# GUIDELINES
# FOR WETLANDS ESTABLISHMENT
# ON RECLAIMED OIL SANDS LEASES

**Third Edition**
**2014**

CUMULATIVE ENVIRONMENTAL MANAGEMENT ASSOCIATION
CEMA

Edited by West Hawk Associates

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## Acknowledgements

On behalf of the editors (David Wylynko and James Hrynyshyn of West Hawk Associates), and the authors listed in Chapter 1, I would like to acknowledge and thank all of the members of the Cumulative Environmental Management Association (CEMA), and particularly the Reclamation Working Group and its Aquatic Sub-Group and Wildlife Task Group for their direction, review, and written contributions to this report.

We also thank the numerous reviewers and advisors, which are listed in Chapter 1, for significantly improving the document. In addition, we wish to thank the former Project Manager, Kyle Harrietha, and Project Manager Kim Dacyk, who were instrumental in guiding the work. We are particularly grateful for the artistic prowess of Derrill Shuttleworth, who produced most of the drawings in this document.

I wish to extend a personal thanks to the editors, authors, and the illustrator, for all the time they invested in the production of this document, as they went well beyond the call of duty to ensure the guide is of the utmost accuracy and quality.

Sincerely,

Theo Charette

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# Chapter 1
# Introduction and Background

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## 1.1 Introduction

Over the next century of oil sands mining, hundreds of wetlands will be reclaimed. They will become common features of the final reclaimed landscape. This document is the culmination of reclamation experience accumulated over the past 50 years of oil sands mining (e.g., Figure 1-1) and includes lessons learned from beyond the oil sands mining region. It presents the scientific and engineering expertise to guide all reclamation activities associated with wetland design and construction as the wetland goes through different stages of reclamation (Figures 1-2 to 1-5).

**Figure 1-1. Bill's Lake, a reclaimed marsh that formed on Syncrude's SW 30 Dump in the late 1990s. Photo courtesy of Syncrude Canada Ltd.**

## 1.2 About this guide

This is the third edition of a document first published in 2000 by a multi-stakeholder group called the Oil Sands Wetlands Working Group. The original guide arose from a recognized regulatory need, with the intent that it would be a working document. It was published by Alberta Environment as a planning tool in support of wetlands reclamation on oil sands leases. The mandate of the Oil Sands Wetlands Working Group was adopted in 2002 by a subgroup of the Cumulative Environmental Management Association (CEMA), the Wetlands and Aquatics Subgroup (WASG) of the Reclamation Working Group, which was tasked with revising the wetlands guide. This third edition provides an update of the state of knowledge regarding reclamation of wetlands in the oil sands region. Although the Guide does not specifically provide guidance on how to reclaim wetlands on in situ oil sands leases, it does provide some information applicable to these leases. In turn, recent advances from in situ revegetation trials were incorporated into this Guide. It presents an integrated approach to the planning, design, construction, monitoring, adaptive management, and certification of wetlands reclaimed on surface-mined oil sands leases. This Wetlands guide is meant to be the definitive resource for planners, landform design teams, regulators, stakeholders and Aboriginal peoples with respect to reclaimed wetlands in the oil sands region. Application of this manual and ongoing research, development, and monitoring should lead to a fourth edition in approximately 10 years.

The target audience for this document is multidisciplinary closure and landform design teams of oil sands mines; it provides background information and detailed guidance for all technical disciplines. This document is also intended to serve as a reference for a broader audience of long-range planners, company managers, regulators overseeing oil sands mining, and stakeholders with a vested interest in the future of the region. Government and regulatory staff may use it as a tool for advising mine lease holders, to review mine development applications, and as a resource in the evaluation and certification of reclaimed wetlands. Aboriginal peoples from the region may refer to it when communicating their specific needs to lease holders or when determining how they wish to be involved in and contribute to the reclamation process. The timescale for each project involved is measured in years and decades, meaning each project will outlast many team members, making a common reference essential.

Oil sands mine operators are required to submit wetland reclamation plans that comply with the *Guideline for Wetland Establishment on Reclaimed Oil Sands Leases*, and undertake the construction of pilot wetlands and their watersheds to support updates of the Wetlands guide. Experts who reviewed the second (AENV, 2008) edition of the document, “agreed that the Wetlands (Guide) is largely adequate from the standpoint of scientific underpinnings, but can benefit from revision, updating, and significantly increased emphasis on the applied design, or engineering, component ” (CH2M HILL, 2010). Most reviewers called for “significant updates regarding peat and wetland reclamation hydrology.” Interviews with current and future users of the Wetlands guide (West Hawk Associates, 2012) produced similar comments.

Each chapter addresses one or more specific discipline(s) and is authored by recognized experts on the subject (Table 1-1). Members of the Aquatics Sub-Group and the Wildlife Task Group of CEMA’s Reclamation Working Group reviewed drafts. Advisors with expertise in oil sands mine reclamation research and practice provided comments and suggestions. However, authors were not obligated to incorporate recommended changes and advisors were not asked to approve the text. Thus, the advisors listed in Table 1-1 do not necessarily endorse chapter context. The entire document was also subjected to an independent (“cold-eye”) review by experienced professionals.

