in terms of material placement locations and methodology to promote or impede infiltration and/or seepage of water?

The extent to which the available mine waste and tailings material types and locations can be incorporated into the closure landscape in a manner most suitable for the closure drainage setting varies significantly between sites. However, this is one area of planning/design work where the teams responsible for integrated EPL designs can have a significant effect on the overall performance of the closure drainage system and the EPL. Careful consideration of options regarding waste material placement locations and design zonation during the integrated EPL design process could lead to significant improvements in salinity and other chemicals of concern and environmental performance for EPLs.

7.2.10 Technologies to be Employed

Two of the primary technologies that must be selected when planning for a new mine are the mining and tailings technologies. A number of other smaller scale mining technologies must be selected as well, such as crushing/breaking technology. However, the effects of those selections on EPL planning and design are limited and so they will not be discussed here.

The primary mining technologies used in the oil sands mining industry are large cable and hydraulic shovels for excavation of the ore and mine waste and haul trucks for transporting the ore and waste to the extraction plant (crusher) and waste dump areas respectively. Other, more continuous mining technologies were used in the past such as bucketwheel excavators, conveyors, and draglines. More recently, mine operators have examined near-face crushing systems (and potentially slurry systems) that would replace ore haul trucks with conveyors or slurry pipelines. However, all existing (and almost all proposed) mines use truck/shovel mining technology; the recently proposed Suncor Voyageur South Mine is the only known operation that would go against this trend. The effects of mining technology selection on EPLs, if any, would be highly site-specific. However, in general, as long as trucks are used to move mine waste it is likely that EPL designs would be relatively unaffected by ore mining technology selection.

Tailings technology is more varied across the industry. Historically, mine operators used conventional tailings technologies that produced primary separation tailings (often called coarse tailings), flotation tailings, and froth treatment tailings streams. Upon deposition, these streams formed relatively stable beach deposits that captured most of the sand and some of the fines that were contained in the tailings slurry. However, some fines segregated and contributed to FFT formation. Conventional tailings deposition, while reduced in scale in some cases, is still planned for all oil sands operations, often in combination with more recently developed tailings technologies.

The mid-late 1990s saw the introduction of consolidated or composite tailings (CT) in oil sands mine operations. This engineered tailings product is created by combining coarse tailings with MFT and a coagulant (e.g., gypsum) with the goal of trapping a larger mass of fines within a given volume of tailings deposit. The goal for CT is to produce a non-segregating product with a sand-to-fines ratio (SFR) between about 3:1 and 5:1 (i.e., 3 to 5 parts sand for 1 part fines) to achieve capture of a significant mass of fines while maintaining relatively rapid consolidation.

Thickened tailings (TT) are another engineered tailings product that was added to the oil sands mining commercial tailings technologies in the early 2000s. It is produced using a large thickener vessel and flocculent addition to create a non-segregating sand-fines mixture. TT is a more efficient method of trapping fines than CT (in terms of sand utilization) with SFRs ranging from about 0.7 to 1.1. However, the rates of consolidation and strength development for TT are expected to be significantly less than for CT. The performance of TT deposits is also thought to be more sensitive to the deposition environment and methodology than CT.

Recent research and development on tailings has led industry in some new directions aimed at attacking FFT inventories directly in off-line processes (i.e., processes not directly tied to the bitumen production line). These include MFT drying (e.g., part of Suncor TRO project), Atmospheric Fines Drying (AFD – Shell), MFT centrifuges, and other less well established concepts. While these technologies are still being explored to determine operating parameters, improve effectiveness, and reduce costs, common elements of these newer engineered tailings products appear to include heavy reliance on the use of flocculent, relatively high sensitivity to depositional methods and environment, and relatively high cost. Rates of consolidation and strength development in these deposits, as well as the mechanisms that contribute to the determination of consolidation rates, are still under investigation. However, consolidation and strength development appear to be relatively good if the material is deposited under optimal circumstances.

Technologies that appear to be more cost effective from the mining perspective may be significantly more costly from a process plant perspective and vice-versa. Additionally, technologies that appear to provide effective tailings management techniques at one mine may not be feasible at another mine due to different geological conditions or constraints on the available surface area for ex-pit facilities.

It is important to recognize that suites of tailings technologies are generally required for effective management of oil sands tailings. Changing the mix of technologies and the timeframe for implementation of each technology can result in significant changes to mine and tailings management plans. A full life-cycle plan must often be produced with each combination to determine the appropriate mix for a particular project.

In addition to impacts on project footprint, dyke construction requirements, and economics, the technologies selected for tailings management can have a significant impact on:

- landform construction material
- contents of the EPL
- solute loading rates to the EPL
- total solute contained in the reclaimed waste tailings deposits
- chemical nature of the solutes

The impacts to landform construction material are discussed in Chapter 8 on EPL design. The other impacts are described in Chapters 5 and 6. However, the simple volumetric storage efficiency differences between the various types of tailings deposits are important mine planning considerations and will be described below.

Mining and processing of a given ore body will produce approximately the same total mass of sand and fines in the tailings streams released from the extraction plant, regardless of the tailings technology. However, there are significant differences in the bulk densities of the potential tailings deposits and in the process-affected pore water volume that is contained in those deposits. The total tailings deposit volume can vary significantly between technology suites due to these differences. Figure 7-5 shows approximate relationships between solids concentration and volume or mass of solid and water components in various tailings deposit types. Note that for simplicity all fluids were assumed to be water (versus bitumen), the specific gravity of all solids was assumed to be 2.65, and all deposits were assumed to be 100% saturated. Additionally, note that in this context “FFT” refers to fluid fine tailings at any solids concentration whereas “MFT” refers to only “mature” FFT (FFT that is >=30% solids by mass).

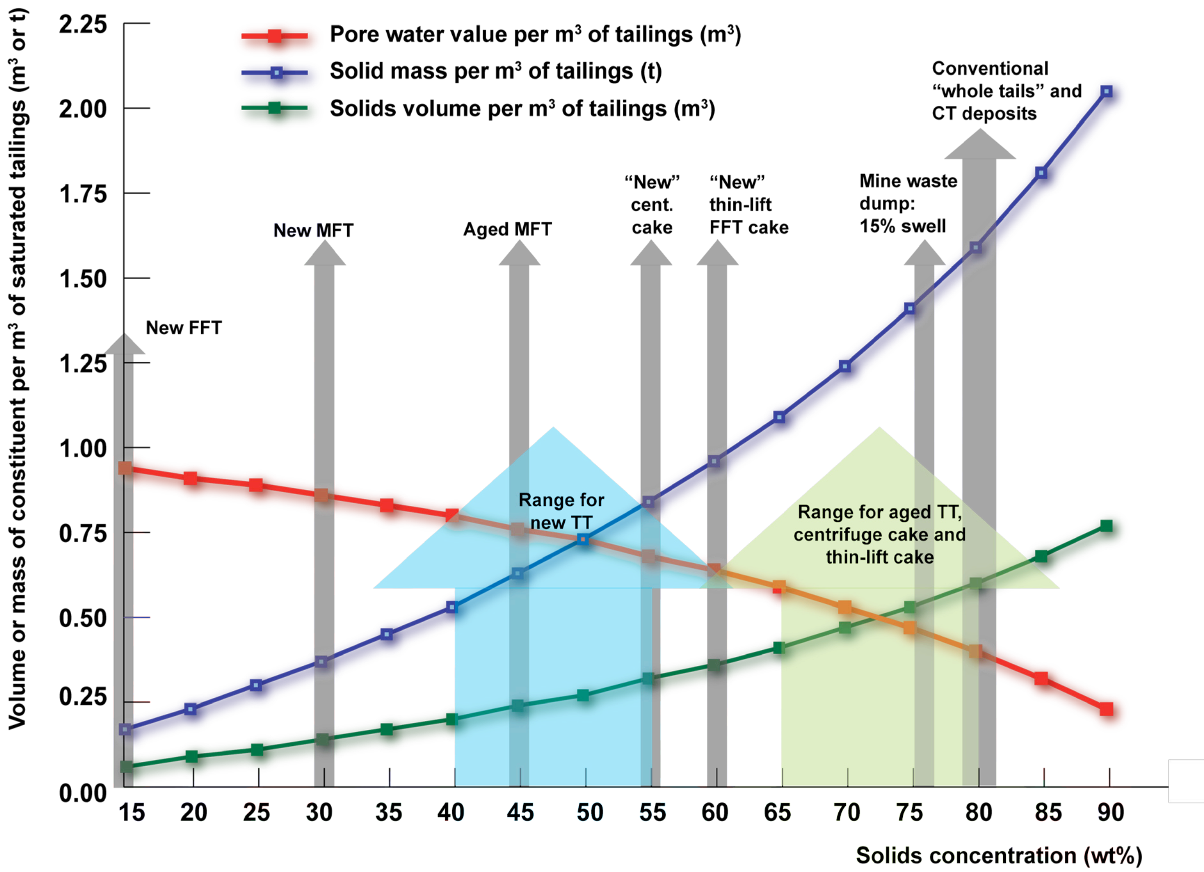

Figure 7-5: Approximate water and solids per m^3 of selected saturated tailings deposits.

As shown in the figure, pore water volume per cubic metre of tailings deposit decreases significantly as solids concentration increases. Volumetrically, newly created FFT at 15 wt% solids would be comprised of mostly water at about 0.94 m^3 water/m^3 of tailings. At the opposite end of the scale conventional tailings or CT at about 80 wt% solids would contain far less water at approximately 0.40 m^3 water/m^3 of tailings.

Incidentally, the volume of pore water release due to consolidation can be estimated as follows using the blue line on the chart to estimate initial mass of solids:

Pore water release volume, $V_r = M_i/S_i - M_i/S_f$, where
V_r = pore water volume released (t or m^3 per m^3 of tails deposit),
M_i = mass of solids in 1 m^3 of tails at the initial solids concentration (t),
S_i = initial solids concentration (wt %), and
S_f = final solids concentration (wt %)

Therefore, for example, consolidation of "New MFT" at about 30% solids to "Aged MFT" at about 45% solids would likely result in a release of about 0.41 m^3 of pore water per m^3 of tailings calculated as follows:

$$V_r = (0.369/0.30) - (0.369/0.45) = 0.41 \text{ m}^3.$$

If this MFT were located in the EPL, then this would represent net release of tailings pore water to the water cap over the time taken to achieve the indicated consolidation.

Tailings pore water is expected to be a significant source of solute that flows into the EPL; the ability to manipulate total tailings pore water volume through tailings technology selection is one of the tools available to project designers and planners. However, in addition to simple volumes of pore water contained in and released from tailings deposits, it must be remembered that the chemistry of the pore water for different tailings types will vary and must also be considered when calculating total solute inventories and possible flux rates. Testing of tailings products from newly developed tailings technologies will likely be required to determine appropriate inputs and rates related to these materials to be used in EPL models.

Finally, a debate exists on whether there should be “tailings” in EPLs. In this context the term “tailings” is typically taken to mean MFT. However, if the concept is endorsed by regulators after successful demonstration, then planners should consider that water capping any of the other potentially soft tailings deposits (e.g., TT, centrifuge cake, dried FFT, etc.) could provide environmental and economic benefits compared with the currently envisioned practices required to turn soft deposits into terrestrial reclamation sites (i.e. use of thin lifts covering large footprint areas, waiting for fines deposit consolidation prior to capping and reclaiming, re-handling sand or mine waste to cap fines deposits, etc). Additionally, the total mass of fines captured in a water-capped soft tails deposit could easily exceed that possible by capping MFT deposits if for example centrifuge cake instead of MFT were placed in EPLs. Volumes, chemistry, and flux rates for tailings pore water would also vary from those that have been examined for MFT water capping. Project planners/operators and regulators should consider the possibilities during the current period of rapid tailings technology research and development. Research regarding the anticipated performance of any alternative deposits types in a water-capped setting will no doubt be required prior to their acceptance as a suitable closure strategy.

7.2.11 Environmental Performance

In addition to meeting objectives regarding EPL performance, several other objectives related to environmental performance for mining operations act as significant drivers for mine plans. A list of some of these objectives would include:

1. Minimize fuel consumption by the mobile fleet to minimize air emissions and improve energy efficiency (as well as reducing fuel costs).
2. Minimize disturbance footprint.
3. Reclaim progressively to reduce net disturbance area (net disturbance = total disturbance area – reclaimed area).
4. Direct-place reclamation material where possible rather than stockpiling.
5. Minimize water use, in part by reusing process-affected water and other degraded sources.
6. Minimize volume of process-affected water stored on site.
7. Ensure adequate water storage exists to facilitate continued operation during low flow periods in the Athabasca River when water withdrawal may not be possible.
8. Locate mine waste and tailings storage areas in a manner that minimizes the risk of failure and reclamation liability.

9. Achieve a closure reclamation landscape that is consistent with agreed end-use objectives of regulators and stakeholders in a reasonable time frame.
10. Minimize greenhouse gas emissions from tailings ponds.

The effort and cost required to achieve each of these objectives varies from site to site. Also, meeting one or more of the objectives listed may require that performance with respect to another objective be compromised to some degree. The same is expected for construction of EPLs. For example, additional mine waste haulage may be required to establish a higher percentage of littoral zones in an EPL. This extra haulage would require consumption of additional fuel, resulting in increased air emissions of pollutants. As another example, fluid or soft tailings (e.g., TT or centrifuge cake) could be placed in the EPL and water capped or they could be placed elsewhere in a form that could be reclaimed to a terrestrial environment. In the latter case, it is likely that additional disturbance and delayed reclamation would be required so that FFT could be incorporated in one or more of the area-intensive thin-lift fines dewatering schemes currently under investigation.

EPL planning teams will be required to consider the competing environmental performance objectives for their project and develop the best overall plans that are feasible from an economic perspective. Currently, there is limited guidance available to assist planners in their evaluations of potential trade-offs between environmental objectives. Each operator must develop strategies and proposals for regulatory approvals based on their best judgement and input from regulators and stakeholders. By exploring options and collecting relevant data during the cyclical mine planning, design, and evaluation process, planners can ensure that assessments of equitable trade-offs can be made based on sound understanding of the options, costs, and impacts on overall project performance.

7.2.12 Cost Drivers

If costs cannot be contained at acceptable levels, then mining won't proceed. From that perspective, it may seem that cost control is the most important driver for mine planning. However, that is only true to a point. Worker and public safety, and an acceptable level of environmental performance are also required to proceed with a mining project. Long gone are the days when meeting safety or environmental performance standards may have taken a back seat to cost control in the Alberta mining industry.

Nevertheless, cost control remains an important driver. During pre-production timeframes, the focus is often greatest on estimated initial capital cost for a project but sustaining capital and operating cost profiles are also important. During the years of mine operations, the focus is on sustaining capital and operating costs. To include consideration of the time value of money when appraising long-term projects, a discounted cash-flow analysis is typically undertaken, wherein expected annual revenues and costs for the project are combined to produce an estimate of the net present value (NPV) of the project; the goal is one of maximizing NPV. In this type of analysis, any revenues or costs that occur earlier in the timeline have greater weight than those revenues or costs that occur later in the timeline. Therefore, general economic goals for planners include:

- Increase or bring forward revenues. Total revenues can be increased by adding oil sands reserves. Revenues can sometimes be brought forward by mining higher-grade ore early and deferring lower-grade ore so that bitumen production can be maximized early in the mine life, thus increasing project NPV. However, if carried too far this strategy can actually reduce NPV if low-grade ore is bypassed (in which case issues may arise with the resource conservation regulator, the ERCB).
- Decrease or defer costs such as initial capital expenditure. Overall decreases in costs are typically best but in some cases deferral of costs will result in a higher NPV for a project than a simple cost reduction in a given year.
- Reduce capital at risk, most often by reducing initial capital costs.
- Maintain flexibility in mine plans to avoid risks and seize opportunities to improve cost/revenue performance where possible.

How can planners contribute to achievement of the economic goals listed above? Some of the strategies commonly used have already been described in previous sections. However, a summary of high level strategies might include the following:

- Layout plant and waste storage facilities for the project in a manner that minimizes construction costs;
- Locate mine opening in a location with low stripping ratio and high ore grade;
- Plan mining sequence so that low-grade and high-stripping ratio areas are mined last;
- Minimize ex-pit disturbance to reduce reclamation material salvage and reclamation and closure costs;
- Optimize ore haul distances in combination with crusher/OPP location/relocation strategies;
- Minimize waste haul distances;
- Minimize dyke construction requirements;
- Minimize selective waste mining and placement requirements to increase earth moving efficiency of the mobile fleet;
- Minimize tailings pumping distances;
- Minimize FFT generation by maximizing fines capture in coarse tailings deposits;
- Choose tailings technologies that minimize costs for treatment of FFT (and potentially process affected water); and
- Defer reclamation of disturbed areas until it is absolutely certain that they will not need to be re-disturbed.

Depending on project specific factors, some of these strategies could result in trade-offs between cost control and EPL design. In those cases, as with other environmental performance goals, it will be necessary for operators and planning teams to establish balanced strategies that result in the best performance that is still economically viable.

A cost-related issue that is somewhat separate from the simple cost-control mandate but which could affect EPL construction is the accuracy of cost estimation. Adoption of plans and commitments related to EPL design and performance early in the project timeline (based on inaccurate assessments of the costs of achieving those plans and commitments) may result in significant plan upsets later in the project life when more accurate cost estimates are completed. All planning and design teams that assume responsibility for EPLs over the life of an oil sands project have reasonable assessments of the costs of constructing the planned landforms, EPL commissioning, and adaptive management/mitigation techniques that may be required to avoid surprises late in the project life. Major cost surprises could be as difficult to manage as major geological surprises. Typically, the later the surprise is sprung the more difficult (and costly) the remedies.

7.3 Conclusion

Planning, designing, constructing, monitoring, and certifying oil sands EPLs is expected be a multi-decade process. Each case is expected to be somewhat unique in this regard but it is not unreasonable to expect that perhaps 100 years will be required from initial planning of an oil sands mine to certification of an EPL at that mine. This extended timeframe brings with it many project management challenges that will need to be managed to ensure a successful outcome for the EPL. These challenges include changes to organizations involved and the people within those organizations, changing geological interpretations, growing scientific knowledge about EPLs both within the region and around the world, changing societal and regulatory expectations, and changing economic climate.

To manage these challenges an adaptive management approach is recommended. Goals for an adaptive management system are described in Chapter 9 and Appendix D. This process has evolved over time and it is believed that evolution will continue as the industry matures and as feedback from monitoring systems at oil sands EPLs, other mining industry EPLs, and fisheries compensation lakes in the oil sands region is received and interpreted.

While EPLs are important closure features for any oil sands mine, all parties involved in the planning, design, and approval of EPLs should keep in mind that the primary goal of the mine operator is not simply to build a lake. The primary goal is to recover the bitumen resources from the lease holdings in a safe, environmentally responsible, and economical attractive way. To achieve this goal, the operator will be forced to deal with circumstances and forces that tend to drive the plans in directions that may be aligned with or contrary to optimum EPL designs. It is expected that many trade-offs will be necessary over the course of the project timelines to achieve the right balance with respect to various environmental, economic, and socio-economic objectives. Teams responsible for EPLs will benefit if they achieve a general understanding of the various mining drivers so that they can work with mine planners to incorporate design concepts necessary for enhancement of EPL function with minimum interference with “normal” mine operations. Similarly, mine planners and designers responsible for mine waste dumps and tailings dams will benefit if they achieve a general understanding of the physical, chemical, and biological requirements for successful EPL development. Such is the nature of interdisciplinary teams.

8. DESIGN ELEMENTS AND CONSIDERATIONS

Angela G. Küpper
AMEC

Chapter 8 Table of Contents

8.1 Introduction

During mining, and especially in its early stages, there is an operational requirement to maintain working space for ore recovery, and therefore both overburden and tailings need to be placed out of pit. Once mining is completed, it may be necessary to re-handle material placed out of pit to completely infill the mined-out open pit. Infilling the mined-out pit with re-handled material would be costly and could have some environmental impacts, especially if out-of-pit material storage areas have already been reclaimed. EPLs present a potential solution to address challenges faced by mine operators regarding reclamation and tailing disposal.

EPLs represent a design solution for the net volume loss from within the mine footprint due to storage of tailings in external facilities, creation of out-of-pit overburden dumps, or in-pit dumps that are higher than original ground elevation. Placement of material out of pit causes a lack of material to backfill the mined out pit even though mining causes the material to bulk up. The removal of bitumen itself has virtually no impact on volumes since the bitumen is encountered in the pores of the natural deposit. Excavation and placement of overburden as a compacted fill and excavation of ore followed by extraction of bitumen and disposal of the tailings create deposits of solid materials with lower densities, thus larger volumes, than the original in situ deposits.

EPLs can provide a suitable location for final storage of fluid or soft tailings that require containment and that would not provide a suitable foundation for the soil cover required for vegetated reclamation landforms. These tailings could be reclaimed by covering them with a water cap, which could then gradually evolve to a functional aquatic habitat of regional value. In addition, EPLs could function as retention/sedimentation ponds for process-affected, runoff, precipitation and seepage waters, thus potentially reducing or mitigating the impact these waters might have on the regional aquatic system. They promote the attenuation or degradation of process-derived components within the water cap through physical, chemical and biological processes.

8.1.1 Design Objectives

A primary objective of the design of an EPL must be the creation and maintenance of the physical integrity of the lake, including geotechnical and hydrotechnical stability of all EPL design elements. Water needs to stay contained in the lake and the lake level needs to be maintained over the long term (albeit with seasonal variations). Once a relatively stable lake is created, a number of key environmental, social, and economic objectives still need to be met, which are discussed in Chapter 2. The design objectives that could be considered today are discussed in more detail below. Exact design objectives may and should vary to some degree from case to case, since final closure objectives and designs should be site specific; they are also expected to vary with time as the expectations and science of oil sands pit lakes evolve. Consequently, there is value in developing a flexible design to facilitate accommodating future changes.

8.1.1.1 Physical Integrity

Physical integrity of the lake depends (1) on the integrity of critical design elements, such as perimeter slopes and outlet channels, and (2) on the long-term maintenance of the lake level. Examples of elements that need to be verified during design to ensure physical integrity of the lake include:

- Outlet channel: erosion of the outlet channel such that the channel bottom becomes gradually lower could eventually lead to breach of the lake containment. Breach of containment, leading to loss of the water cap and exposing fine tailings stored in the lake, would constitute a loss of physical integrity of the EPL.
- A large failure of the perimeter slopes, such that the failed mass significantly fills the lake or leads to significant overflow or breach of lake containment, would characterize loss of physical integrity of the lake. Any structures – either fills or natural slopes – that contain the lake cannot constitute dams according to the definition of dams in the regulations (see Section 8.4.13).
- The natural water balance needs to be such that the EPL continues to function as a lake in the long term. The balance between precipitation, evaporation, contributions of groundwater in and out of the lake (especially important if there are highly pervious substrates), and contributions of surface water in and out of the lake (inlet and outlet channels) needs to allow the lake level to vary seasonally and over the years, while still maintaining lake functions and values.

Maintaining physical integrity does not imply that all elements of the EPL will remain as designed and built. Geomorphic processes will occur as part of the natural evolution of all landscapes, EPLs included. As such, erosion, slumping, and slope failures will occur with time. However, the objective of designing and building an EPL to maintain its physical integrity in the long term means that the EPL will continue to contain the fluids it is intended to store.

8.1.1.2 Environmental Objectives

- Water flow management: There needs to be sufficient in- and out-flow for water quality and maintenance of a sustainable ecosystem representative of the region. There also needs to be an appropriately long hydraulic retention time for water quality. In addition to achieving a sustainable water balance required for its integrity as a lake, the environmental values of receiving systems should not be compromised by the quantity or quality of the water released by the EPL.
- Water quality should not pose a human or ecological health risk in receiving waters. At certification, it must meet criteria that indicate no significant toxicity (naphthenic acids or other chemicals of concern) remains, thus allowing for the development of a regionally representative ecosystem in the lake.
- The EPL eventually must become a sustainable and resilient aquatic ecosystem that is compatible with the surrounding environment. Environmental values of receiving ecosystems should not be compromised. The land is to be returned as a landform that is compatible with the surrounding environment and has similar performances when subjected to the forces of nature (seismicity, floods, weathering, etc.).

- The EPL may need to provide safe storage of fluid or soft tailings.

8.1.1.3 Other Objectives

Each EPL and its performance need to comply with applicable legislative requirements. Stakeholders' needs, concerns and aspirations, including the environmental objectives listed above, need to be taken into account when considering the EPL design. It is important to embed flexibility, resiliency, and redundancy in the design and to review both the objectives and the EPL design on a regular basis during the span of time from planning to implementation, development and commissioning of EPLs. This would allow adjustments to be made such that the system evolves in a manner compatible with the evolution of the science and the stakeholder expectations during this time frame and in a manner that is sensitive to observed performance of each individual EPL.

The EPL also needs to be part of a landscape that eventually achieves sustainable land-use conditions as agreed with the applicable government regulator and affected communities. Finally, it is necessary to avoid or minimize costs and long-term liabilities to the mining companies, government, and public.

8.2 Design Approach

The proposed approach for the design of EPLs is based on the following considerations.

Design objectives for EPLs may not all be met at the same time. Some of the design objectives for EPLs may be conflicting at one particular time but they may be met at different times along the life of the project, as discussed above. In most cases, it may still be possible to meet a number of apparently conflicting objectives if they are not in the same time scale. In other cases, it might be necessary to select the objectives that can be met or meet different objectives in separate EPLs at the same site.

Acknowledge the existence of different levels of control over the various design elements and start on the items over which we have the least control. Figure 8.1 illustrates the landscape elements that affect the design of an EPL, varying from terrestrial to aquatic and from regional to local. The items located on the upper part of the chart are the items over which we have the least degree of control, such as geology and precipitation. Moving down the chart, the degree of control increases. For example, the design can include wetlands or not; the nature of the sediments placed in the lake can be selected by the design and planning team. As planners have no control over certain elements, the design needs to start by taking them into account from the beginning and design the remainder to accommodate the elements that are already fixed, such as geology and precipitation.

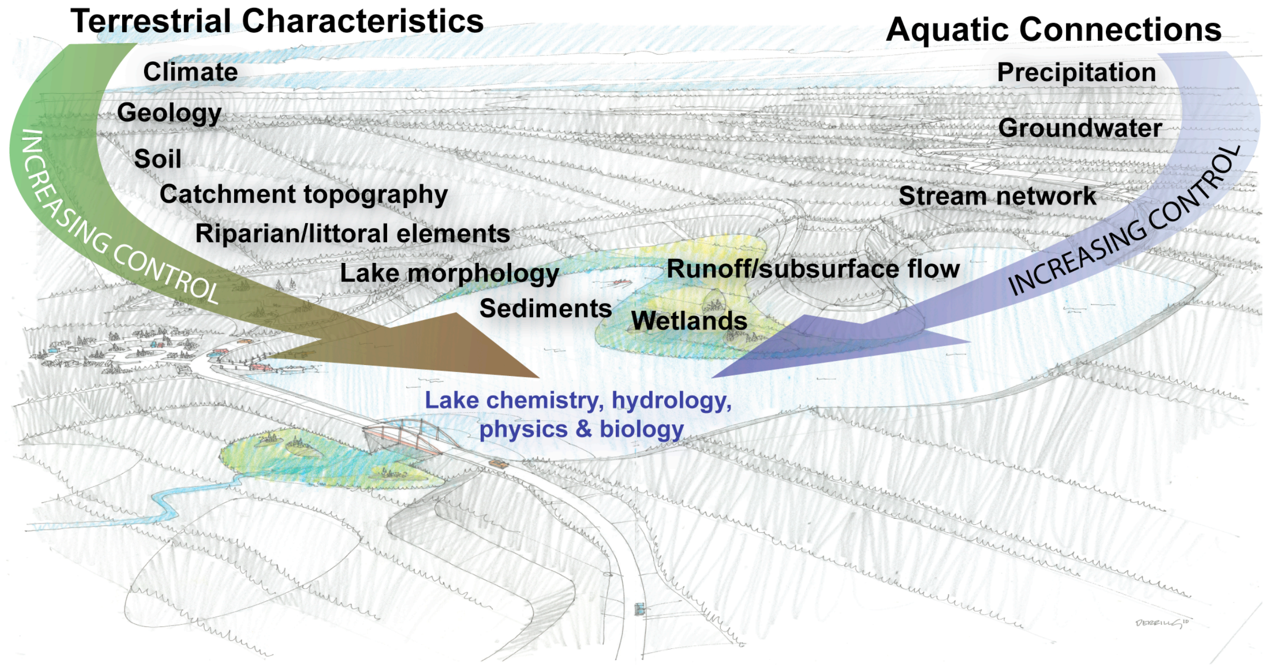

Figure 8-1: EPL landscape elements (modified by Theo Charette, Derrill Shuttleworth, and West Hawk Associates from Sorrano et al., 2009).

Planning and design are intrinsically inter-related, especially in the early stages of the development of an EPL. The planning and design processes are very iterative and there are various competing interests that need to be balanced. Therefore several cycles are likely to be required to achieve an acceptable preliminary design. Figure 8-2 below illustrates the iteration between the planning and design processes that are required to achieve an adequate and balanced design. Often a starting point is the location of the EPL which tends to be defined, initially, mainly from the mine plan. The feasibility of lake containment at this location would then be verified and the suitability of the initially proposed location would be assessed. Other aspects, such as lake geometry, interim and final catchment area topography and lake contents, also need to be determined by planning so a hydrologic balance and preliminary water quality evaluation can be conducted, which along with the design of the inlet and outlet channels will determine the overall lake feasibility. If it is not feasible to keep the lake contained, with a reasonably stable long term water level, other options need to be considered with the planning professionals. When preliminary parameters are available, modelling needs to be done to verify the feasibility of the lake relative to lake hydrodynamics and water quality. Once a configuration is achieved that is compatible with the overall feasibility of the lake, the detailed design of the lake and its systems (e.g., littoral and riparian zones, stable long-term slopes) can be designed. This figure is over-simplified as, in reality, the interaction is very dynamic and not restricted to the arrows indicated in Figure 8-2, which is just intended to illustrate the nature of the iterations required.

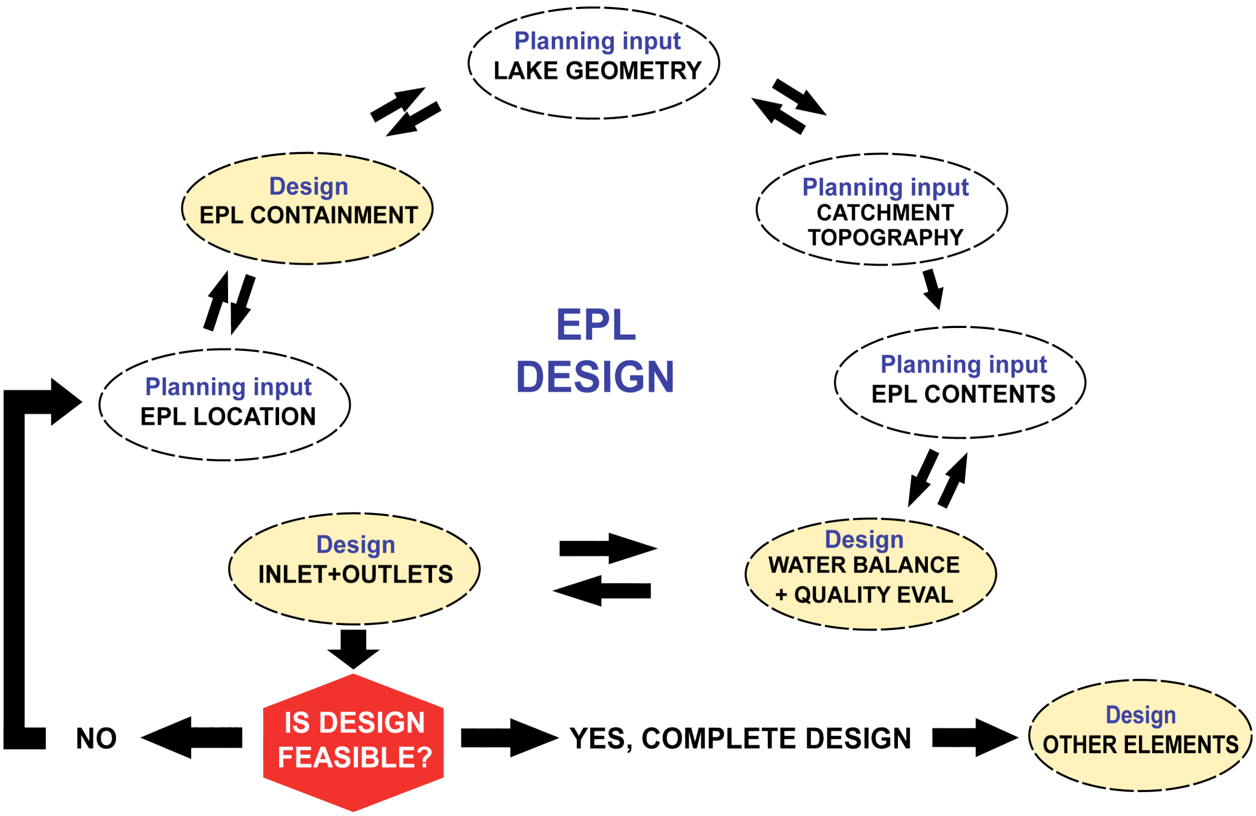

Figure 8-2: Recommended EPL planning and design iterations.

A contemporary application of the precautionary principle associated with the implementation of adaptive management and risk management are a balanced approach to a responsible design. According to the 1992 Rio Declaration (UN, 1992), the precautionary approach should be applied where there are "threats of serious or irreversible damage." In these cases, in view of high scientific uncertainty, decision-making should err on the side of caution. The precautionary principle is important to the application of a risk-based design approach (Stirling, 2007). The development of a resilient design and the adoption of adaptive management are considered central elements of precautionary management (UNESCO, 2005). A resilient design is defined as a design that can tolerate some degree of disturbance while still retaining its key functions and structures. Adaptive management allows an increase in the understanding of the issues and opportunity for adjustments of the design. This approach, associated with a flexible design, allows for effective risk management.

Knowledge gaps related to various aspects of EPLs mean the observational method and adaptive management need to be an integral part of the design and implementation of EPLs. The science and practice of constructing EPLs are still evolving in the mining industry in general and in the oil sands in particular, where EPLs are relatively new. Various uncertainties and knowledge gaps have already been identified and no doubt there will be others identified in the future as these lakes are designed, implemented and monitored. It is therefore considered necessary to design under the assumption that the observational method (Peck, 1969) or adaptive management (Holling, 1978; Walters, 1986) or a similar technique will be used, allowing full-scale site specific data and real performance measurements to help achieve an adequate risk level. These tools are discussed in Appendix D.

The observational method and adaptive management are similar techniques. In both cases, there is a cycle of assessing and conceptualizing the problem, designing, implementing, monitoring, evaluating, and learning and adjusting the design and its implementation to better suit the observed site conditions and/or design objectives. In both methods, it is recognized up front that (1) there is insufficient information or knowledge, (2) there is significant uncertainty and risk, and (3) information can be gathered and knowledge acquired during the process to adequately manage the project in the long run. Also, in both methods, the focus is on collecting data, learning, reducing key uncertainties, and improving design and management. Both are formal, structured and systematic approaches. The observational method, typically used in geotechnical engineering, places a stronger emphasis at the initial design stage on the identification of key performance parameters to be monitored, the anticipation of potential performance issues or failure modes and the development of responses and mitigative measures in case the required performance is not met. The observational method includes defining, up front, a trigger point or monitoring data value when action (implementation of mitigating measures) is deemed required.

The observational method should be used for the management of issues related to physical integrity of the lake. Although there are knowledge gaps, these issues are relatively well understood and quantifiable and the consequences of failure can be significant, thus requiring a more proactive approach. The complex interrelationships among lake dynamics and environmental performance are presently less well understood, and outcomes that depend on biological processes are inherently more difficult to predict. In this case, it may not be possible to adequately define potential performance issues and associated mitigating measures up front. Therefore, adaptive management would be an appropriate approach to adopt.

In both cases, early strategic management and intervention will likely result in better environmental outcomes with lower costs and requirements for ongoing intervention.

The design needs to be "robust" to be effective in view of knowledge gaps and it needs to be flexible so changes can be more easily accommodated and the observational method/adaptive management approach can be effectively implemented. A "robust" design is not sensitive to single issues or elements for its performance, so uncertainties or unknowns that affect aspects of the design do not compromise the entire design and its expected performance. The design also needs to be flexible so changes can be readily accommodated. For example, take a design that includes outlets at slightly different levels or the possibility of developing them at various levels as required. In this case, if the water balance is not quite correct due to the uncertainties in assessing the local hydrology (including catchment basin infiltration, runoff and evaporation, seepage losses, groundwater contributions, etc.), it is relatively simple to adjust the design to establish a more appropriate outlet condition.

Failure Mode and Effects Analysis (FMEA) needs to be an integral part of the design to check the design robustness and to embed an adequate level of risk management. FMEA is a technique that provides a systematic manner of identifying the potential failure modes and hazards in a particular design and assessing the potential consequences should such events occur. The FMEA can be used to include measures in the design that reduce the risk by reducing the likelihood of the occurrence of selected failure modes and/or by reducing the consequences of such failures. It is also relevant, especially in the context of adopting the observational method, to assess the ability to proactively detect each of the critical failure modes identified in the FMEA. This assessment can be used to produce a "ductile" design, i.e., a design that eliminates or significantly reduces potential failure modes that cannot be easily or reliably detected or that cannot be detected early enough for effective mitigation.

8.3 Design Criteria

To achieve the intended design objectives, Table 8-1 summarizes design criteria and the objectives set out in Chapter 2 to which they apply. The design criteria are expected to evolve with input from the wider engineering community as well as with input from other technical and scientific disciplines and in particular with new knowledge developed from research and full scale EPL experiments and compensation lakes currently underway. Moreover, these design criteria are expected to evolve as EPLs are planned, designed, implemented and monitored.

In developing the design criteria, it was implicitly assumed that the implementation of an EPL will be done in stages that include:

- Implementation of design measures.
- Lake filling; this may take a significant period of time.
- Monitoring of geotechnical and environmental parameters. This stage overlaps with the previous stages.
- Observational method/adaptive management stage where changes might be implemented in response to the monitoring data to adjust performance and keep risk within appropriate levels.
- Closure, which includes certification.

It is important to emphasize that EPLs need to support an ecosystem in a changing environment. The EPL is expected to be part of a dynamic environment and retain its function over time. The risks associated with physical events, such as slope failures, erosion, changes in sediment loading, and changes in lake level, need to be comparable to the risks of similar events in the natural setting in the region. These events are part of the geomorphic processes that are the natural evolution of landscapes and therefore viewed as acceptable, provided they do not impair ultimate lake function. The risks associated with events that have a profound impact on lake function, such as loss of containment, need to be minimized.

It is recommended that the design use a contemporary precautionary, risk-based approach, supported by adaptive management and with risks managed to be acceptable within the context of a naturally evolving environment.

Issues that have significant uncertainty, ambiguity or lack of knowledge and that could lead to "serious or irreversible damage" should be dealt with a cautious and conservative approach. The precautionary principle should also be applied to any issues that may not be amenable to monitoring.

All other issues would be dealt with using a risk-based approach combined with adaptive management, in which risks are identified, and managed by reducing the probability of occurrence and/or the potential consequences and are monitored. Results of the monitoring program would then be used as a basis for decision-making and potential adjustments of the system as required.

Risk reduction can be achieved by reducing the consequences of potential failure and/or by reducing the probability of failure. The consequences of failure need to be lowered to a level such that if a failure were to occur, it would impact only a relatively limited area. The probability of failure would also be reduced such that in the closure stage the EPL would be considered to have: (1) an insignificant risk of failure that causes a significant loss of contents; and (2) a risk of failure of less significant events that is comparable with the natural risk of similar events. Table 8-1 describes design criteria for EPLs and corresponding objectives from Chapter 2.

Table 8-1: Design criteria for EPLs.

Objectives	Design criteria	Further discussion
GENERAL		
EPLs need to be designed to support an ecosystem in a changing environment. The EPL will be part of this dynamic environment and retain that function over time. Objective: Sustainable Aquatic Ecosystem (Section 2.5)	The EPL design needs to be robust and resilient with no features that function only over a narrow range of parameters. The design needs to be consistent with the precautionary principle. The design should manage risks such that they are acceptable within the context of a naturally evolving environment. The risk associated with physical events that are part of the geomorphic processes (slope failures, erosion, changes in sediment loading, changes in lake level, etc.) needs to be comparable to the risks of similar events in the natural setting. However, the risks associated with events that have a profound impact on lake function, such as loss of containment, need to be minimized. *Comments:* Risk reduction can be achieved by reducing the probability of failure and/or by reducing the consequences of potential failure. The consequences of failure need to be lowered to a level such that if a failure were to occur, it would impact only a relatively limited area.	8.2 Design Approach

Objectives	Design criteria	Further discussion
PHYSICAL		
Sustainability / Long-term maintenance of lake level range / water balance Objective: Water flow Management (Section 2.2)	A suitable hydrologic balance needs to be achieved to support desired function and performance in the long term. *Comments:* A positive water balance has the advantages of allowing fish passage in the outlet and flushing salts and contaminants from landforms in the watershed and the lake (assuming the receiving water body can take the load). However, the water balance also needs to take into account the required residence time to enable appreciable aerobic decay of degradable toxic constituents, provided the lake remains aerobic. A very high positive water balance, which is necessary to increase the probability of maintaining flow through the outlet at all times, may lead to an excessively short residence time. Small annual changes in water level are considered ideal to support plant establishment, productivity, and diversity in the littoral zone. These ideal conditions may not be met for the stages of the hydrologic cycle that are removed from the mean (very wet or very dry years). A greater focus on maintaining a positive water balance could lead to larger annual variations in lake level.	4 Regional Geography and Ecology 9.4.2 Controlling Water Levels 9.4.4 Integration in the Watershed 9.4.6 Lake Discharge
	The hydrologic balance and the design of catchment area landforms need to take into account appropriately selected Design Precipitation and Inflow Design Flood (IDF). The potential impact of climate change should also be considered.	5.3.1 Hydrologic landscapes
	The design must consider all aspects of seepage in and out of the lake such that the potential risks to the physical integrity of containment and the potential environmental impact of the expected seepage are acceptable. *Comments:* Seepage considerations are important both for the water balance and for stability of the slope surrounding the EPL and slopes in other areas of the landform where seepage might exit. Determination of seepage quality and loading to the EPL and the receiving environment will support determinations of environmental impact.	9.3.14 Water Infilling

Objectives	Design criteria	Further discussion
Geotechnical stability of EPL landform / slope stability Objective: Sustainable Aquatic Ecosystem (Section 2.5)	Gross instability of all slopes, including pitwalls, perimeter and internal slopes (in situ and fill materials), both above and below water, at a rate or size that would disrupt EPL function must be avoided. The containment slopes should be designed to a factor of safety compatible with the consequences of slope failure on the function and sustainability of the EPL. A sufficiently high factor of safety needs to be selected for the failure scenarios that could affect physical integrity of the lake (fluid containment) or when environmental issues are critical or other consequences of failure are very high. Minimum factors of safety (FS) for various types of failure modes need to be selected and justified in each specific case. *Comments:* The risk and potential impact of successive slope retrogressions also need to be assessed and managed. The stability of all the slopes needs to be assessed for the short and long term. The stability analyses need to take into account all the issues that may affect the slopes including: • Shear strength and pore pressure of all materials at all stages of lake development and under all foreseeable conditions, including liquefaction potential. • Stress relief effects and gas ex-solution • Freeze-thaw effects • Long term degradation of shear strength • Impact of dispersivity • Regional seismicity (natural and induced) • Impact of long-term variations in lake levels including rapid drawdown conditions. This requires a well-understood and calibrated hydrologic water balance and the expected geomorphologic behaviour of the outlet channel. Effect of submergence, wave action, erosion, weathering, and potential climate change.	
	Slopes should be designed for a seismic loading with an adequately selected return period.	
	Design and management should take into account and be compatible with the long-term expected range of lake levels and long-term erosional forces caused by wave action. Potential high-erosion zones need to be identified and dealt with appropriately in the design. Shoreline protection construction options may include: • Vegetation of shores protected from most wave energy • Offshore islands and breakwaters • Use of long beaches • Shoreline protection berms	

Objectives	Design criteria	Further discussion
Long-term inlet and outlet channel stability / geotechnical and hydraulic stability Objective: Water flow Management (Section 2.2) + Sustainable Aquatic Ecosystem (Section 2.5)	Design should take into account: ▪ An adequately selected IDF ▪ Stability of slopes in and around the channels such that potential slope instabilities do not affect channel performance in the long term (for appropriate factors of safety). ▪ Maximum required gradients for hydraulic stability of the channel bed. ▪ Natural geomorphological mechanisms, including erosion, sedimentation, meandering and other channel dynamic processes. ▪ Beaver and other biological action. ▪ Significant fires and their impact on run-off and debris. ▪ All potential lake levels and its variations with time. Very low maximum gradients are required for long-term stability of the inlet channels and especially for the outlet channel. The lake location should allow for sufficient distance to the receptor water body such that channels that run perpendicular to existing slopes achieve these low maximum gradients.	
	Extreme events (precipitation, floods, seismicity, fires, impact of climate change) should be considered for the design of EPLs outlet channels. A well-understood and calibrated hydrologic water balance and the expected geomorphologic behaviour of the outlet canal are requirements of the design.	
ENVIRONMENTAL ASPECTS		
	In addition to achieving a sustainable water balance required for its integrity as a lake, the environmental values of receiving systems should not be compromised by the quantity or quality of the water released by the EPL.	
Water flow management Objective: Water flow Management (Section 2.2)	There needs to be sufficient in- and out-flow for water quality and maintenance of a sustainable ecosystem representative of the region. There needs to be some flow but also an appropriately long hydraulic retention time for water quality. See discussion above on the hydrologic balance.	
Acceptable water quality Objective: Water Quality (Section 2.3)	Water quality should not pose a human or ecological health risk in receiving waters. Water quality at certification must meet criteria that indicate no remaining significant toxicity (naphthenic acids, or other chemicals of concern). Water quality should allow the development of a regionally representative ecosystem in the lake. The design needs to consider the management of lake water quality in various stages of lake development such that acceptable water quality for release eventually is achieved. The design needs to provide an adequate balance of all factors that affect water quality, including nature of filling water, lake contents, residence time, filling time, expected total suspended solids, etc.	3.4.3 Water Quality 4.3 Water Quality 5.5.2 Water Quality

<table>
<tr><th>Objectives</th><th>Design criteria</th><th>Further discussion</th></tr>
<tr><td></td><td>Design should consider a suitable lake mixing regime to support desired function and performance. Design should take into account the effect of EPL water column mixing regime on water quality predictions.

Comments:
No EPL is planned to be meromictic. It is recommended that the EPLs be designed for annual summer stratification and fall turnover to supply the water column with oxygen which will enhance treatment of organic constituents.</td><td>3.3.4
Limnology

4.8.5
Natural Meromictic Lakes

6.2.2
Stratification and Meromixis</td></tr>
<tr><td></td><td>The lake filling time should be suitable to support desired function and performance. Selected lake filling time and water source need to support acceptable water quality.