**Table 1-1. Guide structure, authors and primary reviewers.**

| Chapter and Description | | Authors | Advisors/Reviewers | Cold-eye Reviewers |
|---|---|---|---|---|
| **1. Introduction and Background** | Introduces the Guide and provides context for the remaining chapters | Théo Charette, CPP Environmental | Aquatics Sub-Group (ASG), CEMA Aboriginal Caucus | Jonathan Price, Department of Geography and Environmental Management, University of Waterloo. |
| **2. Watershed Hydrology and Geochemistry** | Describes hydrological and hydrogeological processes and properties | Andrew Baisley, Lindsay Tallon, and Mike O’Kane, O’Kane Consultants Inc. | ASG<br>Carl Mendoza, Department of Earth and Atmospheric Sciences, University of Alberta | Jonathan Price |
| **3. Natural Wetlands in the Region** | Describes natural wetlands in the region including physical, chemical and biological conditions | Brian Eaton and Jason Fischer, Alberta Innovates Technology Futures<br>Lisette Ross and Lynn Dupuis, Native Plant Solutions<br>Dale Vitt, Department of Plant Biology, Southern Illinois University<br>Matt Wilson and Théo Charette, CPP Environmental | ASG, Wildlife Task Group (WTG)<br>Suzanne Bayley, Department of Biology, University of Alberta | Jonathan Price<br>Susan Galatowitsch, Department of Horticultural Science, University of Minnesota. |
| **4. Lessons Learned from Wetland Reclamation and Restoration Projects** | Describes lessons learned from the non-oilsands wetland reclamation as well as from the three decades of wetlands design and establishment on oil sands leases | David Cooper, Kristen Kaczynski, Andrea Borkenhagen, and Stéphanie Gaucherand, Department of Forest and Rangeland Stewardship, Colorado State University<br>Gord McKenna, BGC Engineering Inc. | ASG<br>Jan Ciborowski, Department of Biological Sciences, University of Windsor | Jonathan Price<br>Susan Galatowitsch |

| Chapter and Description | | Authors | Advisors/Reviewers | Cold-eye Reviewers |
|---|---|---|---|---|
| **5. Wetland Design for Mine Closure Plans** | Wetland design for mine closure plans | Gord McKenna and Vanessa Mann, BGC Engineering Inc. | ASG, WTG<br>Ann Smreciu, Wild Rose Consulting<br>Line Rochefort, Département de Biologie, Université Laval | Jonathan Price<br>Susan Galatowitsch<br>Norbert Morgenstern, Professor Emeritus, University of Alberta |
| **6. Wetland Design at the Landform Scale** | Overview of the design process from a landform design perspective | Gord McKenna<br>Vanessa Mann<br>Lisette Ross | ASG, WTG | Jonathan Price<br>Susan Galatowitsch<br>Norbert Morgenstern |
| **7. Wetland Construction** | Overview of the construction and revegetation process | Lisette Ross<br>Dale Vitt<br>Gord McKenna Vanessa Mann | ASG, WTG | Jonathan Price<br>Susan Galatowitsch<br>Norbert Morgenstern |
| **8. Operation, Maintenance and Monitoring** | Describes operational, maintenance, monitoring and risk management strategies for wetlands after their construction | Gord McKenna and Jordana Fair, BGC Engineering Inc.<br>Lisette Ross | ASG, WTG<br>Jan Ciborowski | Jonathan Price<br>Susan Galatowitsch,<br>Norbert Morgenstern |

### 1.2.1 How to use this document

*Guidelines for Wetlands Establishment on Reclaimed Oil Sands Leases* should be used with other reclamation planning documents. These include *Landscape Design Checklist* (Millenium EMS Solutions, 2010), *Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region* (AENV, 2010), *Riparian Classification and Reclamation Guide* (Geographic Dynamics Corp., 2011), *End Pit Lake Guidance Document* (CEMA, 2012), and *Criteria & Indicator Framew*ork (CPP Environmental, 2012). Collectively, they support an integrated approach to wetlands reclamation, from planning to certification. In addition to the sources listed above, dozens of wetland design and construction guides may also be referenced.

Wetland design and construction also requires integrated and multidisciplinary teams.

> *"Whereas most construction projects are relatively easy to pigeon-hole into their various sub-disciplines, wetland projects defy this type of compartmentalization. Although contractors and engineers are not biologists and vice versa, the need to understand each other's work and professional approach is much greater than in other projects."* Connell and Hayes (2000).

### 1.2.2 Wetland classes used in this document

To describe the wetlands currently and potentially attainable by reclamation initiatives, this Guide presents a modified version of the Canadian Wetland Classification System (NWWG, 1997). The Canadian system distinguishes among the dominant natural wetland types found in the boreal forest (i.e., peatlands) and it was chosen over other systems used to classify natural wetlands in the Oil Sands Region (e.g., Beckingham and Archibald, 1996; Halsey et al. 2004). Each system provides benefits and challenges to wetland designers. The Alberta Wetland Inventory (Halsey et al., 2004) was designed for classification of wetlands based on the Canadian system, but adapted for remote sensing. *The Field Guide to Ecosites of Northern Alberta* (Beckingham and Archibald, 1996) was designed for on-the-ground classification of the landscape (uplands and lowlands), which makes it versatile and useful in the field. However, the Canadian system was deemed most useful, particularly for reclamation planning and design as it provides critical information and thresholds on landscape positioning, hydrology, hydrological connectivity, and water chemistry, all of which are key to reclamation. This “functional” classification system also emphasizes plant community structure and water chemistry, which are widely regarded as important factors for wetland classification and development. Chapter 3 highlights environmental thresholds to be crossed to achieve particular wetland classes, which is particularly useful for reclamation planning. Importantly, the classification system presented in Chapter 3 differentiates between wetland types (e.g., saline and alkaline fens) considered relevant to oil sands reclamation, which in many cases may be affected by saline process-affected seepage and runoff. This modified classification system includes shallow-water wetland, persistent marsh, wet meadow (intermittent) marsh, swamp, bog, saline fen, and alkaline fen. The modified classification system is presented in more detail in section 3.3 and it is used in subsequent chapters.

A new Alberta Wetland Classification System is being developed as a component of the new *Alberta Wetland Policy* (released on September 10, 2013). The rationale behind this new system is that it reconciles multiple regional classifications and inventories into a consistent system for the entire province that will provide the appropriate level of information for provincial regulation, information, and inventory needs. The classification system used in this document is expected to be aligned to the classification system being developed to support the Alberta Wetland Policy, as both are based on the Canadian system. However, the system used in this document recognizes site conditions associated with oil sands mining and should only be used for oil sands reclamation planning and design purposes.

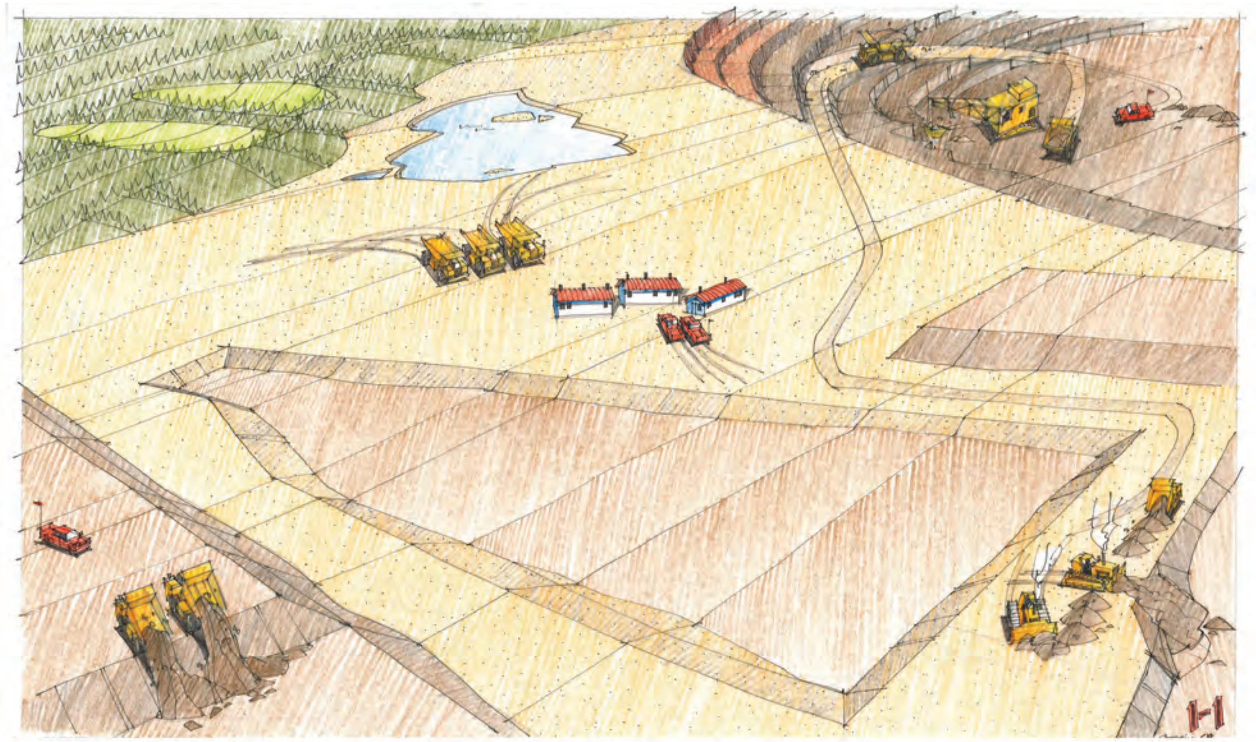


**Figure 1-2. Stage 1 in the life of an oil sands mine reclaimed wetland: Initial earthworks required to rough in the wetland. The location, approximate size and shape of the wetland have been established.**