Comments:
The filling time estimated to achieve acceptable water quality in cases previously analysed was about 10 years. However, this time could be longer if the residence time is short and/or the lake is deep (i.e., deeper than 25 m). In general, longer filling periods will lead to lower concentrations of degradable constituents, such as naphthenic acids, but higher concentrations of salts, at the time of initial discharge.

Fresh water could be used to complement watershed inflows into an EPL, if the lake is to be filled more quickly than the rate that could be supported by the lake's watershed. Fresh water inflows also provide dilution to improve water quality at the start of lake release.</td><td></td></tr>
<tr><td></td><td>Sediment loads to the lake need to be considered.

Excessive, suspended solids can have a negative impact on EPL water and habitat quality. In this case, landscape and landform design should examine opportunities to minimize sediment load from the watershed to EPLs and the natural environment. Some sediment load can be beneficial to add nutrients to littoral zones.</td><td>6.2.3
Sediment Processes</td></tr>
<tr><td></td><td>Salt loads from the watershed need to be minimized. Salt mitigation strategies for the watershed need to be considered.</td><td>6.3.1.4
Other OSPW Properties Known to Affect Toxicity</td></tr>
<tr><td>Safe storage of fluid, soft tailings and safe storage and bioremediation of process affected water

Objective: Storage of tailings

(Section 2.4)</td><td>Optimal water cap depth needs to be considered to reduce or minimize effects of fluid fine tails on the desired function and performance of the EPL.

Comments:
Potential effects of water-capped tailings could include:
• increased sediment oxygen demand resulting in anoxic conditions at the bottom water layer of the lake;
• release of pore water to the water column;
• release of biogenic gases to the water column and atmosphere; and
• resuspension of tailings to the water column.</td><td></td></tr>
</table>

Integration in the regional landscape consistent with target land use Objectives: Sustainable Aquatic Ecosystem (Section 2.5) + Other Uses (Section 2.6)	EPLs should be designed to integrate as well as possible with the natural local/regional landscape.	9.3.1 Constructing the Landform Elements
	Suitable infrastructure and shoreline configuration should be included in the design for desired land uses. Shoreline conditions should be adequate for people and wildlife to have safe access to the lake after certification process is accomplished. Shoreline access and facilities must meet the requirements set out in approved closure plans. *Comments:* As for other natural water bodies in the region, there might be portions of the shoreline that permanently or during certain periods of time do not offer safe access to the lake (areas that are too steep, or too soft or that are under active landslide conditions).	9.3.9 Operational Infrastructure Construction
Creation of a long-term, sustainable and resilient aquatic ecosystem Objective: Sustainable Aquatic Ecosystem (Section 2.5)	EPLs should have suitable quantity and quality of littoral zone to support lake productivity, sustainable ecosystem development, biodiversity and end land uses. *Comments:* Fills that are part of littoral zones need to be designed to have a sufficiently high factor of safety for the expected conditions of the littoral zones. These fills need to be designed in a manner that settlements do not lead to water depths that are excessive for the sustainability of the littoral zone ecosystem. The littoral zone should have a relatively flat floor slope to reduce the impact of lake level variations and support lake productivity and ecosystem development. The littoral zone should have suitable soil conditions to support plant establishment, productivity and biomass. Littoral zone measured as area of vegetative cover should be monitored. Monitoring over a period of at least 10 successive years is recommended to take into account variability.	4.8.1 Littoral Zones 6.2.1 Littoral Zone Processes 9.3.6 Littoral, Shoreline, and Riparian Areas 9.4.3 Maintaining Shoreline and Littoral Zone
	Shoreline complexity: the shoreline should be irregular to provide habitat diversity and to minimize bank erosion resulting from wave action. *Comments:* Shoreline irregularity is measured as “shoreline development ratio,” given as the length of the shoreline to the circumference of a circle whose area is equal to that of the lake. A shoreline development ratio of at least 2:1 has been suggested but an adequate ratio should be determined for each EPL. Island development can increase habitat diversity and encourage utilization by waterfowl.	4.8.2.3 Shoreline Complexity
	Restriction of prohibited noxious weeds. Absence of prohibited noxious weeds in riparian and littoral zones.	4.8.2.1 Vegetation Diversity

Objectives	Design criteria	Further discussion
OTHER ASPECTS		
Must comply with all applicable regulations Must qualify for reclamation certification	Dams are not acceptable in closure scenarios, so pre-existing constructed containment structures (e.g., compacted fill structures or structures formed by a pillar of in situ material) that may have been designed for the operational phase of the mine pit or of a tailings or overburden storage facility need to be re-designed and modified to an extent that they no longer pose risks as a dam and have qualified for de-licensing as a dam. These structures need to meet the criteria set by the Guidelines for De-licensing of Tailings Dams.	5 Watersheds in the Mining Environment

8.4 Technical Considerations

This section lists and discusses a number of technical issues that will typically need to be taken into account in the design of oil sands EPLs. Not all of these issues will necessarily apply to all sites, and there might be sites where additional issues need to be considered by the EPL planners and designers.

Some of the issues in this section have already been discussed in previous chapters and are addressed here for discussion of associated design issues. The technical issues related to water quality have been discussed extensively in Chapter 6; only a few are mentioned here as they relate to other design aspects. This section is intended to provide a technical basis for the design elements that are described in Section 8.5.

Successful EPL design will require that all elements and issues be addressed at each design stage. Typical design stages are listed below but they may vary from case to case depending on the requirements of each project.

- Conceptual design
- Preliminary design
- Permit-level design
- Detailed design and construction drawings
- Landform element construction design

8.4.1 Lake Level

Lake level is a key factor that controls various aspects of EPL function and performance, as listed below. Consequently, defining and controlling the lake level should be a priority in the EPL design process.

- Falling lake levels can lead to instability of perimeter slopes, above water as well as under water, especially if the water level falls at a relatively fast rate.
- The lake level is of paramount importance to littoral zones. A dropping lake level can have a negative impact on the littoral and benthic zone ecosystems.
- A rising lake level could expose dispersive Clearwater Formation clay shales to fresh water, causing accelerated erosion and slope instability.
- A rising lake level could lead to instability of the outlet channel by excessive erosion and possible slope instabilities. Failure of the outlet channel may cause a sudden drop in lake level, which is even more critical to slope stability than a gradual drop in lake level.
- Lake level controls seepage in and out of the lake due to variations in hydraulic heads and exposure of areas of potential infiltration.
- Lake level is important to the maintenance of a minimum water cover over fluid tailings deposits; it is also important to tailings bioremediation processes and the associated risks with poor lake water quality.

The lake level is controlled mainly by the hydrologic balance and by the stability of the outlet. Lake level and its variability are determined by the cumulative impact of the net balance of catchment area run-off, precipitation, evaporation, infiltration and seepage, and the elevation of the lake outlet(s) and the associated outlet flow rates. It can also be affected by debris.

8.4.2 Hydrologic Balance

The hydrologic balance should be one of the first elements to be addressed in the design of an EPL, since the designer has limited control over it. There is clearly no control on precipitation and only very limited control on evaporation; there is some control on seepage and run-off. If a significant portion of the contributing watershed is reclaimed land, then diverting water from various parts of the watershed as required to the EPL is an option. The elements of hydrologic balance include:

- *Precipitation* is accounted for by statistical analyses of data from local weather stations. The uncertainty is reduced for a longer data series from a station located very close to the project area. In the oil sands region, most weather stations have a relatively limited historical series, with the McMurray Airport station having the longest data series. The contribution from precipitation onto the catchment area is accounted for by the appropriate selection of a run-off coefficient that represents the portion of the precipitation that contributes to surface water flow (including inlet channels). The definition of the run-off coefficient can be challenging especially for areas newly reclaimed. For these areas, not only is there less experience to support parameter selection but the run-off coefficient is likely to vary with time as the ground consolidates and settles. It will also vary and the vegetation gets established and evolves into a naturally sustainable vegetation cover. Consequently, the uncertainty of precipitation on the catchment area is much larger than for precipitation directly on the lake surface. Inflows from areas upstream of the reclaimed landscape may form part of the EPL hydrologic balance only once they are reconnected to the natural system.

- *Evaporation* includes evaporation directly from the lake surface and from the contributing catchment area (evapotranspiration).
- *Groundwater flow in and out of the lake* is affected mainly by the effect of precipitation (infiltration) at a regional and local level, by the permeability of the in situ and infilling materials and by the hydraulic heads in the area surrounding the lake (height difference between the groundwater levels in the area surrounding the lake and the lake water level). It is noted that groundwater can also be coming from the pore space of tailings deposits and therefore include process-affected water.
- *Outlet channel(s) flows:* There could be more than one outlet channel and these channels could be at different elevations, so flows in these channels would be triggered at different lake levels.

There could be significant uncertainty in the water balance of an EPL. The main cause of uncertainty is typically the hydrology (precipitation and evaporation). There is a natural and inevitable variability of the climate and thus of the precipitation and the evaporation. In addition to this natural variability, there are uncertainties on the statistical treatment of unavoidably limited data sets. There are also difficulties predicting the variability of surface water flows for each catchment area given its topography, materials, vegetation cover and for the various possible sequences of climatic conditions. Therefore, EPLs will potentially be subjected to significantly variable conditions during their existence and there is uncertainty defining this variability. A detailed hydrologic assessment and a water balance calibrated with site specific data are essential elements of the design of EPLs. Therefore, collection of site specific weather and hydrologic data is very important.

8.4.3 Site Geology

Site geology is another item over which EPL designers and planners have little to no control. The degree of control is limited to the selection of the EPL site in the overall pit area and to the selective use of backfill materials in the pit. The geology of the area defines the ore body characteristics, which is a major factor in the mine plan, which in turn is a major factor in the selection of EPL location(s) and configuration (area, depth, volume, shape).

The geology of the mine pit affects (1) the stability of the cut slopes that surround the EPL as some of the geologic formations have low shear strength materials, (2) the erodability of the slopes and thus their stability if dispersive materials are exposed to fresh water, and (3) the potential for seepage in and out of the lake, i.e., infiltration of lake contents into the ground and contribution of groundwater flows into the lake.

The geology of the region is described in detail in Section 5.2.1.1. It comprises mainly Quaternary sediments at the surface, largely of glacial origin, underlain by the Cretaceous Grand Rapids (Kg) and Clearwater (Kc) Formations which are underlain by Cretaceous McMurray Formation (Km) shale and bituminous sand (oil sand) deposits. In some areas, the Cretaceous shales are not present, having been partially or wholly eroded during glaciation. The Interbedded limestone and shale of the Devonian Waterways (Dw) Formation lie beneath the mineable resource, and are persistent throughout the region. The key geotechnical considerations associated with these formations are presented below.

8.4.3.1 Clearwater Formation

Regionally, the marine clay shale strata in this formation are geotechnically significant. The clay-rich strata have been affected by post-cretaceous glacial activity, resulting in localized or extensive horizontal or sub-horizontal planes of weakness that can adversely impact the stability of slopes in these materials. These strata are typically at residual strength and tend to have significant pore pressure responses to loading, which typically do not tend to dissipate within the time frames of most projects. Residual strength friction angles can be as low as 7 degrees in these strata. Weak layers may also develop as a result of strain-softening induced by stress relief during unloading (e.g., mining). Some of the clay in this formation can be dispersive, and thus when exposed to non-saline fluids can be subject to softening and significant erosion. It can also be very susceptible to internal erosion. In terms of hydraulic properties, the Clearwater Formation has low permeability overall; however, relatively thin siltstone beds that are common throughout the formation and the lowermost member of the formation (Wabiskaw Member) are considered minor aquifers.

8.4.3.2 McMurray Formation

Both the Upper and Lower McMurray Formation are host to clay-rich strata, with the potential for low-strength, pre-sheared planes of weakness that may result in slope instability. Similarly, these strata may be subject to strain-softening on discrete planes, induced by stress-relief during unloading (mining). The Lower McMurray may contain water-saturated fluvial sand deposits, which are considered the primary “basal aquifer” beneath the mineable oil sands and represent a potentially significant seepage pathway beneath EPLs. Overall, the McMurray Formation is considered an aquifer-aquitard system, with some zones of low-permeability and some zones of high horizontal permeability.

8.4.3.3 Waterways Formation

The upper contact of this formation includes, in some cases, localized to extensive high-plastic paleosols, which may exhibit pre-shearing and planes of weakness similar to that described above and with similar potential impacts on the stability of slopes surrounding the EPLs. In terms of hydraulic properties, the Waterways Formation is considered an aquifer/aquitard system displaying characteristics of both regional and local groundwater regimes. Groundwater flow is largely controlled by the presence of more pervious sub-units, fractures, faults, and karst features arising from folding, collapse features, and erosion processes. Fracture, faults and karst features, such as sinkholes, may provide significant vertical hydraulic connections within the formation. Underlying formations that can contain highly saline groundwater may be also be connected, affecting the quality and quantity of seepage in or out of EPLs if these features daylight at the pit bottom.

8.4.3.4 Engineered Fills

Fills are not part of the site geology as they are man-made deposits, but they are derived from the site geology. However, there is control in the mine plan over where these fills may be placed. Materials used to construct in-pit structures such as dykes, dumps and other engineered fills that may form part of the EPL containment are derived from mine overburden. This fill material tends to be primarily derived from quaternary glacial deposits and from the Grand Rapids, Clearwater and Upper McMurray formations. These fills may have low shear strength depending on the material of origin and the placement method. Hydraulic conductivity is typically low but it may be relatively high for specific source materials and low compaction effort.

8.4.4 Tailings Deposits and Mechanisms

Several types of tailings deposits exist in the oil sands industry and, in principle, any of them could be placed in an EPL. Oil sands tailings streams may include fluid fine tailings (FFT), mature fine tailings (MFT), tailings sand (TS), composite tailings or consolidated tailings (CT), non-segregating tailings (NST), "densified" cycloned tailings (DT), centrifuge tailings, froth treatment tailings, etc. As processing and dewatering technology continues to evolve, the composition and physical properties of the tailings may change, and could influence EPL water balance and water quality in the reclaimed landscape. Some examples are described below.

8.4.4.1 Fine Tailings

Fluid Fine Tailings (FFT) begin as a suspension of water, mineral particles, bitumen and a variety of chemical components and over time it consolidates into a colloidal gel. As the solids content increases with time (and other processes occur), the material is termed Mature Fine Tailings (MFT). The properties of MFT vary according to the details of the extraction process which varies from operator to operator. Experience at Syncrude's Mildred Lake Settling Basin indicates that biogenic gas may be generated in MFT, as discussed in Section 6.2.3.2. Generally, MFT settles and consolidates relatively slowly. With time, changes reflected in gas production can result in an acceleration of the consolidation process. These effects could be associated with a physical change of the MFT due to the passage of gas bubbles causing an increase in the macro-permeability of the MFT deposit. Whether these trends are confirmed or will continue over time is a matter of ongoing research and debate.

8.4.4.2 Thickened Tailings (TT)

TT is produced by increasing the solids content of the tailings stream with the addition of a flocculant, typically a polymer, to create non-segregating tailings and to recover hot water. In this case, the fine tailings and the sand do not tend to segregate upon discharge and form a relatively homogeneous deposit. The shear strength of this deposit is typically relatively low.

8.4.4.3 Consolidated Tailings (CT) or Non-Segregating Tailings (NST)

The intent of producing CT or NST is to obtain a non-segregating tailings stream where the fine and coarse particles do not tend to segregate, by increasing the solids content and adding gypsum or lime. The shear strength properties tend to be better than those of TT deposits.

8.4.4.4 Tailings Sand (TS)

In most cases, tailings sand beaches are formed by the segregation of the whole tailings stream as it is discharged at a solids concentration of 60% or less by weight. The sandy particles form a beach that may have a high density and shear strength if discharged subaerially. On the other end of spectrum, if discharged into deep water, the beach may be relatively loose and have lower shear strength or even be liquefiable. Tailings sand may also be compacted in cells and form a dense, high shear strength fill typically used as dyke construction material. Sub-aerial beaches and compacted cell deposits have relatively high shear strength.

8.4.5 EPL Contents

Lake contents can be fluids and solids. Fluids can include water (fresh water and/or process-affected water) and fluid tailings such as fine tailings (FFT) or mature fine tailings (MFT). The viscosity and the density of the fluids in the lake affect the rate of seepage in and out of the lake as well as slope stability mechanisms. The solids in the lake can include tailings deposits, overburden and interburden dumps. The presence of these materials affects slope stability, littoral zone stability, and seepage mechanisms. The density of these deposits (and thus the porosity and volume of pore space) affects the mass balance and the quality of the lake water as fluid from the pores will be gradually released into the EPL. Tailings deposits may contribute significant quantities of pore fluid to the lake water and in this case the fluid will be process-affected water. Overburden materials can have saline pore water, so a landscape design that reduces the amount of recharge through these materials is preferred.

The nature of the EPL contents will vary with time as the EPL gets established and evolves into a self-sustaining lake ecosystem. The processes involved in achieving such a system are complex and not all well understood yet, as discussed in Chapter 6. At this time, studies and field trials are underway and the state of knowledge is evolving through research and monitoring of large scale test cases. This section discusses some of the geotechnical processes that may be associated with EPL contents. However, knowledge of geotechnical or other issues related to MFT is still evolving. The geotechnical behaviour of other types of tailings and overburden material, as EPL contents, is better understood than MFT behaviour and currently can be better taken into account in the design of EPLs.

The MFT deposit in an EPL will likely begin essentially in uniformity with its surface at a relatively constant elevation. However, if the thickness of the MFT layer is significantly variable due to the shape of the pit floor and the pit slope configurations, there could be a relatively large differential settlement between zones of the deposit with significant differences in thickness. As MFT consolidation and settlement progresses, MFT on thinner zones may start to be un-supported as MFT on thicker zones undergo more settlement. Initially, MFT may creep slowly down pit walls or other elements. However, depending on the strength developed in the MFT with time, movements may take the form of turbidity currents and could possibly disrupt the remainder of the MFT deposit, leading to episodic release of sediments into the water cap. As consolidation progresses, water will be expressed from MFT deposits and will affect the chemistry of the water cap.

As MFT consolidates, its permeability tends to reduce significantly (if not overridden by gas generation) which has a positive impact by reducing potential seepage out of the EPL.

8.4.6 Consolidation and Settlement

When soil deposits are subjected to increased loading conditions, the pressure of the fluid in the pores of the deposit ("pore pressure") will increase and the fluid will bear some or even all of the new load. As the excess pore pressures dissipate, the new load is gradually transferred to the particulate structure of the deposit, increasing the effective stresses and causing the deposit to deform. This phenomenon is called consolidation. The pore pressures dissipate by pore fluid draining out into adjacent regions or materials under lower pore pressures or by draining upwards to the top of the deposit. Therefore, the consolidation process leads to a loss of fluid and a reduction in the volume of the deposit and consequently settlement of the deposit surface, as the fill adjusts to the new loading conditions. Increased loading can be due to physical weight placed on the material (e.g., new layers of soil or construction of a heavy structure), dynamic loads (seismicity, wave action) or a drop in the deposit water level. Continuous deposition of material in an area, such as tailings disposal, causes the new layers to add weight to previously deposited lower layers, which then start consolidating. This is called "self-weight consolidation" and it is a very important mechanism in the formation of all deposits, and softer tailings deposits in particular.

The consolidation (and the resulting settlement) of a deposit depends on various factors including:

- permeability and compressibility of the deposit; these properties are affected by deposit density, deposit intrinsic fabric (shape of grains and inter-granular structure) and by material gradation and mineralogy;
- drainage conditions, including hydraulic conductivity and pore pressures in surrounding materials (boundary conditions) as well as the length of the drainage path; and
- magnitude and rate of loading.

Consolidation of tailings or overburden fills in the EPL will cause the lake to get deeper with time (Figure 8-3). If fills are used to form littoral zones, consolidation could cause the depth of the littoral areas to exceed the depths acceptable to support the appropriate ecosystems.

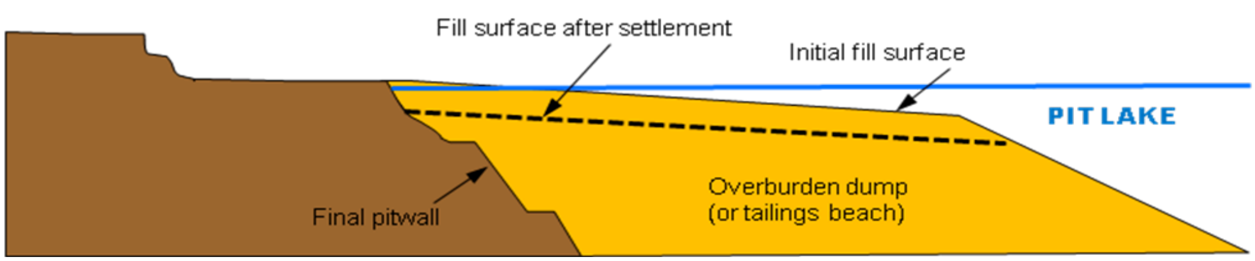

Figure 8-3: Consolidation and resulting settlement of tailings or overburden deposit can affect the depth of littoral zones.

Consolidation of fills that form lake containment could also affect freeboards in areas surrounding the lake. A smaller freeboard may have an impact on the risk level for the EPL. Another point to consider is that significant settlement of MFT could lead to slumps of the MFT deposit if there is significant variability in its thickness. Slumps in MFT can form turbidity currents in the lake, which could impair water quality and benthic habitat.

In addition to settlement, consolidation of fills is associated with the release of pore fluid. This phenomenon involves a continuous, although exponentially decreasing, inflow of process-affected fluid from the tailings deposit into the lake that will affect water quality.

Therefore, consolidation of all fills (tailings and overburden) needs to be assessed as part of the EPL design to estimate various design parameters such as future lake and littoral zone depths, contribution of process affected water to lake water quality and future freeboard. Since consolidation is a time-dependent mechanism all these design parameters will vary (exponentially) with time which will also need to be accounted for in the design.

Consolidation of MFT and soft tailings cannot be analyzed using conventional consolidation theories, which are applicable only when the deformations are small (equations assume small strains). Consolidation of soft tailings deposits needs to be analyzed using finite strain or large strain consolidation theories (Gibson et al, 1967). In most cases, a one-dimensional consolidation analysis will be adequate. Two-dimensional consolidation analyses are not typically required as the large majority of the flow tends to be vertical and for most of the lake area a one dimensional condition prevails (Jeeravipoolvarn et al., 2008).

8.4.7 Liquefaction

Liquefaction refers to a phenomenon where, due to an external static (e.g., rapid loading) or dynamic (e.g., seismic event) trigger, the structure of a soil deposit collapses, generating pore pressures sufficiently high to make the effective stresses zero and thus causing the soil to behave like a thick fluid. Tailings deposits can be liquefiable especially if deposited below water (subaqueously). If liquefaction occurs, there could be a significant negative impact on the integrity and performance of EPLs depending on the location and configuration of the tailings deposit.

8.4.8 Seepage

Seepage issues are important to the physical integrity of containment, to the water balance (and lake levels), to the water quality in the lake and to the potential environmental impact of an EPL on the groundwater and receiving surface waters. Seepage could also affect the stability of the slopes around the lake and cause a risk of development of an internal erosion mechanism. If seepage exits in an area outside the lake, it could also affect the vegetation in the area.

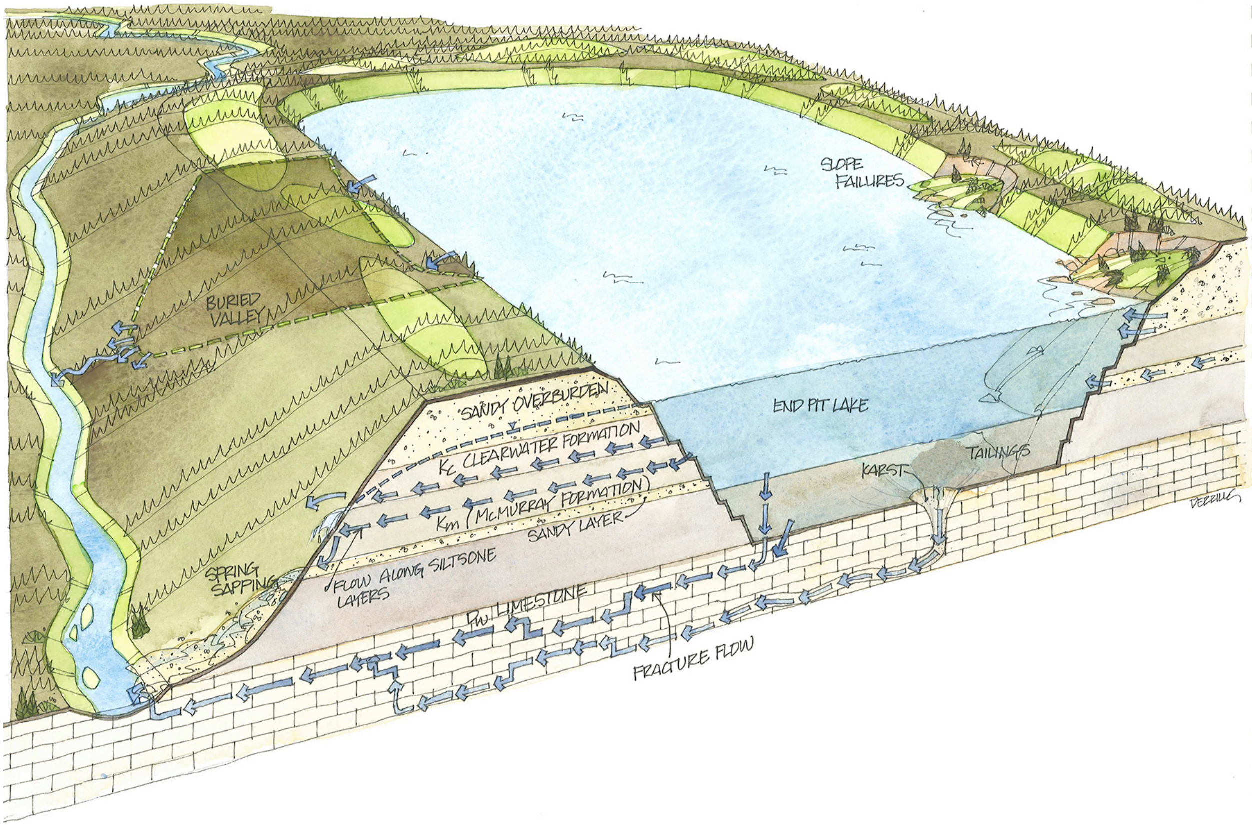

Figure 8-4: Potential seepage paths to and from an EPL and slope failures. Aboveground elevation of EPL is for illlustration purposes only.

Seepage (infiltration) in and out of the EPL is controlled by the nature of the materials that contain the lake, the nature of lake contents and the relative hydraulic heads between the lake and the groundwater in the various geological formations (Figure 8-4). The higher the hydraulic gradient, the higher will be the seepage rate for the same type of materials. The seepage rate can also be influenced by the pond contents. Low permeability materials placed in the pit (lake bottom and lake slopes) will reduce seepage. MFT in the lake may also significantly reduce the seepage. MFT is viscous and tends to create a seal against pervious granular materials, although it may not create a seal in fractured materials.

8.4.8.1 Seepage into Pitwalls and Other Surrounding Slopes

There are some higher permeability units in the typical stratigraphy of the oil sands region, for example: Quaternary sandy deposits, siltstone stringers in the Clearwater and McMurray Formations, sandy units in the McMurray Formation (basal aquifer in particular), buried channels, various pervious subunits, karstic features and fractures zones in the Waterways Formation, etc. Seepage into these zones can occur depending on the connectivity of these zones and whether the hydraulic head of the EPL is higher than the hydraulic heads in the ground. Seepage into these materials, if significant, can potentially affect the water balance and thus the lake level. It can also lead to softening of the slope material and contribute to slope failures. If the hydraulic gradients are too high, seepage into pervious zones and to the environment can increase the risk of internal erosion, or “spring sapping” (erosion of particles at the seepage exit point).

8.4.8.2 Seepage out of Pitwalls and Other Surrounding Slopes

Seepage out of pitwalls and other slopes could occur if the groundwater level in these slopes is higher than the EPL level. If significant, seepage out of the slopes could affect the stability of these slopes and even the EPL water balance. It would also affect the quality of the lake water. Another important point in this case is the potential location of the exit point of this seepage since, if the hydraulic gradient is sufficiently high for the type of material involved, it could lead to internal erosion and possible piping.

8.4.8.3 Seepage in or out of the EPL Bottom

The presence of high-permeability material at the lake bottom, such as a basal aquifer, pervious units of the Waterways Formation, sinkholes, or fractures, could lead to seepage in or out of the EPL bottom depending on the relative hydraulic heads. This seepage could affect lake level and water quality. The Waterways Formation and the underlying Prairie Evaporites can have relatively high hydraulic heads.

There could be a risk of internal erosion at the exit point of the seepage water. Lake contents affect the potential seepage through the pond bottom. The presence of MFT (a viscous fluid or a gel like material that typically has solids content upwards of 30% by weight) can significantly decrease the potential seepage into the pond bottom. It has been observed that MFT over tailings sands leads to the formation of an MFT seal over the tailings sand surface. Experience at Suncor indicates that this seal can be effective at significantly reducing seepage under a significant column of water. Other situations need to be studied in more detail and field data need to be collected to demonstrate actual performance.

Seepage issues related to EPLs can be mitigated by the presence of overburden, MFT and other low permeability tailings materials covering the lake bottom and lining the perimeter slopes. Overburden dumps tend to be low permeability fills and can provide a seepage barrier in some cases. A similar effect could be caused by low permeability tailings materials. MFT is a viscous fluid that does not easily permeate through most granular materials; it is known to form very low permeability “liners” when put in contact with sands as mentioned above.

8.4.9 Surface Water and Erosion

The quantity of surface water reporting to an EPL will be governed by the balance between precipitation, evapotranspiration and groundwater inflow and outflow. The topography of the catchment area upstream of the EPL affects the amount of surface water that reaches the EPL and contributes to the water balance. This contribution can be controlled in some cases by, for example, changing the catchment area topography, designing channels to increase or decrease the amount of water that reaches the EPL by diverting them to the EPL or away from it, creating other EPLs upstream of the one in question, and changing the location of the lake in the watershed.

Surface water will have a certain solid loading due to erosion of the terrain or erosion of the surface water channel itself. Sediment loading can affect water clarity and water chemistry. It can also affect littoral zones by contributing nutrients and changing its geometry. Deposition of sediments in the initial stages of a littoral zone may help compensate for potential settlement of the area.

Surface erosion associated with natural water courses needs to be considered in cases where it could affect containment or any other aspect of an EPL. This is a particular issue for natural water courses that are not incised in the limestone.

The most critical item related to surface water level is the outlet channel. The physical integrity of the EPL may depend on the ability of the surface water outlet to function appropriately over the full range of lake levels. The design needs to account for the geomorphologic processes that would occur in the long term, both as gradual and singular events. It also needs to account for beaver activity, slope instability and other natural phenomena.

8.4.10 Wave Effects

Waves are a function of the fetch, the nature of the winds in the area, and the depth. Waves can lead to erosion of the shoreline, including the littoral zones. They can also promote mixing in the lake. In some cases, mixing can help improve the water quality and reduce the risk of the formation of meromixis. However, if meromixis is the design intent, waves can be a risk to this condition.

The effect of waves can be modelled to determine whether sediment resuspension could occur. Development of waves may be minimized by selecting the shape and orientation of the EPL, and the complexity of its shoreline, to create embayment and protected areas.

8.4.11 Seismicity

The regional seismicity of the Fort McMurray area has been assessed by a working group consisting of all oil sands operators, regulators and consulting companies. Natural and induced seismicity needs to be considered in analyzing the stability of all slopes and structures associated with the EPLs. Although the seismicity in the oil sands region is relatively small, it could be significant in the assessment of some slopes, and it is especially important given the long time frames that the design of EPLs needs to cover.

8.4.12 Slope Stability

Slope stability is a significant issue for the design of EPLs and includes slopes above and below water along the shoreline, littoral zone slopes or inlet/outlet channel slopes. The slopes along the shoreline may include final pitwalls, pervious dyke slopes, overburden dump slopes and natural slopes. Stability of these slopes is controlled by the following variables:

- The shear strength of the materials that form the slope, which can include weak fills (e.g., tailings sand beach deposited below water) and several very weak natural materials of the region.
- Dispersivity: Some of the natural materials, especially the Clearwater Formation (Kc) clay shales, are dispersive when exposed to fresh water. Dispersivity can lead to significant rates of erosion, slumping, formation of sinkholes and slope failure. Dispersivity is expected to be a significant issue for lakes where the Kc shales are in contact with the lake water. It would also be an issue to Kc cut slopes exposed to precipitation, unless the cuts are sufficiently flat to accept a stable soil cover. Kc derived fills and tills may also show dispersive behaviour.
- Pore (water or gas) pressure in the ground and its variability (e.g., sudden drops in lake level or groundwater outflow can lead to slope failures).
- Stress conditions: Slopes around an EPL would be affected by several potential stress changes, such as unloading due to mining and other excavations, which could lead to gas ex-solution and loosening of McMurray Formation materials. There could also be loading due to placement of materials at the crest of the slopes and loading due to sediment accumulation on littoral zone underwater slopes.
- Slope geometry such as slope height and slope angle affect the stability of the slope. Changes in slope geometry over time also need to be considered.
- Seismicity: Seismic events challenge the stability of slopes and thus need to be considered in the design.

Steep and exposed slopes in Clearwater Formation and McMurray Formation exist along the river valleys in the region. However, the geomorphic processes that formed these slopes were very gradual compared to the mining process, which make them a poor analogue for the stability of EPL perimeter slopes. The effect of unloading and gas ex-solution on the geotechnical behaviour of these materials is important and quite time dependent. EPL slope design will need to take these issues into account. Occasional failures of EPL slopes would be expected as part of the natural processes of landscape geomorphic evolution.

Submergence of slope tends to stabilize a slope as the weight of the fluid acts like a buttress for the slope. However, submergence may also lead to instability due to softening of the materials as they get saturated (especially critical if the material is dispersive) and due to the possibility of creating unfavourable pore pressure conditions as the lake level varies with time. Instability of submerged slopes can lead to negative effects on EPLs, which may include:

- Significant impact on the stability of overall containment slopes.
- Significant impact or even loss of littoral zones if the slopes that form the edge of littoral zones fail.

- Creation of waves that could impact lake containment, stability of other slopes, outlet facilities and littoral zones.
- Excessive mixing of lake contents and potential turbid currents, which can affect lake bottom characteristics and water quality.
- Significant increase in sediment loading in the lake or even in the outlet channel.

Submerged slopes may include old pitwalls, overburden slopes, tailings deposit slopes or other pond content material slopes. Submerged slopes may be part of containment structures, littoral zones or lake content materials, including slopes formed by deposition of sediments transported into the EPL by inlet channels. Significant variations in lake level, especially sudden drops, can lead to failure of submerged slopes. Another important issue is the potential dispersivity of Clearwater Formation materials when submerged.

8.4.13 Containment Structures

Containment structures that qualify as dams are not allowed as part of the containment system of an EPL. Dams are defined by regulation in Alberta (Alberta Environment, 2001) as any structure that holds more than 30,000 m^3 of fluid and has a height of 2.5 m or more. If the ideal lake location for the mine plan leads to a lake that needs to be contained by a structure (dam formed by fills or by an in-situ pillar), this location needs to be reconsidered. In this case the lake needs to be moved farther away from the limit of the mine or the valley wall.

Dams, as described above, are not acceptable closure and reclamation elements as they require regular monitoring and maintenance to minimize risks of failure. Therefore, if dams exist, these structures need to be de-licensed as dams before becoming an acceptable long-term containment structure of an EPL. A de-licensed dam is a structure that was formerly classified and regulated as a dam but that has been modified to an extent that it no longer poses risks as a dam. A working group formed by all oil sands operators, all Alberta Government regulators and several consultants is currently in the process of completing guidelines for de-licensing of oil sands tailings dams. These guidelines are based on the concept of implementing measures to reduce the incremental risks to a negligible level, (i.e., the potential risks are comparable to the risks existing in the natural environment). Consequently, the design of EPLs needs to address the issues of man-made containment structures (compacted fill structures or in situ pillars) to ensure that these structures do not constitute a dam and if they do, or did during previous stages of the operation, are properly de-licensed as a dam before the closure stage.

8.4.13.1 In Situ Pillar Containment

Figure 8-5 illustrates an EPL containment provided by a pillar of in situ material that provides separation between the lake contents and adjacent topographic lows (commonly river valleys). This in situ pillar is created by the mine advancing toward a river valley. The pillar is the in situ material that remains between the final pitwall and the river valley slope. In situ pillars may be potentially classified as a dam and thus may be under the regulatory requirements for a dam. In this case, the design guidelines for dams as set out by the Canadian Dam Association and other regulatory bodies would apply and the in situ pillar would not constitute an acceptable closure scenario.

8.4.13.2 Perimeter Pitwall

Figures 8-6 and 8-7 illustrate a common lake perimeter configuration from a number of EPLs that have been planned in the oil sands region where the EPL is contained directly by the final pitwall. In some cases, there were significant external or "out-of-pit" structures above the pitwall (Figure 8-7), including external tailings ponds and more commonly overburden dumps. In some cases, wide intermediate benches on the pitwall were present and provided a location for shallow aquatic habitat (littoral zones). Figures 8-6 and 8-7 show typical configurations, without and with external structures, respectively. Where overburden is present in significant thickness, the pitwall design typically included a wider bench above the ore, and a shallower overall slope in overburden. In both cases, the slopes represent the average overall pitwall slope; although in reality the pitwall slopes have multiple benches.

8.4.13.3 Engineered Fill Perimeter Structures

EPLs may be contained by an engineered fill structure if this structure is sufficiently wide and meets all other requirements, so as not to be classified as a dam. This structure could be an in-pit dyke used during mining for retention of mine tailings or overburden (Figure 8-8), typically at a higher elevation than the design lake level. In some cases, it may include an external engineered fill containment structure.

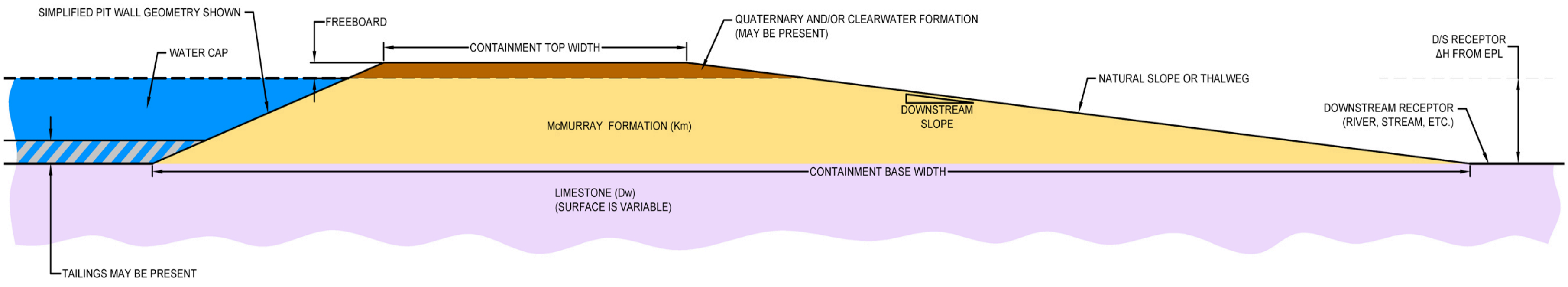

Figure 8-5: An EPL containment provided by a pillar of in situ material.

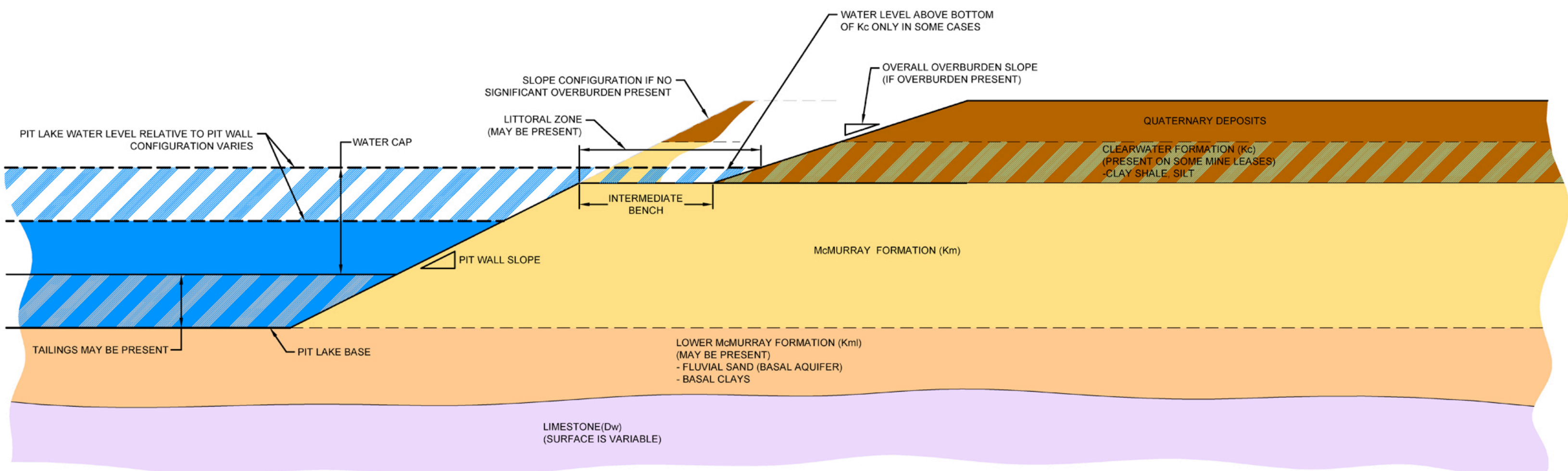

Figure 8-6: A typical EPL perimeter configuration without external structures present.

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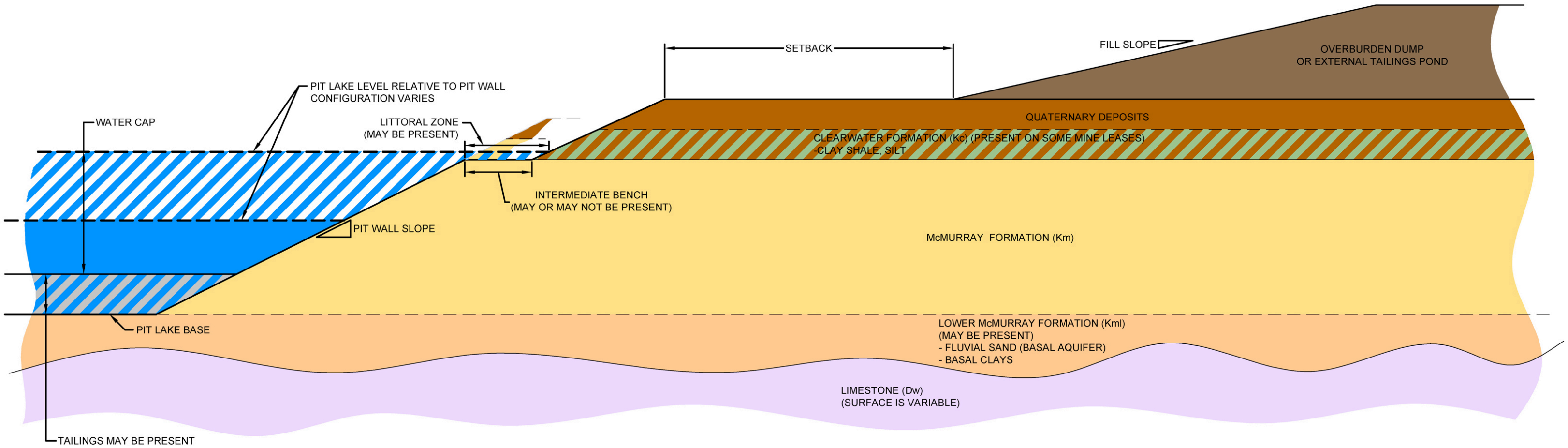

Figure 8-7: A typical EPL perimeter configuration with external structures present.

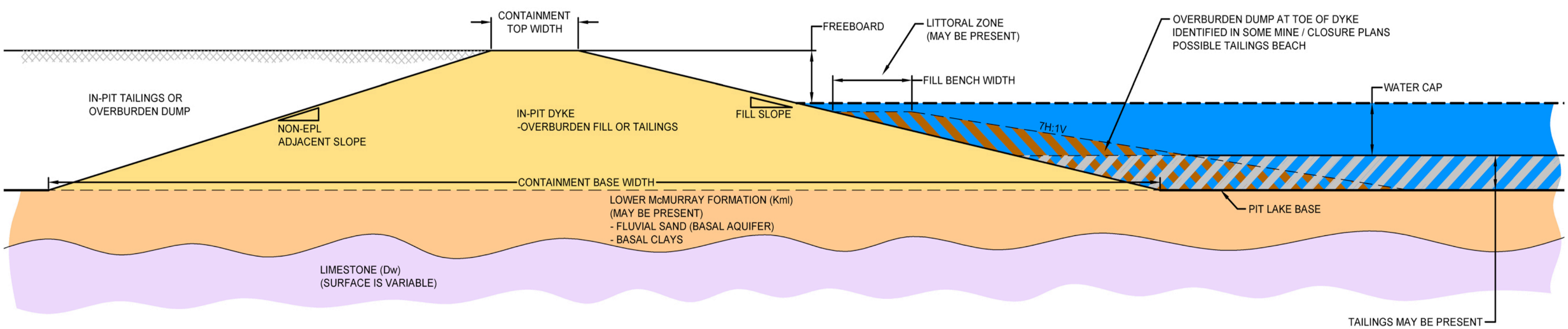

Figure 8-8: Engineered fill perimeter structures would require de-licensing as dams to become part of an EPL.

8.5 Design Elements and Construction Aspects

8.5.1 Introduction

This section describes the elements of the design of an EPL in the oil sands and some of the construction aspects that are related to design. The technical issues related to design have been discussed in detail in Section 8.4. The design of an EPL needs to meet the criteria presented in Section 8.3.

The issues associated with the design of an EPL vary from case to case depending on the particular geometry, stratigraphy and condition of each EPL. Nevertheless, typical issues and design elements of EPLs in the oil sands industry are discussed below. It is essential that each EPL be designed by qualified and experienced engineers working in close collaboration with professionals from other disciplines (geology, hydrology, environmental sciences, planning, construction, operations, etc.) given the multidisciplinary aspect of an EPL design and the particular details of each case.

The following design elements are considered the most critical as they define the physical feasibility of an EPL:

- watershed design
- lake location, configuration and contents
- hydrologic balance
- design of inlet/outlet channels

Other design elements that are important to the design of all EPLs are:

- stability of shoreline and internal slopes
- design of littoral zones

These design elements determine physical performance, environmental performance and costs. They are discussed in more detail below.