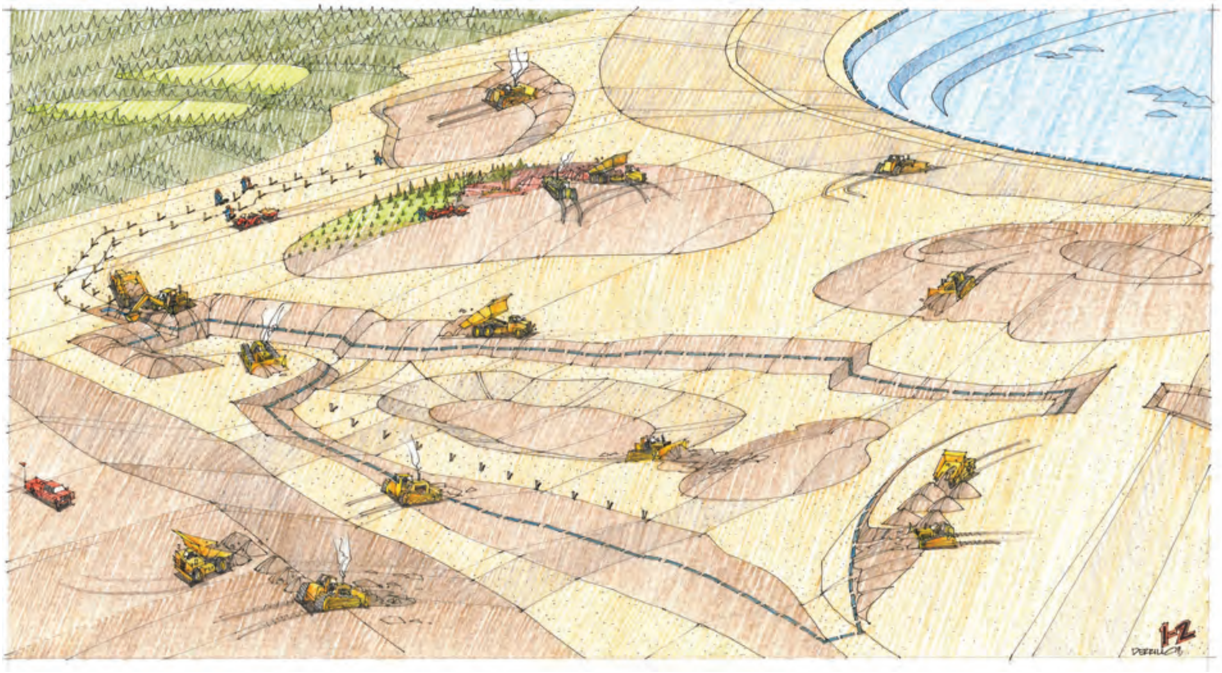


**Figure 1-3. Stage 2: Earthworks required to build and shape finer wetland components. Functional attributes are incorporated at this stage, such as embayments, peninsulas, islands, deeper areas to house open-water pools, and streams.**

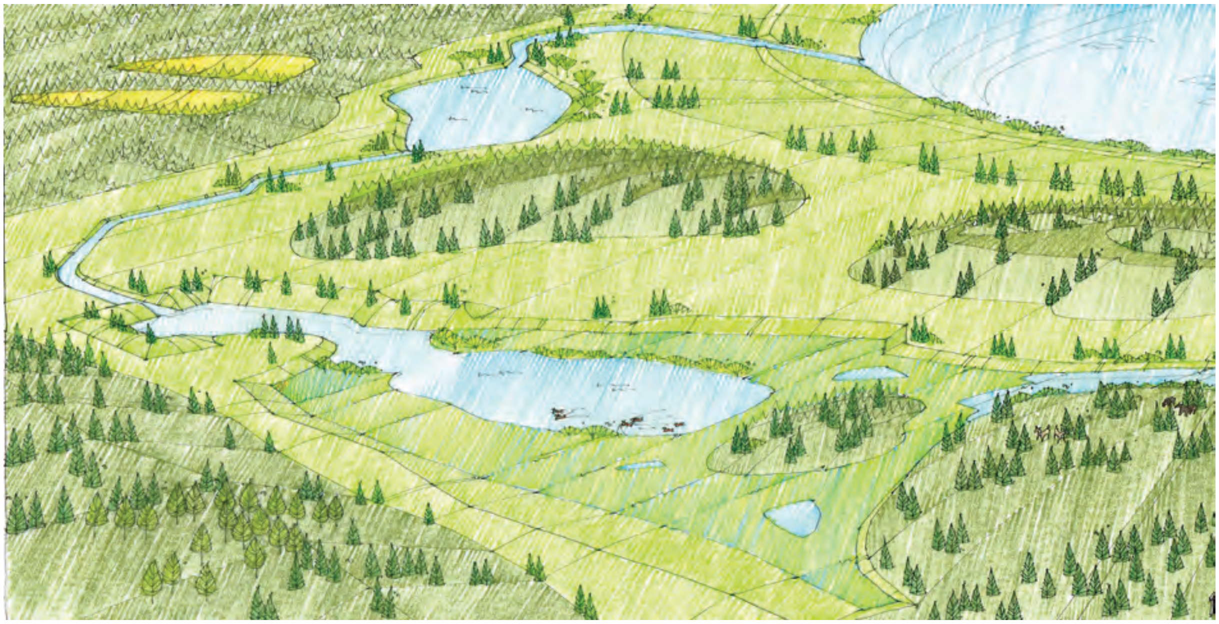


**Figure 1-4. Reclaimed wetland in early stages. The wetland is allowed to fill up and water levels are monitored and managed. Wetland and upland vegetation have been initiated and are managed. Monitoring and adaptive management are very active at this stage, leading to reclamation certification.**

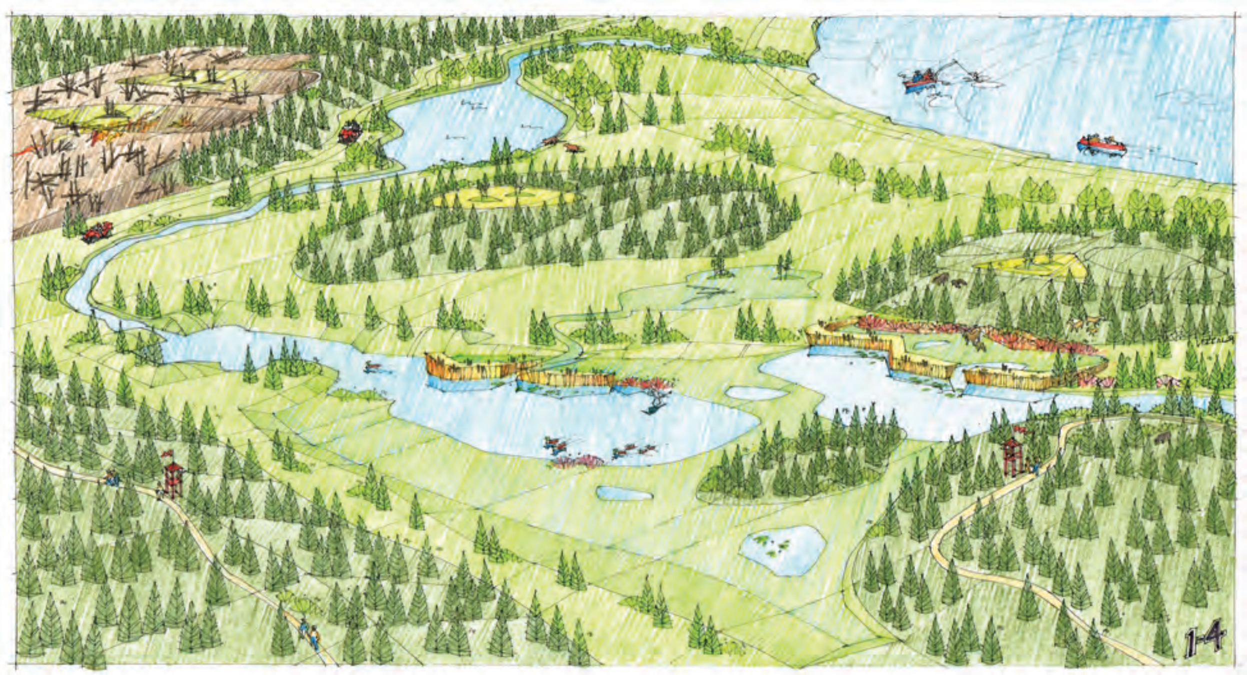


**Figure 1-5. A post-certification wetland years to decades after reclamation was initiated. A reclamation certificate was granted by the regulator. The wetland and surrounding landscape have reached equilibrium and no active maintenance is required. The land supports end land uses.**

## 1.3 Background

### 1.3.1 Ecological and geographical context

The terrain overlying the surface mineable oil sands of northern Alberta is defined by hydrologists, ecologists, Aboriginal peoples and others according to their key interests. Hydrologists and geologists recognize it as part of the Boreal Plain of the Western Canadian sedimentary basin. Foresters and ecologists view most of the area as a central mixed-wood sub-region of the northern boreal forest (Wiacek et al., 2002). Aboriginal peoples have recognized the ecological importance of wetlands for generations. They also have a spiritual and cultural connection to the land (Fitzpatrick, 2003; Section 1.5.3).

The climate is sub-humid, with precipitation less than potential evapotranspiration in most years. The bedrock is sedimentary and deep (often > 50 m below the surface). Surficial soils are the product of riverine deposition, estuarine encroachment, invasion of marine waters and sediments, and glaciation. The topography is flat to gently rolling with the exception of the deeply incised Athabasca River valley. Water movement patterns are largely a function of soil storage and groundwater flow, in contrast with other boreal regions of Canada, where surface runoff dominates. Vertical movement of water through the soil is more important than horizontal movement (AENV, 2008). Traditional land users recognize the importance of storage and delivery of water across or beneath the land (see Section 1.5.3).

**Figure 1-6. A boreal forest marsh/shallow-water wetland.**

Wetlands cover about half the natural landscape, although this varies by location (Kuhry et al., 1993; Vitt et al., 1996; Bayley, 2003). Much of the terrain is saturated for long enough periods to support wet-adapted processes and plants, including hydrophytic vegetation. The resulting wetlands are shallower than lakes, with a mid-summer water depth of 2 m. Unlike streams or channels, they have a non-linear morphology and little to no flow for most of the year (although swamps and fens may have surface sheet flow periodically). In the Athabasca Oil Sands Region, the peat-forming wetlands (fens and bogs) cover 43% of the landscape; marshes 2% (some may be peat-forming in northern Alberta); shallow-water wetlands 1%; and swamps < 1% (Bayley, 2003).

While wetland classification is a critical tool to categorize and describe wetlands at a specific point in time, neither natural nor constructed wetlands are static systems (Chapter 3). They tend to evolve according to biogeoclimatic trends. Natural succession timescales are measured in hundreds or thousands of years, while constructed systems may evolve faster due to elements intentionally or unintentionally introduced during or after construction. For instance, the compaction of upland or wetland soils after reclamation affects the shape and depth of a wetland, water-holding capacity, hydraulic conductivity and water table dynamics (Price, 2003), which in turn affects vegetation. Planting wet-adapted vegetation will accelerate plant colonization and community stabilization. Beavers can dramatically and quickly change the form and function of a wetland or even create them (Naiman et al., 1994). Adaptive management anticipates or enhances the processes of succession, or incorporates flexibility and diversity into reclamation (Chapter 8).

### 1.3.2 Oil sands mining and reclamation

Large-scale surface mining of oil sands in Alberta began in 1967. Five projects were in operation as of January 2013, with others in the planning stage. Production in 2012 exceeded 1.8 million barrels of crude oil per day, with 48% produced by surface mining and 52% by in situ methods. Surface mining activity is currently occurring on about 500 $km^2$ (Alberta Energy, 2013). The first two mines, Suncor's Lease 86 and Syncrude Canada's Mildred Lake lease, are proceeding with progressive reclamation. Wetlands reclamation at these two sites has been underway since the early 1990s (highlighted in Chapter 4). While few reclamation areas have reached the certification stage (Table 1-2), reclamation certificate applications will escalate.