8.5.2 Watershed Design for EPL

The design of the watershed is as important to an EPL's performance as the design of the lake itself. This section provides guidance on watershed design, building on the information provided in Chapter 5. Watershed design occurs at the lease/landscape scale and is best handled as an aspect of closure planning.

An EPL watershed needs to provide the lake with an acceptable quantity and quality of water to allow the lake to eventually support a self-sustaining ecosystem. The combination of uplands, riparian areas, wetlands, and lakes need to provide a host of interdependent functions, especially ecological values.

8.5.2.1 Water Quantity and Quality

EPLs need a sufficiently large watershed to support a sustainable water balance, including replacement of water lost to lake evaporation, losses to seepage, recirculation of water required for water quality purposes, etc. Water balance models that take into account climate, surface water and groundwater are used to determine the minimum watershed area to lake area ratio so that the design will allow the lake to have a net positive water balance. A water balance model is a must for all EPL designs, but as a starting point, a useful assumption is that EPLs need a watershed area approximately three to eight times the size of the lake.

Tailings substrate consolidation and groundwater inflows bring salts and naphthenic acids into the lake, where evaporation concentrates solutes. Therefore a large watershed is needed to help flush the lake water, limit the effects of evapoconcentration and preserve water quality in the lake. Numerical models for water quality are employed. A rule of thumb is that the watershed needs to be eight to 20 times the area of the lake for adequate flushing. The factor is less for watersheds with larger natural areas, higher for those with large tailings landforms.

8.5.2.2 Watershed Components: Natural Areas

One strategy for watershed design is to maximize the natural watershed area reporting to the EPL, which will bolster the water quantity/flushing and dilute waters affected by mining. Over decades and centuries, the quality of the waters from the reclaimed mine land will be similar to that of the natural areas.

Typical annual water yields from most natural areas in the oil sands region is about 80 mm per year, but can vary from 0 to 200 mm in a given year. Very roughly, about one fourth of the yield is base flow, half is snowmelt freshet, and the remainder is storm runoff. Relative proportions will vary widely each year. Water quality also varies (see Appendix B), but is typically good, with pH=8, TDS<500 ppm, and naphthenic acids near zero. Bedload and suspended sediments from natural streams are usually low but not inconsequential for EPL design and performance.

8.5.2.3 Watershed Components: Tailings Areas

Tailings areas will often constitute a significant proportion of the reclaimed watershed reporting to an EPL. There will typically be several different tailings landforms in the watershed. The watershed is designed to capture as much of the runoff and seepage for direction to the EPL for dilution and treatment. The EPL elevation is often governed by this need to drain nearly the entire disturbed watershed.

Annual yields from tailings areas are about 100 mm, mostly as base flow. Tailings seepage and runoff from reclaimed tailings areas typically mixes and is conveyed to the EPL in constructed creeks. Typical tailings seepage water quality is presented in Appendix B, Table B-11. It usually has a pH of 8.3, TDS of 2,000 to 4,000 ppm, and naphthenic acids of 10 to 20 ppm. Depending upon the performance of tailings reclamation, sediment loading from tailings landforms that report to EPL may be considerably elevated.

Tailings landforms can be designed to limit the annual load of compounds of interest to EPLs in a variety of ways:

- Choice and quantities of additives to the ore and to tailings;
- Water use management strategies – more re-use results in reduced water quality. Water treatment can be used to improve tailings water quality and hence control seepage water quality;
- The fines content of tailings landforms can be used to control the rate of release and quality and quantity of water from tailings landform;
- The reclamation cover, position of on-landform wetlands, and the geometry of the tailings landforms can all be designed to influence water quantity and quality, albeit within a modest range, and with economic, land use, and landscape performance tradeoffs.

8.5.2.4 Overburden Landforms (Dumps)

Overburden landforms may be constructed of sandy or clay-based glacial materials, saline sodic Clearwater Formation clay shale, or lean oil sands. Typical yields are 100 mm per year, mostly as snowmelt freshet. Runoff water quality will typically have elevated salts, and naphthenic acids, improving with time. Long-term seepage may be a concentrated and important source of salts to the EPL. The cover design will have a profound influence on the water quality from these landforms.

8.5.2.5 Surface Water System

The surface water system may involve tens of kilometres of constructed streams, several constructed wetlands, and perhaps other EPLs. The main focus of the surface water system design will be safe transmittal of water to the EPL and on to the natural environment. The topography of an EPL watershed is necessarily higher than the EPL elevation. Wetlands upstream of the EPL can be used to attenuate flows, reduce sediment loading, and improve some aspects of water quality reporting to the EPL. The system will also be designed to support wildlife and land use values to accommodate beaver activity. There are opportunities for use of low gradient streams to provide fish connection between EPLs and other parts of the system.

8.5.2.6 Landfills and Other Disturbed Areas

Leachate from reclaimed landfills and plant site areas may eventually migrate through the surface water and groundwater system toward the EPL. Quantities need to be designed to be very small, since the quality may impact the performance of the watershed and the EPL.

8.5.2.7 Other Watershed Design Considerations

Watershed construction and reclamation will proceed at different rates and in different locations at different times, and these areas will be linked to the EPL at different times. In addition to this spatial-temporal evolution of watershed size, vegetation and soils and seepage rates will evolve over time, especially in the first century of EPL operation. Closure planning and watershed design should take this evolution into account.

The watershed has objectives beyond supplying water to the EPL. The watersheds have their own ecological functions and performance to fulfill, and there will necessarily be tradeoffs between wetland, upland, riparian, and EPL performance goals. For example, constructing thick soil profiles will enhance tree growth and evapotranspiration at the expense of providing this water to the EPL. Marshes will experience more evaporation than upland areas, also at the expense of EPLs.

The EPL is a part of the watershed and plays vital ecological and hydrological roles. A watershed cannot be designed exclusively for the EPL, nor the EPL exclusively for the watershed.

A designed watershed may be contiguous to another designed watershed and thus their interaction will require detailed consideration. The quantity and quality of water discharged from a watershed will be a substantial design consideration for a watershed located downstream of it.

With the creation of a region of EPLs in a watershed, regional watershed design will also come more into focus with time. Design for connectivity for fish, mammals, and other animals and ecosystems components will gain prominence. Furthermore, the monitoring and adaptive management approaches that are aimed at EPLs will also need to monitor the EPL watersheds, and so will in reality be landscape/regional monitoring and adaptive management programs.

8.5.2.8 Summary

Key aspects of watershed design of interest to EPL planners and designers are:

- In some cases, the additives and composition of the tailings (tailings technology selection) will have a profound impact on water quantity and quality reporting to the EPL.

- The landform design is highly constrained in attempting to ensure that all process-affected waters flow downstream under gravity to the EPL.

- There are tradeoffs in cover design and designs for land uses for overburden dumps and tailings areas that affect EPLs. Thick covers that trap moisture are good at reducing erosion and promoting vegetation and wetland performance, but reduce the quantity of water reporting to EPLs.

- The ability to incorporate large undisturbed watersheds into the EPL watershed is advantageous, though some would suggest that this “clean water” be diverted away from EPLs and reclaimed landscapes.

8.5.3 Lake Location and Configuration

The EPL location in most cases would largely be defined by the ore body characteristics and mine plan. However, it is important to note that the EPL location cannot be such that it requires containment structures that qualify as dams since these are not acceptable as part of the closure plan. For example, it would not be acceptable to locate an EPL close to a river valley where it is separated from the valley by a narrow pillar of in situ material left in place when mining is done, unless the in situ pillar is sufficiently wide not to qualify as a dam. See more detailed discussion in

Section 8.4.13. The selected location for the EPL also needs to ensure feasibility of the outlet channel. There needs to be sufficient length relative to the required head drop between the lake and the receiving water body for a feasible design of a sustainable channel. Excessively steep channel bottom slopes or placement of channels on a slant along slopes are examples of non-sustainable designs which would not survive the natural geomorphologic events that would control the channel geometry and location in the long term.

Table 8-2: Geometric parameters that need to be considered during the design of the EPL.

Parameter	Significance
Area	The area of the lake is defined by the mine plan and the material balance (including the hydrologic balance). The lake surface area affects both evaporation and fetch (maximum length along the prevailing wind direction).
Depth	The lake depth is controlled by the geology (thickness of the ore body and its depth), the mine plan, placement of solids in the lake, elevation of the outlet channel and the required depth to achieve adequate water quality. The design of the lake depth needs to start with the element over which we have the least degree of control – thickness and depth of the ore body – and determining the optimal amount of solids to be placed in the lake and the elevation of the outlet channel to achieve a final depth in the range of optimum depths relative to water quality. The aspects related to depth that affect the lake water quality are sediment resuspension by wave action (Section 6.2.4), evapoconcentration, and meromixis (see Section 6.2.2). For a given volume, lakes with low total dissolved solids (TDS) can have a larger range of acceptable depths because (1) evaporation may not be as limiting as in a shallow lake since concentrations of constituents would more likely be below water quality thresholds, and (2) lakes with low TDS are less prone to become meromictic, so depth of mixing and re-aeration are likely to be higher in low-TDS lakes. EPLs with high TDS have a narrower range of optimal depths since they are more susceptible to becoming hyper-saline due to evaporation and salt rejection, and meromictic due to a denser hypolimnion becoming a barrier to vertical mixing. Case-specific modelling is required to determine the optimal lake depth required to minimize the effects of evaporation while encouraging sufficient vertical mixing to maintain an aerobic water column, as discussed in Chapter 6. Modelling is also required to address the potential for sediment resuspension for each specific case. The selected EPL depth needs to be compatible with the water balance and the required residence time (see Section 8.5.4).
Volume	The lake volume results from the lake area and depth and thus is a function of the same issues as mentioned above, including mine plan, mass balance, elevation of the outlet channel and water quality. The lake volume needs to be compatible with the required hydraulic residence time, the feasibility of filling and the time period it would take to fill the lake.
Shape	It affects fetch and feasibility of littoral zones. Irregular shapes are better to create embayment areas protected from winds, waves and erosion.
Shoreline complexity	It is defined as the ratio between the perimeter of the lake and the perimeter of a circle with the same area. Basically, the larger the number, the more “irregular” the lake shape will be. Larger shoreline complexity is better because it favours the development of sheltered areas and habitat diversity, resulting in a more resilient ecosystem (see Chapter 4). It also helps minimize shoreline erosion. Table 4-5 illustrates typical shoreline complexities for natural lakes on the Boreal Plain in Alberta. The recommended design is a minimum shoreline complexity ratio of 2:1. Island development could increase habitat diversity and encourage utilization by waterfowl.

Parameter	Significance
Orientation relative to prevalent winds	The orientation of the lake relative to prevalent winds affects wave erosion; it also affects mixing, which could be a significant issue in lakes that are shallow and in lakes that contain MFT and a relatively shallow water cap. For the latter cases, it would be ideal to orient the EPL such that the length of the lake along the prevailing winds (fetch) is relatively small.
Access	The lake shoreline configuration needs to include safe access for people and wildlife that is compatible with the design objectives and the future target land use.

8.5.4 Lake Contents

Lake contents affect depth, potential for mixing, seepage in and out of the lake, chemistry, water clarity and littoral zone. Lake contents include fluids and solids. Fluids typically include fine tailings that may need to be stored in the lake and water.

Several strategies have been proposed to fill EPLs. These include:

- Transfer of fluids (water and possibly MFT) from external sources into a mined out pit which may also contain other materials.
- Conversion of an existing belowground settling or clarification pond into an EPL by providing a suitable water cap to existing MFT or by dredging out a sufficient volume of MFT to allow for an acceptable water cap thickness.

Potential sources of water for EPL filling would include one or more of the following:

- Process-affected water available in the system including decanted water pumped from an external tailings facility.
- Athabasca River or other rivers in the region.
- Run-off and other surface waters from the contributing watershed.
- Direct precipitation on the lake which in the Fort McMurray area is not very significant and in most years tends to be less than the natural evaporation rate.
- Groundwater flow into the lake which is insignificant in most cases. However, it could be significant in some cases of direct connection to the basal aquifer and/or to the limestone.
- Groundwater directly pumped from wells.

These sources can be considered in the design and, within the flexibility of each case, selected as a function of availability, costs, quantity and also quality. Different water sources will affect initial (and even potentially final) lake water quality. Sources of water may be combined to manage the resulting EPL water quality. Although it may not always be possible to control both the lake and inflow TDS, this option may be available in some cases. This flexibility exists where the amounts of oil sands process water and fresh water used to fill the lake can be adjusted, such as EPLs that are filled while a project is still operating. If this flexibility does exist, the likelihood of developing meromixis could be reduced by maintaining similar TDS concentrations in the lake and inflows. One method of doing this would be to adjust the timing of inflow sources such that inflow TDS concentrations are similar to

EPL TDS for as long as possible. Athabasca River water, or natural background flows from local streams, could also be pumped at specific depths into pit.

Athabasca River water or other fresh water could be used to complement watershed inflows into an EPL, if the lake is to be filled more quickly than the rate that could be supported by the lake's watershed. Without supplemental sources, some EPLs would take many decades to fill. Freshwater inflows also provide dilution to improve water quality at the start of lake release. In some cases, additional oil sands process water may be discharged into an EPL with a resulting decrease in the filling period. However, water quality is likely to be poor if process-affected water becomes the dominant source of inflow. It is noted that in general, for the same sources of water, longer filling periods will lead to lower concentrations of degradable constituents, such as naphthenic acids, but higher concentrations of salts, at the time of initial discharge. Direct precipitation and groundwater inflows are nearly always insignificant compared to other filling sources, but local runoff from the reclaimed mine must be accounted for.

When tailings are placed in an EPL, it becomes necessary to have a water cap. Potential effects of water-capped tailings include: (1) increased sediment oxygen demand resulting in anoxic conditions; (2) release of pore water to the water column; (3) release of biogenic gases to the water column and atmosphere; and (4) resuspension of tailings to the water column. Thus, modelling should be completed to determine optimal water cap depths to reduce or minimize these effects. This modelling is discussed in Section 9.5.

Solids can be placed in an EPL during mining, or as part of the implementation of an EPL, for a number of reasons, including:

- Low permeability materials can be placed over high permeability materials intersected by the mining excavation (such as the basal aquifer) to reduce seepage in or out of the EPL.
- Solids may be placed to reduce the lake depth to reduce the requirement for water and/or to manage water quality.
- Solids may be placed in the lake to reduce the lake depth to avoid meromixis.
- Requirement of the mine plan to manage materials during the mining process and/or to manage costs by reducing haul distances or double-handling.
- Formation of a littoral zone shelf.

8.5.5 Hydrologic Balance and Design of Catchment Area Landform

The hydrologic balance and the design of the catchment area landform are critical aspects of the design of an EPL, as discussed in Section 8.4.2. The hydrologic balance needs to be determined for each lake based initially on mean hydrologic data, but also verified for a variety of return periods, as considered appropriate in each case. These may include the extreme hydrological events — PMP (Probable Maximum Precipitation) and PMF (Probable Maximum Flood) — as EPLs are part of the closure scenario.

The definition of the stable lake level is based on the hydrologic balance, including all expected flows in and out of the lake. The surface water flows depend on the size, materials and topography of the catchment area, and the inlet and outlet channels. Design of the surface water management system allows for some control of the amount of water in and out of the lake and the residence time of the water, which is critical for water quality. It is possible to design the catchment area landforms to direct more or less water into the lake, as discussed below.

Seepage assessment needs to be done for various stages of the life of the EPL to:

- Evaluate the contribution of groundwater into the EPL both in terms of quantity and quality.
- Evaluate the infiltration from the EPL into the groundwater.
- Evaluate potential groundwater discharge points including the potential for excess water to affect slope stability and vegetation and the potential impact on the water quality in the discharge areas or water bodies.

If the assessment indicates that there are issues associated with EPL seepage, the design will need to consider mitigative options including different lake contents or depths as discussed in Sections 8.5.2 and 8.5.3.

There needs to be an adequate consideration of the hydrologic balance, filling time of the EPL, design of the outlet channels (elevation and flow rate) and the residence time of process-affected water in the EPL to allow sufficient time to enable significant degradation of toxic constituents. Acceptable water quality has been predicted in examples where the lake residence time and filling time were 10 years or longer. A longer residence time is required as the loading of process-affected water increases. In lakes that contain tailings that will release a quantity of process-affected water that significantly affects water quality in the lake, the required hydraulic residence time will increase. The time-dependent nature of the tailings water release needs to be taken into account in estimating the required residence time. In these examples, the filling time had to be longer if the residence time was short (less than 10 years) and/or the lake was deep (deeper than 25 m). In general, longer filling periods lead to lower concentrations of degradable constituents, such as naphthenic acids, but higher concentrations of salts, at the time of initial discharge.

Fresh water could be used to complement watershed inflows into an EPL, if the lake is to be filled more quickly than the rate that could be supported by the lake's catchment area. Fresh water inflows also provide dilution to improve water quality.

The catchment area landforms can be designed to affect the hydrological balance – directing more or less water to an EPL – but also to result in a more robust EPL design. More water can be directed to the EPL by designing the topography of the catchment area such that more surface water channels are directed to the lake. Less water can be directed into the lake by increasing the storage in the landform (lakes and wetlands) and/or by directing surface water channels away from the EPL. Typically, a positive water balance is favourable. It has the advantages of allowing fish passage in the outlet and flushing salts and contaminants from landforms in the watershed and the lake (assuming the receiving water body can take the load). However, the water balance also needs to take into account the required residence time to enable appreciable aerobic decay of degradable toxic constituents, provided the lake remains aerobic. A very high positive water balance, to increase the probability of maintaining flow through the outlet at all times, may lead to an excessively short residence time. A highly positive water balance may also aggravate flooding problems in periods that are wetter than average, but would reduce the probability of negative impacts on the lake during droughts. The design needs to balance these issues and risks.

There is significant benefit in keeping the lake level and the flow rate through the outlet channel relatively constant. Significant lake level variability can negatively affect residence time, slope stability and the littoral zone ecosystem. Small variations in lake level (say, less than 1 metre per year) would be considered ideal to support plant establishment, productivity, and diversity in the littoral zone. However, these ideal conditions may not be met for very wet or very dry portions of the hydrologic cycle. Moreover, it can be challenging to design stable outlet channels for a very large range of flow rates. Thus, the design should seek to minimize this variability.

The design of an EPL could be made more robust to cope with the variability and uncertainties of the water balance if the catchment area landform is designed to include inter-connected EPLs and several surface water channels. For example, an EPL can have one or more outlet channels built at higher elevations than the main outlet channel (see Figure 8.9). In this case, during wetter years if the EPL level rises above a pre-determined level another channel starts to flow, limiting the variability of the lake level (beneficial for the ecosystem) and limiting the variability of flows in the main outlet channel (beneficial for stability).

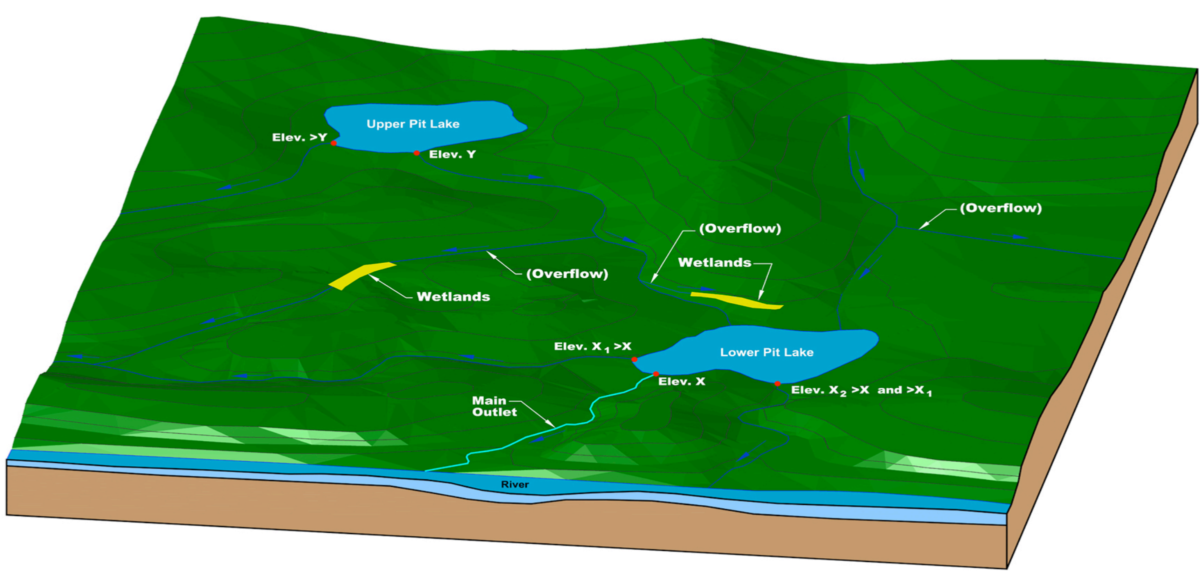

Figure 8-9: Surface water channels and interconnected EPLs in a designed watershed can be part of a robust design.

If the design of the catchment area landform includes interconnected lakes, the upstream lakes can function as buffers for lakes downstream; they could reduce the lake level variability for the downstream lakes, minimizing the challenges to the long-term performance of the downstream lakes and their outlet channels. Additional channels triggered in conditions of higher flows at upstream lakes or even along surface water channels connecting lakes could minimize the variability of flows reaching a downstream lake. The design of wetlands in the catchment area could further reduce variations in inflows to downstream-most EPLs. This type of design would reduce the negative impact of floods on the EPLs and in the case of droughts it would reduce the probability of impact on the downstream-most lake and its outlet channel.

These measures help minimize the variations in water level on the downstream-most lake and its main outlet channel. Although these measures would be more effective to deal with floods than with droughts, they would decrease the probability of significant water balance problems in the system. They would also increase the probability of creating a resilient eco-system that – even if stressed during drought times (no different than natural lakes) – would have a better chance of recovery when the hydrological cycle changes. This is an example of a more robust EPL design.

If a watershed has interconnected lakes and includes the need for storage of MFT in an EPL, consideration could be given to have MFT in an upper lake so that water would be more successfully bioremediated in a lower lake. This case would create more resilience in the system as the lower lake would accept solids from any potential upsets in a MFT filled lake. Large littoral zones in the lower lake would have a purpose to remediate any carry over solids from MFT.

Excessive suspended solids can have a negative impact on EPL water and habitat quality. The landscape and landform design should examine opportunities to minimize the sediment load from the watershed to EPLs and the natural environment. Some sediment load can be beneficial to littoral zones by bringing nutrients and by compensating for some settlement or erosion.

Landform design can also consider salt mitigation strategies from the watershed into the lake. Consideration could be given to:

- Promoting rapid flushing within a shallow sandy aquifer zone across the reclaimed landscape to dilute salts released from deeper zones.
- Designing the landscape to concentrate salts in well-defined areas by groundwater flow path design and topography.

8.5.6 Design of Inlet/Outlet Channels

The stability of the lake outlet for an indefinitely long period of time is one of the most critical elements of the EPL design. The integrity of the EPL may depend on how well planners can design and build a surface water outlet that remains operational for the full range of flows that may be required, under all possible conditions, without losing function. A robust landform design that minimizes the outlet channel range of flow rates, as discussed in Section 8.5.4, would reduce the design challenge, and the risk, associated with the outlet channels. The channel will also evolve according to the geomorphologic processes that would occur in the long term both as gradual and singular events, including beaver activity, slope instability, and other natural phenomena in addition to normal channel processes.

The design needs to consider the range from the smallest flows to the flows associated with the PMF (Probable Maximum Flood). One option to be considered is creating a series of separate channels that activate at different flood levels as discussed in Section 8.5.4. This option highlights the importance of appropriate lake location in the landscape. Another option that can also be considered is the creation of ponds and storage areas upstream of the EPL to dampen floods. The design of the surface water channels in the catchment area landform can also be integrated to the design of the outlet channel, providing additional opportunities for risk management. A density of channels (number of channels per hectare) comparable to the natural environment could be more stable under geomorphologic processes.

The channel bed and side slopes need to be stable for all flow conditions. Very low gradients would be required for long-term stability, and thus the lake location should allow for sufficient distance from the EPL to the receptor water body. If riprap or any type of armouring is required, the issue of durability of the rocks in the McMurray area needs to be considered. If limestone is considered, it is necessary to use only Type A limestone (Mathews et al., 1980).

Additional considerations for the outlet channel stability include:

- Susceptibility of the channel to erosion as a function of channel bedding material and channel slope for the various flow conditions that the channel will be subjected to during its life. A significant erosion of the outlet channel causing a drop in the channel bed elevation would lead to loss of contents of the EPL and a rapid drop in EPL level, which would in turn lead to a higher risk of instability of the slopes that form the EPL.
- If the phenomenon described above occurred in a channel connecting two lakes, it could lead to fast release of the content of one lake into another and possible failure of the receiving lake and its outlet system.
- Outlet channels designed in fills can be affected by consolidation and settlement of these fills with time, which can be magnified by infiltration of water from these channels. Moreover, fills are particularly susceptible to erosion and will pose additional challenges to the long term stability of outlet channel profiles.
- Aggradation of the outlet channel by deposition of sediment or failure of the side slopes and the resulting increase in the channel bed elevation would lead to a rise in the EPL level and potential overflow and/or slope instability.

8.5.7 Stability of Shoreline Slopes

EPLs can be surrounded and contained by one or more of the following elements: pitwalls, overburden dumps, tailings deposits, and de-licensed dykes. The stability of all the slopes needs to be assessed for the short and long term. The stability analyses need to take into account all the issues that may affect the slopes in the long run, including:

- Shear strength of all materials
- Pore pressure at all stages of lake development and under all foreseeable conditions
- Stress relief effects and gas ex-solution

- Freeze-thaw effects
- Long-term degradation of shear strength
- Impact of dispersivity
- Seismicity
- Impact of long-term variations in lake levels
- Effect of submergence

Slope failures will inevitably occur in EPLs; they are part of the natural geomorphologic processes that will take their course during the life of an EPL. The key issue is to determine the acceptable failure modes and the acceptable size of a potential failure. Slope failures involving relatively small soil and rock masses would temporarily cause an increase in sediment loading in the lake, and possible turbidity currents and wave action, which are phenomena that also occur in natural lakes. A significant failure of a perimeter slope involving a very large mass of material could lead to disruption of lake dynamics, major negative impacts on littoral zones, problems related to access to the lake and major impacts on inlet and outlet channels. Such large failures that affect lake dynamics and/or outlet overflow are not acceptable and the design of EPLs needs to reduce the probability of such failures occurring. It is important to keep in mind that some slope failures are a natural part of the region's geomorphology and are common in the natural environment in the oil sands region of Alberta.

Other technical issues important to the stability of the elements that provide containment to an EPL are discussed below.

8.5.7.1 Stability of Perimeter Pitwall Slopes

Both short-term and long-term stability of perimeter slopes need to be evaluated as part of the design of EPLs. The typical configurations of pitwall slopes are designed based on short-term stability requirements, consistent with design criteria and risk management practices of an operational mine. Final pitwalls that are intended to become EPL perimeter slopes need to be designed for long term stability under the conditions that will be expected for the EPL, including submergence, variable lake levels and the mechanisms and potential impact of successive slope retrogressions.

Pitwalls include weak clay zones that may be glacially pre-sheared and prone to significant movements. Final pitwalls that will form EPL containment need to be designed to reduce the risk of major failures. Strain softening of various stratigraphic layers when the slope material is exposed to weathering, including the effects of freeze-thaw, and the potential effect of dispersivity of some materials, increase the risk of failures of these pitwalls. Fluctuating lake levels would further challenge the stability of these slopes. Drops in lake levels may lead to high pore pressures in the materials that form the slope and a consequent decrease in factor of safety against slope instability. The majority of the stratigraphic units that form the pitwall are low permeability materials that do not drain readily and thus are particularly susceptible to this phenomenon. Rising lake levels could wet Clearwater Formation shales that had not been previously submerged. These materials can exhibit dispersive behaviour, depending on the water chemistry, and lose their structure. Significant erosion and possible slope failure would result.

8.5.7.2 Stability of Overburden Dumps and Tailings Piles

Long term stability of overburden and tailings structures can be particularly vulnerable to varying lake levels. The design of these slopes needs to take into account a variety of potential situations expected for the EPL, as defined by a comprehensive hydrologic assessment and detailed water balance.

8.5.7.3 Stability of Shorelines against Erosional Forces

The EPL design needs to consider erosion of the shorelines in the long term due to wind and wave action. Shoreline erosion is affected by various geometric parameters of the lake as described in Section 8.5.3: area, depth, shape and orientation relative to prevalent winds. Once the best lake location and configuration is selected, if potentially high erosion areas remain, mitigative measures need to be designed.

Construction options for shoreline protection include:

- Vegetation of areas protected from most wave energy
- Offshore islands and breakwaters
- Long beaches
- Shoreline protection berms

8.5.8 Design of Littoral Zones

Littoral zones have been described and discussed in Section 4.8.1 and Section 6.2.1. Littoral zones are the shallow, nutrient-rich areas of the perimeter of lakes where rooted plants can grow and fish can find refuge and habitat. A proper design of the littoral zones is important because these are the areas that drive the productivity of the lake. Based on the work of Charette (Chapter 4) and Vandenberg (Chapter 6), the design requirements of the littoral zone include:

- *Depth:* A relatively shallow depth to allow light penetration. Given that the significant issue is light penetration, the maximum depth acceptable for a littoral zone is a function of water clarity (the clearer the water, the larger the depth light can penetrate). Figure 8-10 indicates that the littoral zone should have a maximum depth in the order of 3 to 4.5 m depending on the expected water clarity. According to Charette (2011), water clarity will depend on the availability of nutrients and organic matter, erosion and sediment resuspension, and salinity. As mentioned by Charette, it is widely believed that lakes with water-capped MFT, due to the available carbon source, will be productive. Therefore a littoral zone maximum depth of 3 metres would be a conservative design target that would ensure the colonization of plants regardless of productivity.

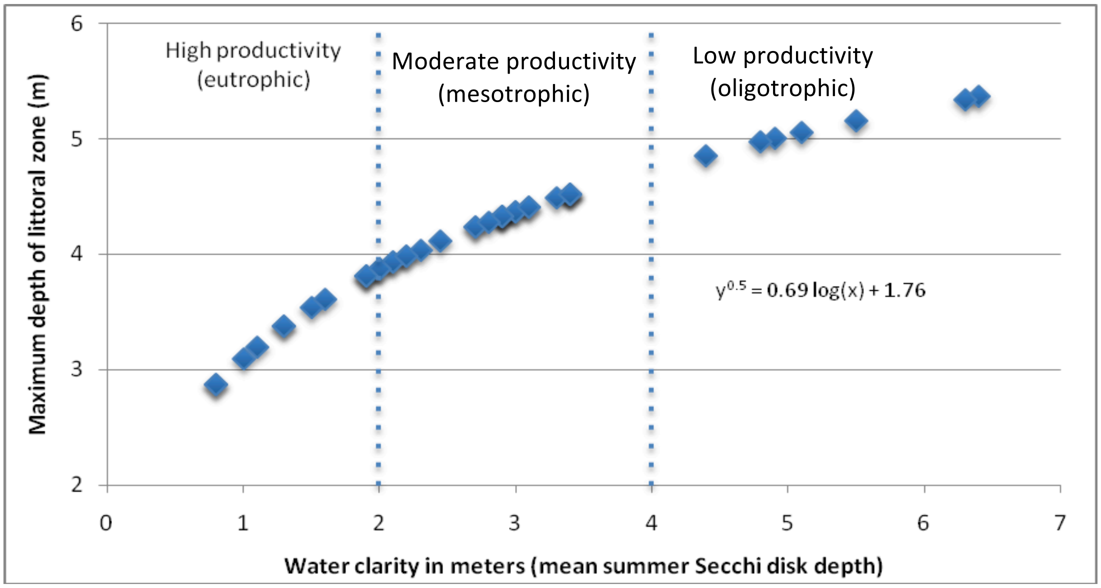

Figure 8-10: Maximum depth of littoral zone in relation to water clarity. Maximum depth of littoral zone was calculated according to Chambers & Prepas (1988). Trophic classes are after Carlson and Simpson (1996).

- *Morphology*: In addition to depth, other geometric parameters that need to be addressed in the design of the littoral zone include:

  a. Shoreline complexity and littoral zones must be integrated in EPL design.
  b. It has been recommended that littoral zones be more than 10% and less than 30% to 40% of the EPL's surface area. However, the required area for littoral zones is considered a knowledge gap. In some cases, shallow areas can be created away from the lake shoreline (e.g., connecting a littoral zone to wetlands) to cover some of the functions of a littoral zone and compensate for possibly insufficient littoral zone area. It could also be considered the provision of areas away from the shoreline (e.g., upstream from the EPL in an inlet channel) that function in a similar manner as the littoral zones.
  c. Length of littoral zone (perpendicular to lake shoreline) should be defined as a function of the expected lake level variability, geometry of lake and shoreline and the littoral shelf construction method. When the lake water level is expected to vary significantly, long gently sloping littoral shelves could provide a reasonable area of littoral zone for a range of lake levels. In this case, littoral zone ecology could adjust to the varying lake levels, provided the rate of lake level variation is sufficiently slow to allow time for re-colonization of the littoral zone. Steeper littoral zones have a smaller area that needs to be re-colonized in case of lake level variation.
  d. The riparian-littoral-deep water slope should be gentle, ideally in the order of 1% to 2%. The littoral zone itself needs to have a slope that is compatible with the stability of the type of substrate material that forms the littoral zone, the type of sediments that may be brought in by any stream discharging into the littoral zone, and the expected wave action in the area.

- *Substrate composition*: The composition of the littoral zone substrate needs to be favourable for plant growth both in terms of particle gradation and nutrient levels. Finer materials and organic matter provide adequate root support and an adequate source of nutrients, whereas sands are less propitious for plant establishment and growth. Assuming that typical substrate material would likely not be completely available from overburden fills (tills, Kg, Kc and Km materials) or tailings sand, it is expected that addition of amendment will be necessary for plant growth.

The littoral zone needs to be well protected from wave erosion, especially in the early stages of development when vegetation is not yet well established. This is especially important given that the substrate would ideally be formed by fine particles, particularly susceptible to erosion. Erosion protection can be achieved by one or more of the measures listed below as examples. Additional measures may also be considered.

- Selection of the location of the littoral zone where the fetch is small and perpendicular to the directions of frequent wind.
- Creation of an embayment to protect the littoral zones from winds and currents.
- Design and construction of permanent and/or temporary breakwaters.
- Use of littoral and riparian vegetation – such as cattails and aspen – that will reduce local wind action or that directly stabilise sediment.
- Placement of large rocks and coarse woody debris such as tree stumps, trunks and branches cleared as part of the operation that can be placed back afterwards. Use of these materials is also beneficial to increase habitat diversity.

The littoral zone location could also be selected to coincide with the location of an inlet creek or stream into the EPL. This emulates typical natural conditions and has the advantage that the stream flow would add nutrients to the littoral zone. Moreover, the stream would likely deposit sediments as the flow slows down at the lake entrance, forming a delta. The sedimentation could counteract potential settlement of the littoral shelf material. In general, the less concentrated the littoral zones are, the more effective they will be in contributing to a lake's stability, productivity and biological diversity.

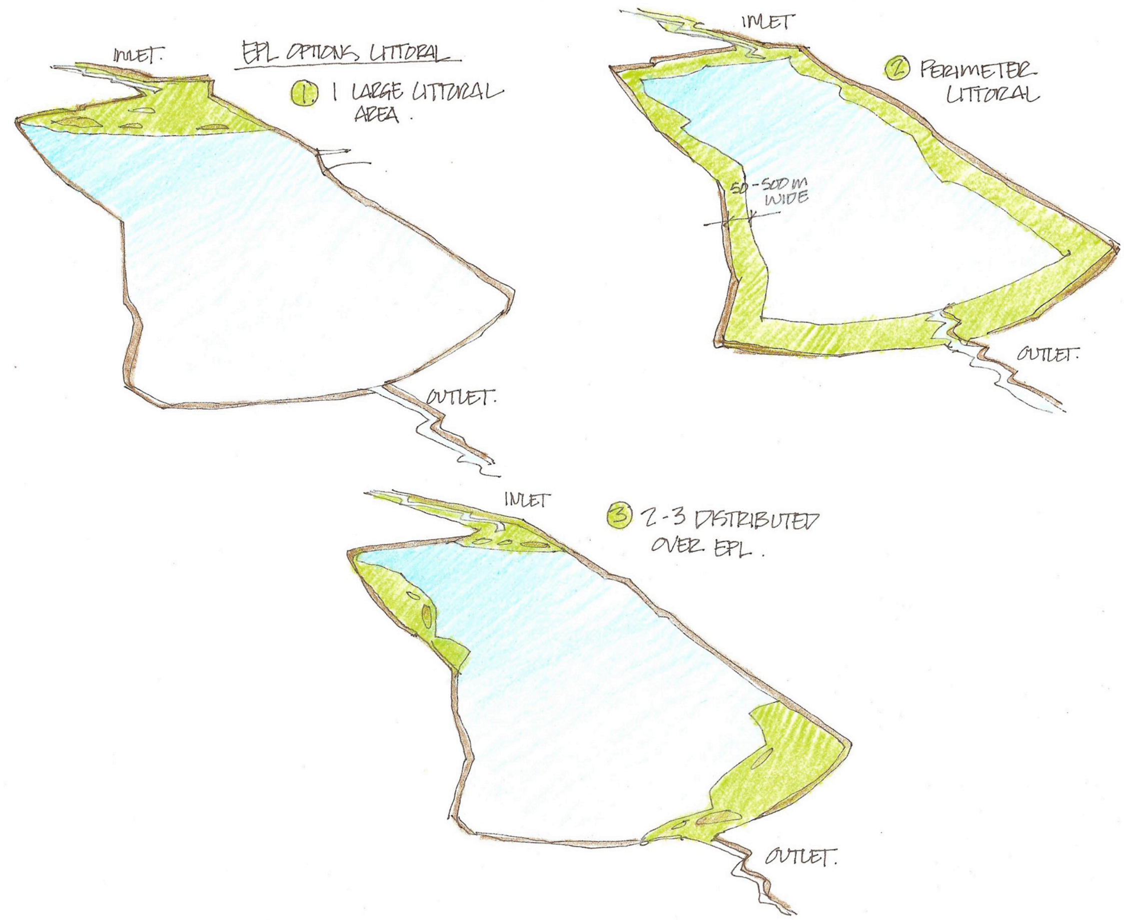

Figure 8-11: Three options for distribution of littoral zones. Option 3 is considered the optimal approach.

The littoral zone shelf can be built by several methods:

- Taking advantage of fortuitous situations where the long-term lake level and the surrounding topography are such that littoral zones will naturally form.
- Cutting back final pitwalls to create a gently sloping surface that could become littoral zone if the equilibrium lake level is around that elevation (see Figure 8-12). This measure could be costly if the excavation volumes are significant but, if this requirement is defined early, there could be an opportunity to minimize the cost (e.g., if the material to be excavated is needed as borrow at a short haul distance from this location). In this case, the littoral zone shelf would be expected to have minimal to no settlement with time. However, there could be some degree of swelling depending on what type of material becomes exposed to lake water. Long-term stability of the pitwall slope would need to be verified as part of the design.

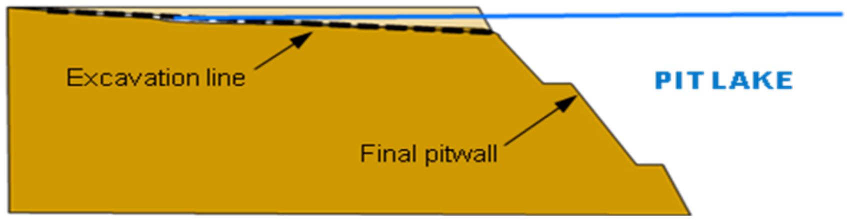

Figure 8-12: Example of construction of littoral shelf by cutting back pitwalls.

- Cutting back an overburden dump built by free-dumping from crest of the pitwall ("high dump") (Figure 8-13). A high dump could also easily be built with a small slope on its surface if the location of the future littoral zone is defined early and incorporated in the mine plans (and transmitted all the way from long range planning to short range planning, where decisions on details like sloping the surface of a dump are made). Stability of the high dump and long term settlements would be significant design issues. The stability of the high dump would be significantly improved if the pit floor is dry and free of loose or weak material prior to deposition of material on it.

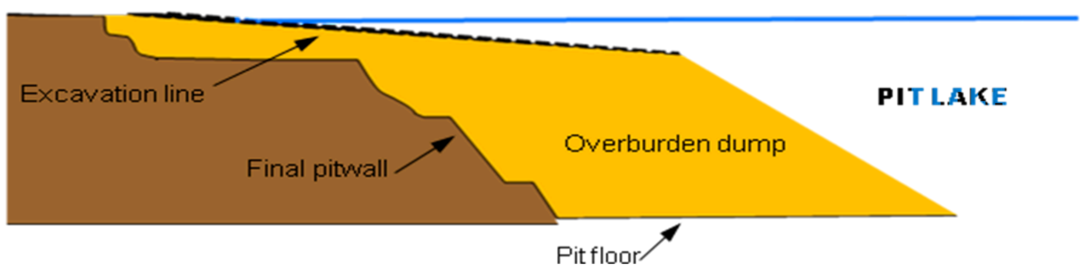

Figure 8-13: Example of construction of littoral shelf using overburden dump

- Building a "high dump" as described above, but starting from a lower location on the pitwall at an elevation compatible with the expected range of long term EPL levels (Figure 8-14). Final pitwalls typically have a wider bench at the base of the Clearwater Formation, which could provide an opportunity for this type of solution. A ramp down to this lower elevation would have to be incorporated in the design, in addition to the other issues mentioned above.

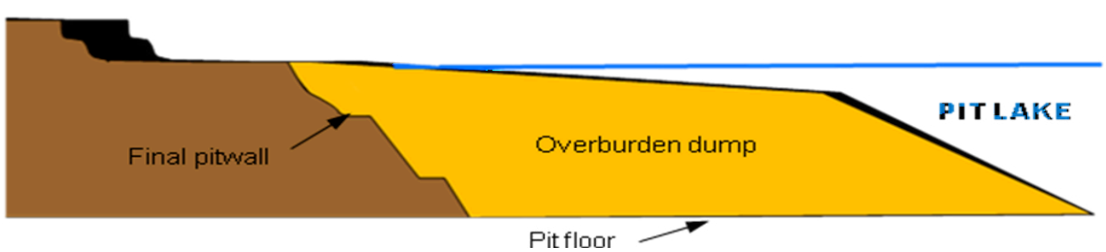

Figure 8-14: Example of construction of littoral shelf with overburden starting at a lower elevation.

- Building overburden dumps from the pit floor up, next to the final pitwall, to create configurations as shown on Figures 8-13 and 8-14. Building from the bottom up allows the elevation of the top of the dump to be selected independently of the location of adequate benches on the final pitwall. In some cases, it might be preferable depending on the location of the overburden (or interburden) being used and the variables related to the construction of the access ramp. The cost would likely be higher but significantly better performance would be expected in terms of stability and settlements in this case.

- Placing a tailings sand beach from the final pitwall (Fig. 8-15) can be done from the crest of the pitwall or another location, as required. This option can have a relatively low-cost and would easily achieve the final sloping configuration, but tailings would occupy a larger EPL volume due to its flatter angles. This may be beneficial or not depending on the case. A tailings beach would be an easy and economical manner of creating very long and gently sloping littoral zones, thus providing a robust solution for significant variations in long term lake levels. A significant disadvantage of this method is the poor quality of tailings sand as a substrate material. Amendment would most likely be required.

Figure 8-15: Example of construction of littoral shelf by placing a tailings beach from the crest of the pitwall.

The design of the littoral zone needs to consider stability of the underwater slope under all loading conditions, including seismicity, wave effects and variations in lake level at various rates.

Consolidation of the deposit that forms the littoral shelf needs to be assessed to estimate the potential future impact of settlement on the effective depth of the littoral zone as discussed above and in Section 8.4.6. Monitoring of the settlement of the littoral zone needs to be incorporated in the long term monitoring plans of the EPL. Tailings sand beaches would likely have significant issues with stability or settlement. However, liquefaction potential needs to be addressed.

The application of the FMEA (Failure Mode and Effects Analysis) method would help define the potential failure modes for any given configuration of the littoral shelf, which would allow a definition of the monitoring requirements and the potential remedial measures should the performance be inadequate.

Habitat features could be added to the littoral zone after the shelf is built. The sooner the habitat features are established, the better the chances are of increasing higher trophic levels. Prohibited noxious weeds should not be allowed in riparian and littoral zones. Detailed recommendations for habitat creation can be drawn from the numerous compensation lakes that have been proposed in the oil sands region. Performance information and lessons learned from the compensation lakes would benefit the implementation of EPLs. Construction of the littoral zone may also include breakwaters, peninsulas, groynes and other design elements.

The creation of littoral zones could be economically challenging. However, the cost impact could be significantly minimized if the littoral zones and its requirements are incorporated early in the mine planning stage and in the overburden and tailings operations.

8.6 Conclusion

This section has discussed design objectives and has proposed preliminary design criteria and guidelines to be applied to key aspects of the design of EPLs in the oil sands region of Alberta. These objectives, criteria and guidelines are expected to lead to further discussion within the oil sands community. These points are expected to evolve with input from the wider community and especially as new knowledge is gained from research and full scale experience as EPLs are planned, designed, implemented and monitored over time. Therefore, it is recommended that the preliminary design guidelines proposed in this guidance document be reviewed at least every five years or as new significant data and experience become available. It is also recommended that site-specific studies be developed to provide further guidance on the design and implementation of EPLs, where necessary. It is recommended that the oil sands industry continue to share technical and scientific data related to EPLs in order to facilitate and promote the development of EPLs that meet the overall societal objectives of safe and sustainable oil sands mining.

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9. CONSTRUCTION AND OPERATION

Gord McKenna
BGC Engineering
+
Jerry Vandenberg
Golder Associates

Chapter 9 Table of Contents

9.1 Introduction

This chapter describes the actions needed to turn the preparatory work – mining out the pit, placing the dumps, roughing out the littoral zone and identifying the inlets and outlets – into the final lake configuration, one that is suitable for application for a reclamation certificate and return of the land to the Crown. These activities will evolve, along with design, throughout the life of the project. The pre-mining and lease development work, as described in Chapter 7, involves all the planning, design, and construction prior to the first ore production. The general location and approximate elevation of the EPL is chosen at that time. The chapter also discusses the role of modelling, monitoring, and adaptive management.

9.2 Planning

As the mine is opened and the watersheds disturbed, development-range planning continues, and the design of the lake, still very conceptual, evolves over time. With each iteration (and as mining and tailings placement continues), the options narrow, and the design becomes more fixed. Eventually, the EPL construction falls within the 10-year long-range plan, and is included in budgets and staffing needs. Closure plans, typically done every five years, become more detailed and can be considered preliminary engineering designs. Ongoing mining, tailings, and dump construction for the lake area are guided by short-range plans and the annual budget cycle. See Chapter 7 for a detailed description of EPL planning tasks, timelines, and drivers.