**Table 1-2. Oil sands mine reclamation status as of December 2012. Note that percentages are calculated based on the EPEA-approved oil sands mining footprint. Source: ESRD**

| Area ($km^2$) | Percent | Status |
|---|---|---|
| 689.6 | 45.0 | Not disturbed |
| 763.4 | 49.8 | Cleared or disturbed for mining operations |
| 3.7 | 0.2 | Ready for reclamation; no longer needed for mine or plant operations |
| 14.5 | 1.0 | Soils are placed (terrestrial and aquatic) |
| 38.3 | 2.5 | Permanently reclaimed (terrestrial) |
| 12.2 | 0.8 | Permanently reclaimed (aquatic) |
| 12.3 | 0.8 | Temporarily reclaimed (terrestrial areas that will be disturbed in the future) |
| 1,534 | 100 | EPEA-approved mining footprint (excludes land certified as reclaimed) |
| 1.0 | < 0.001 | Certified (the operator has no further reclamation liability; land can be returned to the province) |

Activities that produce landforms and materials relevant to wetlands reclamation include:

mining excavations produce pits and in-pit and out-of-pit disposal areas;

extraction of bitumen from oil sands (using an aqueous process) produces tailings, which is composed of sand, silt, clay and water. Soluble constituents that are relatively elevated in tailings include organic chemicals (such as naphthenic acids and hydrocarbons), ammonia, certain heavy metals and salts (CEMA, 2012). Many wetlands are planned to be constructed on in-pit and out-of-pit tailings disposal areas;

overburden may be coarse-grained (sand or shale), fine-grained (silt or clay), non-saline, saline or sodic depending on whether it originated in Pleistocene soils or the Clearwater Formation (CEMA, 2005);

the mining process increases the volume of tailings and separated soil components such as overburden and peat by 10-15% over the initial pre-disturbance volume. This process, combined with the presence of out-of-pit disposal areas, can often create greater relief on the mined landscape as compared to the surrounding landscape, which in turn affects water movement.

Saline and sodic leachates and process-affected water are a particular challenge for wetlands reclamation, as many species of boreal wetland plants are sensitive to elevated conductivity and sodium (Howat, 2000; Crowe et al., 2002; Purdy et al., 2005). Many reclaimed wetlands will be under the influence of process-affected water for decades or more. For more information, CEMA (2012) provides a description of the chemistry of process-affected water.

### 1.3.3 Mine planning

An oil sands mine has an average production period of 42 years and a lifetime possibly exceeding 100 years (CEMA, 2012). Although reclamation certification occurs in a relatively short period toward the end of a landform's life cycle, performance depends on the progressive execution of reclamation over time (CPP Environmental, 2013). The decades-long execution time makes planning and management of reclamation extremely important. Moreover, recent work has identified the need to incorporate traditional knowledge and land use information throughout timelines (O'Flaherty, 2011; SENES Consultants Ltd., 2010). Activities throughout the mine life cycle include: 1) Closure planning, 2) Landform design, 3) Construction design, and 4) Operation, maintenance, and monitoring (OMM), reclamation certification and custodial transfer (Table 1-3, Figure 1-7).

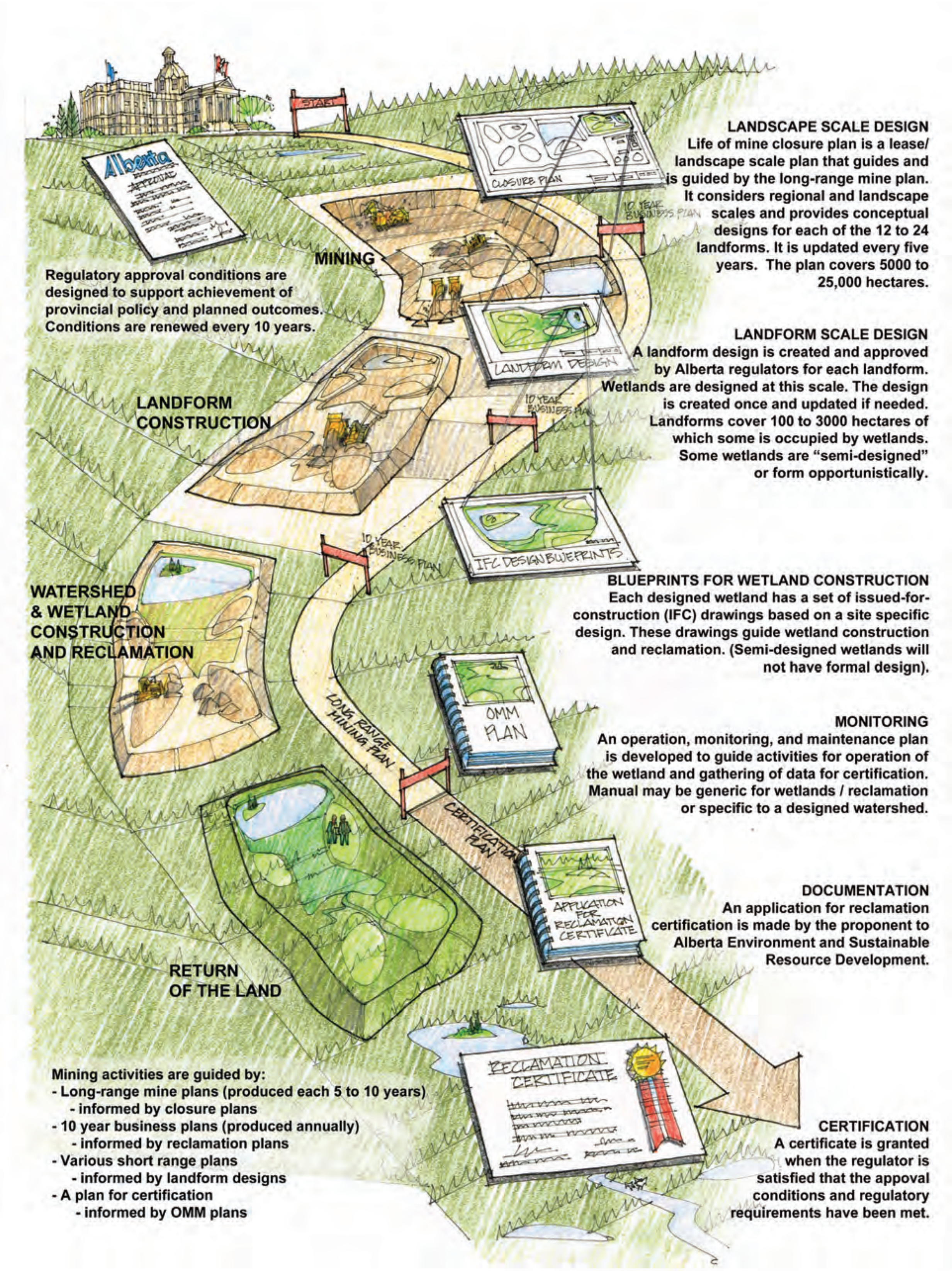
### 1.3.4 Characteristics of existing and planned wetlands