9.3 Construction

9.3.1 Constructing the Landform Elements

It is useful to consider the EPL as a set of landform elements, each of which can be considered one or more projects in itself. The following sections provide a logical sequence of construction for these elements. In reality, many will run in parallel depending upon the local conditions.

9.3.2 Watershed Dump and Dyke Construction

Some EPLs will be constructed while mining and tailings activities are ongoing elsewhere in the watershed, whereas others will be the last landform constructed. Both situations provide challenges and opportunities. The annual operational water balance during this time is a central feature of the watershed and EPL design. Planners are starting to consider designs for water treatment facilities to allow the safe discharge of treated process affected waters back into the environment as part of maintaining this operational water balance. Prior to treatment or discharge, the EPL waters will be recycled.

All mines have fresh water diversions during operations, and many EPLs will receive this fresh water when the diversions are reconfigured or removed. Planning and design to accommodate this source of fresh water will be a central design and scheduling feature for the lake. Similarly, there may be instances where water from disturbed areas will be rerouted from reclaimed mines on other leases; the planning and schedule are critical elements of the lake design.

9.3.3 Watershed Dump and Dyke Grading and Reclamation

The rough plateaus and slopes of dumps and dykes left behind by mining will be landform graded, capped with reclamation material, and revegetated. Most of the reclaimed landscape will be made into upland forest, with wetlands interspersed. Tens of kilometres of creeks will be constructed to carry water from these landforms and the undisturbed landscape to the end pit lake. In a few cases, there will be a second end pit lake within the watershed at a mine site and several within the overall watershed.

Perhaps with some exceptions, only water from reclaimed landforms will be directed to the end pit lake. As the mining landscape is reclaimed progressively, runoff and baseflow from more and more reclaimed areas will be directed to the end pit lake. Water quality from each sub watershed will change seasonally and over the years.

The watershed will produce waters of three general qualities: fresh water from undisturbed areas, runoff from reclaimed landscapes (which is likely to have somewhat elevated salts and in some cases naphthenic acids and sediment), and baseflow seepage from tailings landforms. The design of the landscape to deliver water of acceptable quality and quantity to the lake will be critical. In some cases, the lake may be able to accept water of lower quality than other elements of the upstream watershed. Notably, the design and construction of the watershed is at least as important of that of the end pit lake.

9.3.4 EPL Dump and Dyke Construction

The dumps and dykes immediately adjacent to the EPL are constructed next. In most cases, there will be some additional effort (different compaction, lift heights, internal configuration) required to make sure that the dumps and dykes will be stable during and after end pit lake infilling. The dykes need to be constructed such that they will some day no longer be considered as dykes. The dumps need to be designed so that they don't slump or settle excessively. Both of these kinds of landforms will end up being part of the EPL shoreline. Littoral zones will need to be roughed in at this point.

9.3.5 EPL Commissioning (Regrading, Reclamation and Construction)

The dumps and dykes adjacent to the EPL will be landform-graded, littoral zones will be constructed, reclamation material will be placed and initial vegetation will be planted.

Mining leaves behind steep pitwalls and different fills in various geometries in the mined-out pits.

- Pitwalls will be resloped to provide geotechnically stable topography suitable for reclamation material placement to meet landscape performance and land use goals. Spoil from this resloping may be a useful borrow source for other earthworks (especially littoral zone development) or may be pushed into the pit.

- In some cases, oil sands waste pillars or mine backfill will occur at elevations higher than the proposed lake water levels. It may be desirable to reconfigure these areas as islands in the lake, or push them down to create littoral zones. Another possibility is to trim these areas so as to simply become a lake bottom.

- It may be desirable to cap some pit floor materials to limit leaching of salts and naphthenic acids into the water column.

- Where high permeability zones are present in the pitfloor or pitwalls, to limit inflows or (more likely) outflows, it may be necessary to cut off seepage paths with fill or tailings placed on the pitfloor, cut off walls outside of the lake perimeter, or place low permeability material against pitwalls. Regrading and fill volumes are often large and may influence the mine plan.

- Where islands, littoral zones, or breakwaters are required, it may be desirable to bring in additional fill to build up topography left by mining. Ideally, these elements will have already been considered during mining to minimize the amount of import fill.

- In some cases, it will be desirable to buttress slopes with tailings beaches. In this case, a method to discharge tailings along the shorelines in needed. Consideration should also be given to removing tailings water and fluid tailings. Since above water and below water beaches are typically quite shallow, large volumes of sand are required for even small beaches.

Major safety issues exist in pushing loose fill into fluid tailings or water, and large, sudden slope failures may result, putting people and equipment at risk. Earthworks generally have to be constructed to avoid this situation. Where there is no need to dump fill into fluid, the placement of fills can be done concurrently with infilling of tailings or water.

Mining typically leaves steep highwalls and steep, unfinished benched overburden dumps. Tailings sand placement typically leaves behind featureless beaches. These landforms require landform grading to control surface water and groundwater, provide topographic diversity, provide a topographic surface accessible for reclamation material placement, and to meet land use and aesthetic goals.

There are four zones of interest to end pit lake construction:

- Below water zones: Regrading to a depth of at least 3 m below the lowest water level will generally be required. Littoral zone construction is particularly important and dealt with in the next section.

- Wetlands: Much of the EPL watershed will be comprised of wetlands, some contiguous with the EPL, and all will affect the water balance, quality, and hydroperiod. The CEMA Wetlands Guide provides guidance for wetland planners and designers.

- Riparian zones: These are the areas from the water level up to a certain point on the land. Regrading will be required to meet riparian goals.

- Terrestrial zones: These are areas well above the lake and generally covered off by other guides (such as the CEMA LCCS and CEMA vegetation manual). They form part of the lake watershed.

For economic reasons, most of the fill in landform grading is pushed downslope, and consideration of the final location of this fill is a critical consideration in the design. Care in avoiding oversteepened slopes in the riparian and below water zones is critical, as is the need to avoid pushing fill into standing water or tailings.

Reclamation material placement use large mining equipment, and thicknesses of 0.5 to 1.2 m are common for terrestrial applications. Revegetation for terrestrial areas follows next. The next section covers littoral and riparian reclamation.

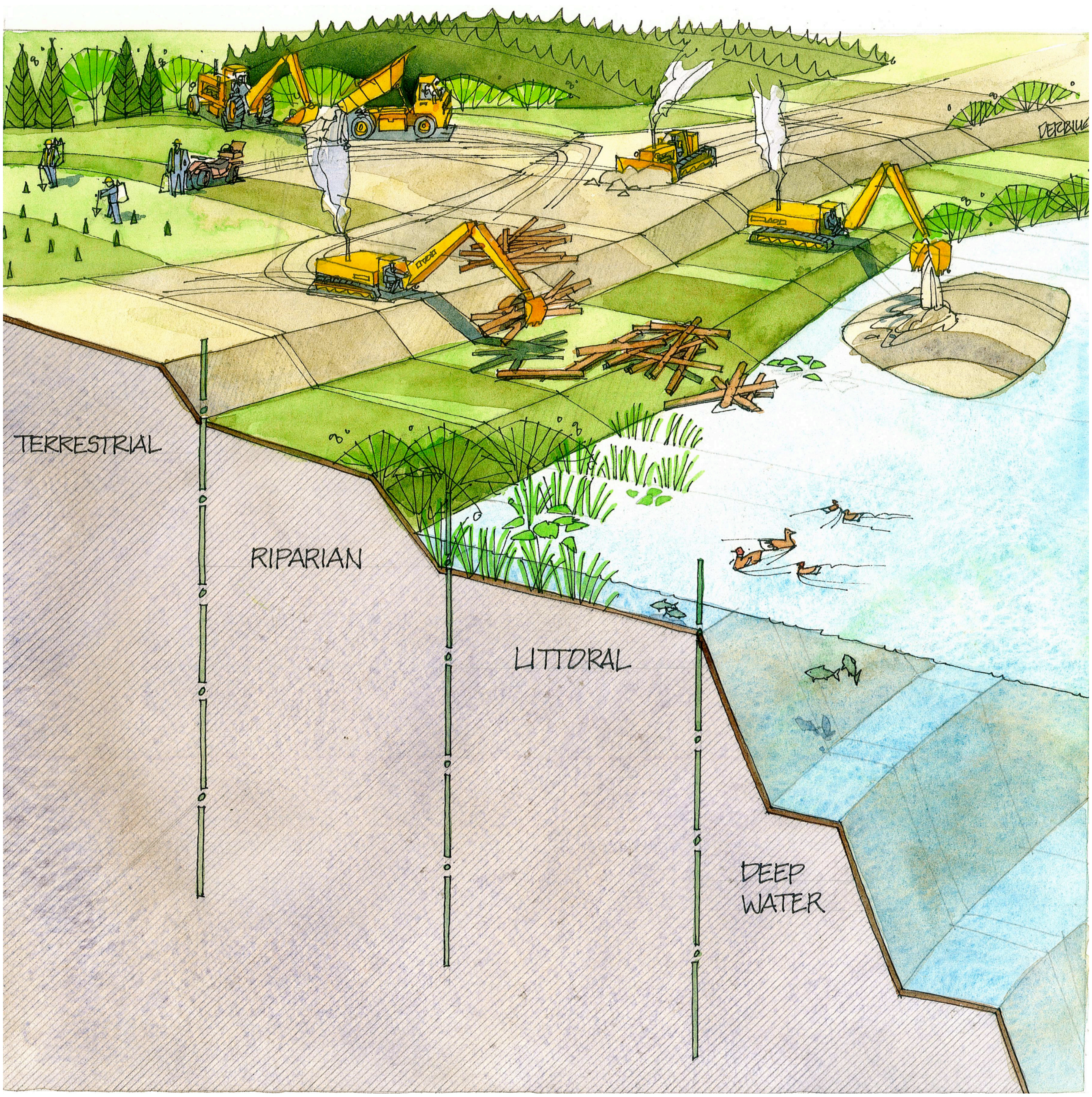

Figure 9-1: Landform grading involves four zones of interest to EPL construction teams.

9.3.6 Littoral, Shoreline, and Riparian Areas

Shoreline, littoral, and riparian zone design is covered in Chapter 8 (see also Van Etten, 2011). The construction of these areas will be done with a variety of small and large equipment in advance of flooding. Access will be required for large equipment for construction, and for any future repairs identified under adaptive management contingencies.

Where practical, it is desirable to have mature forest vegetation in the riparian zone and shorelines, and perhaps mature terrestrial vegetation in the littoral zone prior to flooding with water to provide some protection against shoreline erosion. While most of the fill will be placed using large mining equipment, there are other opportunities that will be useful in particular situations:

- Hydraulic placement of tailings beaches
- Hydraulic placement of reclamation material (beaching or rainbowing)
- Barge transport and/or dumping of material for littoral zones and shorelines, either as part of initial construction or for repairs.

9.3.6.1 Littoral Zones

Littoral zones will be constructed through a combination of leaving in-situ benches, controlling heights of overburden dumps, and placement of overburden or tailings fills. Designing and constructing to control future settlements is a significant issue, requiring a “structures” approach, such as that used in the oil sands for in-pit dykes. This translates into the need to build up the littoral zones with compacted fill to reduce settlements, including first time wetting settlements. Alternatively, or as a contingency, it may be necessary to remove reclamation material and add additional fill to future settled littoral zones where the fills have settled excessively. In any case, the differential settlement of any fill will help to add to the diversity of the littoral zone.

Littoral zones should include islands constructed from fill, perhaps with riprap. The islands may be created to enhance diversity or habitat, and they may also be required to act as breakwaters for shore protection. They should have at least 0.2 to 0.5 m reclamation material placed on them to provide a rooting zone for plants. Coarse woody debris may be employed to provide diversity, microsites, and to help stabilize the littoral zone during first filling. It may be necessary to anchor this debris to keep it from floating during high water in the early years.

The littoral zones should also be revegetated. Since they will be vegetated prior to flooding, a plan to transition the vegetation from terrestrial to littoral ecosystems will need to be considered. There may also be an opportunity to “pre-flood” areas by pumping in water to establish wetland-like vegetation prior to flooding by the lake. Considerable engineering would be required to use this method as the fills are generally highly pervious (due to construction and settlement cracks), and the overflow water would need to be addressed. Littoral zone revegetation over broad areas and within an operational context is a critical area for EPL performance, and one for which there is little experience.

Littoral zones will likely need considerable monitoring and maintenance during filling and during the initial years to ensure their reclamation and performance meet expectations.

9.3.6.2 Shorelines

Unprotected shorelines will undergo significant wave erosion and retreat. As with reservoir slope protection, EPL shoreline protection will involve one of the following strategies:

- Vegetation of shores protected from most wave energy
- Offshore islands and breakwaters
- Use of long beaches
- Shoreline protection berms (riprap).

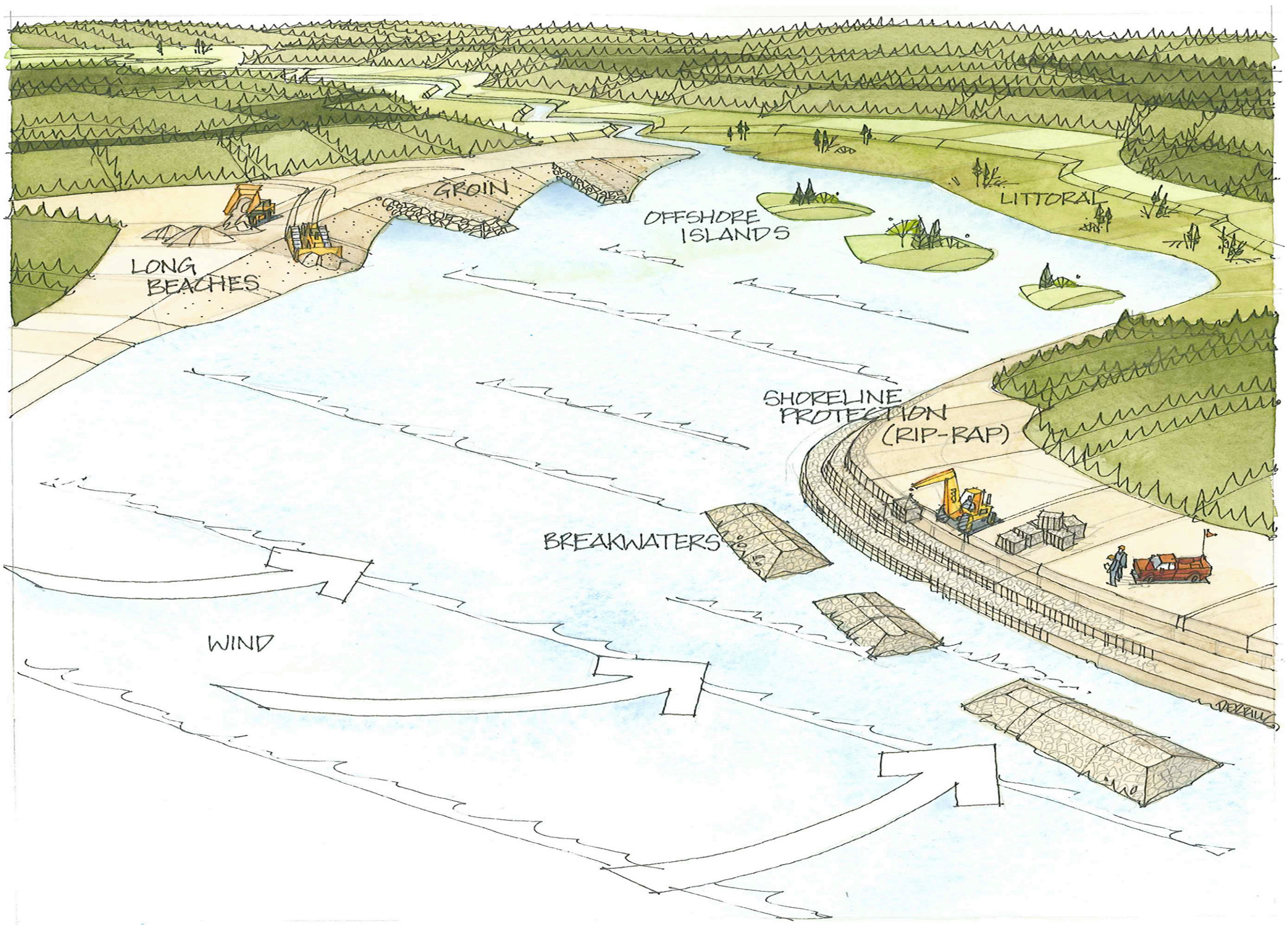

Figure 9-2: EPL shorelines are vulnerable to a variety of forces and will require protective measures.

Creating the geometry suitable for these four strategies is a critical element of design and rough construction of the end pit lake. Adding these elements as a contingency would likely be extremely expensive unless the geometry is constructed in advance for the potential use. For example, an offshore island would be easy to add to a littoral zone but would require a 50-metre-high pyramidal berm after the fact. The ability to lower the lake level to allow modifications to shoreline configuration should be provided in the lake design.

Creation of stable shorelines in the absence of long-term maintenance, or designing for acceptable rates of shoreline erosion for lakes bounded by erodible fills, will be extremely challenging. There is a rich literature for civil engineered and bioengineering methods available to designers (for example, U.S. ACE, 2002), all of which includes ongoing management.

9.3.6.3 Riparian Areas

Riparian areas are the transition from the littoral zone to the upland/terrestrial zone. They will have elements common to both. A guide for designing for riparian areas in the oil sands is anticipated. In the meantime, they can be considered to have mostly upland features and design.

9.3.7 Inlets

Most EPLs will have several inlets, fed by natural or constructed channels. These inlets will need to be constructed prior to or during infilling. In some cases, the inlet geometry will be complex, requiring islands to act as energy dissipation structures. The ability to deal with sediment deposition at the inlet will be a key design feature. In other cases, water treatment at the inlet will also be required.

9.3.8 Outlets

Outlets will control the lake levels both during active operation and under passive conditions during the certification qualification period and beyond. The outlet will generally be constructed on original ground to minimize settlements and maximize geotechnical stability. The outlet may include a low-level intake pipe to facilitate drawing down the lake level far below the outlet for winter operations or repairs to the outlet or elsewhere in the lake. A provision for blocking the low-level pipe at closure will be an important element of design.

The outlet will be designed to safely manage the probable maximum flood, so will be wide, deep and highly armoured. Access across the outlet may be required via culverts, a bridge, or paved ford. In some cases, the outlet will not be constructed or made operational until the certification qualification period or past certification. Rather, the lake level will be controlled by a robust pumping system, either for water re-use in the extraction plant or discharge to the environment. To deal with extreme events, the outlet may be constructed in advance regardless to provide for extreme flood events.

To reduce the risk of erosion and downcutting, the outlet will usually involve excavation into original ground, placement of compacted fill, and layers of sand and gravel overlain by a thick layer of large-diameter riprap. The excavation for this material is generally several metres below the lake elevation, requiring companies to: construct the outlet prior to water infilling, devise a method to pump down the water level, and construct a cofferdam upstream of the outlet. Major repairs to the spillway in the event of poor performance will also require operators to work in the dry. Thus the outlet should be designed to allow either pumping down of the water, or more likely, the real estate to build a robust temporary cofferdam.

If a water treatment plant is required near the outlet, there will be synergies in the treatment and outlet design, construction, operation, and monitoring.

Fish habitat and transit at the outlet and downstream of the lake are important design considerations. Extensive use of riprap at the outlet may have a major impact on this goal. Similarly, severe lowering of lake levels for winter or construction/maintenance periods may have a significant impact on the ecology of the lake. Both of these important aspects will need to be dealt with in planning and design. Trash racks and other constructs used for dam spillways will likely be required at the outlet. Operators will also need to decide whether to take action to control beaver activity.

As noted elsewhere in this guide, present requirements for reclamation certification require a self-sustaining landscape free from long-term maintenance. Given the high demands for the outlet, the high consequence of failure, a long and incomplete list of failure modes, the lack of non-erodible bedrock used in spillways at metal mines, and competing duties for the outlet structures, EPL outlets may prove impractical to be designed for maintenance free conditions.

9.3.9 Operational Infrastructure Construction

To provide access to the lake for instrumentation, monitoring, and maintenance, infrastructure will be required (Table 9-1 and Figure 9-3).

Table 9-1. Infrastructure needs.

Access use	Infrastructure required
Operational access to the lakeshore	Haulroad access Boat ramp Dock facilities with a cranepad for launching barges Boats Access to other littoral zone monitoring stations, perhaps with docks or boardwalks, paths
Monitoring facilities	In-lake instrumentation Floating monitoring stations that are either resistant to ice forces or can be relocated each spring Island or lakeshore instrumentation stations, including a high-end climate station Research and monitoring trailer for equipment storage, sample storage, telemetry and data management, lunchroom, comfort station
Outlet facilities	Robust outlet weir with good monitoring Access to be able to remove debris, make repairs, potentially reconfigure Ability to control water levels to within 10 to 20 cm (stoplogs) Access for downstream monitoring
Visitor facilities	Trailers, roads, paths, boardwalks, tour routes
Water management facilities (as needed)	Ability to control inlet waters Upstream settling pond near inlet for sediments where required Fresh water source, intake, pump, pipeline, flow meter, control system, discharge, power, access

Access use	Infrastructure required
	Water return system, barge, intake, pump, pipeline, flowmeter, control system, discharge, power, access Consideration for any pumped water to have inlets and outlets located near the final inlets and outlets is worthwhile to start to establish the natural flow paths within the lake as soon as practical
Water treatment facilities (as needed)	At inlet, in-lake, outlet Roads, power, disposal area for water treatment wastes, water treatment, operating facilities, laydown, equipment shed, operating facility, power, communications. Barges where required. The cost and areas required for infrastructure will be considerable.

Clearly, there is potential synergy to co-locating some of these facilities. There will be several considerations, including whether winter access is required, whether there will be work on ice, whether there will be pumping and/or outflow in winter, and whether bubblers will be required to keep barges operational in winter.

Design of the operating facilities should include provision for their removal or re-purposing during the certification qualification period.

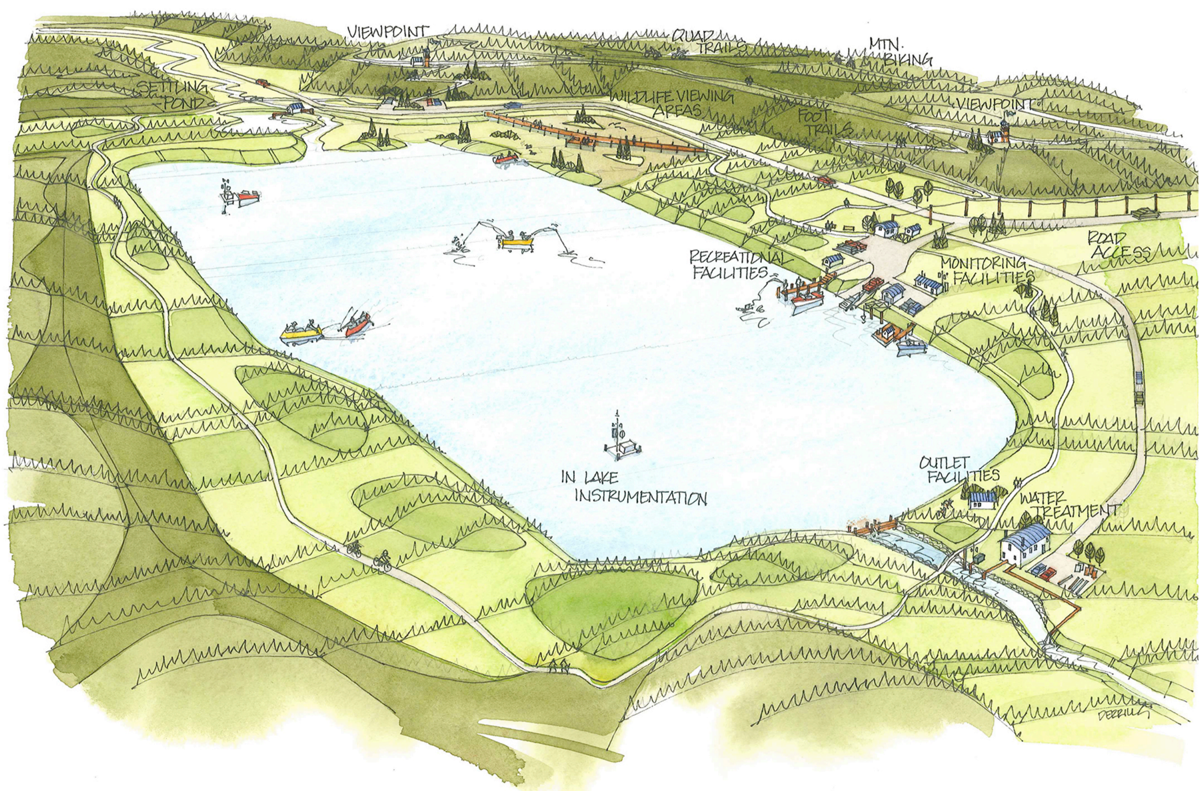

Figure 9-3: Infrastructure for instrumentation, monitoring, and maintenance will be required following completion of the EPL.

9.3.10 Constructing Final Land Use Infrastructure

Depending upon the proposed land uses, there may be need for infrastructure such as:

- Road access, off-road vehicle or foot trails
- Recreational facilities (beach, boat launch, campground, picnic area, parking lot, dock, wharf, wildlife viewing areas)
- Interpretive centre, interpretive trails, signage, wildlife-viewing towers.

There is an opportunity to re-purpose some of the operating facilities for long-term needs. Some final land use infrastructure can be designed and built during the certification qualification period.

9.3.11 Tailings Infilling

It is not yet known how many EPLs will contain tailings. Those without tailings will involve fewer design considerations and simpler management regimes, although they may still serve as collectors of process-affected water and/or accommodate seepage from tailings facilities. Planners and designers of non-tailings EPLs will not have to deal with as many water quality issues, but they should still be familiar with the in-lake processes associated with tailings and process-affected water described in Chapter 6.

9.3.12 Tailings Placement

Placement of tailings substrates in the lake (where designed) is an important element of construction. The process may involve the following:

- Beaching of tailings from shorelines to provide beaches to control wave erosion, or disposal of tailings sand. The tailings water or fluid fine tailings may or may not be moved (to other tailings facilities or treated for water discharge) during or after tailings discharge.

- Placement of tailings in the base of the pit as a substrate (fluid tailings, tailings sand, petroleum coke, centrifuge cake, thickened tailings, froth treatment tailings, composite/consolidated tailings). These deposits may be a thin layer covering some or all of the base of the pit, or may fill half or nearly all of the pit.

- Tailings landforms that are partly in the lake, partly forming riparian/terrestrial zones may also be constructed.

- The end pit may be used as an operational tailings pond for many years prior to construction and operation of the lake.

Typically, fluid tailings will be stored in the base of EPLs. This material would be pumped from the last tailings pond on the lease and discharged into the mined-out pit to be reclaimed using water capping. Typical fluid tailings volumes are about 100 million cubic metres and as much as 400 million cubic metres. Typical fluid tailings pumping rates are 3,000 to 12,000 cubic metres per hour, indicating it will generally take three to eight years to transfer fluid tailings to the end pit lake, pumping year round.

Pumping fluid tailings causes a short-term increase in densification rates, and several metres of process-affected water will be released each year during this transfer. Put differently, the fluid tailings level will drop several metres each year as water is expressed upward. Volumes of several cubic metres of water per square metre of fluid tailings would accumulate. The water will form a cap on the fluid tailings and may be left in place, or pumped back into the tailings system. Designs to deal with this water are clearly required. A water return system mounted on a floating barge on the infilling tailings area will generally be required. Booms to manage floating bitumen and cannons to control waterfowl will be required during this period.

If tailings *sand* slurry is being pumped into the lake area, the slurry will generally be 40% to 50% solids by mass, the rest being water with some residual bitumen (FTFC, 1995). Where fines are entrained in the beach below water tailings sand, long term consolidation may occur.

Other tailings products will produce different qualities of water during deposition, from high (composite tailings) to very little (thickened or centrifuged tailings being subjected to drying). The water quality of release water from these tailings will have different signatures depending upon any chemical amendments used. The rate of tailings densification/consolidation has large error bands and is likely not fully predictable in advance. If tailings consolidation is faster or slower than anticipated, operators may elect to remediate the tailings in situ as part of the adaptive management program. Even fluid tailings will form a slope and local depressions, both of which can have impacts on design, operation, and performance of the lake.

At the end of tailings deposition, process-affected water will cap the tailings, typically to a minimum of several metres. The design may call for use of this water as the initial water cap, but more commonly will require removal of the water and replacement by fresh water. Water pumping rates are similar to that of MFT transfer rates, indicating it would take a year or more to remove the process water cap. Initial fluid tailings consolidation rates are likely in the 1 m/year range, and small depressions in the tailings means that not all of the process-affected water can be removed.

9.3.13 EPLs Without Tailings

EPLs without tailings will generally have larger water residence times, lower flushing rates, and more room for aquatic ecology. The EPLs will be designed to accommodate seepage water from other tailings deposits elsewhere in the reclaimed watershed. If such seepage is significant, water management for these ponds will involve issues similar to lakes with tailings. Conversely, EPLs without tailings may experience more groundwater seepage than some lakes with tailings, as the tailings could serve as an effective aquitard. There may also be other substrates stored in EPLs, such as paste, thickened tailings, centrifuge tailings, coke, tailings sand, and composite tailings, all of which may have a reduced set of issues as they may be stronger or more consolidated than more fluid tailings.

9.3.14 Water Infilling

While many end pit lakes will have no tailings substrates, almost all of these lakes will still receive process-affected waters from the watershed. Depending on the specific operation, the pit may be used to store the remaining inventory of process-affected materials, such as process water, fluid tailings or solids. The lake will also begin to receive surface runoff and groundwater seepage from the surrounding landscape as it becomes reclaimed.

9.3.14.1 Process Water Infilling

The selection of starting conditions will be important in setting the path of lake development. Planners will need to choose materials (OSPW, fluid tailings), determine the physical aspects of the lake (elevation, water cap depths, depth and properties of the fluid tailings, water surface area, topography of lake setting, size and composition of littoral zone, watershed) and establish a flow-through operation. Changes in water quality in the lake component will be a function of the initial OSPW, substrate quality, potential for wind-mixing, rate of dilution (recharge rates) and in-situ degradation processes.

During this stage, some EPLs will be intended to function as bioreactors, as toxic constituents within the OSPW undergo degradation (Section 6.3.1.3). Initially, microbes may be the only organisms to inhabit the EPL, notably methanogenic, iron- and sulphate-reducing and hydrocarbon-degrading microbes (Penner and Foght, 2010), and the lakes will not be connected to downstream surface waters. Detoxification will proceed through a combination of passive biodegradation and dilution as the lakes are filled with a combination of OSPW and fresh water. This stage will be most effective if the lakes develop a diverse group of functional microbes.

Throughout the filling stage, the emphasis for pit lake operators and designers will be on maintaining a trajectory toward acceptable water quality so that the lakes can be connected to the receiving environment by the time the lakes are full. Maintaining the trajectory will entail confirmation of key parameters through continued monitoring and predictive modelling of the pit lake and the stressors that are affecting its performance. The most important constituents to monitor will be those that contribute to toxicity or limit ecological success; their removal or mitigation will be the first indication of an EPL's success. As the biota develops, success will be indicated by the colonization by less stress-tolerant species (Section 6.3.2). Provided the trajectory of these constituents is confirmed by monitoring and modelling, planners should have a high level of confidence in pit lake success. Conversely, if the monitoring and predictive modelling indicate that the trajectory toward desired water quality objectives will not be maintained, the monitoring will inform which adaptive management strategies (Appendix D) may be necessary. Until the lakes are deemed suitable for release, they must be maintained within the closed-circuited hydraulic system that was established during mining operations.

9.3.14.2 Post-tailings Infilling

EPL designs may call for a quiescent period at the end of tailings operation before final removal of the process-affected water cap and infilling with fresh water. The freshwater volumes needed to fill oil sands end pit lakes are typically about 100 million cubic metres and up to 400 million cubic metres, and operators have planned an average of about eight years (and up to 20 years) to cap.

If the fresh water is allowed to flow in from surface flows, a spillway or penstock will need to be designed to limit slope erosion as the water flows down the 6- to 55-metre drop from the lip of the lake to the base of the pit. Where fresh water is pumped in, a discharge area will need to be constructed. Water pumping rates are similar to that of MFT transfer rates and involve large diameter pipelines.

The fresh water import volume is often several times the annual permitted water withdrawal by the oil sands operators, and water withdrawal may be restricted to certain times of the year. Clearly, a plan for water withdrawal and an amended regulatory approval will be required well in advance of filling.

The initial water cap will typically be a mixture of process-affected water and fresh water. It could include tailings water from the consolidating substrate and tailings landforms in the watershed, and fresh water from pumped or surface water sources. In some cases, groundwater will also be a component. In the transition period during infilling, designs and operations need to account for several key failure modes:

- Windstorm/wave erosion events eroding pit walls or fills, undermining slopes and shore protection areas
- Bitumen and bird management
- Erosion at inlets
- Settlement and slumping due to first time filling
- Substrate erosion or turnover events.

In many ways, having a short period of water infilling (a few years) is preferable to a long period as the window or risk is reduced. There may be an opportunity to amend the import water (perhaps with nutrients) as part of the EPL operation. Downstream areas will need to be designed and constructed well in advance of potential discharge.

There is some discussion of starting EPLs with purely process-affected water rather than fresh water. While this may be expedient, it would greatly increase the transition and monitoring period, and may create many undesired consequences and is not recommended.

9.4 Operation

There are a variety of operational aspects to be considered once the lake has been constructed. These are guided by the Operation, Monitoring, and Surveillance Manual, the Adaptive Management Plan, and a host of standard operating procedures developed by the operators.

9.4.1 Controlling Access

A system and plan for controlling public access to the lake during construction, during operation for water treatment, during the certification qualification period, and at certification is required. There may also be additional controls with respect to boating, fishing, hunting, and water use during each of these periods.

9.4.2 Controlling Water Levels

The water level in the lake will need to be controlled by ensuring there is sufficient inflow to maintain a positive water balance, and by adjusting the outlet elevation (likely initially through a weir/stoplog system as is done with dams). As mentioned above, a low-level outlet may be required to be able to periodically lower the water level in the lake below that of the outlet for repairs or maintenance to the outlet, shoreline, or littoral zones. Water levels may also be controlled by pumping water (or tailings) to or from the lake.

9.4.3 Maintaining Shoreline and Littoral Zone

It is likely that some early maintenance of shoreline and littoral zones will be required. These earthworks will address areas of excessive shoreline erosion, and will accommodate adjustment of the elevations or configurations of littoral zones.

9.4.4 Integration into the Watershed

A central milestone will be reached when the EPL attains its final elevation. At this point, there needs to be enough water inflow (natural or pumped) to maintain a positive water balance and to avoid evapoconcentration, and enough outflow (through the outlet or pumped) to maintain lake levels and avoid flooding or overtopping.

A period of at least a decade, and perhaps much longer, will be required until untreated water can be released out the outlet to the environment. During this operational period, the excess water in the lake will either need to be re-used in the plant, pumped to another holding pond, pumped to a plant on another lease, or treated for discharge. All of these options require long lead times (five years or more) for design, approval, construction, and commissioning. Water treatment could hasten this schedule, but requires the same planning considerations for water balance as described below.

As the lake becomes ready, and as the watershed is ready, water from different areas of the natural and reclaimed landscape will be directed toward the end pit lake. The design and schedule need to consider each of these events. As noted above, some inlets may need to be designed and constructed many years prior to reconnection of the surface water inflows.

As water management equipment (pumps and pipelines and associated infrastructure) is no longer needed, it will need to be deactivated or removed and the areas reclaimed.

9.4.5 Operating for Water Treatment

EPLs will act as water treatment landform elements for the first years or decades, passively as bioreactors for reduction of naphthenic acid concentrations, as dilution vessels for salts, or actively with more traditional water treatment (in lake, or at the inlet or outlet). Traditionally, at metal mines, the water quality within the EPL is secondary to the effluent (outlet) water quality, either for some period of time, or in perpetuity.

For oil sands mines, planners may want to control the water quality within the lake during this water treatment operational phase. Table 9-2 provides an overview of the various treatment types and their potential applicability to treating influent, lake, and effluent waters in the oil sands.

Table 9-2: Options for treating water.

Water treatment option	Method
Wait until water quality naturally improves	Reduce the quantity of poor quality influent Increase the quantity of fresh water influent (dilution) Treat the influent water
Change the loading or quality of seepage / consolidation water	Control groundwater inflow Enhance or retard tailings water release Remove the tailings Cap other substrates
Change the water quality in the lake	Replace poor-quality water with fresh water Treat the lake water by removing constituents Treat lake water by adding chemicals Treat lake water by physical means

It may not be necessary to locate influent treatment at the inlet of the EPL; rather, it could be located at the source, farther upstream in the watershed. Water treatment is likely not an option for treating the consolidation water from tailings under the EPL, perhaps necessitating in-lake or effluent treatment. Options for controlling the quality of the outflow include all of the above, as well as physical or chemical treatment of the effluent water.

As in conventional water treatment and wastewater treatment, an array of processes and technologies are available for use. There are biological, physical, or chemical means to remove contaminants of interest such as total suspended solids, total dissolved solids, metals and organic chemicals from waters. One of the main factors in the design of water treatment plants is the design flow. It would be impractical to design a water treatment plant to cope with extreme flows as they are handled in the landscape. One of the considerations in design is when it will be acceptable to bypass the water treatment system during extreme events. To some degree, the landscape can also be designed to attenuate flows to downstream facilities with the use of large wetlands and enhanced infiltration. Handling the (cold) snowmelt waters in the freshet and extreme summer rainfall events will be challenging for on-line water treatment systems. Climate change would also need to be explicitly considered. Many of these considerations can be addressed with in-lake treatment.

In-lake active treatment would need to cease when the lake enters the reclamation certification qualification period, but there may be cases where there is active treatment of influent and effluent waters at this time. Present provincial certification criteria require that the reclaimed landscape be self-sustaining, prohibiting the perpetual use of water treatment; presumably the water quality in the lake and its outflow will improve with time, allowing decommissioning of active treatment plants. Decommissioning plans should be provided up front.

Most water treatment methods create water treatment sludges, which would need to be landfilled. Volumes of treatment sludge produced over time can be quite high and need to be planned for in the initial closure planning for the site. While there are several options for landfilling, construction of a modern landfill on in-situ ground is usually the best option.

The need for water treatment is sometimes known in advance, while at other times there is a small chance it will not be required. The failure modes and effects analysis (FMEA), contingency planning, and monitoring, as part of the overall adaptive management systems, will allow designers and planners to have ready-made contingencies ready to go in time to be effective. Most of the water treatment methods would require a year or more of piloting to determine their efficacy. This piloting should be done in advance if the contingency planning is to rely on this technology.

9.4.6 Lake Discharge

Once the EPL waters are suitable for discharge, they can be reconnected to the receiving environment recharge and discharge locations. The criteria to be deemed “acceptable for release” have yet to be defined by the AESRD, the regulatory agency responsible for water releases (OSWRTWG, 1996). However, EPLs have been conceptually approved through joint provincial-federal panels on the basis that their initial release water will not cause adverse effects to receiving watercourses, when considered cumulatively (ERCB, 2011). This approach is consistent with Alberta Environment’s approach to water releases from other industries (AEP, 1995).

During this stage of EPL development, it is anticipated that biological processes will function at most trophic levels, as described in Section 6.3.3. It is generally understood that every lake, whether an EPL or a natural lake, is unique and that there will be differences between EPLs and natural lakes in the region. While steps can be taken to tailor the design of EPLs toward natural lakes (Chapter 4), during this operating period the primary function of EPLs will be to provide ongoing treatment and attenuation of flow and chemistry from the reclaimed mine prior to discharge to the natural environment.

9.4.7 Operating for Certification Qualification

After the water treatment phase, active management of inputs into lake performance would be curtailed and the lake would move into the certification qualification phase. Most of the activity on the lake would involve monitoring of physical, chemical, and biological processes (see Section 9.6) while the lake is in its quiescent state.

Rather than being quiescent, there may be decreasing levels of maintenance. Ongoing record keeping of activities and expenditures is all the more important during this stage, as a company builds the case for custodial transfer.

9.4.8 Certifying and Transferring Custodianship

Before certification, the ERCB requires that the area to be certified is first abandoned. This involves a submission to the ERCB that indicates that all of the ore that was supposed to be removed has been removed, that the area is no longer required for mining or tailings operations, and that the land is geotechnically stable.

Reclamation certification for oil sands is presently governed under EPEA and executed following the White Book (Alberta Land Conservation and Reclamation Council, 1991). Applying for reclamation certification entails:

- Making an application
- Supporting the application of a document, essentially a biography of the landform, showing how it has met the EPEA and approval requirements
- Review and field inspection (called an inquiry)
- Issuance of a reclamation certificate (or refusal to issue the certificate, or to issue a certificate for a portion of the site, followed by reworking of the site to address deficiencies and reapplication).

TransAlta's East Pit Lake west of Edmonton was certified even before final filling as all indicators pointed to a successful lake. This provides a model, or at least a data point, for oil sands end pit lakes. There are numerous other pit lakes in the coal mines and sand and gravel pits of Alberta that should be monitored for developments.

Presently, CEMA is developing a revised description of the certification process to replace the White Book, and is working to develop criteria and indicators to be used to judge reclamation success. If this is accepted by AESRD, it will change the way EPLs are certified.

Federal polluter pays legislation suggests that operators maintain some liability for reclaimed sites. It may not be in the best interest of an operator to give up control of the lake for fear of incurring further liabilities with time. But it would be beneficial to develop a system of progressive signoff by regulators for various aspects of the end pit lake design, construction, operation, and eventual certification.

9.5 Modelling

Most EPLs will not be constructed until several decades after the start of mining, and no other lakes exist that share both limnological and chemical characteristics. While information will improve with the establishment of demonstration pit lakes, there are presently no available studies that document the development of a full-scale EPL. Therefore, numerical modelling is the most practical way to estimate and assess the effects of many of the processes described in Section 6.2 and 6.3 on water quality. It is important to be mindful that, while numerical models can provide useful information, they cannot be fully calibrated or validated until a demonstration pit lake that represents the majority of end pit lakes in the sector is established.

It should be noted that there are about a dozen models in addition to lake-process models that will be part of the design. These will include models of climate, surface water, groundwater, ecological and geotechnical parameters, wildlife, and mining and tailings. Designers and modellers will need to resist the temptation to create some kind of coupled/combined “super model” in favour of a consistent set of conceptual models and largely stand-alone numerical models.

9.5.1 Lake Process Models

While there are unique aspects of EPLs, most of the basic processes described in Sections 6.2 and 6.3 are included in water quality model software packages as generic processes that can be modified to suit individual applications. Certain processes, such as those associated with tailings consolidation and biogenic gas production, are not available in existing water quality models, but are being developed as part of CEMA’s Oil Sands Pit Lake Model. The model, source code and documentation will be distributed freely once the model development is finalized.

The CEMA model incorporates tailings consolidation and biogenic gas production to be better suited for EPLs. However, there are other models available that could be used for oil sands EPLs. Currently, the applicability of numerical modelling for oil sands pit lake design is limited by the lack of field data to calibrate and substantiate the model results. However, until full-scale (demonstration) EPLs are implemented and monitored, current numerical modelling would still be used to provide ranges of values and preliminary evaluation of performance sensitivity to various parameters.

Key lake processes to be studied include:

- Variation of lake water quality as a function of time, source of infilling water, contribution of pore water from consolidating tailings, contribution to and from groundwater and interaction with the bottom sediments and pitwall slope materials.
- Hydrodynamic effects, such as currents and waves, and water/sediment interaction including sediment resuspension.
- Vertical mixing as a function of temperature and salinity, including potential for development of meromictic conditions.
- Interaction among various inter-related parameters such as depth, lake configuration (fetch), winds, lake contents, water quality, etc., as part of determining the feasibility of a particular EPL.

After studying the lake processes described above, the design should include an estimate of the probable water column mixing regime and take into account its effect on water quality predictions. Currently, no EPL is planned to be meromictic. In most cases, the design is for annual summer stratification and fall turnover to supply the water column with oxygen, which will enhance treatment of organic constituents.

For EPLs that will provide storage and bioremediation of process-affected materials, the impact of these elements needs to be considered in the modelling. The potential effects of water-capped tailings include: (1) increased sediment oxygen demand, resulting in anoxic conditions at the bottom water layer of the lake; (2) release of pore water to the water column; (3) release of biogenic gases to the water column and atmosphere; and (4) resuspension of tailings to the water column. The optimal water cap depth for managing these potential effects needs to be considered and provided as input into the design of the EPL. The objective of modelling lake processes is to support designs that will meet water quality goals.

9.5.2 Guidance for Developing EPL Models

Environmental modelling for EPLs will presumably follow the best available practices. Thus, this section is not intended to discuss general guides to modelling, but rather to focus on how the available tools are best directed to EPLs. For general modelling guidance, the reader is referred to other documents such as *Guidance on the Development, Evaluation, and Application of Environmental Models* (USEPA, 2009) and *Guidance for Quality Assurance Project Plans for Modeling* (USEPA, 2002). More specific to the mining industry are *Predicting Water Quality at Hard Rock Mines* (Maest et al., 2005), *Comparison of Predicted and Actual Water Quality at Hardrock Mines* (Kuipers et al., 2006) and *Mine Pit Lakes; Characteristics, Predictive Modelling and Sustainability* (Castendyk and Eary, 2009). In addition, most models have detailed user manuals that lay out the steps for setting up the application. An excellent example is the CE-QUAL-W2 user manual (Cole and Wells, 2001), which provides guidance that is applicable to all hydrodynamic and water quality modelling.

A common theme of the generic model guidance documents is that there will be a general workflow that should be followed when modelling, regardless of stage or complexity. Although there are subtle differences in the recommendations of the documents listed above, modelling should follow these fundamental steps, remembering that their application may need to be modified to incorporate the specifics of each EPL, as detailed in Table 9-3.

Table 9-3: EPL-specific modelling steps.

Modelling step	Details
Define the objectives for modelling	Examples of objectives for EPL modelling are: (1) predict whether the lake will be meromictic; (2) predict whether the water column will be deep enough to minimize tailings resuspension; (3) predict the concentration of naphthenic acids at various snapshots in time. All subsequent modelling tasks should be completed with a clear aim of meeting the objectives. Among other things, the objectives will determine the type of modelling that is required. For example, sensitivity analyses can be completed to determine key driving variables, without putting too much weight on the accuracy of the values themselves. In contrast, stochastic modelling can be used for risk assessment modelling, where each output value or consequence is attached to a frequency or likelihood of occurrence.
Develop a conceptual model	Define the inputs to the lake and physical characteristics of the system. Describe the key processes that will influence the possible water quality. Process diagrams or schematics can be helpful to visualize the relevant physical and chemical processes.
Select the appropriate model software	The model software selection will be a function of physical and chemical factors that could influence chemistry, model objectives, the conceptual model and available data. Consider domain, dimensionality, functionality, input data requirements, reliability and computational effort. More than one model software package may be necessary to simulate all key processes in an EPL. For example, it may be necessary to employ a groundwater model, a geochemical model, a hydrodynamic model and a water quality model. If an appropriate model is not available that fits the conceptual model, development or modification of an existing model may be necessary. An example of the code modification that is necessary for EPLs is salt rejection. This process was added to CE-QUAL-W2 for CEMA's Phase II Pit Lake Modelling (Golder, 2007), and was used in subsequent EPL modelling.
Establish key output metrics	Examples of output metrics are constituent concentrations, turnover rate, outflow rate or lake water level. The model must be able to predict and report key metrics.
Establish screening criteria in advance of model runs	Examples of screening criteria are applicable regional water quality guidelines, concentrations in natural lakes and aquatic health benchmarks. Choosing the appropriate screening criteria to meet the objectives of the modelling will allow the modeller to view preliminary results in context, and to adjust assumptions and inputs throughout the modelling exercise.
Gather input data	Compile and assemble all necessary input data for the selected model(s). Data could include surface water and groundwater flow, surface water and groundwater chemistry, climate data or

Modelling step	Details
	analogue data from comparable sites. In many cases, the EPL in question may be decades from construction, so input data may be unavailable. If data are not available, the modelling exercise may need to be delayed while data are collected, or a simpler model may need to be developed. Methods for dealing with lack of data will vary, depending on the stage of modelling and objectives.
Implement quality assurance procedures	Screen input data for outliers, unit conversion errors, analytical or instrument malfunctions and other issues. A useful procedure is to view graphs of all model input time-series along with the raw data used to generate the formatted inputs. Additionally, graphing inputs and outputs on the same figure can be done to compare the model software response with the expectations of the conceptual model. For example, graphing meteorological input data next to simulated water temperature can indicate whether a model is responding appropriately.
Calibrate and validate, wherever possible	If the lake is in the filling stage, compare model predictions with observed data. If a future lake has not been filled, validate and refine inputs to the model whenever information becomes available. Validation can also be done at a smaller scale using bench-top physical models, or by evaluating surrogate systems.
Conduct an uncertainty or sensitivity analysis	Quantify confidence limits and identify key sensitivities, as discussed in the following subsections.
Compare results to criteria	If the modelling indicates that design objectives will be met or that water quality criteria will be achieved, this stage of modelling may be finished. If the objectives or criteria are not met, changes to the mine closure plan or additional mitigation may be required.
Continuous improvement loops	When any time changes are made to the mine closure plan, the updates should be fed back into the process and modelling can be resumed. Depending on the type and magnitude of change, the feedback may warrant updates to the conceptual model, additional data collection and revisiting the model software selection.
Conduct a post audit	Once the lake develops, compare predicted values to observed values and calibrate the prediction model as needed to match observations (Anderson and Woessner, 1992).

9.5.3 Stages and Objectives of Modelling

While many discrete stages could be defined for planning, three stages of modelling are defined here as they relate to the availability of information, the objectives of the modelling and the type of modelling that will be employed. The main stages of modelling are the preliminary design stage, the

EIA stage and the operational stage. The operational stage in this context includes the life of mine operations and all three stages of lake development described in Section 9.1. As the planning proceeds through these stages, pit lake modelling will increase in complexity of inputs and confidence in predictions.

9.5.3.1 Preliminary Design Stage

The objective of modelling at the preliminary design stage is to advise mine planners whether an EPL is a potential closure option for their mine plan. At this stage, information is generally limited. Inflow chemistries and volumes are usually not known, and information from similar operations and the watershed is often used as surrogate inputs. A good geologic model is typically available, and a complementary groundwater model is developed. Due to the uncertainties inherent in applying surrogate inputs, only key variables can be evaluated; moreover, they can only be evaluated at a high level. The types of questions that need to be answered in the preliminary stage are as follows:

- Is there a suitable water source to maintain hydrologic sustainability (i.e., will it have continuous outflow or will there be extended periods with no outflow?). Note that terminal pit lakes have not been proposed in oil sands applications.
- How much river water will be required for filling, and will this fit within anticipated water license abstraction limits (and withdrawal of water for multiple pits at the same time)? All oil sands mining applications have included fresh water imports for EPL filling.
- Will the pit shell intercept saline groundwater sources, such as the basal aquifer (Section 4.2.7)? If so, what are the expected inflow rates, and what sort of mitigation can be implemented to reduce inflows?
- What volume of process water and tailings will be transferred to the EPL?
- What are the physical dimensions?
- What is the hydraulic residence time?
- What is the anticipated concentration of TDS, and naphthenic acids at the time of initial discharge? How certain are these estimates?

These types of questions are generally answered by using spreadsheet models to calculate water levels, outflow rates and concentrations. Appropriate safety margins are applied to all estimates because the level of uncertainty is high. If the EPL is deemed feasible based on this preliminary evaluation, the EPL design within the mine closure plan may be proposed and more detailed information can be generated for subsequent stages.

Monitoring for calibration of the hydrologic model is critical and it should include at a minimum:

1. Daily data from a complete weather station.
2. Daily data from a local standard evaporation pan that is calibrated to the lake surface evaporation.
3. Daily flow rates of inlet and outlet channels.

4. Flow rates of any fluids transferred in or out of the pit lake.
5. Daily readings of lake level.
6. Density of lake content materials (fluid and solid).
7. Bathymetry of lake bottom configuration performed at an adequate frequency to determine potential slope failures, consolidation of deposits, sedimentation and scour features, and any other relevant processes that could develop within the lake.

The hydrologic balance prepared at the design stage should be calibrated to the monitoring data above to be developed into a predictive tool that can be used to assess potential future conditions and adjust the design and potential mitigative measures to best manage the EPL performance.

In addition to environmental monitoring, geotechnical monitoring will be required to monitor settlement and stability of the slopes in the area. Inclinometers, piezometers, settlement gauges, etc., may need to be considered.

9.5.3.2 Environmental Assessment Stage

The next stage of EPL modelling is the Environmental Impact Assessment (EIA). A provincial and/or federal EIA may be required for a mine or an expansion of a mine. An EIA is a multidisciplinary assessment of a project's impact on the natural and human environment. It includes an evaluation of any potential effects on air, land, water, plants, animals and humans, and it identifies mitigation that can be applied to reduce or eliminate these effects. The EIA is used by regulators to determine whether a project, on the whole, is in the public interest.

At the EIA stage, operators apply for approval to construct, operate and reclaim the mine. As one component of the EIA, operators are required to describe water and sediment quality conditions and suitability for aquatic biota in constructed water bodies. The objective of EPL modelling for an EIA is to predict concentrations of constituents such as those in Tables B-4 and B-6, both within the mine footprint and in all potentially affected waterbodies and watercourses. The concentrations are then evaluated as part of separate aquatic, wildlife and human health risk assessments. Predicting concentrations with some confidence requires much more detailed information than that which would be available at the preliminary design stage. In addition to the high-level questions posed above, the following questions must be answered in an EIA:

- What are the predicted concentrations of metals, metalloids, PAHs, whole effluent toxicity, salinity and other constituents of concern?
- What are the predicted concentrations of these constituents in receiving watercourses and waterbodies?
- What is the predicted sediment quality?
- What is the level of uncertainty in these predictions?

The complexity of these questions necessitates a concomitant increase in level of model complexity. To satisfy stakeholder and regulatory concerns, an EIA must address the issues described in Section 6.2 and 6.3. Specifically, the EIA must predict water quality, accounting for seasonal and long-term stratification and turnover, inputs from OSPW and tailings, groundwater inflows, filling sources, tributary inflows, and all other potential inputs described in Chapter 4. To do so, estimates are required for the volume and chemical profiles of each inflow source.

The volume and chemistry of inflow sources are the main factors that will determine the success of an EPL. Of particular importance are sources of toxicity, such as OSPW (Section 6.3.1). Given that some mines will not be producing OSPW at the time of an EIA, alternate sources of data must be obtained or derived to represent the inflows as accurately as possible. For OSPW, water chemistry from other operators can be used. Confidence in model inputs increases if the operations from which data are derived have similar ore bodies and employ similar extraction processes and tailings technologies to the planned operation. Chemical profiles can also be derived through mine water balance models that account for the sources and processes that will affect process waters throughout the life of the mine (Kaminsky and Shaffer, 2010; Reid et al., 2010). In the case of tributary and groundwater inflows, chemical profiles will be available from baseline programs conducted for the project, and a hydrologic assessment is required to estimate inflow rates as part of all EIAs. Example profiles for natural and OSPW are listed in Appendix B.

Predicting seasonal and annual stratification and turnover requires the use of a hydrodynamic model. For pit lakes of other mining industries, a one-dimensional model such as DYRESM (Imberger and Patterson, 1981) is often employed. A discussion of hydrodynamic and water quality models used for pit lakes of other mining industries is provided by Castendyk and Eary (2009). DYRESM may be appropriate for the deepest EPLs with small surface areas, which are more likely to exhibit one-dimensional behaviour. For EPLs that are shallower or have larger surface areas, a two-dimensional model such as CE-QUAL-W2 (Cole and Wells, 2001) or a three-dimensional model such as GEMSS (Buchak and Edinger 1984) may be more appropriate.

Prediction of limnological behaviour using a hydrodynamic model requires detailed information about pit geometry, as well as meteorological data. By the time an EIA is completed, pit geometries are available as part of the mine closure plan. Meteorological data in the oil sands region can be obtained from Environment Canada and the Regional Aquatics Monitoring Program, and occasionally from site-specific meteorological stations.

As part of all EIAs, the level of confidence in model predictions must be evaluated and communicated to reviewers through use of uncertainty analyses. In practice, distributions and bounds cannot be defined for some key drivers at the EIA stage because some inflow waters have not yet been generated. Uncertainties that cannot be quantified are addressed almost exclusively through one of two methods. The simplest method is often to assume a conservatively high value for an input or process. For example, in a conservative approach, the lowest recorded degradation rates may be used in models, even though this inevitably leads to over-prediction of final concentrations. If the final concentrations are below applicable guidelines and thresholds despite a bias on the high side, then the objective of EIA modelling is met, despite uncertainty in the inputs.

A second method of dealing with uncertainties that cannot be quantified is for the proponent to commit to additional mitigation. In this case, the operator assumes the cost for mitigating the potential effects, and will be bound by regulatory commitments to ensure the mitigation is effective. Modelling mitigation can be done through a sensitivity analysis, with several options being evaluated as model scenarios. Once a mitigation strategy has been chosen, the full EIA model can be updated with the mitigation incorporated into the mine closure plan. In this case the model has also met its objective; it was used to identify a potential cause of adverse effects, then to identify appropriate mitigation, then to assess the effects with mitigation in place.

9.5.3.3 Operational Stage

The operational stage, as defined for the purposes of water quality modelling, begins when the mine begins operations and starts generating OSPW. The objective of EPL modelling at the operational stage is to ensure the EPL is following a desired trajectory, and to inform adaptive management where necessary. During mining operations, a database of OSPW quality can be generated and analysed for temporal trends. Although the pit may not be developed for several years, the EIA models can be updated using site-specific data, and further refinements to the mine closure plan may be implemented.

9.5.3.4 Filling, Initial Release and Certification Stages

When the pit is ready for filling, models can be calibrated to observed behaviour. As the EPL is filled, the trajectory toward desired outcomes can be modelled and monitored. If the model is updated and validated frequently throughout the filling period, the model accuracy and confidence will improve. If water quality is not projected to meet guidelines or objectives, modelling can be used to inform decisions regarding adaptive management. By completing “what if” scenarios, outcomes of potential mitigation can be predicted. Modelling during these stages should begin as soon as a water column develops, and should continue at least until a final reclamation certificate is obtained. The frequency of model updates should reflect the degree of deviation from expected conditions.

9.5.4 Sensitivity Analysis

In the early stages of EPL modelling, input data on design factors will be limited because a mine closure plan may not be fully developed and baseline data may not have been collected. At this stage, models are used most effectively for identifying key sensitivities. In a sensitivity analysis, one input variable is modified per model scenario, and the model results are compared to show a relative change in an output variable. This type of modelling is used to answer “what if?” types of questions. By modelling several scenarios of design or management options, the differences in results can indicate the optimal design. For example, a mine closure plan may have the option to route one, several, or no upstream tributaries through the EPL at closure. Each of these scenarios can be simulated relatively easily, and each scenario will result in different concentrations of salinity, naphthenic acids, ammonia, and other constituents of interest. In another example, water quality in a given EPL can be simulated with no FFT, or with various amounts of FFT under a water cap. Each scenario would include the depths, volumes and pore water release rates that correspond to the EPL with the various amounts of FFT. The model results could indicate different concentrations of constituents as well as different depths, frequencies and durations of stratification. Although information is most limited at the early design stage, this is when the range of design and management options available to mine planners is broadest.

9.5.5 Modelling Naphthenic Acids Degradation

As discussed in Section 6.3.1.3, individual compounds and fractions within the group of naphthenic acids have different levels of toxicity and rates of degradation. For the purpose of modelling degradation of naphthenic acids in EPLs, source concentrations can be divided into different fractions, each with individual kinetic rates. The most applicable studies from which modelling rates can be derived are Scott et al. (2005) and Han et al. (2009). Scott et al. (2005) found that about 25% of total naphthenic acids were degraded within 40 to 50 days in a laboratory study. They attributed most of this degradation to removal of naphthenic acids with fewer than 18 carbons. Han et al. (2009) measured naphthenic acids concentrations in a test pond containing aged OSPW. The test pond had no major inflows or outflows, so concentrations were not substantially affected by dilution. They found that after 13 years, total naphthenic acids concentrations had declined by about 50%.

To date, no field or laboratory studies have measured naphthenic acids degradation beyond 13 years. It is likely that some portion of the remaining 50% of naphthenic acids will continue to degrade at rates comparable to those observed by Han et al. (2009), while some portion will be effectively inert within timeframes that can be practically modelled.

The findings of Scott et al. (2005) and Han et al. (2009) can be used to derive kinetic rate constants for modelling the degradation of naphthenic acids in EPLs. Typically, degradable substances are modelled according to first-order kinetics. The following approach is recommended for applying these studies to long-term predictions of naphthenic acids concentrations:

- For all process-affected inflow sources, such as direct inputs of OSPW or groundwater inflows from tailings areas, 25% of total naphthenic acids are assumed to be labile, with a half-life of 0.22 years.
- For all process-affected inflow sources, 75% of total naphthenic acids are assumed to be refractory, with a half-life of 23 years (which yields a 50% decline in total naphthenic acids at 13 years).
- For all natural sources, 100% of total naphthenic acids are assumed to be refractory, with a half-life of 23 years.
- Total naphthenic acids can be calculated at any time as the sum of labile and refractory naphthenic acids.

To address the uncertainty in predicting degradation beyond 13 years, a separate constituent, "inert naphthenic acids," can be simulated, which assumes no degradation. For all sources, 50% of total naphthenic acids can be assumed to be inert for the sensitivity analysis. If the predicted inert naphthenic acids concentration exceeds the predicted total naphthenic acids concentration, the two predictions can be presented as a lower and upper bounds. The lower bound indicates concentrations that may occur if degradation continues at the rates measured by Han et al. (2009).

The upper bound indicates concentrations that may occur if naphthenic acids do not degrade beyond 13 years.

An example of predicted concentrations from a single source, relative to initial concentration and assuming no other fate processes, is shown in Figure 9-4.

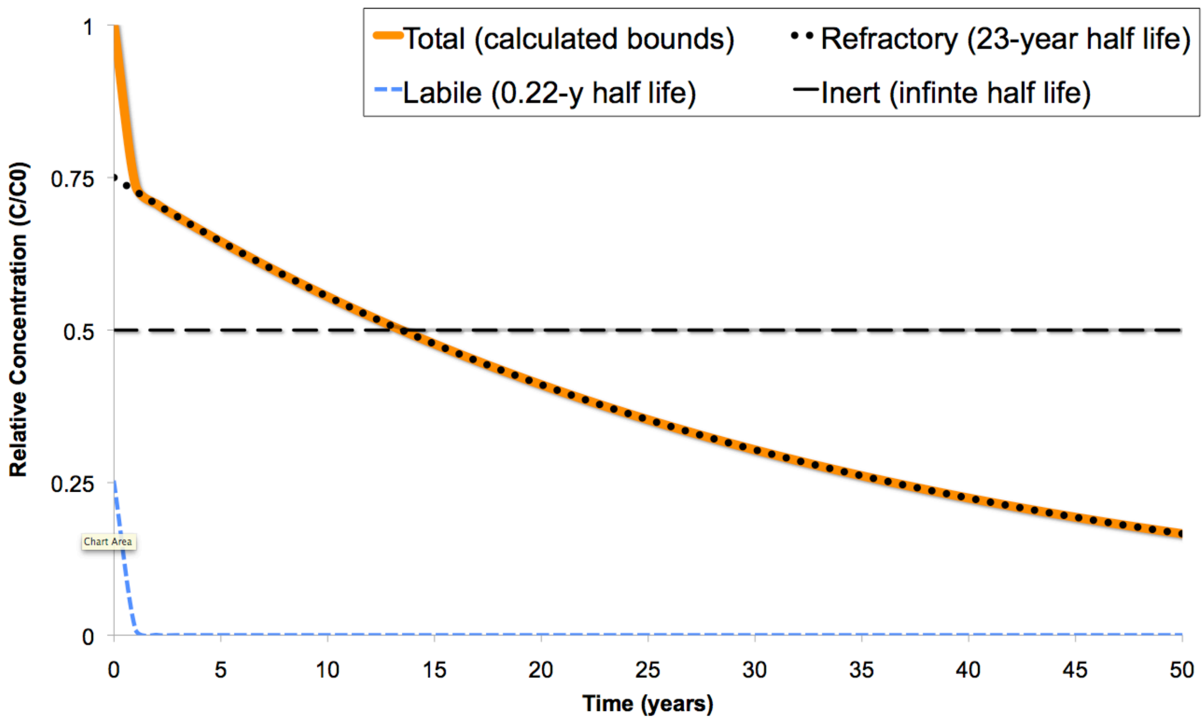

Figure 9-4: Modelled degradation of a single source of naphthenic acids.

There is ongoing work to better define, measure, and model naphthenic acids and their degradation; our understanding of these complex materials and phenomena is growing rapidly.

9.6 Monitoring

An aquatic monitoring program is essential to ensuring EPLs remain on an acceptable trajectory toward successful certification. Detailed monitoring programs, which are beyond the scope of this document, will need to be prepared for each EPL, ideally involving regulators to ensure the "right" parameters are being monitored. Pit lake-specific monitoring programs will need to account for site-specific environmental conditions, regulatory obligations and commitments to local stakeholders. Monitoring frequency, in particular, will be site-specific, because monitoring frequency should be adapted to local environmental variability. Monitoring programs should also be coordinated with other environmental monitoring that is conducted by operators and by regional organizations.

9.6.1 Monitoring Stages and Objectives

Monitoring programs for EPLs will be long-term commitments that begin with baseline data collection and continue at least until certification. The objectives and requirements will vary at each stage of development and at each stage of modelling. An overview of monitoring is provided for each of these stages.

9.6.1.1 Preliminary Design and EIA Stage

Baseline data collection is generally the first stage of environmental monitoring for an oil sands mining project. Baseline data collection is completed as a requirement of all oil sands EIAs. The objective of baseline data collection is to characterize the environment in which the project will be located.

Aquatic baseline programs generally comprise the following components: water and sediment quality; benthic invertebrates; hydrology; hydrogeology; fish and fish habitat; and fish health. Baseline data are collected seasonally, annually or continuously, depending on the component, for one to three years, depending on the amount of data available from other sources. Data collected during baseline programs for oil sands developments are usually combined with data from various sources, including RAMP, Alberta Environment, Environment Canada and previous baseline programs in the region.

Data collected for baseline programs are compiled and published in baseline reports that accompany EIAs. Baseline flow and chemistry data are also used to set up and calibrate EIA models, including the pit lake models and receiving watercourse models. Flow is measured continuously in local streams during the open water season and synoptically under ice. Water and sediment quality monitoring includes a suite of field parameters, ions, nutrients, total and dissolved metals, organic compounds and whole effluent toxicity, similar to the list of parameters in Table 6-1. A more comprehensive list is available in RAMP (2010). Baseline reports and EIAs for all oil sands mines are published on the website of the Canadian Environmental Assessment Agency (https://external.sp.environment.gov.ab.ca/ DocArc/EIA/Pages/default.aspx).

9.6.1.2 Operational Stage

While the mine is operational, but before the pit is ready to begin filling, monitoring should focus on waters that will be used to eventually fill the EPL. The objectives of monitoring during operations are to: verify that inputs are similar to what was predicted in the EIA; to refine model inputs and assumptions where conditions deviate from expectations; and to evaluate the suitability of source waters as inputs. Monitoring throughout operations will allow models to be updated and predictions to be refined. Mine planners will then have the ability to modify closure plans, if necessary, to account for any changes in projected water quality as early as possible.

The chemistry of all anticipated inflows should be monitored throughout the operational period. The chemical makeup of these waters will determine the chemical makeup of an OSPL, and by extension, will affect many processes in the lake. Therefore, a detailed knowledge of these waters is essential.

On-site waters that should be monitored during operations include: OSPW, tailings pore water, runoff from reclaimed areas and groundwater. The list of parameters that were monitored in the baseline program would also be applicable to these waters. This list should be revisited frequently, given that analytical techniques for substances such as naphthenic acids are evolving rapidly (Grewer 2010). Sampling frequency should meet modelling needs, but in general, a quarterly schedule should be sufficient for waters that are relatively stable over time, such as groundwater. Monitoring frequency should be increased for waters with high temporal or seasonal variation, such as runoff from reclaimed areas.

Reclaimed areas include the various landforms described in Chapter 5. Runoff from each of these landforms should be monitored separately as they will all have different chemistries and water yields. Furthermore, both the discharge rate and chemistry will vary by the surface and subsurface flow component within each landform (Kelln et al., 2007; 2008; 2009).

As soon as tailings are produced and deposited in tailings ponds or as backfill in mine pits, consolidation rates and water release rates from these tailings should be measured to allow estimation of the amount of pore water that will eventually enter the EPL.

Surface waters in the surrounding environment that will eventually become an inflow to the EPL will normally be adequately monitored as part of other monitoring programs by operators, regional organizations and government. The ability of existing monitoring programs to characterize inflows and receiving waters should be verified on a project-by-project basis.

9.6.1.3 Water Infilling Stage

Water and sediment quality should be monitored in the EPL from the start of the filling period. The objective of monitoring during this stage is to confirm that EPL waters are following a trajectory toward being acceptable for release. At this stage, if waters do not follow the desired trajectory, adaptive management may be necessary.

Monitoring should include the same list of water and sediment quality parameters that were monitored in earlier stages, plus additional parameters. Gases such as methane, ammonia, and hydrogen sulphide should be measured in the sediments, water column and in the atmosphere, particularly if the EPL contains tailings. Vertical profiles of pH, temperature, conductivity and DO should be measured with continuous dataloggers to monitor the development of vertical gradients within the lake. A full suite of water quality parameters should be collected at multiple depths at least seasonally.

As biota become established, monitoring should be expanded to track the establishment of aquatic communities and provide early warnings of potential undesirable trajectories in ecosystem development. Biological monitoring endpoints should include species composition and abundance of aquatic communities and indicator species. Communities to be monitored include phytoplankton and zooplankton, benthic invertebrates and aquatic and riparian plants. The intensity of lower trophic monitoring should be sufficient to collect representative data in each major habitat type (e.g., benthic, littoral, profundal). The frequency of monitoring should generally be seasonal during the open water period, but this may need to vary by community type to adequately document within-year patterns.

Throughout this period, monitoring conducted during the operational phase should be continued for all inflow sources that have not yet been adequately characterized.

9.6.1.4 Initial Release Stage and Downstream Receptor Monitoring

When the EPL is hydraulically connected to the receiving environment, monitoring requirements will be prescribed by *EPEA* approval conditions and likely as part of a *Fisheries Act* authorization. The main objectives during this stage will be to monitor aquatic environmental effects in the receiving environment and to track progress toward certification.

Monitoring requirements during this stage will likely be similar to the recommendations provided for in the filling stage, with the addition of frequent chemical and biological monitoring downstream of the EPL discharge at both near-field and far-field locations.

Once fish are added or naturally colonize the EPL, monitoring should include fish assemblage and health surveys. Fish assemblage surveys track metrics such as species composition and abundance. Fish health surveys track tissue concentrations of metals and PAHs, biomass and length and incidence of internal and external abnormalities or deformities. Waterfowl should also be monitored with similar metrics.

9.6.1.5 Certification Stage

Once an EPL is certified, it is not presently known what the monitoring requirements will be, if any. Regardless of regulatory obligations, EPL monitoring should be continued by industry, government and academia, as these systems will present research opportunities.

9.7 Adaptive Management

The certification of an EPL is unlikely to occur without a plan that takes advantage of both the monitoring program and FMEA. The plan must adapt to new scientific insights into the physical and ecological process at work in the evolution of EPLs, the arrival of new information, and changes in the legislative and regulatory environment. The lack of experience with EPLs in the oil sands only compounds the challenge. These circumstances necessitate what is known as an adaptive management program.

Adaptive management has been defined in various ways since its introduction more than 50 years ago, and there is no off-the-shelf program that can be easily modified for the purposes of EPL design and construction. At its core, however, is the careful execution of an iterative, seven-step process. Active, formal, and systematic adaptive management approaches will reduce uncertainty and improve management plans. In the oil sands, they should include the participation of First Nations, stakeholders, regulators, management, operations people, engineers, and scientists.

Such programs will be critical to the widespread acceptance of what is effectively a large-scale experiment, to the business interests of the oil sands operators constructing and operating these lakes, and to the regulators and stakeholders who will be impacted (positively or negatively) by the cost and landscape performance of EPLs being constructed from reclaimed land. Appendix D explores the practical and historical foundations of various approaches to adaptive management. A key component of the adaptive management program will be updating the EPL guide, ideally on a five-year basis.

9.7.1 Modified Seven-Step Adaptive Management Program for EPLs

Table 9-4 and the accompanying discussion provide the details of the modified adaptive management program, with an explanation to accompany each of the seven steps. It includes a discussion and partial listing of failure modes deserving of good design and adaptive management, and the outline of a monitoring plan to evaluate performance, aid learning, and finally a look outside the oil sands for ongoing scanning for world developments.

Table 9-4: Steps for modified adaptive management.

Steps	Description and comments
1. Define the problem and objectives	Identify management responsibility (roles and responsibility) for each lake and for the lake district. For each proposed end pit lake, identify the watersheds, the watershed components, and the end pit lake. Define the landscape performance objectives for the lake and surrounding area. For the region, identify the location, conceptual designs, and timing for each end pit lake. Define the regional performance objectives with respect to an end pit lake district.
2. Establish governance	Establish institutional governance for the end pit lake district. Charter: determine who is ultimately responsible for what. Governance needs to be transparent and explicit. Define a system to review any potential decisions or design changes that may be made. For adaptive management to be successful, all parties involved need to be rigorous and scrupulous. Establish a data management system/repository. An Independent review board can provide technical governance through review throughout the course of the project. Adjust the regulatory framework as needed to allow adaptive management to flourish. Continue to learn, subject to continuous improvement. Actively scan and monitor EPL developments (and lake research outside the oil sands). Fund research into natural lake processes in the region and monitor the performance of select lakes in the region. Enhance understanding of the performance of reclaimed landscapes in the region, especially as it relates to end pit lake design and performance.

Steps	Description and comments
3. Design the lake and its monitoring plan	A regional closure plan that includes all lakes in the lake district is required to be designed, and updated on an annual basis with new lease plans, schedules, and learnings from design, construction, operation, and monitoring of end pit lakes. For each end pit lake and its watershed, create a closure plan and update this plan as new information becomes available. The level of detail in these closure plans is higher than historically provided in the mining and oil sands industries. Each landform in the watershed and the end pit lake need to go through a formal iterative landform design process. This guide provides the methods. Using this base case design, perform a failure modes and effect analysis (or similar) and identify potential failures as well as areas for improvement in the design. Revise the design. Have a well-developed contingency for each failure mode. Design the monitoring program to provide advance warning of failure modes, and to better understand the lake and ecosystem processes. Keep track of all activities and performance and plans in the watershed.
4. Implement the design (construct the lake)	Follow the plan as per the design. Create communication pathways so that all parties are involved and up to date. Document any changes that have occurred to the design during implementation. Install instruments and sampling stations. Be mindful of the inter-connectedness of environmental systems. One change can have an effect of multiple elements. Prior to implementation of selected design, have a contingency plan in place to reduce the potential of failure.
5. Monitor and observe performance	Monitor for compliance, effectiveness, model validation, and understanding. Adjust monitoring program as needed using continuous improvement. Ensure good data management. Continue research and development monitoring system, methods and tools.
6. Assess and evaluate the performance of the design against the objectives	Evaluate outcomes to what was anticipated during design. Determine where short-comings or design deficiencies exist. Determine what key factors play what role in the system. Identify any changes to the design or strategies to move forward. Determine whether objectives are being met and if not, identify potential design changes to meet the objectives. Communicate results to all parties involved, such as stakeholders, management teams, designers, and researchers. Due to project duration, the project goals and requirements may change with time. Determine if overarching goals or objectives need to be redefined throughout the course of the project.
7. Revise design/operation (cycle back)	Design and evaluate changes or adjustments that will enable objectives to be met. Implement change to meet objectives. Cycle back when there is new information, annually, and on a five-year basis.

9.7.2 Requirements for Adaptive Management for EPLs

Building on the long and storied history of adaptive management, paying attention to the criticisms, and looking at the specific needs of the oil sands end pit lakes, the following are offered as requirements of the system:

- Explicit recognition and acceptance that the performance of each end pit lake will be different, is uncertain, will change with time, and that the objectives may also need to change with time.
- Embrace continuous learning for all participants, but also recognize when an endpoint is reached and one could signoff (certify) on each lake as complete.
- Application of the program to individual EPLs (and their watersheds) and to the region comprised of the 30 EPLs (and the regional watersheds).
- Broad participation by proponents, regulators, and stakeholders with joint decision making.
- Full and open sharing of design, model, and performance information on an annual basis, with a good filing system accessible to all.
- A formal technology transfer program.
- Strong leadership and an organization to coordinate.
- Ability to change and adapt itself over a century or longer.
- Well-funded organization and well-conducted monitoring programs that are no more complex than necessary.

9.7.3 Risk Assessment and Failure Modes

An ability to check the design robustness and to embed an adequate level of risk management are essential elements of a responsible EPL plan. Failure Mode and Effects Analysis (FMEA) is a technique that provides a systematic manner of identifying the potential failure modes and hazards in a particular design and assessing the potential consequences should such events occur. The results of the FMEA can be used to include measures in the design that reduce the risk by reducing the likelihood of occurrence of selected failure modes and/or by reducing the consequences of such failures. It is also relevant, especially in the context of adopting the observational method, to assess the ability to proactively detect each of the critical failure modes identified in the FMEA. This assessment can be used to produce a “ductile” design — a design that eliminates or significantly reduces potential failure modes that cannot be easily or reliably detected or that cannot be detected sufficiently early for effective mitigation.

In support of Step 3, Table 9-5 provides a list of potential failure modes, management interventions, and monitoring opportunities. The list is far from exhaustive (McKenna, 2002), but helps establish contingencies *a priori* and develop a suitable monitoring program.

Table 9-5: Examples of failure modes and potential management interventions.

Type	Failure mode	Causes or triggers	Potential effects	Potential interventions	Post-reclamation monitoring
Geotechnical (physical instability)	Outlet failure, erosion and downcutting	Blockage, erosion and downcutting, fluctuating water levels	Outburst flooding, loss of contents or littoral zone, exposure of tailings substrates	Maintain or repair outlet, redesign and reconstruct outlet	Visual inspection of outlet Water level monitoring
	Landslide	Failure of slopes into reservoir, failure of containment dykes, submarine (substrate) slumping	Tsunami, loss of contents, heave of substrate into water column, suspended sediment, change of lake geometry and dynamics, loss of riparian zone	Maintain to avoid failure, repair after failure	Geotechnical monitoring of slopes (using visual and geotechnical instrumentation)
	Soft littoral zone trapping people, wildlife	Substrates too soft	Injury or death	Replacement or capping of substrate	Visual inspection
Surface water and chemical	Shoreline instability	Shoreline erosion by waves, slumping	Landslides, suspended sediments, loss of recreational facilities	Monitor and construct shoreline erosion protection berms, islands, land use controls	Visual inspection, remote sensing
	Insufficient inflow to sustain water, evapo-concentration	Error in water balance, diverted or lost inflow streams, climate change	Poor water quality, low water levels, lack of water for downstream ecosystem	Pump in fresh water, reconfigure watershed geometry, reduce lake size, reduce groundwater losses	Water level monitoring Water quality monitoring
	Excessive water level fluctuation	Poor outlet/ lake design, periodic blockage of outlet, error in water balance	Poor littoral zone performance, poor ecological performance	Redesign outlet, reconfigure watershed/ lake	Water level monitoring
	Widespread meromixis and periodic overturning		Reduced bio-degradation lakes, periodic fish kills, odours, unwanted ecosystem	Reconfigure inlet/outlet and lake, conduct managed pumping, artificial	Water quality sampling, continuously monitoring water quality sensors at numerous lake locations

Type	Failure mode	Causes or triggers	Potential effects	Potential interventions	Post-reclamation monitoring
			function, methyl mercury production	mixing of lake from time to time	
	Lake waters too saline	Poor net inflow quality or quantity, saline groundwater inflows, leaching from substrates and shoreline, consolidation waters from tailings substrates	Unacceptable water quality for discharge, failure to support desired lake ecosystem	Change input water quality, cap poor substrates, control groundwater, reconfigure watershed, treat water in lake or at inlet or at outlet	Water quality sampling, continuously monitoring water quality sensors at numerous lake locations, biological monitoring, monitor tailings consolidation
	Naphthenic acid concentrations too high in lake	Poor net inflow quality, slow degradation of naphthenic acids, insufficient residence time	Impact on ecosystems, benthic organisms, and fish health	Change input water quality, cap poor substrates, control groundwater, reconfigure watershed, treat water in lake or at inlet or at outlet	Water quality sampling, biological monitoring
	Nutrients levels too high in lake	Poor inflow water quality, accumulation of nutrients	Impact on ecosystems, fish health	Change input water quality, cap poor substrates, control groundwater, reconfigure watershed, treat water in lake or at inlet or at outlet	Water quality sampling, visual monitoring, biological monitoring
	Excessive substrate gas production (methane, carbon dioxide, hydrogen sulphide)	Substrate biogeophysical characteristics	Impact on fish and ecosystem	Water treatment in lake, amend substrates	Visual monitoring, gas sampling
	Groundwater contamination from lake water	Flows through pervious substrates	Downstream impacts	Pumping, cutoff walls and blankets	Sampling from wells

Type	Failure mode	Causes or triggers	Potential effects	Potential interventions	Post-reclamation monitoring
Ecological/ land use	Poor littoral vegetation performance	Poor water quality, wave action, fluctuating water levels, poor substrate, presence of noxious vegetation	Low lake productivity, ecosystem impacts, shoreline erosion	Redesign littoral zone, substrates, vegetation.	Biological monitoring
	Introduction of unwanted fish/biota	Natural or artificial introductions	Changed ecosystems, failure to meet desired end land uses	Regulatory controls, harvesting	Biological monitoring
	Overfishing	Lack of regulatory control	Failure to meet desired land uses, shifts in lake ecology	Regulatory controls	Biological monitoring
	Acute or chronic toxicity to aquatic or terrestrial organisms	Salinity, naphthenic acids concentrations too high	Illness, injury, death, lack of fully functioning ecological community	Revised design, water treatment	Biological monitoring
	Human drowning	Diving into shallow water from cliffs	Death or injury	Avoid cliffs in EPL design	
Management	Governance failure: lake not built to design, insufficient monitoring, insufficient operational management, inconsistent water treatment	Lack of time, care, budget	Many of the failure modes listed above	Management or regulatory intervention, monitoring and maintenance of management	Annual reporting

9.8 Conclusion

No EPL will exist in isolation. Each will evolve from within an active mining site, interact with the surrounding landscape while under construction, and eventually play an important ecological role in local and regional watersheds. At each stage of an EPL project, there are numerous factors that must be taken into account and a long list of experts must be involved in the construction and management process. It will be a genuinely multi-disciplinary team effort. The common objective is the reclamation of the natural boreal forest in the form of a water quantity and quality management structure that functions as a sustainable ecosystem.

The team needs to incorporate numerous elements into each EPL, depending on both the local geography and desired end use of the lake. Some will have multiple inlets and outlets that require complex geometry, others will be relatively simple in design. The presence or absence of tailings and the nature of the process-affected water to be stored and treated within the EPL will determine the parameters that must be monitored and managed for decades before the certification stage.

To ensure each EPL remains on a trajectory to successful certification, numerical modelling at each stage of the project and good monitoring throughout will be essential, as will Failure Mode and Effective Analysis techniques and an adaptive management program. There remains a long list of uncertainties associated with the use of the EPL as an oil sands reclamation tool, from climate change to stakeholder expectations. But if each of these tools are used in a systematic approach, it should be possible to maximize the chances of realizing the objectives set forth in this guide.

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END PIT LAKES GUIDANCE DOCUMENT APPENDICES

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A. APPENDIX A: A VIRTUAL END PIT LAKE

A.1 Introduction

As part of the development of this technical guidance document, the Cumulative Environmental Management Association commissioned the creation of a virtual mine with a Virtual End Pit Lake (VEPL) model. It helps explain how EPLs are designed and created, with a focus on the overall mining process and the input factors that have an effect on the EPL. The intention is to show that there are many factors that can affect the EPL, such as fines content of the ore body.

What follows provides a basis and summary of a “base case” virtual mine design along with results for several scenarios in which parameters for the virtual mine or EPL have been varied. The accompanying illustrations were designed not only to provide additional supplementary information, but also to be a stand-alone representation of the VEPL and associated watershed components.

The concept of a virtual oil sands mine originated in the mid-1990s, when Golder Associates and Suncor Energy jointly developed a document[1] that included every kind of landform proposed in oil sands closure landscapes, with relevant biogeochemical and mining information. This document is not currently available. More recently, Dave Devenny[2] considered a “generic” oil sands project producing 100,000 barrels per day (bpd) of synthetic crude oil in a tailings technology screening assessment. In 2010, BGC Engineering prepared a draft VEPL for CEMA, but without explicit description of the mine and landscape around the lake. The EPL presented in this document has essentially the same physical characteristics as the earlier version, but with explicit watershed, mine, and mining landforms.

In crafting the Virtual Oil Sands Mine, the following strategy was adopted:

- The mine is generic: the mine and the elements differ from existing and proposed facilities in the region, but share some general similarities.
- There is one of each of the major landforms commonly found or planned for oil sands mines – one overburden storage area, one external tailings facility, one

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[1] Oil Sands Reclamation Research Network, University of Alberta. Virtual Oil Sands Mine. Online posting. http://www.osern.rr.ualberta.ca/vmintro.htm

[2] Devenny, D W. 2010. A Screening Study of Oil Sand Tailings Technologies and Practices, Rev 1. Consultants report prepared for Alberta Energy Research Institute, March 2010. 43p

soft tailings deposit, one EPL, and one plant site. Most mines will have several or many of these elements.

- The mine has a nominal production rate of 100,000 bpd and a 1:1 strip ratio (thickness of overburden to thickness of ore).
- The geology of the mine fits the regional geology. In the case of the Virtual Oil Sands Mine, there is some Clearwater Formation which is commonly found in about half of the mines.
- The mine has a 90-square-kilometer watershed, much of which is relatively undisturbed. Some mines have much smaller watersheds, a key difference for EPL designs.
- The mine is nominally set on some actual topography in the Fort McMurray region – a shallow eastward sloping area between two incised creeks. The geology chosen for the Virtual Oil Sands Mine does not correspond to actual conditions at this location but is similar to that of mines in the region. Mines east of the Athabasca typically have lower average strip ratios and lack Clearwater Formation – two key differences.
- The mine has a realistic mass and volumetric balance – all the fines in the orebody are accounted for in tailings, the landform sizes correspond to the tonnages mined, and the mine schedule corresponds to a 100,000-bpd operation operating for about 10 years. This production rate is adapted from Devenny (2010).
- The EPL is similar in size and stratigraphy to those proposed in the region as described in more detail below.

In short, this document attempts to provide a simple but realistic setting for a VEPL and the supporting reclaimed and natural watershed that captures the major elements of oil sands mining in the Fort McMurray region. There may be opportunities to use this virtual mine for other CEMA activities.

A.2 Design Components

Figures A-1 through A-4 provide plan and sectional views of the Virtual Oil Sands Mine and VEPL. The initial design parameters for the VEPL considered the range of characteristics for currently planned EPLs from the CEMA 2007 Review Document and as such, the VEPL dimensions are close to the median values reported for EPLs planned for the region.

Table A-1: Summary of Virtual End Pit Lake design (VEPL) parameters.

Design Parameters	Units	VEPL Values	Planned EPLs[1]		
			Minimum	Median	Maximum
Length	km	3			
Width	km	1.5			
Surface area	km^2	4.5	0.6	3.7	13
Watershed area	km^2	90			
Initial water depth	m	25	6	27	55
Initial tailings depth	m	25			
Minimum freeboard height	m	10			
Volumes					
Water	Mm^3	112.5	4.3	115	427
Tailings		112.5	0	70-100	400
Time to fill	years	8	1	8.2	20
Residence time	years	10.9	1.1	21	155
Initial lake salinity	ppm	190	114	190	808
Salinity of inflow	ppm	200	110	200	527
Freshwater inflow rate	Mm^3/yr	10.4	0.5	13	53

Note 1: Values from Table 2.1 (CEMA 2007)

The Virtual Oil Sands Mine is designed to place the VEPL within an actual watershed and provide a conceptual mine plan that is volumetrically and mass balanced. Tables A-2 and A-3 provide a summary of the Virtual Oil Sands Mine design details.

Design components of the Virtual Oil Sands Mine include:

- Plant site and production details.
- Mining details including the life cycle of the mine and production.
- Properties of the ore, overburden and tailings, specifically Mature Fine Tailings (MFT), Thickened Tailings (TT), and tailings sand.
- Storage requirements.
- Storage volumes for In-Pit, External Tailings Facility (ETF), overburden.
- Reclamation material balance.

Table A-2: Summary of planning assumptions and factors.

Design Assumption	Units	Values	Description/ Comment
Volume of synthetic crude oil to volume of oil sand ore	$bbls/m^3$	1	
Density of oil sands ore	kg/m^3	2,100	See Dusseault, M. B., and N. R. Morgenstern (1979), Locked sands, *Quarterly Journal of Engineering Geology* 12: 117-131.
Orebody thickness	m	30	
Strip ratio (thickness of overburden and interburden to thickness of ore)	–	1:1	Interburden is assumed to be part of strip ratio. Similar to that assumed by Devenny (2010).
Orebody fines content (<44 micron)	%	22	See Fine Tailings Fundamentals Consortium, and Alberta Energy (1995), *Advances in oil sands tailings research*, 104 pp., Alberta Department of Energy, Edmonton. MFT density equivalent to 30% solids (most oil sands ponds now have MFT at higher densities)
Average ore grade (mass of bitumen to total mass of ore)	%	8	
MFT fines content (mass of dry fines to mass of dry solids)	%	85	
MFT density (wet density)	kg/m^3	1228	
Percentage of fines in ore that report to MFT	%	25	Similar to that assumed by Devenny (2010).
Specific gravity of tailings solids	-	2.62	
TT fines content	%	40	
TT density (wet density)	kg/m^3	1448	Equivalent to 50% solids
Overburden swell factor	%	10	

Note: Many of these factors are slightly simplified from those used for commercial operations

Table A-3: Summary of Virtual Oil Sands Mine and End Pit Lake (VEPL) design parameters.

	Design Parameters	Values	Comment
General	Plant site area, hectares (ha)	100	Typical for 100,000 bpd
	Production rate, barrels per day (bpd)	100,000	Common size
Ore	Conversion from cubic meters of oil sands to barrel of synthetic crude oil	1	Typical range is 0.8 to 1.1. Assumes no dilution, 100% recovery, full bitumen to SCO conversion.
	Ore mining rate, ore, m^3/day	100,000	Calculated
	Ore mining rate, ore tpd	210,000	Calculated
	Total thickness of ore, m	30	Excludes interburden
Overburden	Strip ratio	1:1	Common in region
	Overburden thickness, m	30	Calculated

	Design Parameters	Values	Comment
	Overburden mining rate, m^3/day	100,000	Calculated
	Reclamation material thickness salvage, m	2.0	Stockpiles are depleted at closure and are not shown.
	Total mined, m^3/day	200,000	Calculated
	Area mined per day, ha	0.33	Calculated
Life of mine	Active mine life (ore mining), years	9.8	Calculated
	Total volume of ore mined, Mm^3	358.8	Calculated
	Total mass of ore mined, MT	753.4	*Calculated.* Includes solids, water, bitumen.
	Dry mass of sand (>44 micron) in ore mined, MT	499.5	*Calculated.* Oil sands planning assumes that all materials >44-micron diameter on the wet sieve is sand, all material <44-micron is fines. A unique set of definitions.
	Dry mass of fines (<44 micron) in ore mined, MT	140.9	Calculated
	Total volume of overburden mined, Mm^3	358.8	Calculated
	Total mined volume, Mm^3	717.6	Calculated
	Mined out area, ha	1196	Calculated (12.0 km^2)
EPL	Initial depth of water, m	25	Based on average conditions for planned EPLs in region
	Initial depth of tailings, m	25	
	Initial volume of water, Mm^3	112.5	Calculated
	Initial volume of tailings, Mm^3	112.5	Calculated
	EPL Footprint (including littoral zone), ha	450	
Soft tailings storage area	Average sand cap thickness, m	5.0	Common design cap
	Sand cap volume, Mm^3	37.3	Calculated
	Soft tailings initial volume, Mm^3	265.6	Calculated
	Soft tailings footprint, ha	750	
External tailings facility	Average height, m	50	
	Tailings sand storage volume, Mm^3	245	Calculated
	ETF footprint area, ha	850	Calculated (8.5 km^2)
Overburden storage area	Overburden storage volume, Mm^3	340.8	*Calculated.*Some overburden / interburden used for in pit dyke storage
	Average height, m	30	
	Overburden footprint area, ha	1315	*Calculated* (13.2 km^2)
	Length of new permanently flowing creeks,	42	26.3 km on original

	Design Parameters	Values	Comment
Reclamation	km	42	ground, 16.2 km on landform. Does not include ephemeral creeks
	Total disturbed area, ha	3300	Includes 100m buffer around all landforms
	Upland area, ha, %	2100 / 64	
	Wetland area, ha, %	832 / 25	
	Lake area, ha, % (excluding littoral zone)	365 / 11	Littoral zone counted as open water wetland
	Total reclamation material volume, Mm^3	20.3	1.2 m thickness on overburden, 0.5m thickness on tailings sand, 0.2m thickness in wetlands and buffer zones
Reclamation	Total number of trees and shrubs (M stems/ha)	5.2	2000 stems per hectare trees and 500 stems per hectare shrubs in upland area.
Abbreviations	Mm^3 = million cubic metres MT = million tonnes ha = hectare. One hectare (ha) is 10,000 m^2.One hundred hectares is a square kilometer. It is perhaps easiest to visualize a hectare as a 100 m x 100 m area, or consider that one hectare is the same size as 1.23 CFL football fields (or 1.67 if one does not include the end zones). One hectare is 2.47 acres. tpd = tonnes per day bpd = barrels per day (in this case of synthetic crude oil) SCO = synthetic crude oil		

A.3 EPL Sensitivity Analysis

To observe the sensitivity of the effects on the EPL with respect to changes to input parameters and EPL dimensions, several scenarios were modelled. The primary focus was to determine how various changes would affect the MFT and water cap thicknesses, which are each 25m in the base case.