Wetland reclamation is an essential component of closure plans that meet end land-use goals and a statutory requirement of "equivalent land capability." In recent closure plans submitted to the provincial government, stated functions include wildlife habitat (generally, and for specific species), biological diversity, opportunities for aboriginal use, water flow management, and water quality improvement (and, in some cases, wetlands engineered specifically for treatment).

**Table 1-3. Activities during the life cycle of a typical oil sands mine.**

| Activity | Elements |
|---|---|
| **Closure planning design** | Closure plans list, examine, and discuss all activities required to produce acceptable reclamation outcomes for a mine. They reflect the financial and technical requirements of the mine plan, regulatory demands, and stakeholder needs. They also identify conflicts among drivers, provide solutions, and emphasize coordination and integration. They include baseline information, performance goals, regulatory requirements, conceptual designs, end land-use considerations (from discussions with stakeholders), predicted performance, research needs, long-term monitoring and maintenance, schedules and costs. Traditional knowledge can play a role at this stage. Closure plans are updated and submitted to the province every five years to stay current with changing mine plans and regulatory and stakeholder requirements. This stage is the focus of Chapter 5. |
| **Landform design** | This “permit-level design” is a multi-disciplinary effort that results in a combination of terrestrial and aquatic ecosystems that are considered holistically. It includes information on location and boundary, design objectives, geology, watershed components, hydrology, water quality, water levels and freeboard, wetland placement, wetland/shoreline/riparian zone morphometry, design of inlet/outlet channels, model details, slope stability, erosion control, and scheduling and budgets.<br>Landform design will dictate hydrogeological processes that will then determine terrestrial and wetland performance, diversity of vegetation, and forest productivity. Landform construction is the most costly activity to modify at later stages, making early validation essential to minimize future expenses. This design is the focus of Chapter 6. |
| **Construction** | Construction activities can include a combination of roughing out the wetland, shoreline and riparian areas, as well as placing the inlet(s), outlet(s), erosion controls, infrastructure (roads, trails, signage, etc.), soil and vegetation, and infilling the water. Construction is the focus of Chapter 7. |
| **Post-construction activities: operation, monitoring, adaptive management, reclamation, certification and custodial transfer** | Post-construction activities include monitoring and management of water levels, vegetation, wildlife, access, and infrastructure.<br>When a reclaimed land parcel meets regulatory requirements, the operator may apply for a reclamation certificate. Upon approval, the land can be returned to the owner in a state of equivalent capability to its pre-mining condition. The operator is relieved of reclamation liability, although liability for contamination remains with the operator. Aboriginal communities in the region have indicated their desire for greater involvement in the reclamation certification process. Post-construction is the focus of Chapter 8. |

A review of the plans reveals a diversity of approaches, designs, and detail. Variation in number (4 to 43) and area (422 to 3,141 hectares) is high (Tables 1-4 and 1-5). Still, the typical percentage of project area covered by wetlands falls in a narrow range of 2 to 9.7%, reflecting operational and geotechnical constraints. Wetland coverage in the surrounding natural environment, however, is closer to 50%, with some variability. Some plans assume that “general wetland” or “unclassified” wetlands will evolve and do not specify classes. This approach reflects either the desire for greater flexibility in closure planning or the presumption that uncertainties (e.g., climate change) in watershed performance preclude determining wetland type at the closure planning stage.



**LANDSCAPE SCALE DESIGN**
Life of mine closure plan is a lease/landscape scale plan that guides and is guided by the long-range mine plan. It considers regional and landscape scales and provides conceptual designs for each of the 12 to 24 landforms. It is updated every five years. The plan covers 5000 to 25,000 hectares.

Regulatory approval conditions are designed to support achievement of provincial policy and planned outcomes. Conditions are renewed every 10 years.

**LANDFORM SCALE DESIGN**
A landform design is created and approved by Alberta regulators for each landform. Wetlands are designed at this scale. The design is created once and updated if needed. Landforms cover 100 to 3000 hectares of which some is occupied by wetlands. Some wetlands are "semi-designed" or form opportunistically.

**BLUEPRINTS FOR WETLAND CONSTRUCTION**
Each designed wetland has a set of issued-for-construction (IFC) drawings based on a site specific design. These drawings guide wetland construction and reclamation. (Semi-designed wetlands will not have formal design).

**MONITORING**
An operation, monitoring, and maintenance plan is developed to guide activities for operation of the wetland and gathering of data for certification. Manual may be generic for wetlands / reclamation or specific to a designed watershed.

**DOCUMENTATION**
An application for reclamation certification is made by the proponent to Alberta Environment and Sustainable Resource Development.