Scenario descriptions with the corresponding resultants are shown below in Table A-4.

Table A-4: Sensitivity scenario descriptions and resultant effects to EPL.

Scenario	Description	Resultant Effect	Resulting MFT Volume (Mm^3)	MFT Thickness (m)	Water Cap Thickness (m)
Base case	As above (22% fines, 1500 m wide, 3000 m long, TT is 40% fines)	n/a	112.5	25.0	25.0
1	Ore has a fines content of 28% (6 percentage points higher than base case)	Assume 25% of all fines in the orebody report as MFT to EPL, ultimately increasing required MFT storage volume.	143.2	31.8	18.2
2a	EPL is 1,250 m wide (a reduction of width of 250m).	MFT volume remains the same as base case (112.5 Mm^3); EPL is more narrow which results in a thicker MFT deposit and thinner water cap.	112.5	30.0	20.0
2b	EPL is 2,500 m long (a reduction of length of 500m).	MFT volume remains the same as base case (112.5 Mm^3); EPL is shorter which results in a thicker MFT deposit and thinner water cap.	112.5	30.0	20.0
3	TT has a fines content of 30% (a reduction in fines capture of 10 percentage points).	Reductions in fines capture of TT results in higher fines tonnages reporting to MFT in EPL.	173.9	38.6	11.4
4a	MFT has a fines content of 75% (a reduction in fines content of 10 percentage points).	The fines content per cubic metre of MFT will be reduced, requiring a greater volume of MFT to store the fines from the orebody.	127.5	28.3	21.7
4b	MFT has a fines content of 95% (an increase in fines content of 10 percentage points).	The fines content per cubic metre of MFT will be increased, requiring a lower volume of MFT to store the fines from the orebody.	100.7	22.4	27.6

Scenario	Description	Resultant Effect	Resulting MFT Volume (Mm^3)	MFT Thickness (m)	Water Cap Thickness (m)
5a	MFT has a solids content of 25% (a reduction of five percentage points).	The solids content per cubic metre of MFT will be reduced, requiring a greater volume of MFT to store the fines from the orebody.	140.1	31.1	18.9
5b	MFT has a solids content of 40% (an increase of 10 percentage points).	The solids content per cubic metre of MFT will be increased, requiring a lower volume of MFT to store the fines from the orebody.	87.6	19.5	30.5
6	Watershed area is reduced to 80 km^2 (a reduction of 10 km^2).	A reduction in watershed area will reduce the annual volume of inflow into the EPL.	112.5	Scenario 6 residence time of 12.3 years. Residence time for base case is 10.9 years.	

Through the sensitivity analysis, the following may be noted:

- The design is able to accommodate fairly major changes to the orebody fines content.
- The EPL MFT storage volume is sensitive to the fines capture of the TT. Relatively small changes in TT fines content creates a significant additional volume of MFT.
- Changes to the fines and solids content have a minor impact on the volume of MFT produced, but can have a significant impact on the compressibility and permeability parameters that are related to the consolidation process.
- Lower solids and fines contents consolidate much more rapidly, which results in more rapid settlement of the MFT mudline and increases the rate of consolidation water release. In particular, this is most evident in the first 20 years of the EPL.
- The watershed area has a minor affect on residence time. Relatively large decreases in watershed area have a minor impact on the residence time, considering the time scale for EPLs and consolidation of MFT.

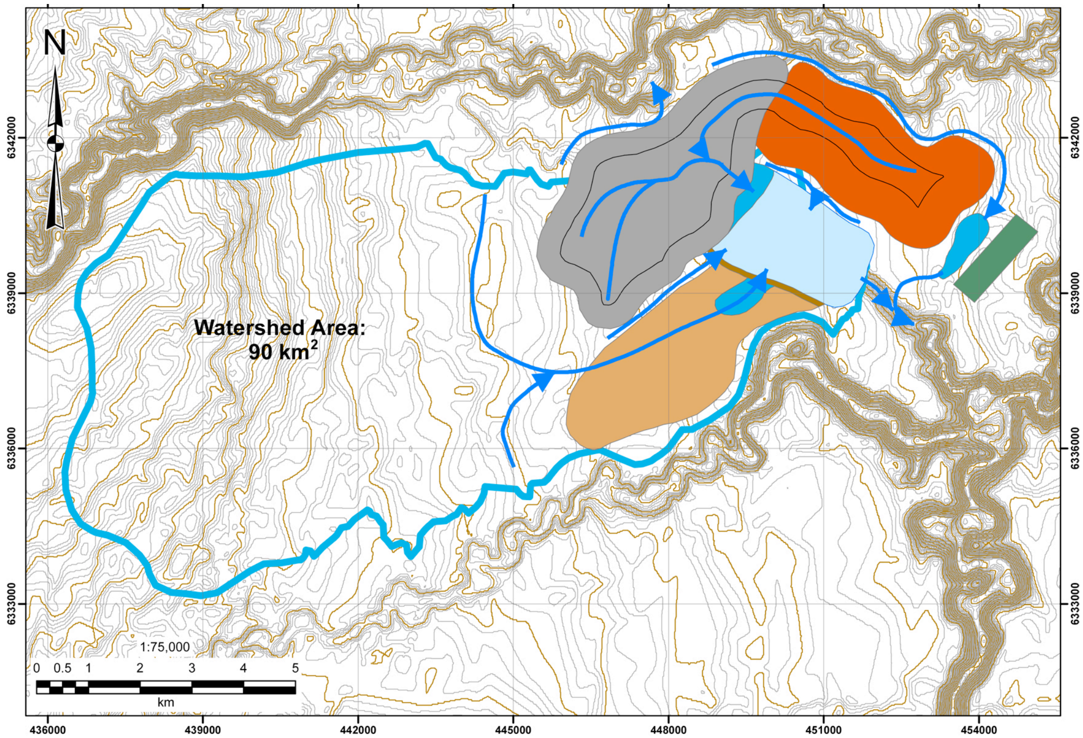

Figure A-1: VEPL watershed plan view.

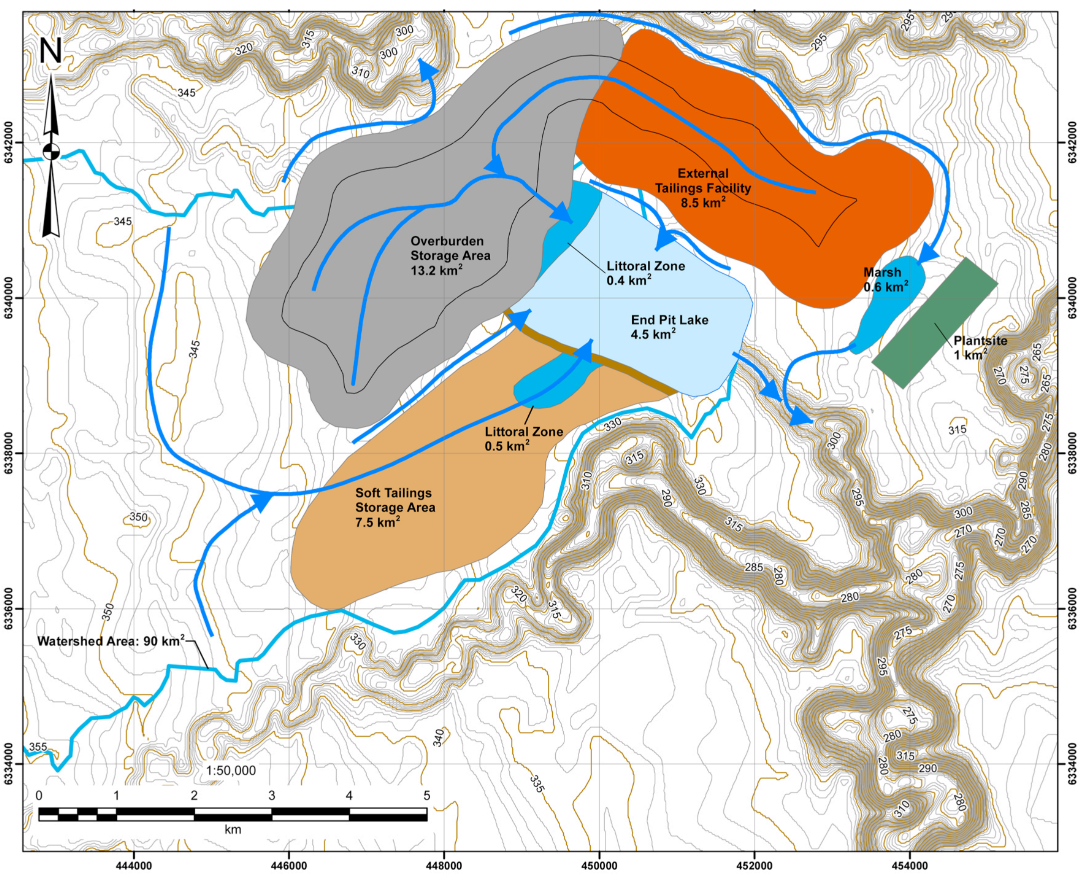

Figure A-2. VEPL mine site plan view.

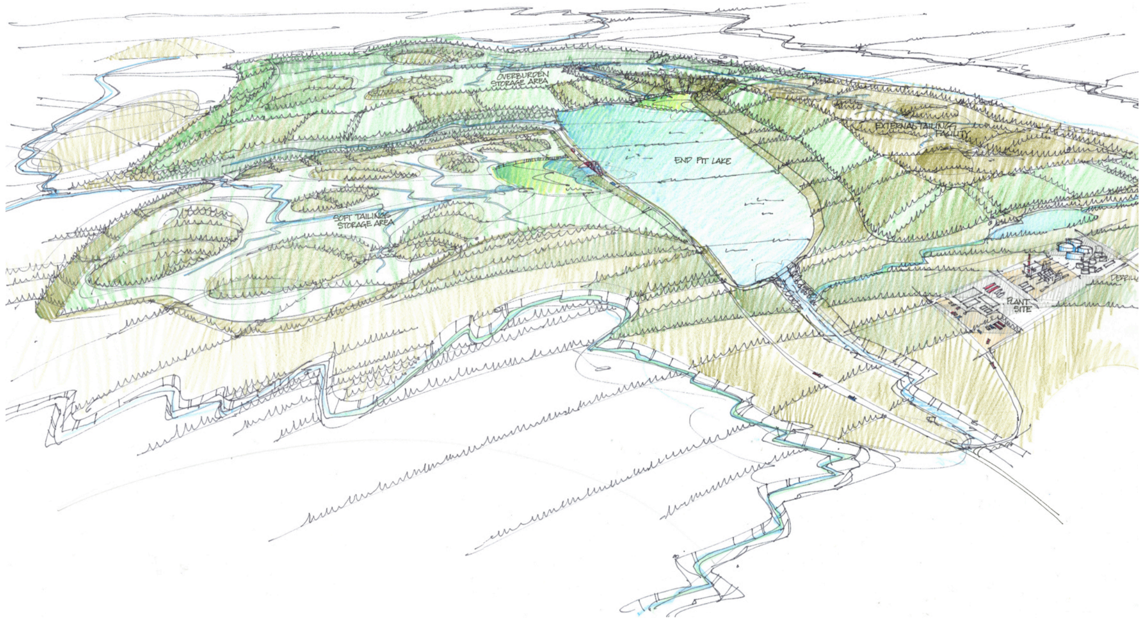

Figure A-3: VEPL oblique view.

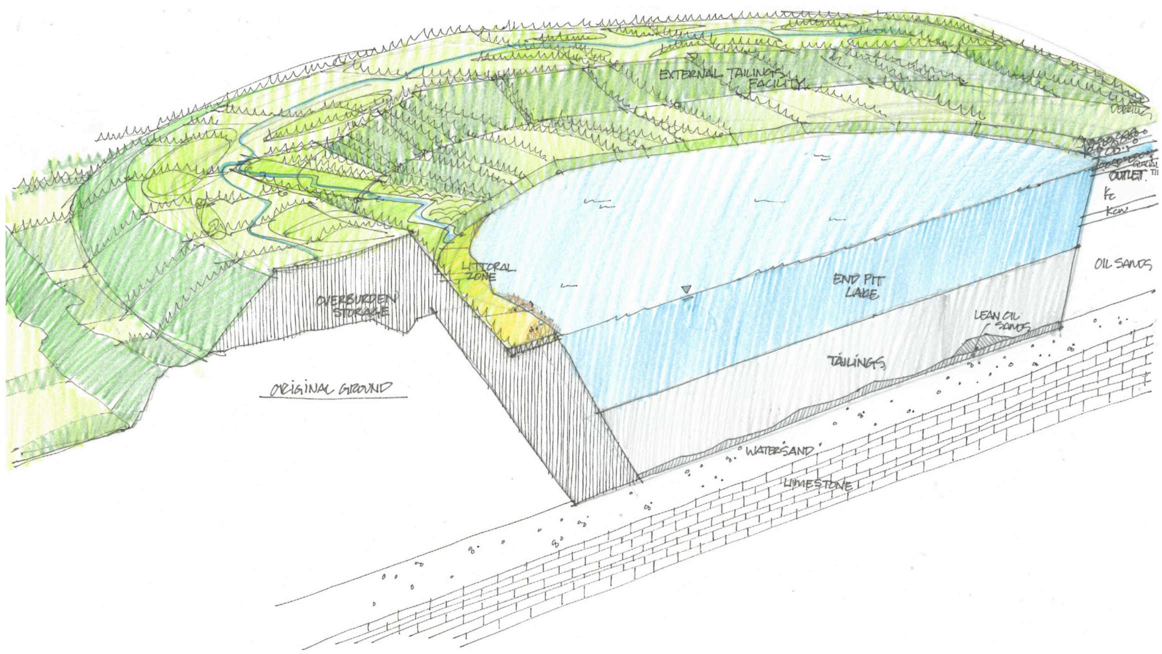

Figure A-4: VEPL cross-section view.

B. APPENDIX B: TABLES

Table B-1: Select publications that provide observations from non-oil sands EPLs. See Section 3-2.

Category	Mine	EPL Location	Reference
Physical Limnology	Gunnar	Saskatchewan, Canada	Tones, 1982
	Multiple	Nevada, USA	Atkins et al., 1997
	Multiple	Saskatchewan, Canada	Doyle and Runnells, 1997
	Brenda	British Columbia, Canada	Stevens and Lawrence, 1998
	Brenda	British Columbia, Canada	Hamblin et al., 1999
	Sleeper	Nevada, USA	Atkin and Schrand, 2000
	Island Copper Berkeley	British Columbia, Canada Montana, USA	Fisher and Lawrence, 2000 Jonas, 2000
	Enterprise	Northern Territory, Australia	Boland and Padovan, 2002
	Yerington	Nevada, USA	Jewell and Castendyk, 2002
	Goitsche	Central Germany	Boehrer et al., 2003
	Lake 111	Lusatian, Germany	Karakas et al., 2003
	Summer Camp	Nevada, USA	Parshley and Bowell, 2003
	East Sullivan	Quebec, Canada	Tassé, 2003
	Island Copper	British Columbia, Canada	Stevens and Fisher, 2005
Geochemistry	Berkeley	Montana, USA	Davis and Ashenberg, 1989
	Multiple	Nevada, USA	Price et al., 1995
	Multiple	USA	Miller et al., 1996
	Multiple	USA	Davis and Eary, 1997
	Multiple	Germany	Klapper, H., Schultze, M., 1997
	Berkeley	Montana, USA	Robins et al., 1997
	Multiple	Nevada, USA	Shevenell, et al., 1999
	Harvard	California, USA	Savage et al., 2000
	Multiple	Nevada, USA	Shevenell, 2000
	Multiple	Nevada, USA	Shevenell and Conners, 2000
	Multiple	Global	Bowell, 2002
	Berkeley	Montana, USA	Madison et al., 2003
	Summer Camp Berkeley	Nevada, USA Montana, USA	Bowell and Parshley, 2005 Pellicori et al., 2005
	Multiple	Germany	Schultze et al., 2010
Combined Physical Limnology and Geochemistry	Spenceville	California, USA	Levy, 1997
	Multiple	Utah, USA	Castendyk and Jewell, 2002
	Udden	Northern Sweden	Ramstedt et al., 2003
	Elizabeth	Vermont, USA	Seal et al., 2003
	Berkeley	Montana, USA	Gammons and Duaime, 2006
	Multiple	Slovakia	Otahel'ová and Oťahel', 2006
	Multiple	Spain	Sánchez España et al., 2008
	Collinsville	North Queensland, Australia	McCullough et al., 2008
	Collie	Western Australia, Australia	McCullough et al., 2009
	Multiple	Australia	Kumar et al., 2009

Table B-2: Processes influencing epilimnion water quality of existing non-oil sands EPLs compared to future oil sands EPLs (adapted from Gammons et al., 2009). See Section 3.3.4.

Process	Description	Reference	Relevance
Evapoconcentration	Concentration of all solutes in proportion to water lost to evaporation. May lead to precipitation of gypsum, calcite, and other salts.	Levy et al., 1997; Eary 1998; Shevenell, 2000	Medium
Dilution	Lowering of TDS due to the addition of relatively fresh water from the melting of lake ice, rainfall, or snowmelt.	Wetzel, 2001	Medium
Photosynthesis by algae, bacteria and plants	Increase in primary producer biomass which provides carbon sources for higher food chain organisms. Increases DO and pH.	Ledin and Pederson, 1996; Nixdorf et al., 1998; Kalin et al., 2001	Medium (nutrient levels unknown)
Eutrophication	High productivity rates of primary producers, such as algae, and vascular plants due to high nutrient levels. Blocks sunlight at depth.	Antosch, 1982	Low
Photoreduction	Photoreduction of Fe^{3+} or iron hydroxide to Fe^{2+}. Possible photoreduction of Mn oxides to Mn^{2+}.	Collienne, 1983; Friese et al., 2002	Low
Leaching of soluble salts stored above the water line	Increase in salinity and concentrations of trace metals and metalloids.	Newbrough and Gammons (2002); Maest et al., (2004)	Low
Freezing	Increase in salinity of water during ice formation due to salt exclusion. Dilution of surface water during spring thaw.	Gibson, 1999	High
Acid drainage added from runoff and groundwater	Oxidation of sulfide minerals along flow paths. Lowers pH and increases concentrations of dissolved solids, especially Fe and SO_4.	McLemore, 2008	Low
Oxidation and precipitation of hydrous metal oxides	Decrease in dissolved Fe and Mn concentrations. Increase in turbidity from suspended mineral particles. Possible lowering of pH.	Eary, 1999; Jonas, 2000; Pellicori et al., 2005	Low
Adsorption onto suspended mineral particles or organic matter	Decrease in concentrations of heavy metals and metalloids. Enhanced removal of As, Se, at low pH. Enhanced removal of Cd, Cu, Pb, Zn, (V?) at high pH. Important phosphorus sink.	Eary, 1999; Temple et al., 2000; Kalin et al., 2001	Medium
Dissolution of minerals exposed on submerged wall rocks	Dissolution of carbonate and silicate minerals in wall rocks raises pH. If lake is acidic, may see the conversion of feldspar and other rock-forming minerals into clay.	Eary, 1999; Shevenell et al., 1999; Bowell and Parshley, 2005; McLemore, 2008	Low

Sub-aqueous oxidation of pyrite	O_2 and Fe^{3+} promote pyrite oxidation in submerged wall rocks. Decreases pH and increases dissolved heavy metals and sulfate concentrations.	Madison et al., 2003; Pellicori et al., 2005	Low
Mixing with hypolimnion water	Caused by seasonal turnover. Can increase nutrient concentrations and dissolved CO_2 levels. Homogenizes dissolved solids with depth.	Wetzel, 2001	High
Exchange with atmospheric gases	O_2 dissolves into the lake at increased rates with surface wave action. Surface pH increases as CO_2 bubbles out.	Wetzel, 2001	High
Aerobic respiration of organic carbon	Decrease in concentrations of residual bitumen, naphthenic acid, and PAH's by aerobic respiration of heterotrophic organisms	Hypothetical	Unknown

Table B-3: Processes influencing hypolimnion water quality of existing non-oil sands EPLs compared to future oil sands EPLs (adapted from Gammons et al., 2009) (See Chapter 3). See Section 3.3.4.

Process	Description	Reference	Relevance
Aerobic respiration of organic carbon	Dissolved oxygen is depleted or completely consumed. Possible removal of organic COCs through methanogenesis.	Alvarez-Cobelas, 1990	Medium
Mixing with epilimnion water	Caused by seasonal turnover. Can increase dissolved O_2 levels. Homogenizes dissolved solids with depth.	Wetzel, 2001.	High
Sub-aqueous oxidation of pyrite	O_2 and Fe^{3+} promote pyrite oxidation in submerged wall rocks. Decreases pH and increases dissolved heavy metals and sulfate concentrations.	Madison et al., 2003; Pellicori et al., 2005	Low
Microbial reduction of Fe and Mn oxides	Increase in dissolved Fe^{2+} and Mn^{2+} concentrations. Increase in pH. May increase salinity. May release adsorbed metals and nutrients to the water column such as phosphate and arsenic.	Wendt-Potthoff et al. 2002; Sanchez-España et al., 2007	Low
Microbial reduction of nitrate	Reduction of dissolved nitrate (if present) to N_2 and/or ammonia.	Helmer and Labroue, 1993	Medium (nutrient levels unknown)

Microbial sulfate reduction	Decrease in dissolved sulfate. Increases in hydrogen sulfide (H_2S or HS^-), pH and bicarbonate alkalinity. Drastic decrease in concentrations of metals (e.g. Cd, Cu, Fe, Ni, Zn, V?) that form insoluble metal sulfide precipitates. Possible buildup of H_2S (a poisonous gas) to dangerous levels.	Castro et al., 1999; Lewis et al., 2003; Harrington et al., 2004	Medium (product of sulfate-rich tailings added to the lake)
Methylation of Hg	If present, inorganic Hg may be microbially converted to methyl-Hg, resulting in rapid bio-accumulation in organisms	Wolfe and Norman, 1998; Gray et al., 2003	Unknown
Methanogenesis	May occur in pit lake sediment with a high organic carbon when sulfate is limited. Increase in concentrations of dissolved organic carbon, CH_4 and H_2.	Blodau et al., 1998; Holowenko et al., 2000	Moderate

Table B-4. Range of selected indicator parameter baseline concentrations (CEMA, 2010). See Chapter 4.

Interval	Concentration (mg/L)					
	TDS	Cl	NH_3	As	NAs	Phenols
Surficial sands Min	62	0.25	0.005	0.0001	0.5	0.00005
Max	3,740	1,550	1.96	0.0144	6.6	0.77
Median	380	2	0.18	0.0005	0.5	0.001
Count	127	109	53	72	65	73
Birch channel Min	109	1	0.11	0.0002	0.5	0.0005
Max	1,150	46	1.98	0.0033	1	0.002
Median	690	4	1.39	0.0002	0.5	0.0005
Count	16	16	8	9	15	14
Kearl channel (main) Min	384	2.7	--	0.0016	5	0.0005
Max	1,101	54	--	0.0017	8.6	0.019
Median	529	11	--	0.0017	6.8	0.0045
Count	7	7	--	2	2	6
Kearl channel (upper) Min	399	2.8	--	0.0025	3.7	0.003
Max	399	2.8	--	0.0025	3.7	0.003
Median	399	2.8	--	0.0025	3.7	0.003
Count	1	1	--	1	1	1
Wabiskaw Member Min	1,080	43	18.8	0.0012	3	0.0005
Max	22,400	13,400	19.4	0.0025	4	0.005
Median	22,100	12,800	19.1	0.0019	3	0.0028
Count	4	4	2	2	3	2
Basal McMurray (AMU 1) Min	182	2.6	0.76	0.0002	0.5	0.001
Max	470	53.3	0.76	0.0006	6.3	0.02
Median	453	12	0.76	0.0005	6.1	0.003
Count	12	10	1	7	5	8
Basal McMurray (AMU 2) Min	511	18	0.89	0.0001	3	0.0001
Max	3,973	1540	1.22	0.006	32	0.72

Interval	Concentration (mg/L)					
	TDS	Cl	NH_3	As	NAs	Phenols
Median	2,380	604	1.06	0.002	15	0.002
Count	71	69	2	19	25	30
Basal McMurray (AMU 3) Min	4,351	500	2.1	0.0002	12	0.0005
Max	23,300	13350	9.9	0.01	24	0.09
Median	8,896	3110	6	0.001	15	0.005
Count	39	38	7	13	7	4
Basal McMurray (AMU 4) Min	36,500	21,600	5.6	0.0002	7	0.005
Max	278,340	171,800	23	0.006	7	0.005
Median	52,530	29,600	14.3	0.001	7	0.005
Count	17	16	2	10	1	1
Methy Formation Min	614	107	--	0.005	5	0.005
Max	337,600	43,563	--	0.005	7	0.005
Median	21,872	9,606	--	0.005	6	0.005
Count	12	11	--	3	2	3

Notes: 1. Extremely low values are at or approaching method detection limits and are therefore subject to lower confidence. 2. AMU – aquifer management unit, extending from the top (AMU 1) to bottom (AMU 4) of the Basal McMurray interval.

Table B-5: Stratigraphic column for the Athabasca Oil Sands Region. See Sections 4.2.2.

<table>
<tr><th>Era</th><th colspan="2">Period</th><th>Group</th><th>Formation</th><th>Member</th><th>Lithologic Description</th><th colspan="2">Regional Hydrostratigraphic Units</th></tr>
<tr><td rowspan="2">Cenozoic</td><td colspan="5">Holocene</td><td>Muskeg/organic soils, alluvium</td><td rowspan="10">K to Q</td><td rowspan="3">Quaternary aquifer and aquitard system</td></tr>
<tr><td colspan="5">Pleistocene</td><td>Sand, gravel, silt, clay, till</td></tr>
<tr><td rowspan="8">Mesozoic</td><td colspan="6">Erosional Unconformity (major gap in geologic sequence)</td></tr>
<tr><td rowspan="6">Cretaceous</td><td rowspan="6">Lower</td><td rowspan="6">Manville</td><td colspan="2">Grand Rapids (Kg)</td><td>Lithic sand and sandstone</td><td>Grand Rapids aquifer</td></tr>
<tr><td rowspan="2">Clearwater (Kc)</td><td></td><td>Lower and upper estuarine sand, silt, and clay</td><td>Clearwater aquitard</td></tr>
<tr><td>Wabiskaw (Kcw)</td><td>Glauconitic sandstone</td><td>Wabiskaw aquifer</td></tr>
<tr><td rowspan="3">McMurray (Km)</td><td>Upper</td><td>Marine sand, silt, and clay</td><td rowspan="3">McMurray aquifer/aquitard system</td></tr>
<tr><td>Middle</td><td>Lower and upper estuarine sand, silt, and clay</td></tr>
<tr><td>Lower</td><td>Continental fluvial sand, floodplain and lagoon clay</td></tr>
<tr><td colspan="6">Erosional Unconformity (major gap in geologic sequence)</td><td rowspan="7">Beaverhill Lake aquifer system</td></tr>
<tr><td rowspan="15">Paleozoic</td><td rowspan="14">Devonian</td><td rowspan="5">Upper</td><td rowspan="8">Beaverhill Lake</td><td rowspan="4">Waterways (Dw)</td><td>Moberly</td><td rowspan="4">Alternating sequence of argillaceous limestone, calcareous shale, and clastic limestone</td><td rowspan="5">D2</td></tr>
<tr><td>Christina</td></tr>
<tr><td>Calumet</td></tr>
<tr><td>Firebag</td></tr>
<tr><td colspan="3">Paraconformity</td></tr>
<tr><td rowspan="9">Middle</td><td colspan="2">Slave Point</td><td>Dolomitic Limestone</td><td rowspan="10">D1</td></tr>
<tr><td colspan="3">Paraconformity</td><td rowspan="5">Prairie-Watt Mountain aquiclude system</td></tr>
<tr><td colspan="2">Fort Vermillion</td><td>Anhydrite and dolomite</td></tr>
<tr><td rowspan="6">Elk Point</td><td colspan="2">Watt Mountain</td><td>Shale, siltstone, and anhydrite</td></tr>
<tr><td colspan="2">Muskeg</td><td>Anhydrite and dolomite</td></tr>
<tr><td colspan="2">Prairie Evaporite</td><td>Salt and anhydrite</td></tr>
<tr><td colspan="2">Methy</td><td>Reefal dolomite</td><td rowspan="2">Methy-McClean aquifer-aquitard system</td></tr>
<tr><td colspan="2">McClean River</td><td>Dolomite, claystone and evaporite</td></tr>
<tr><td colspan="2">La Loche</td><td>Claystone and arkosic sandstone</td><td rowspan="2">Basal aquifer</td></tr>
<tr><td colspan="6">Erosional Unconformity (major gap in geologic sequence)</td></tr>
<tr><td>Proterozoic</td><td colspan="5">Precambrian</td><td>Metasedimentary rocks and granite</td><td></td><td>Aquiclude</td></tr>
</table>

Table B-6: Water chemistry for four major tributaries to the Athabasca River. See Section 4.31.

			Muskeg River				Steepbank River				Ells River				Firebag River			
Analyte	**Group**	**Unit**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**
pH	Field measured	pH units	62	6.9	8.6	7.8	17	7.2	8.5	8.0	33	6.8	9.5	7.9	16	6.9	8.1	7.4
Specific Conductance	Field measured	µS/cm	70	190	665	440	18	78	609	250	41	74	350	216	25	138	257	212
Temperature	Field measured	°C	74	< 0.1	20	6.8	19	0.072	18	8.9	44	< 0.185	20	9.9	26	<0.2975	18	7.4
Dissolved Oxygen	Field measured	mg/L	63	4.1	13	9.4	17	4.3	13	10	36	6.8	13	9.8	25	4.1	11	7.2
Dissolved Oxygen (Winkler)	Field measured	mg/L	25	4.2	12	8.9	1	13	13	13	10	8.4	13	11	9	5.0	9.3	6.2
Redox Potential	Field measured	mV	2	280	323	302	0	-	-	-	3	29	317	303	1	195	195	195
Colour	Conventional Parameters	T.C.U.	37	28	120	67	23	17	149	90	36	34	100	50	27	20	80	50
Specific Conductance	Conventional Parameters	µS/cm	72	207	668	368	26	123	677	234	57	146	363	214	26	161	276	220
Dissolved Organic Carbon	Conventional Parameters	mg/L	73	13	27	20	26	9.0	26	16	50	11	24	15	28	4.9	16	8.5
Hardness	Conventional Parameters	mg/L	59	107	350	192	26	58	277	109	47	71	142	95	27	82	138	117
pH	Conventional Parameters	pH units	76	7.3	8.4	7.8	26	7.7	8.5	8.1	58	7.5	8.3	7.9	27	7.4	8.2	7.9
Total Alkalinity	Conventional Parameters	mg/L	76	104	312	197	26	56	341	120	57	64	147	92	27	79	137	112
Total Dissolved Solids	Conventional Parameters	mg/L	63	129	459	248	26	103	395	181	46	86	251	160	25	92	199	160
Total Organic Carbon	Conventional Parameters	mg/L	49	15	30	23	23	9.1	28	20	43	12	22	15	22	5.0	16	12
Total Suspended Solids	Conventional Parameters	mg/L	80	< 1.1	16	3.6	26	< 3	56	4.5	51	< 3	83	5.0	28	< 3	21	4.0
Bicarbonate	Major Ions	mg/L	42	129	382	267	26	68	416	145	36	85	191	119	27	97	167	137

			Muskeg River				Steepbank River				Ells River				Firebag River			
Analyte	Group	Unit	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median
Calcium	Major Ions	mg/L	73	27	108	57	27	15	72	29	56	18	39	25	27	22	37	31
Carbonate	Major Ions	mg/L	28	< 5	4.3	< 2.75	26	< 5	< 0.5	< 5	29	< 5	< 5	< 5	21	< 5	< 5	< 5
Chloride	Major Ions	mg/L	77	1.4	16	4.1	26	0.83	8.3	2.7	58	< 0.575	6.0	2.0	28	1.9	3.7	2.0
Magnesium	Major Ions	mg/L	74	7.2	19	12	26	4.7	24	8.8	57	5.3	12	7.4	27	6.7	11	9.5
Potassium	Major Ions	mg/L	75	0.39	1.9	1.1	26	< 0.3	2.5	0.95	57	0.78	2.3	1.3	27	< 0.5	1.5	0.9
Sodium	Major Ions	mg/L	77	7.4	28	13	26	6.0	49	13	59	5.8	25	11	28	3.0	5.7	4.0
Sulphate	Major Ions	mg/L	73	0.5	67	5.1	26	2.4	16	4.8	59	12	52	18	26	2.0	9.3	4.1
Sulphide	Major Ions	mg/L	43	< 0.01	0.021	< 0.001	23	< 0.003	0.009	0.0052	45	< 0.01	0.014	0.003	25	< 0.003	0.012	0.003
Nitrate + Nitrite	Nutrients and Chlorophyll a	mg/L	76	< 0.1	0.24	0.0055	26	< 0.1	0.48	< 0.05	59	< 0.1	0.42	< 0.05	28	< 0.1	0.2	< 0.1
Nitrogen - Ammonia	Nutrients and Chlorophyll a	mg/L	26	< 0.05	0.29	< 0.015	26	< 0.05	0.06	< 0.05	34	< 0.05	0.07	< 0.05	26	< 0.05	0.08	< 0.05
Nitrogen - Kjeldahl	Nutrients and Chlorophyll a	mg/L	61	0.44	1.6	0.87	23	< 0.15	1.6	0.6	48	0.4	1.5	0.6	28	< 0.06	1.2	0.4
Phosphorus, total	Nutrients and Chlorophyll a	mg/L	71	0.007	0.17	0.027	26	0.013	0.11	0.041	58	0.014	0.27	0.035	28	0.03	0.075	0.049
Phosphorus, dissolved	Nutrients and Chlorophyll a	mg/L	38	0.004	0.021	0.012	24	0.005	0.03	0.017	37	0.0068	0.03	0.014	28	0.015	0.042	0.027
Chlorophyll a	Nutrients and Chlorophyll a	µg/L	29	< 1	5.0	< 1	13	< 1	5.8	< 1	14	< 1	7.9	1.0	13	< 1	9.4	1.0
Biochemical Oxygen Demand	Biological Oxygen Demand	mg/L	49	< 2	3.0	0.9	23	< 2	5.0	< 2	35	< 2	3.0	< 2	27	< 2	3.0	< 0.1
Naphthenic acids	General Organics	mg/L	16	< 1	1.0	< 1	26	< 1	2.0	< 1	28	< 1	1.0	< 1	19	< 1	1.1	< 1
Total Phenolics	General Organics	mg/L	60	<0.001	0.011	0.004	25	< 0.001	0.0088	0.002	56	< 0.001	0.01	0.0025	27	< 0.001	0.0064	0.001
Total Recoverable Hydrocarbons	General Organics	mg/L	46	< 1	2.9	0.1	26	< 1	2.6	< 0.5	42	< 1	2.5	< 0.5	20	< 1	< 0.5	< 0.5

			Muskeg River				Steepbank River				Ells River				Firebag River			
Analyte	**Group**	**Unit**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**	**N**	**5th %ile**	**95th %ile**	**Median**
Aluminum	Total Metals	mg/L	30	0.016	0.24	0.054	26	0.033	1.6	0.11	29	0.052	2.8	0.28	21	0.02	0.4	0.1
Antimony	Total Metals	mg/L	23	<0.0008	0.0005	0.000023	23	< 0.0008	0.00079	0.000017	25	< 0.00072	0.00078	0.00007	17	< 0.000004	0.00012	0.000013
Arsenic	Total Metals	mg/L	37	< 0.001	0.00052	0.00022	26	< 0.001	0.00083	0.00047	36	< 0.001	0.0017	0.00089	27	< 0.00067	0.00051	0.00034
Barium	Total Metals	mg/L	37	0.029	0.095	0.05	26	0.027	0.11	0.038	36	0.031	0.088	0.039	26	0.025	0.036	0.029
Beryllium	Total Metals	mg/L	30	< 0.001	0.0012	< 0.00004	26	< 0.001	0.00019	< 0.001	29	< 0.001	0.00029	< 0.000003	21	< 0.001	0.0003	0.0000043
Boron	Total Metals	mg/L	29	0.033	0.072	0.048	26	0.031	0.35	0.086	28	0.042	0.16	0.064	20	0.012	0.022	0.017
Cadmium	Total Metals	mg/L	20	< 0.000029	0.0006	< 0.000008	10	< 1.55E-05	0.000012	< 0.000006	19	< 0.00002	0.00043	0.0000091	18	< 0.000047	0.000094	0.00000052
Calcium	Total Metals	mg/L	25	35	111	52	23	17	69	31	28	19	35	25	20	23	34	28
Chromium	Total Metals	mg/L	36	< 0.00085	0.0043	0.00036	26	< 0.0008	0.007	0.00045	36	< 0.001	0.004	0.00079	27	< 0.00094	0.002	0.00032
Cobalt	Total Metals	mg/L	35	< 0.00065	0.0011	0.00012	26	< 0.003	0.0005	0.00011	35	< 0.001	0.0012	0.0002	26	< 0.001	0.0002	0.000071
Copper	Total Metals	mg/L	36	< 0.001	0.0031	0.00034	24	< 0.001	0.0025	0.00051	36	< 0.001	0.0039	0.001	27	< 0.001	0.003	0.0003
Iron	Total Metals	mg/L	37	0.23	1.6	0.69	26	0.43	2.1	0.76	36	0.29	3.2	0.56	27	0.45	1.0	0.65
Lead	Total Metals	mg/L	30	< 0.0001	0.00086	0.000069	23	< 0.0001	0.0012	0.0001	29	0.000087	0.0017	0.00031	20	0.00003	0.00097	0.00014
Lithium	Total Metals	mg/L	29	0.006	0.014	0.0094	26	< 0.006	0.03	0.0088	28	0.011	0.019	0.015	20	< 0.006	0.0061	0.0034
Magnesium	Total Metals	mg/L	9	7.7	18	11	14	5.3	24	9.7	12	5.4	11	7.2	4	7.6	9.9	8.5
Manganese	Total Metals	mg/L	37	0.016	0.45	0.037	26	0.015	0.059	0.025	36	0.0088	0.072	0.025	27	0.021	0.086	0.043
Mercury	Total Metals	mg/L	10	< 3.29E-06	0.00000039	< 1.2E-06	15	< 1.2E-06	0.000018	< 6E-07	24	< 1.2E-06	0.0000064	< 9E-07	20	< 1.2E-06	0.000002	< 1.2E-06
Methyl Mercury	Total Metals	mg/L	0	-	-	-	3	< 4.2E-08	8.4E-08	3.0E-08	3	< 2.4E-08	0.00000012	3.0E-08	0	-	-	-
Molybdenum	Total Metals	mg/L	32	< 0.001	0.00063	0.000089	23	0.00016	0.0006	0.00027	35	< 0.001	0.0015	0.00072	25	< 0.001	0.0018	0.00016
Nickel	Total Metals	mg/L	37	< 0.0006	0.012	0.00026	26	< 0.0002	0.0052	0.00061	36	0.00096	0.0054	0.0021	27	< 0.001	0.002	0.00016
Potassium	Total Metals	mg/L	9	0.54	2.0	1.1	14	0.62	2.2	1.2	12	1.2	2.2	1.4	4	0.6	1.3	0.82
Selenium	Total Metals	mg/L	37	< 0.0008	< 0.0001	< 0.0004	26	< 0.0008	0.00073	< 0.0003	36	< 0.0008	0.00085	< 0.0001	27	< 0.00071	0.00019	< 0.0001
Silver	Total Metals	mg/L	10	< 0.000005	0.0000081	< 2.09E-06	15	< 0.000005	0.000013	< 5E-07	24	< 9.25E-06	0.000046	0.0000044	19	< 0.00001	0.000012	0.00000097
Sodium	Total Metals	mg/L	9	8.4	47	12	14	5.9	51	20	12	6.4	23	12	4	2.6	4.9	3.5

			Muskeg River				Steepbank River				Ells River				Firebag River			
Analyte	Group	Unit	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median
Strontium	Total Metals	mg/L	29	0.079	0.23	0.13	26	0.063	0.33	0.11	28	0.093	0.23	0.13	19	0.051	0.089	0.069
Sulphur	Total Metals	mg/L	6	< 0.3525	2.5	1.2	10	0.93	5.9	1.4	12	3.9	9.5	5.9	12	< 0.6	1.5	0.46
Thallium	Total Metals	mg/L	19	< 0.0001	0.00016	0.000005	16	< 0.0001	0.000011	< 0.000003	25	< 0.0001	0.00009	0.0000073	19	< 0.0001	0.000041	0.0000045
Titanium	Total Metals	mg/L	25	0.0011	0.0035	0.002	26	< 0.0045	0.019	0.0033	26	< 0.003524	0.062	0.0081	20	0.0013	0.0083	0.0039
Uranium	Total Metals	mg/L	25	< 0.0001	0.00032	0.000095	24	< 0.0001	0.00023	0.000089	28	0.00012	0.00039	0.00023	19	< 0.0001	0.00014	0.000051
Vanadium	Total Metals	mg/L	52	< 0.002	0.003	0.00027	26	< 0.0002	0.0055	0.0006	36	< 0.002	0.0086	0.0011	27	< 0.002	0.002	0.00057
Zinc	Total Metals	mg/L	33	< 0.001	0.045	0.002	26	< 0.002899	0.058	0.0075	36	0.0012	0.025	0.0047	27	< 0.000532	0.018	0.0034
Aluminum	Dissolved Metals	mg/L	19	< 0.01	0.03	0.0034	24	< 0.01	0.094	0.014	28	< 0.01	0.079	0.019	20	0.0021	0.021	0.0052
Antimony	Dissolved Metals	mg/L	18	< 0.0008	0.0012	0.000017	24	< 0.0008	0.00097	0.000019	28	< 0.0008	0.0009	0.000058	19	< 0.0008	0.000022	0.00001
Arsenic	Dissolved Metals	mg/L	34	< 0.0004	0.00071	0.0003	24	< 0.0004	0.00073	0.0005	28	0.0004	0.001	0.00075	20	< 0.0004	0.00046	0.0003
Barium	Dissolved Metals	mg/L	19	0.026	0.15	0.033	24	0.017	0.11	0.033	28	0.026	0.048	0.034	19	0.019	0.033	0.024
Beryllium	Dissolved Metals	mg/L	25	< 0.001	0.0000023	< 0.0005	24	< 0.0005	0.00001	< 0.0005	34	< 0.001	0.00011	< 0.00027	25	< 0.001	0.000089	< 0.00001
Boron	Dissolved Metals	mg/L	32	0.032	0.13	0.052	24	0.026	0.33	0.074	28	0.041	0.15	0.065	20	0.013	0.022	0.017
Cadmium	Dissolved Metals	mg/L	19	< 0.0001	0.000022	< 0.00001	24	< 0.0001	0.0001	< 0.00001	28	< 0.0001	0.000075	< 0.000004	19	< 0.0001	0.000015	< 0.000006
Chromium	Dissolved Metals	mg/L	19	< 0.0004	0.00097	0.00014	24	< 0.0004	0.0025	< 0.0003	28	< 0.0004	0.002	0.00018	20	< 0.0004	0.00051	0.00014
Cobalt	Dissolved Metals	mg/L	19	< 0.0001	0.00025	0.000076	24	< 7.75E-05	0.00075	0.0001	28	0.00007	0.00092	0.00014	20	< 0.0001	0.0001	0.00004
Copper	Dissolved Metals	mg/L	19	0.000048	0.0017	0.00043	24	< 0.0006	0.003	0.00039	28	0.00056	0.0027	0.0009	20	< 0.0006	0.00071	0.00019
Iron	Dissolved Metals	mg/L	26	0.059	0.69	0.27	24	< 0.00145	0.66	0.31	26	0.1	0.59	0.23	20	0.15	0.5	0.26
Lead	Dissolved Metals	mg/L	19	< 0.000019	0.0011	0.000064	24	< 0.0001	0.001	0.000055	28	< 0.0001	0.00081	0.000091	19	< 0.0001	0.00012	0.00003
Lithium	Dissolved Metals	mg/L	19	0.0069	0.013	0.0093	24	0.005	0.033	0.0076	27	0.011	0.019	0.013	20	0.0023	0.0061	0.0033
Manganese	Dissolved Metals	mg/L	26	0.0044	0.25	0.015	24	0.0015	0.019	0.0098	26	0.002	0.026	0.0091	20	0.0025	0.039	0.011
Mercury	Dissolved Metals	mg/L	8	<0.00005	< 0.00001	< 0.000045	10	< 0.00005	0.000018	< 0.000045	21	< 0.00005	0.0000012	< 0.00001	16	< 0.00005	0.000005	< 0.000025

			Muskeg River				Steepbank River				Ells River				Firebag River			
Analyte	Group	Unit	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median	N	5th %ile	95th %ile	Median
Molybdenum	Dissolved Metals	mg/L	19	0.000041	0.00021	0.00009	24	0.00015	0.0007	0.00026	28	0.0006	0.0011	0.00078	19	0.0001	0.0003	0.00014
Nickel	Dissolved Metals	mg/L	19	< 0.00006	0.004	0.0002	24	< 0.000094	0.0041	0.00034	28	0.00073	0.005	0.0013	20	< 0.0001	0.00022	< 0.000005
Selenium	Dissolved Metals	mg/L	32	< 0.0005	0.00028	< 0.0002	24	< 0.000485	0.000091	< 0.0004	28	< 0.0005	0.0007	< 0.00025	20	< 0.0005	0.00018	< 0.00015
Silver	Dissolved Metals	mg/L	8	< 0.000005	0.0000013	< 0.000005	10	< 0.000005	0.0000078	< 0.000005	21	< 0.000005	0.00001	0.00000058	16	< 6.25E-06	0.000013	< 5E-07
Strontium	Dissolved Metals	mg/L	19	0.093	0.24	0.12	24	0.055	0.33	0.12	28	0.09	0.17	0.12	19	0.051	0.089	0.064
Sulphur	Dissolved Metals	mg/L	6	< 0.34975	2.4	1.2	8	0.93	4.3	1.1	12	3.8	9.3	5.7	12	< 0.6	1.4	0.43
Thallium	Dissolved Metals	mg/L	13	< 2.18E-05	0.000082	0.000004	16	< 0.00005	0.000014	< 0.000003	25	< 0.00005	0.00011	0.0000039	19	< 0.00005	0.000041	0.0000011
Titanium	Dissolved Metals	mg/L	19	0.00033	0.0017	0.0009	24	< 0.00021	0.0017	0.0012	28	0.0003	0.0044	0.0013	20	0.0006	0.0021	0.0013
Uranium	Dissolved Metals	mg/L	19	< 0.0001	0.00026	0.00007	24	< 0.0001	0.00029	0.00009	28	0.00011	0.00033	0.0002	19	< 0.0001	0.0001	0.000041
Vanadium	Dissolved Metals	mg/L	19	< 0.0001	0.00041	0.00022	24	< 0.0001	0.00066	0.00023	28	0.000077	0.0011	0.00029	20	0.0001	0.0004	0.00023
Zinc	Dissolved Metals	mg/L	19	< 0.002	0.023	0.0014	24	0.00047	0.028	0.0036	28	< 0.001147	0.12	0.0036	20	< 0.002	0.0057	0.0017

Notes: Mine Expansion (Muskeg), and Synenco Northern Lights (Firebag) data are from RAMP, AENV, and the following baseline studies: Suncor Voyageur South (Steepbank), Total Joslyn North (Ells), Shell Jackpine.

Table B-7. Typical chemical properties and constituents of concern in the Oil Sands Region. See Section 5.2.1.

		Constituents of Concern (COC)							
Landform Type	Flow Type	Dissolved Organic Carbon	Total Dissolved Solids	Calcium	Chloride	Magnesium	Sodium	Sulphate	
		mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L	
Watershed									
Athabasca River	Surficial	10	200	40	30	10	20	30	
Natural Sand	Surficial Groundwater	7	400	70	7	20	10	30	
Natural Clay	Surficial Groundwater	15	3000	80	800	50	700	300	
Reclaimed Overburden Dump									
Overburden	Overland / Subsurface	20	300	40	10	10	20	90	
Saline / Sodic Overburden	Overland / Subsurface	20	4000	300	80	100	1000	2000	
Tailings									
CT	Release Water	52	2000	100	800	30	1000	1000	
MFT	Release Water	52	3000	20	600	10	1000	20	
Process Affected Water / Seepage	Dissolved Free Water	56	3000	20	800	10	900	200	

		Constituents of Concern (COC)							
Landform Type	**Flow Type**	**Sulphide**	**Nitrogen - Ammonia**	**Toxicity - acute**	**Toxicity - chronic**	**Naphthenic acids**	**Total Phenolics**		
		mg/L	**mg/L**	**Tua**	**Tua**	**mg/L**	**mg/L**		
Watershed									
Athabasca River	Surficial	0.004	0.04	0	0	0.03	0.004		
Natural Sand	Surficial Groundwater	0.06	0	0	0	0.6	0.001		
Natural Clay	Surficial Groundwater	0.06	0	0	0	1	0.002		
Reclaimed Overburden Dump									
Overburden	Overland / Subsurface	0.01	0.2	0	0	1	0.01		
Saline / Sodic Overburden	Overland / Subsurface	0.01	5.0	0	0	1	0.01		
Tailings									
CT	Release Water	0.03	5	2	6	70	0.01		
MFT	Release Water	0.1	10	1	3	60	0.03		
Process Affected Water / Seepage	Dissolved Free Water	0.01	7	2	5	60	0.02		

		Constituents of Concern (COC)							
Landform Type	**Flow Type**	**Arsenic (As)**	**Boron (B)**	**Iron (Fe)**	**Manganese (Mn)**	**Mercury (Hg)**	**Molybdenum (Mo)**	**Selenium (Se)**	**Strontium (Sr)**
		mg/L	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**	**mg/L**
Watershed									
Athabasca River	Surficial	0.001	0.04	1	0.05	0.00004	0.002	0.0002	0.3
Natural Sand	Surficial Groundwater	0.0002	0.04	0.6	0.2	0.00005	0.005	0.0003	0.2
Natural Clay	Surficial Groundwater	0.001	1	0.1	0.2	0.00005	0.005	0.0003	0.2
Reclaimed Overburden Dump									
Overburden	Overland / Subsurface	0.001	0.1	0.1	0.01	0.00003	0.002	0.004	0.2
Saline / Sodic Overburden	Overland / Subsurface	0.001	3	1	2	0.00003	0.002	0.004	4
Tailings									
CT	Release Water	0.01	3	0.01	0.1	0.00005	0.5	0.001	1
MFT	Release Water	0.01	4	0.2	0.02	0.00003	0.03	0.003	1
Process Affected Water / Seepage	Dissolved Free Water	0.01	2	0.04	0.02	0.00004	0.05	0.004	1

		Constituents of Concern (COC)							
Landform Type	**Flow Type**	**PAH Group 5 (b)**	**PAH Group 6 (b)**	**PAH Group 8 (b)**					
		ug/L	**ug/L**	**ug/L**					
Watershed									
Athabasca River	Surficial	0	0	0.01					
Natural Sand	Surficial Groundwater	0	0	0					
Natural Clay	Surficial Groundwater	0	0	0					
Reclaimed Overburden Dump									
Overburden	Overland / Subsurface	0	0	0					
Saline / Sodic Overburden	Overland / Subsurface	0	0	0					
Tailings									
CT	Release Water	0.1	0.1	0.3					
MFT	Release Water	1.2	0.06	0.4					
Process Affected Water / Seepage	Dissolved Free Water	1.2	0.06	0.4					

Table B-8. Substances Included in polycyclic aromatic hydrocarbon groups (Shell 2007). See Section 5.4.1.2.

Group	Constituent Compounds
PAH Group 1	dibenzo(a,h)anthracene; benzo(a)pyrene; methyl benzo(bandk) fluoranthene/methyl benzo(a)pyrene; C2 substituted benzo(bandk) fluoranthene/benzo(a)pyrene
PAH Group 2	benzo(a)anthracene/chrysene; methyl benzo(a)anthracene/chrysene; C2 substituted benzo(a)anthracene/chrysene; benzo(bandk)fluoranthene; Indeno(c,d-123)pyrene
PAH Group 3	benzo(g,h,i)perylene; chrysene; carbazole; methyl carbazole; C2 substituted carbazole
PAH Group 4	acenaphthene; methyl acenaphthene; acenaphthylene
PAH Group 5	anthracene; phenanthrene; methyl phenanthrene/anthracene; C2 substituted phenanthrene/anthracene; C3 substituted phenanthrene/anthracene; C4 substituted phenanthrene/anthracene; 1-methyl-7-isopropyl-phenanthrene (retene)
PAH Group 6	biphenyl; methyl biphenyl; C2 substituted biphenyl; C3 substituted biphenyl;
PAH Group 7	fluoranthene; fluorene; methyl fluorene; C2 substituted fluorene
PAH Group 8	naphthalene; methyl naphthalenes; C2 substituted naphthalenes; C3 substituted naphthalenes; C4 substituted naphthalenes
PAH Group 9	methyl fluoranthene/pyrene; pyrene

Table B-9: Inorganic water chemistry of oil sands process waters, the Athabasca River, and regional lakes (Allan 2008). See Section 5.4.2.3.

Variable (mg/L unless otherwise noted)	Syncrude MLSB (2003)[a]	Syncrude demonstration ponds (1997)[b]	Suncor TPW (2000)[c]	Suncor CT release water (1996–97)[d]	Suncor CT Pond seepage (1996–97)[d]	Athabasca River (2001)[e]	Regional lakes (2001)[e]
TDS	2221	400–1792	1887	1551	1164	170	80–190
COND ($\mu S \cdot cm^{-1}$)	2400[f]	486–2283	1113–1160[f]	1700	1130	280	70–226
pH	8.2[g]	8.25–8.8	8.4	8.1	7.7	8.2	7–8.6
Sodium	659	99–608	520	363	254	16	<1–10
Calcium	17	15–41	25	72	36	30	2–25
Magnesium	8	9–22	12	15	15	8.5	1–8
Chloride	540	40–258	80	52	18	6	<1–2
Bicarbonate	775	219–667	950	470	780	115	9–133
Sulphate	218	70–513	290	564	50	22	1–6
Ammonia	14[g]	0.03–0.16	14[f]	0.35	3.4	0.06	<0.05–0.57

Note: MLSB, Mildred Lake Settling Basin; TPW, tailings pond water; CT, consolidated tailings; TDS, total dissolved solids; COND, conductivity; data represent mean values from samples collected during the year indicated; ranges indicate mean values for multiple sites.

[a](MacKinnon 2004).
[b](Siwik et al. 2000).
[c](Kasperski 2001).
[d](Farrell et al. 2004).
[e](Golder Associates Limited 2002).
[f](MacKinnon and Sethi 1993).
[g](MacKinnon 2001).

Table B-10: Organic chemistry of oil sands process water, the Athabasca River, and regional lakes (Allan 2008). See Section 5.4.2.3.

Variable (mg/L)	Syncrude MLSB (1985–1998)	Syncrude demonstration ponds (1996–97)[a]	Suncor tailings ponds (1982–1998)	Athabasca River (2001)[b]	Regional lakes (2001)[b]
DOC	58[c]	26–58	62–67[c]	7	14–27
BOD	25[d]	-	<10–70[e]	<2	-
COD	350[d]	-	86–525[f] 260–973[e]	40[d]	-
OG	25[d]	-	9–31[f] 92[e]	<0.5	-
NA	49[g]	3–59	68[g]	<1	1–2
Phenols	0.008[h]	0.001–0.003	0.03–1.8[f] 0.03–1.4[e]	<0.001	0.002–0.004
Cyanide	0.5[d]	-	0.01–0.04 [e]	0.004[d]	-
PAHs	0.01[h]	-	-	-	-
Toluene	-	-	1–3[e]	-	-
Benzene	-	-	<0.6–6[e]	-	-
BTEX	<0.01[h]	-	-	-	-

Note: DOC, dissolved organic carbon; BOD, biochemical oxygen demand; COD, chemical oxygen demand; OG, oil and grease; NA, naphthenic acids; PAH, polycyclic aromatic hydrocarbon; BTEX, benzene, toluene, ethylbenzene, xylene; MLSB, Mildred Lake Settling Basin; data represent mean values from samples collected during the year indicated; ranges indicate mean values for multiple sites.

[a](Siwik et al. 2000).

[b](Golder Associates Limited 2002).

[c](MacKinnon and Sethi 1993); MLSB and Suncor Ponds 1–3.

[d](MacKinnon and Boerger 1986).

[e](Gulley 1992); Suncor Ponds 1A, 4.

[f](Nix 1983); Suncor Ponds 1A, 1, and 2.

[g](Holowenko et al. 2002); MLSB and Suncor Pond 5.

[h](Rogers et al. 2002*b*).

Table B-11: Process affected seepage chemical profile (regional operators) (Shell 2007). See Chapter 6.

Parameter	Units	Distribution	Max Limit	95th Percentile	Median	Count	Post-Screening Count
aluminum	mg/L	delta-lognormal	2.6	0.16	0.037	58	53
ammonia	mg/L	normal	18	11	4.9	187	187
antimony	mg/L	lognormal	0.035	0.0084	0.0015	31	31
arsenic	mg/L	normal	0.025	0.0069	0.0042	34	31
barium	mg/L	normal	14	0.25	0.16	58	57
beryllium	mg/L	lognormal	0.12	0.003	0.00049	60	59
boron	mg/L	normal	5.0	3.9	2.7	58	58
cadmium	mg/L	delta-lognormal	0.2	0.021	0.0019	58	57
calcium	mg/L	lognormal	616	229	38	789	789
chloride	mg/L	delta-lognormal	795	246	68	560	560
chromium	mg/L	lognormal	0.074	0.015	0.0021	68	68
cobalt	mg/L	lognormal	0.052	0.013	0.0024	58	58
copper	mg/L	lognormal	0.067	0.014	0.0022	58	58
dissolved organic carbon	mg/L	normal	150	94	50	85	85
iron	mg/L	lognormal	9.4	0.059	0.013	281	254
lead	mg/L	lognormal	0.04	0.0018	0.00031	58	54
magnesium	mg/L	lognormal	120	44	16	792	792
manganese	mg/L	lognormal	3.8	1.9	0.081	120	120
mercury	mg/L	lognormal	0.00002	0.0000076	0.00000048	163	163
molybdenum	mg/L	normal	1.6	1.1	0.53	58	58
monomer	mg/L	constant	0	0	0	0	0
naphthenic acids-labile	mg/L	normal	102	72	36	228	228
naphthenic acids-refractory	mg/L	normal	44	31	16	228	228
naphthenic acids-total	mg/L	normal	145	103	52	228	228
nickel	mg/L	normal	0.13	0.037	0.018	58	54
PAH Group 1	μg/L	delta-lognormal	0.55	0.16	0.16	26	21
PAH Group 2	μg/L	delta-lognormal	2.5	0.72	0.46	26	25
PAH Group 3	μg/L	constant	0	0	0	27	27
PAH Group 4	μg/L	lognormal	1.7	0.42	0.079	26	24

Parameter	Units	Distribution	Max Limit	95th Percentile	Median	Count	Post-Screening Count
PAH Group 5	µg/L	lognormal	11	1.4	0.13	26	25
PAH Group 6	µg/L	delta-lognormal	0.75	0.28	0.19	23	23
PAH Group 7	µg/L	delta-lognormal	3.8	0.85	0.27	26	26
PAH Group 8	µg/L	delta-lognormal	10.0	1.4	0.27	26	25
PAH Group 9	µg/L	lognormal	2.0	0.43	0.067	26	26
potassium	mg/L	normal	38	23	13	516	516
selenium	mg/L	delta-lognormal	0.035	0.0048	0.0013	34	23
silver	mg/L	lognormal	0.0025	0.00033	0.000092	57	34
sodium	mg/L	lognormal	1,310	691	158	524	524
strontium	mg/L	lognormal	3.8	2.1	1.1	59	59
sulphate	mg/L	lognormal	1,735	915	184	823	823
sulphide	mg/L	lognormal	0.24	0.048	0.0069	35	35
tainting potential[a]	Tpot	100/U	1,000	168	20	0	0
total dissolved solids	mg/L	lognormal	4,453	2,541	1,286	154	154
total nitrogen	mg/L	lognormal	46	13	3.0	35	35
total phenolics	mg/L	delta-lognormal	0.24	0.044	0.0089	78	76
total phosphorus	mg/L	lognormal	14	0.27	0.043	82	80
toxicity – acute	TUa	normal	6.7	3.1	1.7	27	26
toxicity – chronic	TUc	normal	20	14	6.2	27	27
vanadium	mg/L	normal	0.12	0.051	0.021	59	58
zinc	mg/L	lognormal	0.37	0.065	0.0078	59	59

(a) Tainting potential is estimated as 100/U, where U follows a uniform distribution between 0.1 and 10.

Source: BOVAR (1996); Cooper (2004); Golder (1995, 1997a,b, 1999, 2000, 2001a,b, 2002); Hydroqual (1996); Komex (2006); Shell (2007); Syncrude (2006); Yasuda (2006).

Table B-12: Mature Fine Tailings Flux Water Chemical Profile (Shell 2007). See Chapter 6.

Parameter	Units	Distribution	Max Limit	95th Percentile	Median	Count	Post-Screening Count
aluminum	mg/L	delta-lognormal	14	8.8	0.47	47	47
ammonia	mg/L	lognormal	65	27	6.4	218	218
antimony	mg/L	delta-lognormal	0.017	0.004	0.0014	18	17
arsenic	mg/L	lognormal	0.073	0.016	0.0022	83	75
barium	mg/L	normal	0.31	0.23	0.13	46	46
beryllium	mg/L	delta-lognormal	0.01	0.0041	0.0024	29	29
boron	mg/L	normal	5.4	3.8	2.3	253	252
cadmium	mg/L	delta-lognormal	0.013	0.0033	0.0016	56	45
calcium	mg/L	lognormal	147	78	18	320	320
chloride	mg/L	lognormal	1,000	869	139	327	327
chromium	mg/L	delta-lognormal	0.13	0.022	0.0044	56	56
cobalt	mg/L	delta-lognormal	0.052	0.014	0.0047	47	47
copper	mg/L	delta-lognormal	0.072	0.006	0.0025	55	50
dissolved organic carbon	mg/L	lognormal	207	80	56	79	78
iron	mg/L	delta-lognormal	14	1.0	0.076	329	309
lead	mg/L	delta-lognormal	0.02	0.0042	0.0012	36	34
magnesium	mg/L	lognormal	66	34	10	319	319
manganese	mg/L	delta-lognormal	2.8	0.42	0.063	133	124
mercury	mg/L	delta-lognormal	0.00016	0.000042	0.000047	25	23
molybdenum	mg/L	delta-lognormal	1.9	0.41	0.069	95	82
monomer	mg/L	constant	0	0	0	0	0
naphthenic acids-labile	mg/L	normal	78	58	37	125	125
naphthenic acids-refractory	mg/L	normal	34	25	16	125	125
naphthenic acids-total	mg/L	normal	112	83	53	125	125
nickel	mg/L	delta-lognormal	0.078	0.031	0.012	56	56
PAH Group 1	µg/L	delta-lognormal	0.55	0.16	0.16	26	21
PAH Group 2	µg/L	lognormal	1.2	0.57	0.23	8	8
PAH Group 3	µg/L	constant	0	0	0	8	8

Parameter	Units	Distribution	Max Limit	95th Percentile	Median	Count	Post-Screening Count
PAH Group 4	µg/L	lognormal	2.0	0.86	0.34	8	8
PAH Group 5	µg/L	delta-lognormal	2.6	1.1	0.59	8	8
PAH Group 6	µg/L	delta-lognormal	0.75	0.28	0.19	23	23
PAH Group 7	µg/L	lognormal	0.39	0.19	0.075	8	8
PAH Group 8	µg/L	delta-lognormal	2.9	1.2	0.66	8	8
PAH Group 9	µg/L	lognormal	0.57	0.27	0.11	8	8
potassium	mg/L	lognormal	82	24	12	186	184
selenium	mg/L	delta-lognormal	0.1	0.0043	0.001	63	52
silver	mg/L	delta-lognormal	0.005	0.00035	0.00017	27	4
sodium	mg/L	lognormal	1,190	913	405	321	321
strontium	mg/L	lognormal	2.8	1.3	0.52	225	224
sulphate	mg/L	lognormal	891	489	96	321	321
sulphide	mg/L	delta-lognormal	18	10	0.87	24	24
tainting potential[(a)]	Tpot	100/U	1,000	168	20	0	0
total dissolved solids	mg/L	normal	2,600	1,814	1,159	135	135
total nitrogen	mg/L	lognormal	113	43	13	15	15
total phenolics	mg/L	lognormal	6.1	1.9	0.094	38	38
total phosphorus	mg/L	lognormal	1.9	0.38	0.055	53	53
toxicity – acute	TUa	normal	37	26	13	19	19
toxicity – chronic	TUc	normal	54	46	36	0	0
vanadium	mg/L	lognormal	0.34	0.085	0.0031	50	50
zinc	mg/L	delta-lognormal	0.45	0.096	0.02	53	53

(a) Tainting potential is estimated as 100/U, where U follows a uniform distribution between 0.1 and 10.

Source: BOVAR (1996); Cooper (2004); EVS (1989, 1990, 1992, 1993); FTFC (1995); Golder (1995, 1997a,b, 1999, 2000a, 2001a,b, 2002, 2007); Hydroqual (1996); Komex (2006); MacKinnon et al. (1982); Nelson et al. (1993); Nix (1982, 1983); Noton (1980); Syncrude (2006); Yasuda (2006); Zenon Environmental (1986)

Table B-13: Processes influencing EPLs and treatment. See Chapter 9.

Treatment Type	Processes	Description	Unit Processes/Applicable Technologies	Target Criteria	Influent Treatment (Inlet)	Lake Treatment	Effluent Treatment (Outlet)
Biological Treatment	Suspended Growth	Microorganisms responsible for the degradation and reduction of undesirable constituents are maintained in suspension in the liquid. Processes may be aerobic, anoxic, or anaerobic.	Activated Sludge Processes, Aeration, Nitrification, Denitrification, Anaerobic Digestion	BOD, COD, Large Organics, TSS (if followed by Sedimentation), Ammonia, Nitrogen, Sulphur	YES	NO	YES
	Attached Growth	Microorganisms responsible for the degradation and reduction of undesirable constituents are attached to an inert medium such as rocks, slag or specially-designed synthetic materials. These inert media may also provide additional removal as filtration. Processes may be aerobic, anoxic, or anaerobic. Usually followed by Sedimentation.	Trickling Filters, Rotating Biological Contactors (RBC), Membrane Bioreactors (MBR)	BOD, COD, Large Organics, TSS, Ammonia, Nitrogen, Metals	YES	NO	YES
	Lagoon Processes	Uses ponds or lagoons for treatment.	Algae Processes, Free-water Surface (FWS) Wetlands	OD, COD, Large Organics, TSS (if followed by Sedimentation), Ammonia, Nitrogen, Sulphur, As, Ba, Co, Ni, Naphthenic Acids	YES	YES	YES
Physical Treatment	Sedimentation	Solid-liquid separation using gravitational settling to remove suspended solids.	Solids Contact Clarifiers, sedimentation basins, Free-water surface sedimentation	TSS, Large Organics	YES	YES	NO
	Granular Filtration	Solid-liquid separation where the liquid passes through a porous medium to remove suspended solids.	Slow Sand Filtration, Multi-media Filters, Granular Activated Carbon (GAC) Filters, Green Sand Filtration	TSS, Large Organics	YES	NO	YES

	Adsorption	Mass transfer process whereby a constituent in the liquid phase is transferred into the solid phase across a suitable interface. Activated carbon is commonly used as an adsorbent surface.	Powdered Activated Carbon (PAC), GAC, Green Sand Filtration, Organophyllics	TSS, Large Organics	YES	YES	YES
	Membrane Processes	Selectively permeable barriers that allow the passage of certain constituents while retaining others. Reverse osmosis and electrodialysis are two common types.	Microfiltration, Ultrafiltration, Nanofiltration, Reverse Osmosis (RO), Electrodialysis	TSS, Colloids, TDS, TOC, VOC, Refractory Organics, Ammonia, Nitrate, Phosphorus, TSS, Bacteria, Protozoa, Viruses	YES	NO	YES
	Ion Exchange	Ions of a given species displaced from an insoluble exchange material by ions of another species in solution. Typically used to remove divalent metals to reduce hardness.	Ion Exchange Media/Reactors	Various Metals, Ca, Mg, Silica, Nitrate, TDS			
Chemical Treatment	Coagulation and Flocculation	Coagulation and Flocculation are the adding of floc-forming chemicals to a water to form with unsettleable colloids and slow-settling suspended solids to produce a rapid-settling floc. Coagulation refers to the addition and rapid mixing of a coagulant, and the initial aggregation of suspended particles. Flocculation refers to the gentle agitation to further aggregate the colloids to form settleable flocs.	Reactor Clarifiers, coagulant and polymer addition	TSS, TDS	YES	YES	NO
	Oxidation	Conventional/Advanced Oxidation Processes (AOP) are used to oxidize complex organics that are difficult to biodegrade. In many cases, partial oxidation is sufficient to convert specific compounds to be more easily biodegradeable or less toxic. AOPs typically involve the generation and use of the hydroxyl free radical (HO·) as a strong oxidant, although other oxidants may be used such as oxygen, ozone or chlorine.	Conventional Oxidation (Chlorine, Chlorine dioxide, Potassium permanganate), Advanced Oxidation (UV peroxide, UV ozone, Ozone peroxide)	TOC, Refractory Organics, VOC, Naphthenic Acids	YES	NO	YES
Disinfection	Disinfection	Disinfection is the destruction or inactivation of pathogenic microorganisms. Disinfection does not pertain to the destruction of these microorganisms existing in the spore state, which is known as sterilization.	Chlorine Disinfection, Ultraviolet (UV) Irradiation	Bacteria, Protozoa, Viruses	NO	NO	YES
Much of this table is adapted from Reynolds and Richards (1996), Metcalf and Eddy (2008), and builds upon work on oil sands tailings technology review for the Oil Sands Tailings Consortium (2011).							

C. APPENDIX C: KNOWLEDGE GAPS

C.1 Introduction

Not all the information needed to build cost-effective EPLs exists. This chapter provides a table of data gaps and opportunities to bridge or narrow some of those gaps identified in this guide. A modified adaptive management strategy (presented in Appendix D) provides a framework to deal with the uncertainties associated with such large and complex systems through a “learning by doing” approach.

Much of the learning will be through capturing, sharing and acting upon ideas and techniques that arise through design, construction, operation, monitoring, and the certification process for each of the 30 EPLs in the region. A more complete list of learning opportunities includes:

- Learning by doing (design, construction, operation, monitoring, and certification)
- Capturing traditional environmental knowledge
- Ongoing scanning and evaluation of developments for natural lakes, other EPLs, and management systems from the literature
- Participating in and hosting conferences
- Discussing details with experts
- Funding and focusing pure and applied research.

The notion of an information gap implies there is presently insufficient information to build successful EPLs. But even where there is sufficient information and knowledge, there are opportunities for additional improvement – for example, better and more efficient methods of monitoring, which could be considered part of a continuous improvement and technology development program. This chapter covers both gaps and opportunities.

The main idea is that this list of gaps and opportunities would be maintained, enhanced, and revisited periodically to guide further research and development activities. A system to maintain the list, evaluate priorities, and fund research should be developed as part of the adaptive management program.

C.2 Method

The data gaps presented within this chapter were generated by examining and compiling the data gaps identified by authors who were asked to produce their lists during development of their chapters, and by reviewing the design process to see what further information would be available. The data gaps identified in a previous draft of this report (Westcott and Watson, 2007) were also examined and adapted.

The master table was also filled out to suggest the specific questions to answer, and provide an idea of when the question would need to be answered.

It is recognized that most of these research needs are interdisciplinary and multidisciplinary.

- Management, regulatory, planning, and design
- Traditional environmental knowledge
- Geotechnical
- Surface and Groundwater
- Limnology (physical chemical)
- Lake ecology
- Opportunity

The table scores the urgency in starting research work using the following system:

- High: 1 to 2 years
- Medium 2 to 5 years
- Low 5+ years

Many of the questions in Table C-1 have two parts. The first is a more science/research question. The second is a more applied/design/operation question.

C.3 Results

Table C-1: Information gaps

Category	Gap / question to answer	Priority to start research
A. Management, regulatory, planning, and design	What are suitable regulatory criteria for end pit lake water quality at various stages? And for discharge from the outlet to the environment at various stages?	M
	How much will the climate change in the oil sands region?	H
	What will be the impact of climate change on watershed hydrology for end pit lakes?	M
	How can the end pit lake design and performance objectives be improved?	M
	How will equivalent capability for the lake be judged? How does this fit into equivalent capability for the site as a whole?	M
	What are the regulatory trends regarding end pit lakes? How should trends be incorporated into design and operation of end pit lakes?	M
	What will be the requirements for certification of an end pit lake?	M
	How do oil sands end pit lakes fit into a sustainability framework?	M
	Can some level of long-term ongoing active maintenance of end pit lakes	M

Category	Gap / question to answer	Priority to start research
	be acceptable? Can the lake still receive reclamation certification from the government of Alberta?	
	What natural ecosystems/community structures exist in current small lakes in Alberta? Can an end pit lake be constructed to have a hypersaline ecosystem similar to some other lakes in Alberta? Would it be sustainable? Would this be an acceptable end land use?	L
	How will the output of 30 end pit lakes in a lake district affect the Athabasca River and its tributaries over time? What could be done if the impacts were unacceptable?	L
	What are the minimum requirements for successful end pit lake monitoring plan?	M
	How would a data management system be designed for an end pit lake district in adaptive management?	M
	What has been learned from end pit lakes from coal mines and quarries in Alberta? How do these learnings translate into the design and operation and certification of oil sands end pit lakes?	M
	What options are realistic for end pit lakes if water quality isn't sufficient to meet goals?	H
	What should the planning basis be for active water treatment? What facilities are required? What is the cost? How well can extreme events be managed? What options exist for treating inflows, the lake, and the outflow?	H
	What is the best way to build littoral zones?	L
	What is the importance of water-level fluctuation on end pit lake performance? How can it be controlled? To what degree should it be controlled?	M
	What is the performance of a full scale end pit lake?	M
B. Traditional environmental knowledge	What traditional environmental knowledge can be applied to end pit lake design, construction, operation, and certification? How can this knowledge be gained and incorporated?	M
	What are planned and desired uses of end pit lakes by First Nations? What design or operational elements can be changed to enhance this use?	H
C. Geotechnical	How much will fills around the lake settle? What will this settlement look like over time? How can this settlement be incorporated into design?	M
	How can fluid tailings be stored safely in end pit lakes?	M
	What is the water quality and flux of oil sands tailings from the base of end pit lakes? What can be done to control fluxes?	M
	What lakeshore erosion rates can be expected under various conditions? What is the impact of shoreline erosion on the lake? On land uses?	L
D. Surface and Groundwater	How important are constituents leaching from fills and other substrates in the base of end pit lakes? What can be done to control fluxes?	M
	What is the water quality of seepage/groundwater from reclaimed oil sands landforms?	M

Category	Gap / question to answer	Priority to start research
	What is the water quality of natural groundwater that will feed end pit lakes?	M
	What is the water quality of natural streams that will feed end pit lakes?	M
	What is the water quality of surface water runoff from reclaimed oil sands landforms?	M
	How can beaver-proof outlets be constructed?	L
	Is our ability to predict surface and groundwater flow sufficient for end pit lake design? What can be done through design to minimize the impact of uncertainty?	M
E. Limnology (physical chemical)	What can be done in design and operationally to minimize the development of meromixis in end pit lakes? What can be done to change this situation after it is observed?	M
	How does the warmth of the tailings substrates affect lake behaviour? How do discharge water temperatures affect downstream ecosystems?	M
	How well can we model the water chemistry of end pit lakes?	M
F. Lake ecology	What tailings technologies for the end pit lake and its watershed would produce acceptable water for end pit lakes? How can this be evaluated? What water quality would be clearly unacceptable?	H
	What are the benefits from littoral zones connected by channels rather than being in lakes?	M
	What species should be introduced into the end pit lake? How? Which ones will come naturally? How fast should we expect colonization?	L
	Is there a risk of bioaccumulation?	M
	What are naphthenic acids? What is the character of the labile and refractory compounds? How do they relate to whole effluent toxicity? How do they each degrade? What are the maximum levels acceptable for the lake (at various stages)? For discharge out the outlet?	H
	What are the risks of acute or chronic toxicity to aquatic or terrestrial organisms? How can these risks be controlled?	H
	What is the likelihood and potential effects of biogenic gas production? What is the cause? What is the fate? How do these gases affect lake performance? How do they affect the tailings performance?	H
	What is the limit of acceptable suspended solids in various areas of the lake? What can be done to control suspended solids through design or operation?	M
	What is the minimum size of a littoral zone? How should it be configured? What is an optimal size?	H
	What trophic status will develop in end pit lakes? What governs the trophic status? How can you design or operate a lake to provide a certain trophic status?	M

	How well will end pit lakes act as bioreactors? What can be done to enhance this function through design or operation?	H
	What water quality is needed to provide health conditions for fish? What constituents are desirable? Undesirable?	M
G. Opportunity	Opportunity: Develop a visual monitoring system around a computer tablet linked to a database.	M
	Opportunity: Develop on-line analysers for various constituents of interest	M
	Opportunity: Development of techniques for monitoring water quality using satellite imagery	M
	Opportunity: Develop a demonstration EPL to address the uncertainties and knowledge gaps.	?

C.4 Tackling the table

The table of data gaps is lengthy but manageable, with future work being required by a variety of disciplines to tackle it. A research and development steering committee, as part of the adaptive management process, could tackle the list by rounding it out, assigning priorities, and setting up a framework to tackle each item. Much of the research is already ongoing under various umbrellas. In some cases, a single approach could be applied to answer both kinds questions raised in the data gap – for example, an MSc thesis with a chapter to address the science question followed by one to address the design question. More commonly, the design question will require the work of a multidisciplinary design team, using the virtual end pit lake or a real end pit lake to frame the answer.

REFERENCE

Westcott, F., and Watson, L., 2007, End Pit Lakes Technical Guidance Document. Edmonton: Cumulative Environmental Management Association (CEMA), 71p.

D. APPENDIX D: INTRODUCTION TO ADAPTIVE MANAGEMENT

D.1 Introduction

The design, construction, operation, and certification of the proposed 30 end pit lakes in the oil sands region over the next century is an unprecedented undertaking. While there is an emerging body of literature and case histories from pit lakes in other mining industries (see Chapter 3), the only experience within the oil sands industry thus far involve large experimental test ponds and the Syncrude Base Mine Lake, which is still under construction.

Managing complex environmental systems is replete with daunting uncertainties. “Adaptive management” is one approach for addressing these uncertainties. It has been formally defined and redefined many times over the past 30 years, and sets up different expectations with different people. But in general, adaptive management could be applied to oil sands reclamation and oil sands end pit lakes in particular.

While ultimately settling on a slightly modified adaptive management definition, this chapter provides a foundation for the selection of adaptive management by looking at various management system options, offering a better understanding and history of adaptive management, and describing the needs and potential pitfalls of such a program. It then goes on to set out an adaptive management framework for the oil sands EPLs. Finally, it focuses on a partial list of failure modes for these lakes, contingency measures to correct such failure modes should they arise, and outlines a monitoring program to provide timely warning and data for these mitigative measures. While this approach is similar to Peck’s (1969) geotechnical observational method, it adds an additional feature: scanning and research into both fundamental and applied aspects of EPL behaviour and design that continues until the last EPL receives reclamation certification, sometime midway through the next century.

To foreshadow the result of this work and provide the reader with a frame for discussion of adaptive management in the oil sands, the proposed modified adaptive management program is the iterative combination and careful execution of the following seven steps:

1. Define the problem and objectives
2. Establish governance
3. Design the lake and its monitoring plan
4. Implement the design (construct the lake)
5. Monitor and observe performance
6. Assess and evaluate performance of the design
7. Revise design/operation (cycle back)

A formal program to manage each lake, and the system of building some 30 lakes, is critical, considering the size and complexity of the systems being created, the uncertainty in their operation, the opportunity for gaining knowledge over time, and the likely requirement to change the design and operation of a given EPL. Furthermore, this program is critical to the widespread acceptance of these large scale experiments, to the business interests of the oil sands operators constructing and operating these lakes, and to the regulators and stakeholders who will be affected (positively or negatively) by the cost and landscape performance of the EPLs being constructed from reclaimed land.

More specifically, a formal, industry/region-wide management program is required because:

- Predictions of final cost, physical, ecological, and land use performance of each EPL are highly uncertain, with a variety of opinions regarding risk. Not enough is known about the physical and environmental performance to construct the lakes using conventional engineering design methods.
- Sequential construction of 30 EPLs as major features of the regional reclaimed landscape provides (and requires) the opportunity to reduce costs, enhance performance, reduce uncertainty and risks, and capture learnings from each constructed project.
- While monitoring is expensive, the funds, access, infrastructure, knowledge, and trained people already exist and systems are in place to teach the next generation.
- The consequences of not having EPLs likely would cost industry, the government, and society tens of billions of dollars (to backfill the mined out pits, use alternative methods for tailings deposition, and capital and operating costs of dozens of water treatment plants) and the land use opportunity costs of not having new deep lakes in the region are significant.

No existing, off-the-shelf management technique is available that can simply be applied to this situation; indeed, rigid management practices are seldom optimal. The management system will need to be adapted over time as new information and new management techniques become available. There are currently, however, several tools from which we can draw upon. Given that the system will be in place for a hundred years or more, and since there is no precedent for the task at hand, any system adopted will need to be modified over time. A key finding from the work behind this chapter is that a truly regional approach, including an active regional management team, will be needed to manage construction of the reclaimed areas, as will a management team for each EPL (and its watershed). These teams will need to be set up for the long term, given the timeframe for this reclamation undertaking.

D.2 Approaches to Management and Selection of Adaptive Management

Scientists and policymakers rarely have a full understanding of all the facets of adaptive management, including its framework, the magnitude of the commitment over generations, or its rather poor track record (Allen et al., 2011). This chapter argues that a modified adaptive management program represents a solid framework. First, a review of the numerous approaches to managing large scale environmental plans that involve inherent uncertainty is warranted (see Table D-1).

Table D-1: List of adaptive management tools.

Tool	Description	Example reference	Comment	Limitations
Unmonitored experience	Casual observation applied anecdotally.	Lee, 1999	Common in regulatory policy.	Inefficient, little chance for improvement.
Walk away with undocumented learning	Construct to standard of day, minor monitoring, improve design of subsequent landforms.	McKenna, 2002	Common in mine reclamation.	Only applicable for simple situations with modest goals.
Conventional design	Conduct site investigation, design to specific goals, design to avoid known failure modes, stay within precedence, construct, operate, monitor, maintain.	Petroski, 1996	A foundation design is a good example.	Only applicable to simple situations with lots of related experience.
Safety case	Investigations and a detailed argument demonstrating that a system is safe (or in our case, that the lake will meet the goals set out).	Inge, 2007	European approach in nuclear and railway industries to manage risks.	Requires large amount of information regarding likely future performance. Little or no room for residual uncertainty at end of study.
Best practice	Agreeing to use documented industry methods that have been found to provide superior results.		Helps to standardize practices within an industry.	Assumes best practices are known, and that a collection of best practices will provide good results.
Continuous improvement, incrementalism	Once constructed, seek to continually improve the functionality with small incremental changes.	Deming, 1982	Used widely by oil sands industry as an operational tool at all levels.	Assumes that minor tweaks and incremental improvements are sufficient.

Geotechnical observational method	Careful site investigation, design for most probable conditions with well-crafted contingencies for all recognized failure modes, close monitoring, selection and application of best contingency if needed.	Peck, 1969	Common approach, used in dam construction, used for oil sands landforms extensively.	Assumes all failure modes are well understood in advance and that contingencies can be designed, opportunity to only pay lip service to process.
Adaptive management	Setting objective, carrying out large, full-scale experiments testing competing hypothesis over many years, monitoring, evaluating, and selecting best outcome, continue to monitor. "Learn by doing."	Holling, 1978 Walters, 1986	Fairly common in large resource management projects.	Limited success, long time frames, high cost, opportunity to only pay lip service to process.
Scenario planning	Scenarios are developed, and using game theory used to shape management strategy.	Kahn, 1966	Used to argue nuclear war was winnable.	More suited when there is less control.
Structured decision making	Involves setting out objectives, looking at alternatives and consequences, evaluating tradeoffs and risks, and choosing best course of action based on available information. Often performed with a cost-risk-benefit approach.	US Fish and Wildlife, 2009	Some consider adaptive management as a subset of structured decision making. Structured decision making common in oil sands.	Does not explicitly include all interested parties. Does not explicitly indicate need for ongoing management.
Trial-and-error	Incremental testing or repairing of elements until desired outcomes are reached. Sometimes called incrementalism or sequential learning.	Popper, 1963	The most common approach employed in environmental management.	Uncertainty whether this approach will yield acceptable results. Inefficient.

None of the approaches in Table D-1 as presently described in the literature are likely to be completely suitable for the challenge of constructing oil sands EPLs and their watersheds. The rest of the chapter proposes that the adaptive management approach (modified with elements of some other the methods listed) is the most suitable for EPL construction, operation, monitoring, maintenance, and certification for the oil sands.

Alternatively, one could choose to start with one of the other approaches and modify it (especially the structured decision-making approach or geotechnical observational method, if they involved a more explicit time component), or scenario planning (if one believes there is less control over the outcome than suggested by Figure D-1 below).

Furthermore, some aspects of the other methods have applicability as modifications to the adaptive management process: conventional design for elements with precedence (geologic containment, dump construction, aspects of the inlet and outlet), continuous improvement in all aspects, and walk away with undocumented learning for non-critical element of the lake and watershed. No matter what method is chosen for EPLs, it is critical to document the methodology and decision-making processes at the beginning of the project and continue with the chosen management strategy. Changing strategies or decision-making processes can hinder and confuse the process, ultimately reducing the method's effectiveness.

Figure D-1 provides a graphical representation of what decision tools might be useful under different levels of ability to affect change and uncertainty in future performance.

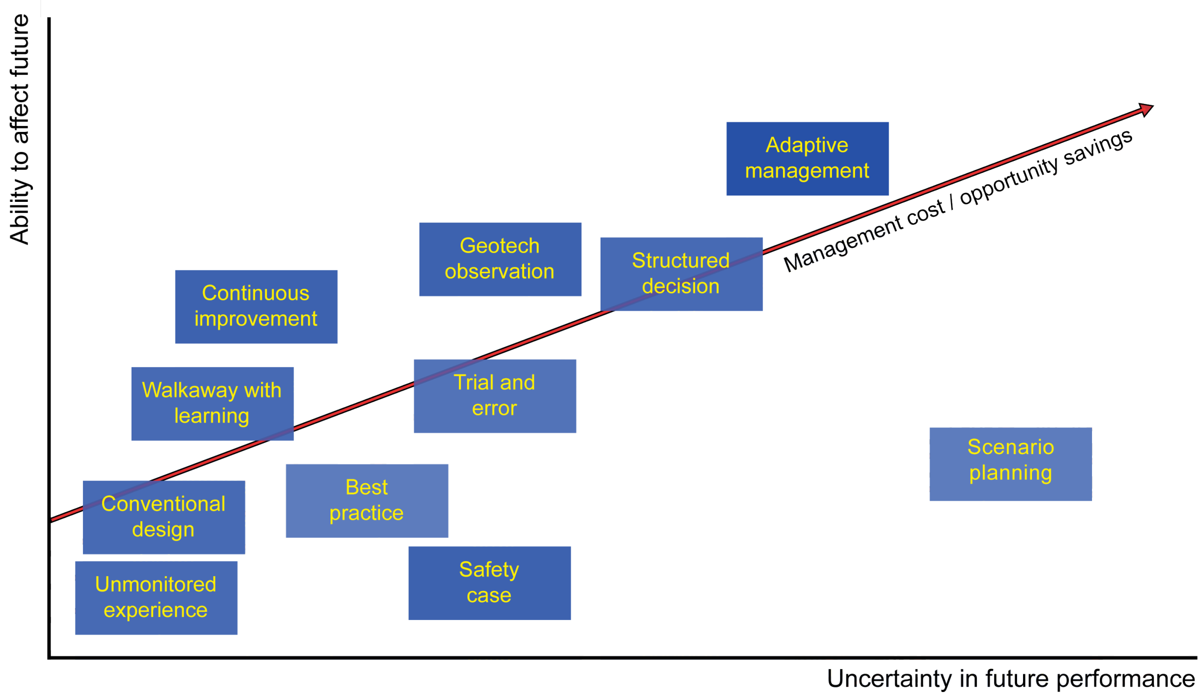

Figure D-1: Management options.

Adaptive environmental management was introduced by Buzz Holling (1978), advanced and popularized by Carl Walters (1986), and recently summarized in a guide by Allan and Stankey (2009). It is a formal system generally applied to resource management (such as fisheries, hunting, forestry, or rangelands) to actively manage an ecosystem, adapting management plans over time until desired outcomes are achieved. Resorting to use of adaptive management, which requires complex, costly, and often contentious programs lasting decades or longer, is generally only applied to complex situations with clearly defined goals, high degrees of uncertainties, and opportunities for measurable management controls. It is often characterized more recently as “learning by doing” (Allen et al., 2011). Adaptive management is often offered by proponents in oil sands mining as a way of managing long-term liability in the face of uncertain reclamation and landscape performance (e.g., Kwasniak, 2010) and is of interest in the design of EPLs in the oil sands region.

Figure D-2 provides a visualization of the rapid and stepwise decrease in the ability to make changes to an EPL with time. Costs of major changes become all but prohibitively expensive as time goes by. Getting the design right in the first place is critical because once mining and tailings productions begin, the opportunities to alter the design are severely constrained. Put differently, poor planning or poor choices in the initial design stages can handcuff operations for the life of the mine, resulting in an EPL that is more costly and provides reduced environmental benefit.

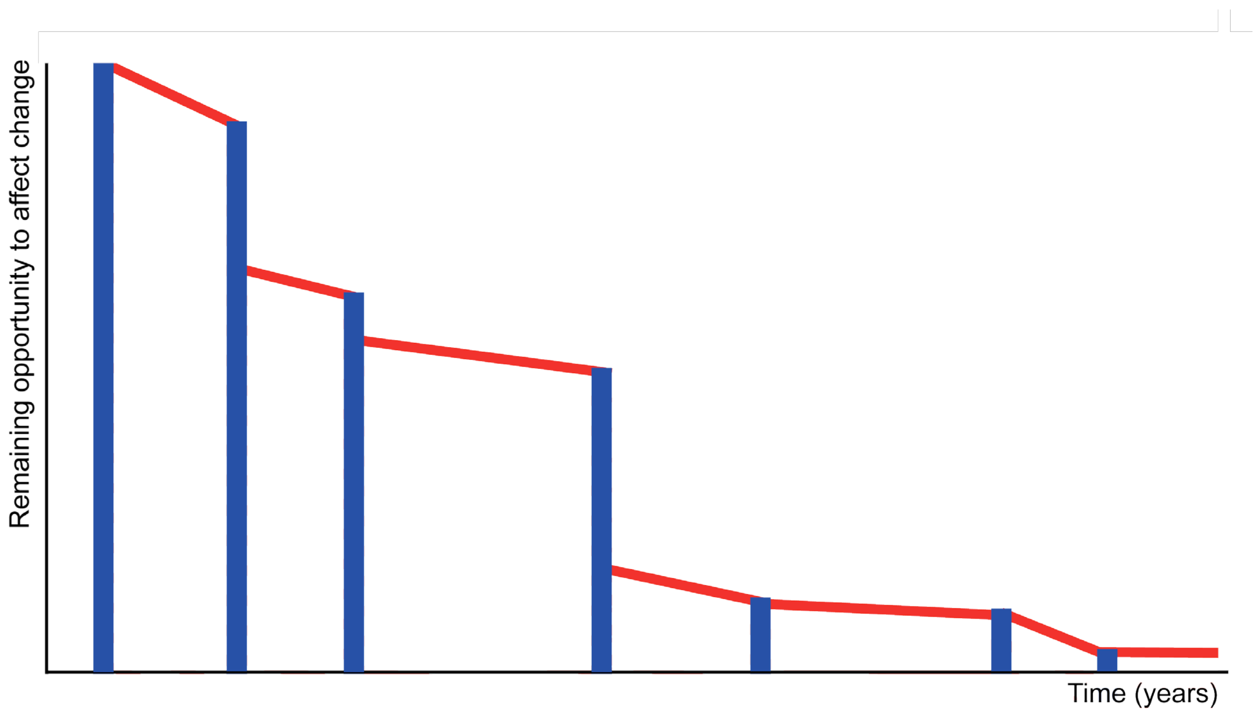

Figure D-2. How opportunities for change decrease with time.

D.3 Adaptive Management Defined

D.3.1 History of Adaptive Management

This section looks at the history of adaptive management in some detail to provide a sound foundation for its adoption here.

There are dozens of definitions of adaptive management, and most seem to have departed from Holling and Walter's original framework, resulting in considerable confusion and wide ranges of expectations regarding its use (e.g. Fontaine 2011). Numerous papers point to the near lack of success in applying adaptive management, yet nearly every paper champions the *ideals* of adaptive management and recommends its wise use.

Building on the early work of Beverton and Holt (1957) for fisheries management, Holling (1978) designed adaptive management to move away from the notion of doing a one-time environmental impact assessment with an implicit notion of a static world. He sets out his seven steps as recommendations that can be paraphrased as follows:

1. Environmental aspects of projects need to be considered up front along with economic and social dimensions. (Ironically, we are now trying to add the social dimension to economic and environmental aspects).
2. After design, there should be alternating periods of innovation and periods of monitoring to see how the systems adapt.
3. The program design should seek out the benefits of better knowledge of social, economic, and environmental effects.
4. The experimental program should include experiments for gaining knowledge.
5. The design, monitoring, and remedial measures should not be ad hoc, but an integral part of the whole process.
6. It needs to be recognized that not all impacts can be mitigated in the initial design, but that there are tradeoffs and the need for change.
7. Institutions and legislation need to change to recognize the uncertainties and opportunities for adaption.

Walters (1986) expanded upon Holling's work (with his help), focusing on bringing more rigour to numerical modelling and some of the techniques for carrying uncertainty in the models. While his book focuses on modelling, he offers the following general steps to adaptive management:

- Bounding the management problem
- Creating dynamic numerical models
- Propagating uncertainty through time in the models, carrying alterative hypotheses
- Designing and implementing balanced policies, and ongoing probing for improvement

Lee (1993) showed the central importance of social aspects and stakeholder involvement in adaptive management, forming the modern framework for adaptive management.

D.3.2 A modern definition of adaptive management

BCFR (2011) describes the elements common to all adaptive management programs:

- Reducing uncertainty through learning
- Applying learnings to change practice and policy (and sometimes objectives)
- Focusing on improving management, design, policy, operation
- Involving well-crafted large-scale experiments to explore competing hypothesis
- Using a structured, formal, and systematic approach; it is not simply an ad hoc approach.

BCFR (2011) provides a useful definition for the purposes of this chapter:

> *Adaptive management is a systematic process for continually improving management policies and practices by learning from the outcomes of operational programs. Its most effective form – "active" adaptive management – employs management programs that are designed to experimentally compare selected policies or practices, by evaluating alternative hypotheses about the system being managed.*

There are dozens of papers and books on the application of adaptive management, most tracing the history, explaining various steps with diagrams, and providing a series of case histories, almost all of which have failed to live up to the ideals. One guide stands out for its simplicity, completeness, and presentation. *Adaptive Management: The U.S. Department of the Interior Technical Guide* (Williams et al., 2009) recommends nine steps for adaptive management.

- Involving stakeholders
- Setting objectives
- Setting out management actions
- Creating models
- Designing monitoring plans
- Making decisions, taking action
- Conducting follow-up monitoring
- Assessing results
- Iterating

D.4 Criticisms of adaptive management

Many papers document the shortcomings and failures of adaptive management (these criticisms provide “data” for design of an improved process for EPLs). Some of these criticisms are summarized below:

- The approach is often poorly defined, and promised without a good understanding of the implications. “Adaptive management is one of the buzz terms of the times.” (Hauser 2008).
- Difficult to initiate, coordinate, sustain and is often unaffordable (Lee, 1999).
- Difficult to evaluate success (Allen and Jacobson 2009), track record has been very poor with almost no successful examples, (Allen et al., 2001; Allen and Jacobson, 2009), a “paucity of success stories” (Tyre and Michaels, 2011). Successful examples deviate considerably from the theoretical ideal (Doremus, 2011).
- Places too much emphasis on quantitative scientific knowledge over other kinds of knowledge (McLain and Lee, 1996).
- The approach is naïve regarding how environmental management decisions are made and implemented (McLain and Lee, 1996).
- “Adaptive management is a poor fit for solving problems of intricate complexity, high external influences, long time spans, high structural uncertainty and with low confidence in assessments.” (Allen and Gunderson, 2011).

Following their criticisms, nearly all authors voice the same advice as that expressed by Lee (1999): “This mode of learning is important, possibly essential, in the search for a durable and sustainable relationship between humans and the natural world.”

Similarly, for end pit lakes, it is difficult to envision a system other than one that embraces the ideals of adaptive management to meet the goals of this grand experiment with an uncertain outcome.

In adapting the list above for use in oil sands, we can additionally use the list. Allen and Gunderson (2011) set out documenting failures of the system, and turn this around so that the oil sands EPL adaptive management system incorporates the following:

- Ensure there is a system of technology transfer and communication to provide designers, operators, regulators, and decision makers with timely information and options.
- Formally select and agree upon which components of end pit lake design, operation, and management will be subjected to adaptive management.
- Design the adaptive management system to include operators, regulators, and stakeholders, sharing decision-making and sharing responsibility for outcomes.

- Avoid prescriptive results (in design guides, approvals, regulators) that unduly limit adaptation to local conditions, experimentation, creativity, and creation of diverse conditions within and between lakes and watersheds.
- Provide clear, strong leadership for the program.
- Clearly distinguish monitoring for performance vs monitoring for research interests.
- Use shared decision-making among diverse stakeholders, invest in the process.
- Build consensus.
- Focus on learning in all aspects, be open to surprises, embrace hard truths.
- Budget for, and allow time for, monitoring and learning.
- Recognize that a lot of the things we'd like to know we probably can't know.
- Recognize the limitations of experimentation, especially where there is a large downside risk.
- Take action, don't only focus on planning, measuring – be bold.

D.5 Requirements for adaptive management for oil sands end pit lakes

Building on the long and storied history of adaptive management, paying attention to the criticisms, and looking at the specific needs of the oil sands end pit lakes, the following are offered as requirements of the system:

- Explicitly recognize and accept that the performance of each end pit lake will be different, is uncertain, will change with time, and that the objectives may also need to change with time.
- Create a program that embraces continuous learning for all participants, but also recognizes when an endpoint is reached and one could signoff (certify) on each lake as complete.
- Create a program that is capable of being applied to individual EPLs (and their watersheds) and to the resulting lake district (and the regional watersheds).
- Encourage broad participation by proponents, regulators, and stakeholders with joint decision-making.
- Full and open sharing of design, model, and performance information on an annual basis, with a good filing system accessible to all.
- A formal technology transfer program.
- Strong leadership and coordination.
- Create a program that can change and adapt itself over a century or longer.
- Establish well-funded organization and well-conducted monitoring programs, no more complex than necessary.

D.6 Modified adaptive management for EPLs

Given all the definitions, criticisms, opportunities, and requirements listed, the following seven steps have been proposed for the design, operation, management, and certification of oil sands EPLs:

1. Define the problem and objectives
2. Establish governance
3. Design the lake and its monitoring plan
4. Implement the design (construct the lake)
5. Monitor and observe performance
6. Assess and evaluate performance of the design
7. Revise design/operation (cycle back)

These steps are largely based on the Holling/Walters approach, but this modified adaptive management approach:

- is less concerned with full-scale experimentation and hypothesis-testing in favour (but not exclusively so) of identifying failure modes and designing contingencies (from the geotechnical observational method);
- uses models – not one overarching ecological model but instead a variety of geotechnical, physical, and biogeochemical limnology models, watershed hydrology models, groundwater models, etc. It values and seeks non-numerical inputs;
- embraces the need to involve stakeholders and regulators (from Kerr's modification to adaptive management);
- includes the novel approach that the lake, its watershed, and its ecosystem will be designed, constructed, and operated and that these activities will occur in parallel with profitable oil sands mining over a period of a century;
- establishes simple (but suitably onerous) success criteria;
- applies both to the individual lake and the sequence of 30 constructed EPLs as part of a lake district with the opportunity to learn and experiment with each lake;
- uses risk assessment and structured decision-making to help inform and document decision-making;
- relies on a robust monitoring, data management, and technology transfer program that will run a century or longer; and
- requires full disclosure and open sharing of all construction details and monitoring data and analysis.

D.7 When should adaptive management start?

Two parallel processes of adaptive management are needed. For the full reclamation area, the adaptive management program is needed now. Adaptive management is a program that is perhaps just underway with the preparation of this design guide. It will take advantage of the previous 15 years of research and development and the impeding completion of Syncrude's Base Mine Lake. A team and an institution are needed now.

For each individual end pit lake, adaptive management should start formally at the start of lease development as an integral part of closure planning, mining and tailings operation, lake design, construction, and operations, and eventual certification as described in this design guide. The program cannot wait until construction of the lake is ready to begin or until the filling of the lake is complete; most of the opportunities for management have passed by these points in time.

In the design and ultimate performance of EPLs, all aspects of mining and tailings, planning, design, operation, construction, and reclamation need to be considered. Arguably, adaptive management should not be solely focused on EPLs, but on the future reclaimed mining landscapes and indeed the region as a whole.

D.8 Isn't adaptive management just some sort of con?

Adaptive management is not:

- A replacement for good design, or a tool to fix a poor design or outcome. We still need good designs, probably in greater detail than currently provided in closure planning.
- A dodge to cheap out; actually adaptive management is a burden, and should not be entered into lightly.
- A delay tactic; construction and monitoring efforts are required now. Time is of the essence.
- Trial and error - failure modes and contingency plans are provided up front.
- A big research project in itself, but recognizing that ongoing learning is an essential and central component.
- The domain of just scientists, or engineers. It requires Aboriginal and other stakeholders, regulators, management, operations teams, engineers, and scientists.
- A carte blanche to dodge responsibilities. If the lake does not meet the goals, either the goals will need to be adjusted, or the lake adjusted or reversed. But there is a shared responsibility of all for successful outcomes.

D.9 How will we recognize success?

Walters (1986), Lee (1999) and others have identified the difficulty of defining whether a management program has been successful. The following are offered as essential and sufficient measures of success for adaptive management in oil sands EPLs:

- There is enthusiastic stakeholder involvement and support.
- Management objectives have been clearly identified, enunciated, and communicated.
- Management systems, both for individual lakes (with dedicated teams) and the lake districts (a regional institution), are in place and functioning well.
- An excellent system of monitoring, data management, and data analysis is in place and functioning well.
- Learnings from data analyses are reflected in modifications of lake design, operation, and regulation.

The outcome of doing all these things well is a new landscape that is: built economically, performs as intended, provides agreed-upon end land uses, and results in acceptable lake ecosystems. Planners need to define what success means relative to the EPL and the landscape area, as "success" can mean different things to different people.

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E. APPENDIX E: THE EDITORIAL PROCESS

E.1 Evolution of the modern technical guidance document

In 2007, CEMA published an EPL Technical Guidance Document (Wescott and Watson, 2007). Upon review, the Alberta Energy Resource and Conservation Board (ERCB) deemed the document unacceptable for use as regional guidance for the reclamation of oil sands EPLs. CEMA then commissioned 12 experts from academia and industry to undertake an exhaustive review of the document. Published in 2009 (CH2M HILL, 2009), the review concluded that the document was not acceptable in its current form. The reviewers identified unexamined assumptions, a lack of references, technical and factual errors, omissions of important research, contradictory statements, and lack of familiarity with critical subject matter. They determined that these errors would have been caught and corrected in a peer-review process. Moreover, the reviewers rejected one of the document's key underlying assumptions: that the oil sands EPLs are unique, making comparisons with other pit lakes irrelevant. The review also suggested that the document did not contain sufficient content of practical use to the technical managers, planners, and engineers who would constitute its intended target audience.

CEMA did not attribute the failings of the 2007 document to the authors. Rather, the review recommended that a second document be prepared with resources appropriate for the scale of the task and employ an entirely new process, one more akin to a scientific study than a consultant report. The steps set out for developing a viable guidance document, slated for release in 2012, were as follows:

1. Retain managing editors to oversee development of the document, work with authors, reviewers, and the task group, and edit and design the final product;
2. Hire expert authors and expert peer-reviewers. Provide forums for coordination and exchange of information across disciplines;
3. Use peer review to control quality and to review and approve draft chapters.

Such a process is not revolutionary. It draws on established techniques from the academic and research communities. But it is not commonly used to generate regional guidance for mine closure and reclamation. To that extent, embracing the recommendations represented a commitment to taking advantage of necessary expertise, no matter where it is found. It was equally groundbreaking to coordinate the knowledge of these experts into a quality guidance document on a novel mining reclamation instrument.

E.2 Principles for developing regional reclamation guidance

E.2.1 Selection of project team

Creating a project team comprised of key personnel with a stake in the oil sands was key to producing a suite of regional reclamation guidelines. The team was created to develop and steer the project. Members were familiar with regional oil sands industry issues and had the technical background that enabled them to provide relevant input. The team's responsibilities included:

- Develop project approach (process) and provide direction for the duration of the project;
- Decide on general content of guideline document;
- Approve the international suite of authors established by the managing editors; and
- Approve draft documents.

The project team's involvement is crucial to ensuring the needs of the regional industry, government representatives, and stakeholders are addressed. In the oil sands context, CEMA established a project team from its membership, named the End Pit Lakes Guidance Document Task Group (EPLGDTG). The group included representatives of several oil sands operators and aboriginal stakeholders, in addition to federal, provincial, and regional government agencies. The task group was instrumental in directing the scope of work. This resulted, at times, in heated debates. However, ultimately these discussions built the foundation that met regional needs.

E.2.2 Selection of an experienced managing editor

Coordination of submissions from multiple authors requires careful management. For this purpose, selection of an experienced managing editor was critical. Responsibilities of the managing editor included:

- Establish a list of authors and act as their point of contact;
- Ensure communication and coordination among authors and reviewers;
- Ensure the objectives of the task group were met;
- Ensure regular contact with the project team;
- Ensure consistency in language usage, composition, and style; and
- Eliminate redundancy among authors' skill base and chapter content, and ensure appropriate cross-referencing among authors.

The task group did not consider it critical that the managing editor(s) be intimately familiar with the technical aspects of the subject matter. Indeed, a fresh perspective was considered more valuable, allowing the expert authors to be responsible for the expertise contained in their chapters. Moreover, a non-technical managing editor was thought better able to ensure that the document is comprehensible to an audience that may include individuals not fully specialized in the subject matter (although industry operators are the main audience).

However, the task group did consider it essential that the managing editor become familiar with the industry and important contacts. The task group openly tendered the service. The selected company was West Hawk Associates Inc., a communications and editing firm with over 15 years experience in environmental issues and natural resources. The company has extensive experience producing large documents, including guidance documents, for committees with government and industry representation, often involving extensive stakeholder consultations. West Hawk was charged with ensuring that independent peer review would be integral to the process of preparing the next guidance document.

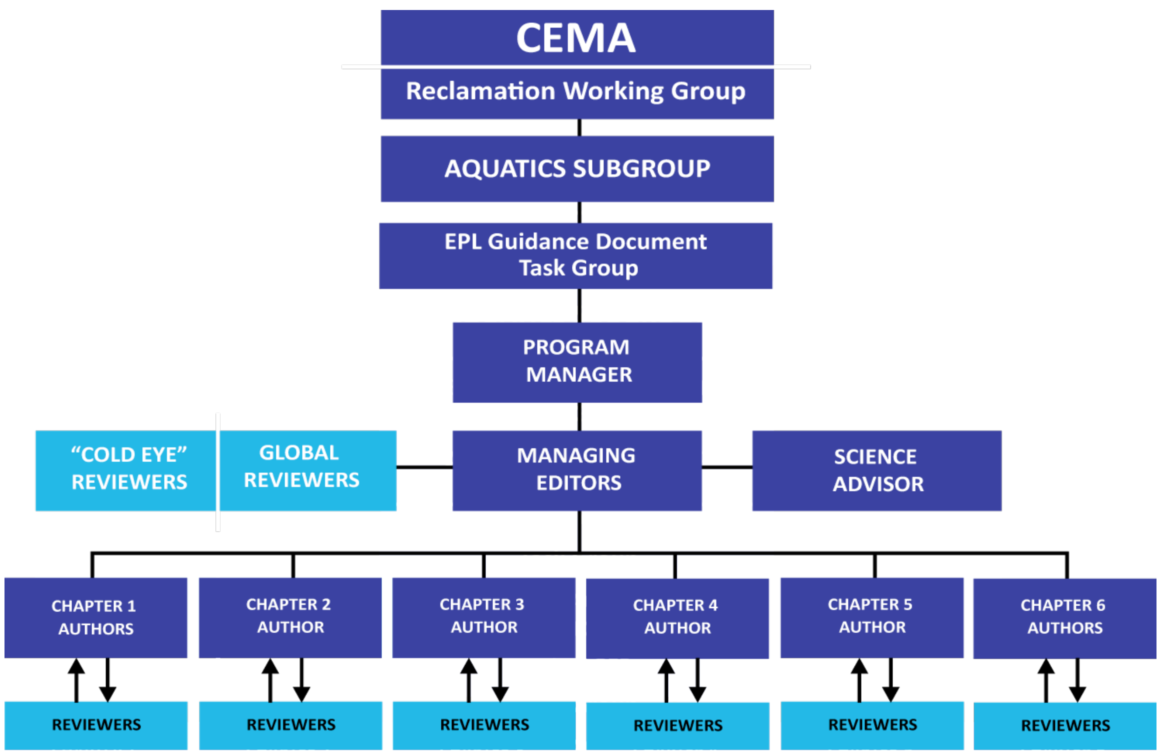

Figure E-1. The End Pit Lake Guidance Document management and production process. The full document has nine chapters and six appendices, all of which were subject to review.

West Hawk assigned its two senior associates, David Wylynko and James Hrynyshyn, to the project. Both are former journalists, each possessing 25 years of professional writing and editing experience. They began by familiarizing themselves with the industry by reviewing background material, interviewing key industry contacts as provided by the project team, and conducting a site visit to the oil sands. West Hawk devoted considerable resources to overseeing the research, writing, and review processes. The firm worked closely with the task group. Regular conference calls and frequent meetings in Alberta monitored each step of the document's evolution. These meetings were crucial to ensuring that the project remained on track, especially in the early stages.

E.3 Adapt to user needs

E.3.1 Determine the primary users of the guidance

To ensure maximum usability, a guidance document must be tailored to its primary users. Guidelines intended for all members of industry, government, and stakeholders may provide high-quality broad information, but will ultimately not be particularly useful to a specific end user group. A specific target audience must be identified and the document must be written to the requirements of that audience, which in this case are oil sands industry design engineers. The managing editors conducted a user-needs assessment, holding interviews with mine and reclamation planners in the oil sands industry to gather input on potential authors, content, style and format.

E.3.2 Add experience to the team, where needed

To meet user needs, it is important that the project team draw upon the experience of the target audience. In the oil sands context, the user-needs assessment revealed that additional experience was needed in the design of large landforms in the oil sands region. Indeed, the review of the 2007 report indicated it failed to contain sufficient content of practical use to the technical managers, planners, and engineers. Thus, the task group added to the project team an independent science and engineering advisor with substantial experience in the industry in designing aquatic landforms in the oil sands region (Gord McKenna, BGC Engineering).

E.3.3 Ensure that stakeholder perspectives are understood

Depending on the stakeholder, there may be a number of objectives, directions and desired outcomes for EPLs. It is critical to understand stakeholder perspectives related to EPLs, such as performance and management expectations and desired end land uses. Knowledge of these perspectives provides context for design decisions, research direction, and the development of performance objectives and criteria.

The purpose of stakeholder involvement is to ensure that stakeholders are kept informed about the project throughout the process; and allow stakeholders the opportunity to comment and provide input. Stakeholder input should be viewed as a multi-step process. Input is sought from stakeholders, this input is considered, and the stakeholders are consulted on how their advice was used or offered the reason if it was not.

Attempting to include traditional knowledge in processes or institutions of authority was most certain to fail without allowances for the many ways by which these stakeholder groups typically develop or transmit this knowledge (Ellis, 2005). Aboriginal stakeholders, in particular, draw on a broad range of knowledge and experience when communicating. Many considerations – environmental knowledge, cultural values, history, politics, and a range of concerns and aspirations – can influence a land user's views when participating in a technical session. Such stakeholders rarely limit themselves to a specific topic, but rather provide holistic analyses and broad statements. Metaphors may often play a large role in stakeholder knowledge communications, which are usually framed in personal experience and may take the form of stories (Paci et al., 2002). These discussions can encompass many subjects, including personal history, Aboriginal identity and values, and previous industrial developments and their impacts upon people and the land (Ellis, 2005).

End pit lake design, construction, and management are often very technical in nature and commenting on this subject can require significant scientific expertise. Among many stakeholder groups, it is difficult to find individuals who are technically able to participate in environmental governance processes. Because of these challenges, much thought was put toward ensuring the appropriate approach was taken when seeking stakeholder views.

Figure E-2: Discussion with stakeholders.

E.3.4 Interviews

To obtain stakeholder input, the managing editors and the task group arranged interviews with stakeholders with a direct interest in the development of end pit lakes. This included non-governmental groups, Aboriginal groups, industry, and government. Included in this process were two of four Caucuses that oversee the work of CEMA: The NGO Caucus and the Aboriginal Caucus. Through their involvement with CEMA over the years, members of both caucuses were familiar with the general aspects related to reclamation which was key to the discussions that ensued. A semi-directed interview was used to obtain stakeholder input. By this method, participants are guided in the discussions by the interviewer, but the direction and scope of the interview are allowed to follow the participants' train of thought. The semi-directed interview is more of a conversation than a question-and-answer session. Through this method, participants shared insight into their views on the design and construction of end pit lakes.

E.4 Production of content

E.4.1 Assemble a strong team of authors

The design of an EPL is a multi-disciplinary exercise, requiring input from several areas of expertise, including but not limited to hydrology, hydrogeology, biology, and lake physics. Thus, a team approach is usually adopted to design and construct a pit lake. A similar approach should be adopted for generating regional design guidance for EPLs.

Figure E-3: Authors, reviewers and task group members attended several workshops organized to coordinate the evolution of the document.

In anticipation of preparing the End Pit Lakes Guidance Document, the managing editors and the task group identified the leading experts in several fields with knowledge of EPL design. This process included identifying experts with knowledge of existing pit lakes and aquatic ecosystem evolution in reclaimed environments. Much of the expertise necessary to ensure that the document would reflect the latest and most sophisticated understanding of the challenges involved in designing EPLs for the oil sands was available in Canada. However, input from experts in the U.S. and Australia was also pursued in order to ensure that the design and construction of EPLs in the oil sands benefited from the most current knowledge on pit lakes. In detail, the process for author selection was as follows:

- Review of the previous version of the End Pit Lakes Technical Guidance Document (2007) and its critique that CEMA commissioned in 2009. The critique was prepared by a senior manager/editor who had the 2007 document reviewed by 12 pit lake experts in Canada, the U.S., Australia, and Germany. The managing editors reviewed the work and expertise of these 12 reviewers to gage their knowledge and interest;

- The managing editors, the task group, the technical program manager and the technical advisor (Gord McKenna), identified 12-15 potential authors who were qualified, and might be available, to contribute chapters of the 2012 guidance document;

- The managing editors interviewed the potential authors either in person or by telephone. It was critical to determine their availability and interest, as well as their qualifications given that designing and constructing end pit lakes in the oil sands is an entirely new area of reclamation;

- The managing editors, in consultation with the task group, narrowed down the list of potential authors by concentrating on those individuals with the most relevant expertise. Previously published materials of these authors were also consulted to ensure their writing and general communication skills were adequate.

The authors are:

Devin Castendyk *(Chapter 3)* Devin was a Chancellor's Award for Excellence in Teaching recipient, at State University of New York in Oneonta, where he teaches water quality and geology courses. He is the co-editor of *Mine Pit Lakes - Characteristics, Predictive Modeling, and Sustainability, Volume 3 - Management Technologies for Metal Mining Influenced Water.*

Théo Charette *(Chapter 4)* is an aquatic ecologist and director of Charette Pell Poscente Environmental Corp., an environmental consulting company that focuses on incorporating environmental objectives and outcomes into land and watershed planning and management processes. He completed his Masters degree at the University of Alberta in 2001 and as technical Program Manager for CEMA, works with multiple stakeholders on leading practice reclamation in the Oil Sands Region of Alberta.

James Hrynyshyn *(Chapters 1 and 2, managing editor)* is a senior associate and writer, editor, and graphic designer for West Hawk Associates. He has 25 years of professional writing and editing experience. He has a journalism degree from Carleton University and a Bachelor of Science degree from the University of British Columbia. In addition to working with West Hawk, he has written for major Canadian, British, and U.S. newspapers and magazines.

Angela Küpper (*Chapter 8*) is based in Edmonton, where she is a senior Geotechnical Engineer with AMEC. She has 30 years of experience in various countries, including Canada, U.S., Brazil, Congo, Colombia and Suriname. Her experience is mostly in the areas of mining, hydroelectric dams, risk assessment, geotechnical testing, instrumentation and automation, infrastructure projects and industrial and municipal waste management.

Gordon McKenna *(Chapters 1 and 9, Appendices A, C and D)* is a senior geotechnical engineer at BGC Engineering in Vancouver with 24 years experience, including 17 working at Syncrude Canada's Mildred Lake oil sands operation in northeastern Alberta, Canada. He has a PhD from the University of Alberta in geotechnical engineering focusing on landscape engineering and sustainable mine reclamation.

Brent Mooder *(Chapters 4 and 5)* spent nine years as Senior Hydrogeological Engineer with WorleyParsons before joining BGC Engineering in 2009. There he specializes in physical hydrogeology, mining industries, groundwater modelling, aquifer testing, baseline hydrogeology, environmental impact assessment, and mine closure. He received his BSc in mechanical engineering from the University of Waterloo and his MSc in hydrology from the University of Alberta.

Aaron Sellick (Chapter 7) has 20 years of oil sands mining engineering experience, including four years at Syncrude Canada's Mildred Lake operations and 10 years with the Alberta Energy and Utilities Board (now ERCB) in various regulatory roles. Currently, as Vice President of Mining and Tailings with Norwest Corporation, his focus is on project optimization through integration of mine planning, geotechnical design concepts, and tailings technology selection and management approaches.

Derrill Shuttleworth *(Illustrations)* of Studio Two Ltd. on Gabriola Island is a graphic artist with over 30 years experience in architectural renderings and graphic design and has worked on oil sands tailings and reclamation projects since 1996. Derrill's sketches and paintings provide support of geotechnical and closure activities to help communicate technical concepts to technical and non-technical staff, regulators, and stakeholders.

Jerry Vandenberg (*Chapters 6 and 9*) is a water quality modeller with Golder Associates with a focus on northern mine pit lakes. He has developed and applied several water quality models for oil sands pit lakes in Northern Alberta and hard rock mines in Arctic Canada. His other modelling experience includes the development and application of thermal and chemical models of cooling ponds, chemical fate modelling in constructed wetlands, and hydrodynamic and water quality models throughout Western Canada.

David Wylynko (managing editor) is the principal associate at West Hawk Associates, which provides writing, editing, research, design, and project management services. He has 25 years of professional writing and editing experience and possesses a journalism degree from Carleton University and a Master of Literature degree from Queen's University. Before launching West Hawk Associates, David worked for several years as a journalist for major Canadian newspapers and magazines.

Given the importance of technical peer review to the success of the next edition of the EPLTG, three global reviewers were selected by West Hawk and CEMA-EPLSG to asses the document as an integrated whole:

- **Gord McKenna**, Senior Geotechnical Engineer, BGC Engineering Inc, Vancouver, British Columbia, Canada
- **Clint McCullough**, Senior Lecturer (Aquatic Ecotoxicologist), Mine Water and Environment Research Group, School of Natural Sciences, Edith Cowan University, WA, Australia
- **George Dixon**, Professor, Department of Biology, University of Waterloo, Waterloo, Ontario, Canada

Academics were selected to provide technical review of specific chapters based on feedback from the EPLSG.

The Guide also went underwent a cold-eye review, in which independent reviewers who were not previously involved in the editorial process provided an objective and comprehensive review of the Guide. Their written comments and suggestions were addressed by the authors. The cold-eye reviewers, selected based on their expertise in areas integral to the design of EPLs, were:

- **Chris Gammons,** Geochemist and Professor, University of Montana
- **Kim Kasperski**, Chemist, Manager, Water Management at Natural Resources Canada

- **Norbert Morgenstern**, PEng, Geotechnical Engineer and University Professor Emiritus, University of Alberta
- **Vivienne Wilson**, Botanist, CH2M HILL

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F. APPENDIX F: GLOSSARY

The following definitions are restricted to usage in an EPL context; usages associated with other contexts and disciplines have been omitted for clarity and ease of use.

Aboriginal people − descendents of the original inhabitants of North America, including First Nations and other Native American Indians, Métis and Inuit.

Acid − having a pH value of less than 7.0.

Acid mine drainage (AMD) − acidic water formed when mining activity exposes geological material to weathering by oxygen and water, typically elevated in concentration of metals, metalloids and sulphate. Sometimes also referred to as acid rock drainage (ARD).

Adaptive management – a management approach that involves (1) defining the problem and objectives, (2) establishing governance, (3) creating design and monitoring plans, (4) implemented design (construction), (5) monitoring and observing performance, (6) assessing and evaluation performance of design against objectives, and (7) revising design and operation. Within an adaptive management framework, these steps continue to occur in a cycle to allow information to be fed back into the planning and design process so that future projects will meet objectives. Adaptive management is a tenet of ecological management, in which human resource users can change the way they interact with the environment, based upon need and the availability of new information.

Advection − the horizontal movement of water.

Aerobic − an environment with oxygen or other oxidizers present.

Alkaline − having a pH greater than 7.0.

Allocthonous – organic material sourced external to the lake (e.g., from riparian plant growth).

Amendment − with reference to soil, an alteration of the properties of a soil by the addition of substances such as lime, gypsum, manure, or sawdust to make the soil more suitable for the growth of plants; technically a fertilizer is an amendment, but the term is most commonly applied to other types of added substances.

Anaerobic – an environment without oxygen or similar oxidizers such as nitrate or sulfate.

Anoxic – lacking oxygen.

Aquatic − growing, occurring, or situated in or around water.

Aquifer − a permeable geological layer that stores quantities of groundwater.

Autochthonous – organic material sourced from within a lake (e.g., from aquatic plant growth).

Bathymetry – a lake's shape, sides, and bottom underwater as a function of depth.

Bedrock − the solid rock that underlies soil exposed at the surface.

Benthic − living in association with the bottom substrate of aquatic environments.

Bioaccumulation − a biological process that produces a higher concentration of a substance within an organism than is found in its environment; includes uptake of substances from water and from food; can be harmful in the case of toxic compounds or beneficial, as in the case of freshwater fish, which must maintain a higher concentration of cellular salt than present in their aquatic habitat.

Biodegradable − able to be decomposed through the action of microorganisms such as bacteria.

Biodiversity − the variety of living components in an ecosystem; most often expressed as number of species but can involve genetic or landscape diversity (e.g., variety of vegetation types across the landscape); can also describe structural and functional elements of an ecological community or ecosystem.

Biomass − total living material in a unit area or volume; can be expressed at different biological levels (e.g., population, community).

Bioremediation − the use of microorganisms or plants to remove contaminants from soil or water.

Bitumen − the heavy, viscous hydrocarbon associated with the Athabasca oil sands deposit that is mined for its oil content; more generally, a class of viscous organic materials such as asphalt, petroleum and naphtha; contains some minerals and sulphur compounds.

Bog − a class of peat-accumulating wetland that has no significant outflows or inflows, is kept wet by direct precipitation with a water table at or near the soil surface, supports acid-tolerant mosses (particularly *Sphagnum*), generally very acidic and low in nutrient concentrations; may be treed or treeless and dominated by mosses and heathland shrubs.

Breakwaters – artificial structures built on the margin of a waterbody to reduce the energy of wave impacts on shoreline erosion.

Cap water – water put over the top of oil sands process-affected materials to fill a pit lake.

Certification – determination by an authorized government agency that lands disturbed by mining lands have been reclaimed to an acceptable state and meet regulatory requirements; may mark cessation of an oil sands operator's reclamation obligations.

Clay − a fine-grained textural class of soil, made up largely of minerals, but commonly also having amorphous free oxides with a grain size less than 0.002 mm.

Coke – a by-product of upgrading bitumen to synthetic oil. At Syncrude it is black fine-grained sand-sized carbon particles with some sulphur and trace metals. Suncor has similar chemistry, but the coke is a sandy gravel. It is a potential source of energy. Also referred to as petrocoke.

Compaction − the moving of soil particles closer together by external forces, in the process, reducing porosity; major causes are natural consolidation during soil forming processes (e.g., the weight of glaciers during the ice ages) and use of heavy equipment (as in the process of levelling the overburden during mining).

Composite tailings (CT) – non-segregating mixture of chemically altered fine and coarse tailings that consolidates relatively quickly to a semi-solid, loose, silty sand deposit; the purpose of producing CT is to consume both mature fine tailings and thin fine tailings to create a land surface reclaimable to upland or wetland vegetation; CT has a sand-to-fines ratio (SFR) that is greater than about 3:1 to allow rapid consolidation but less than about 5:1 to permit useful levels of fines capture.

Compression − a system of forces or stresses that tends to decrease the volume or compact a substance; the change in volume produced by such a system of forces; compression of a saturated soil is consolidation and compression of an unsaturated soil is compaction.

Conductivity − a measure of the resistance of a solution to electrical flow; conductivity increases with increasing ion content; normally reported in the SI units of siemens per centimeter (S/cm), millisiemens/metre, or as mohms/cm (1 mS/m = 10 mohms/cm).

Connectivity − the extent to which ecosystems are linked to one another to allow movement of organisms from one place to another.

Consolidation − the gradual reduction in volume and increase in density of fine-grained material by the release of water, typically in response to pressure from the weight of a water and tailings cap.

Contaminant of concern (COC) − a chemical compound that is known to be toxic.

Dam – the Canadian Dam Association (CDA) definition requires a dam to provide a fluid barrier that can impound 30,000 cubic metres or more and with a height of 2.5 metres or more. Fluid usually refers to water but may also refer to other liquids and potentially liquefiable materials (therefore tailings pond berms are considered dams). To provide a maintenance-free landscape, no structures that require monitoring and maintenance under CDA guidelines may be left behind.

Decomposition − break-down of organic matter through fragmentation, chemical alteration or biological activity.

Detritus layer – a layer of partially decomposed, non-living organic matter containing, for example, fallen vegetative matter, dead organisms, and often supporting a population of micro-organisms. In aquatic ecosystems the layer is suspended in the water body, and in terrestrial ecosystems, the layer is on the ground.

Dimictic − a description of a lake with two distinct mixing periods each year; covered by ice in winter and thermally stratified in summer.

Discharge − in reference to groundwater, movement of water from an aquifer in the subsurface to the surface, as in mining activities to the surrounding environment.

Drainage − the removal of surface and groundwater from an area.

Ebullition – the process of overflowing a containment structure.

Ecosystem − a region's complex of living organisms interacting with each other and their non-living environment, linked together by energy flows and material nutrient cycling.

End pit lake (EPL) – an artificial, engineered water body within a mined out pit. In the oil sands region, some proposed pits will be filled with varying amounts of tailings and capped with fresh water; receives surface and groundwater from surrounding ecosystems and discharge water to downstream environments. Many such lakes will be designed as bioreactors – allowing natural biodegradation of organic acids in the tailings waters.

Equivalent capability – offering services of equal value to those that existed prior to the disturbance; in an EPL context, individual land uses need not be identical to be considered equivalent.

Epilimnion – surface layer of a stratified body of water.

Erosion − removal of soils and rocks from the land surface, including water body margins, by water, wind, ice, and other geological, biological, or human activities.

Eutrophic − water bodies with high concentrations of nutrients promoting high rates of algal growth, which can lead to depletion of oxygen and death of aquatic organisms.

Evapotranspiration − a collective term for the processes of evaporation of water from the soil and surface, and plant transpiration.

Failure Mode and Effects Analysis (FMEA) – a common form of engineering risk assessment, widely used in the mining and petrochemical industries and often applied to earthworks projects.

Fen − a peat-accumulating wetland characterized by a high water table at or above the ground surface and waters that are mainly nutrient-rich and minerotrophic from mineral soils; dominant materials are sedge peat; vegetation consists of sedges, grasses, reeds, and brown mosses, with some shrub cover and, at times, a sparse tree canopy.

Fetch − the length of open water on a waterbody over which wind can blow unobstructed to form waves.

Fine tailings − a mixture of fine silts, clays, residual bitumen, and water derived from extraction of bitumen from oil sands using the traditional hot-water extraction process; typically 85% water and 15% silty materials.

Fines – silt and clay sized particles with a diameter of less than 75 microns (geotechnical definition). For oil sands tailings, fines are generally defined as having a diameter of less than 44 micron using a wet sieve analysis. Fines are defined as grains with diameters less than 44 micron grain size (specifically those passing a #200 wet sieve, but also often measured using laser diffraction).

First Nations – various indigenous peoples of Canada, usually not including Inuit or Métis.

Flocculant − a substance that promotes binding of particles together to form larger particles and thereby accelerate settling rates in water.

Food chain − a description of the process by which organisms in higher trophic levels gain energy by consuming organisms at lower trophic levels; the dependence for food of organisms upon others in a series beginning with plants and ending with the largest carnivores; a less precise term for a food web.

Freeboard – the height difference between a level of a lake and the lowest possible entry or exit point during flooding or large waves.

Groundwater − underground water reserve, also called aquifers; water that is stored in the pores of subsurface geological deposits.

Guidance − non-binding advice on non-regulatory conduct; less prescriptive and more general than a manual or handbook.

Habitat − a specific environment in which a species of plant or animal lives.

Holomictic – a condition in which a lake experiences an annual breakdown in stratification.

Hummock – a small knoll or mound of earth.

Hydraulic conductivity − a measure of the ability of water to move through the ground; a function of both the soil medium and the fluid; sometimes used interchangeably with permeability.

Hydrocarbon − an organic compound consisting of only carbon and hydrogen atoms.

Hydrology − a broad term encompassing all physical processes involved in the physics of water.

Hypolimnion – lower layer of water in a stratified lake.

Infiltration − downward water movement into the soil; typically vertical.

Inoculum – material added to another material to introduce a new property.

Inorganic − not derived from plant or animal origins; a chemical or other substance that does not contain carbon.

Interflow − water moving more or less laterally through the soil above the water table, sometimes produced by an impermeable layer that impedes infiltration; can be considered a type of groundwater flow.

Keystone species − a species whose role in an ecosystem is disproportionate to its abundance, and without which significant changes to the community would occur.

Lacustrine − pertaining to lakes or lake shores; characteristic of lakes.

Landscape − the natural features such as fields, hills, forests, and water bodies that distinguish one part of the surface from another part.

Littoral zone − the productive shallow-water area at the edge of a lake that extends outward from the mean water level at the shore to the water depth where there is just enough light available (typically 1% of light intensity at the surface) for submerged rooted plants to grow; in the Athabascan region, this zone is thought to correspond to a sloping bed (typically with an overall slope of 0.2 to 1%) with water depths from 0 m (mean water level) to 3 m.

Limnetic zone – well-lit, open surface water of a lake where photosynthesis can occur.

Limnology – the study of lakes, rivers and other inland waters**.**

Macrophyte − herbaceous vegetation; larger than algae, includes mosses and flowering plants.

Marsh − a class of wetland that is periodically inundated by standing or slowly moving water, with surface water levels that may fluctuate seasonally and, where open water occurs, a variety of submerged and floating aquatic plants.

Mature fine tailings (MFT) – a suspension of fine silts, clays, residual bitumen, and water; characterized by slow settling rates and remains fluid-like for decades or centuries; typically 30% solids by mass.

Meromixis − lake stratification that forms distinct layers of water that never mix.

Methanogenesis − the generation of methane gas through microbial action; can occur in anaerobic lake sediments.

Minerotrophic – an ecosystem that obtains nutrients from ground water and precipitation, as opposed to solely from precipitation (ombotrophic).

Monimolimnion – the lowest, most dense layer of water in a meromictic lake; a layer that does not mix with the layers above it.

Monomictic – a description of a lake with layers that mix only once a year.

Muskeg − a large natural expanse of peatlands or bogs across northern North America; covered with *Sphagnum* mosses, tussocky sedges, and an open growth of scrubby trees.

Naphthenic acids (**NAs**) − a diverse class of saturated, polycyclic and acyclic carboxylic acids that naturally occur in petroleum deposits; processing of bitumen in oil sands mining releases these chemicals, and may concentrate NAs in process-affected water and tailings found on reclaimed landscapes; prior to microbial decomposition, some types of naphthenic acids are highly toxic to aquatic organisms.

Nutrient − a chemical essential for the growth and development of organisms.

Oil sands − a subterranean sandy deposit containing between 4% and 18% bitumen; also known as tar sands.

Oil sands leases – long-term agreements between oil sands operators and the provincial government. They permit the leaseholder to extract bitumen within the specified lease area.

Oligotrophic − nutrient poor; most often used with reference to lakes; a condition characterized by slow growth and low biomass; the opposite of eutrophic.

Organic − chemical compounds based on carbon; often associated with living systems.

Overburden − geological materials of little value that lie above the mining resource; the layers of material (typically sand, gravel and shale) that must be relocated to extract oil sands; a general term describing the upper part of a sedimentary deposit.

Peat − a heavy turf consisting of unconsolidated, partly decomposed vegetation, such as *Sphagnum* moss; typically found as a thick sediment in bogs.

Periphyton – a complex mixture of algae, bacteria and other microbes covering submerged surfaces that can serve as food for higher trophic-level organisms such as aquatic insects; sometimes referred to as biofilm.

Permeability − ability of a material (e.g., porous rock or soil) to transmit or store water.

Phenols – a group of chemical compounds similar to alcohols but with higher acidities; can be toxic.

Phytoplankton − photosynthesizing microscopic organisms found in water bodies that form the base of many lake food webs.

Polycyclic aromatic hydrocarbons (PAHs) − a group of more than 100 complex organic compounds present in oil sands; may also be formed during combustion processes (burning of coal, oil and gas, wood, etc); some are highly toxic to aquatic organisms.

Primary productivity − the rate at which solar energy is converted by photosynthetic organisms (plants and algae) into organic matter that serves as food for the base of a food web.

Process-affected water − water that has been altered in chemical composition by activities associated with oil sands mining; includes raw tailings water, dyke seepage, process water, and water released from tailings.

Progressive reclamation − interim or concurrent reclamation undertaken during the extractive phase of mining.

Pycnocline – the sudden gradient change in chemistry (e.g., temperature, salinity), between two different layers in a stratified lake.

Recharge − with reference to groundwater, movement of water from the surface into an aquifer; the process by which water is absorbed and added to the zone of saturation; opposite of discharge.

Reclamation − the process of converting disturbed land to its former or other productive uses to ensure: (1) stable, non-polluting, and appropriate conditions that achieve end use objectives, and (2) equivalent land capability; the removal of structures, the decontamination of structures and land or water, the stabilization, contouring, maintenance, conditioning, or reconstruction of the surface of land, and any other procedure, operation, or requirement specified in the regulations.

Restoration − the process of restoring site conditions to a condition comparable to what they were before disturbance.

Riparian − vegetation or area adjacent to or associated with the semi-aquatic edge of a waterbody such as a lake margin.

Runoff − the portion of the total precipitation on an area that flows in a water body or entering the soil and recharging ground water.

Saline − salty; an aqueous environment containing high concentrations of dissolved salts; dominated by sodium and sulphate ions rather than calcium and bicarbonate ions.

Sediment − solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its origin by air, water, gravity, or ice and has come to rest on the surface.

Seepage − the flow of water into or from a soil; the emergence of water from the soil over an extensive area in contrast to a spring where it emerges from a localized area.

Silt − a soil constituent consisting of particles between 0.050 and 0.002 millimetres in diameter.

Sodic – saline soil containing high levels of sodium salts.

Solids (tailings) – the mineral grains (largely quartz particles and clay minerals).

Soft tailings − formed by injecting mature fine tailings from the tailings ponds into the regular (whole) tailings sand stream, with a flocculent such as gypsum; this mixture is sent to the tailings ponds to form a non-segregating mixture.

Strata − layered geological units, as in the layered soils of the oil sands region (laid down by different marine and freshwater sedimentation events).

Substrate − a solid surface that supplies a place of attachment or place of dwelling of an organism; may be rocks, sand, mud, or the surface of a plant.

Suspended sediment − solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its origin by air, water, gravity, or ice and has come to rest on the surface.

Suspended solids − organic or inorganic particles suspended in water; includes sand, silt, and clay particles and unicellular animals and plants.

Swale – a low-elevation or trough-like feature of a landscape designed to increase rates of water recharge into underground aquifers.

Tailings – the waste residue produced in the process of extracting bitumen from oil sands.

Tailings ponds – man-made impoundment structures containing tailings. Tailings ponds are enclosed by dykes made with tailings and/or other mine waste materials. Their function is to store solids and water and to act as a settling basin to clarify process water so it may be reused.

Tailings sand – a byproduct of oil sands extraction comprised of sands, process water, and minor amounts of fine particles and residual bitumen; oil sands with the bitumen removed.

Terminal lake – the ultimate collection point where water presents in a watershed; a lake that lies at the lowest elevation on a landscape.

Thickened tailings (TT) – tailings with the addition of a substance that promotes binding of the active minerals for rapid settlement.

Topography − the shape of the ground surface, describing features that determine changes in elevation, such as hills, mountains, or plains.

Total dissolved solids (TDS) – a measure of the concentration of dissolved solids per unit volume of water.

Toxicity − the inherent potential of a chemical to cause adverse health effects to living organisms.

Trace metal – a metallic element present in a sample to a concentration of less than 100 parts per million.

Treatment − chemical, biological, or mechanical procedures applied to a fluid discharge or other sources of contamination to remove, reduce, or neutralize contaminants or toxicity.

Trophic level − position in a food chain or web; the first trophic level includes plants and microorganisms, the second includes herbivores and so on up to the top predators (meat-eaters); the number of energy transfer steps to that level.

Turbidity − degree of cloudiness of a liquid due to suspended solids, such as the murkiness of lake water.

Upland zone – terrain at higher elevation than the riparian, where vegetation shows no aquatic or amphibious characteristics.

Water table − the upper limit of the soil or underlying rock material that is wholly saturated with water; the upper boundary of an aquifer.

Water treatment − the process used to make process-affected water acceptable for reuse as recycled water within the extraction plant or for discharge to the environment. Active water treatment typically involves pumping and amending or physically manipulating water within a vessel or pipeline. In some cases, water may be treated in holding ponds or even end pit lakes through active addition of amendments. Passive water treatment occurs without the addition of amendments.

Watershed − all lands draining into a specific water body, also called catchment.

Weathering − physical and chemical disintegration; a physical and chemical alteration of rocks and minerals exposed at or near the earth's surface to atmospheric agents such as water and oxygen.

Wetland − land having the water table at, near, or above the land surface or which is saturated for long enough periods to promote aquatic processes and characterized by biological activities that are adapted to the wet environment; the Canadian Wetlands Classification System identifies five primary classes of wetlands, namely bogs, fens, marshes, shallow waters and swamps.

Zooplankton − animal life, usually microscopic, found floating or drifting in the water column of water bodies; the trophic link between microbial primary producers (such as phytoplankton) and higher trophic levels (e.g., fish, waterfowl, and, humans).