Mining activities are guided by:
- Long-range mine plans (produced each 5 to 10 years)
  - informed by closure plans
- 10 year business plans (produced annually)
  - informed by reclamation plans
- Various short range plans
  - informed by landform designs
- A plan for certification
  - informed by OMM plans

**CERTIFICATION**
A certificate is granted when the regulator is satisfied that the appoval conditions and regulatory requirements have been met.

**Figure 1-7. Oil sands planning life cycle.**

Some plans outline the objective of creating specific wetland types — fen, marsh, littoral, shrubby riparian, treatment, or swamp — and how this will be accomplished. Some go further and detail soil prescriptions, such as 20 cm of peat-mineral mix (based on research demonstrating that peat amendments over tailings in reclaimed marshes accelerate marsh establishment (e.g., Ciborowski et al., 2011, and Cooper, 2004)). Some fen plans call for direct placement of peat (e.g., 2 metres deep) from donor sites.

All closure plans, however, highlight the emerging nature of the science and practice of wetland design and construction in the oil sands. Closure plans contain information on soil/substrate, water depth/hydrology, water quality, location, and area. They recognize that the success of reclamation is based on hydrology, hydrogeology, soil placement and revegetation prescriptions. Revegetation prescriptions are based primarily on site characteristics. Recommended species include those that are salt-tolerant and/or species of traditional and ecological significance, such as rat root, sedges, and cattail. Native species are preferred, although revegetation techniques vary, and include the use of propagated or salvaged species and donor material. Chapter 5 addresses the need for a regionally standardized approach to closure planning.

**Table 1-4: Summary statistics (per plan) for wetlands from the seven oil sands mine closure plans submitted in 2011.**

| Wetland Type | Mean | Min | Max |
|---|---|---|---|
| Wetland area (ha) | 1,396 | 422 | 3,141 |
| Number of wetlands | 20 | 4 | 43 |
| Percentage of project area covered | 7.3 | 2 | 9.7 |

**Table 1-5: Summary statistics for wetland classes included in the oil sands mine closure plans submitted in 2011.**

| Wetland Type | Number | Total area (ha) | Average % of Project Area |
|---|---|---|---|
| Marsh (incl. littoral) | 45 | 1,807 | 1.7 |
| Fen | 36 | 768 | 1.4 |
| General wetland | 35 | 6,780 | 3.0 |
| Swamp | 7 | 46 | 0.2 |
| Treatment | 6 | 247 | 0.7 |

### 1.3.5 Wetland design teams

Landscape engineering is best performed by teams of professionals with specialized skills and expertise (McKenna, 2002). They may include company representatives, consultants, researchers, and knowledgeable community members. Comprehensive recommendations and designs should be based on best practices.

When planning and design activities are at a minimum, only a small subset of the teams may be engaged. Other stages will call for many specialists to be assembled. It can take 100 years from the start of operations to mine closure (CEMA, 2012), and the resulting significant personnel changes pose challenges. Robust information and document management systems and data warehousing will be necessary. Table 1-6 is an example of a typical team's composition and the level of effort that each member may expend at various stages of the project.

**Table 1-6. Conceptual planning/design team composition at various stages of reclamation and level of impact/effort. H = High. M = Medium. L = Low. + = level of impact/effort is highly variable.** Adapted from CEMA, 2012.

| Discipline | Operational planning, design & construction | | | Mine closure stages | |
|---|---|---|---|---|---|
| | Development Range (life of mine plans) | Long Range (10 yr plans) | Short Range (1-2 yr plans) | Commission | Pre-certification |
| Traditional Land Use Expert | + | + | + | + | + |
| Geologist | M | M | L | n/a | n/a |
| Geophysicist | L | L | L | n/a | n/a |
| Hydrogeologist | L-M | L-M | L | L | L |
| Mining Engineer | M-H | M | H | L | n/a |
| Tailings Engineer | M-H | M-H | L | L | n/a |
| Geotechnical Engineer | L-M | M | H | L | M |
| Closure Designer | H | L | L | L | M |
| Reclamation Specialist | L | M | H | H | L |
| Vegetation ecologist | L | L | H | H | L |
| Process Engineer | L | n/a | n/a | L | n/a |
| Hydrologist | L | L | L-M | L | M |
| Geochemist | L | n/a | n/a | M | L |
| Limnologist | L | L | L | H | H |
| Aquatic Biologist | L | L | n/a | L | H |
| Toxicologist | L | L | n/a | H | H |
| Wildlife Biologist | L | L | n/a | L | M |

One of the disciplines is Traditional Land Use Expert. Currently, the engagement effort for this discipline varies widely. Several CEMA reports highlight the need for consistent inclusion of Aboriginal community participation in reclamation, from planning to building to monitoring (O’Flaherty, 2011; SENES Consultants Ltd., 2010). This supports the involvement of Aboriginal communities to guide reclamation plans and activities in their homeland. CEMA is developing a Traditional Knowledge Framework to this end. This framework will provide guidance to planners on how to work with Aboriginal communities to identify Aboriginal goals and objectives for reclamation outcomes and to incorporate traditional knowledge values and practices into the reclamation planning process. This includes identifying culturally appropriate methods to communicate and share information with Aboriginal peoples and using a participatory process consisting of a flexible, collaborative team-based approach.

## 1.4 Founding management frameworks

### 1.4.1 Landscape limnology framework

Wetland ecosystems will be shaped by complex interactions among terrestrial and aquatic features at multiple spatial and temporal scales (Figure 1-8). Landscape limnology is determined by the patchy pattern of aquatic ecosystems (Wiens, 2002; Chapter 3) and their location relative to other elements of the landscape. For example, the position in the hydrological flow system can influence baseline solute concentrations. Terrestrial elements (geology, soils, watershed topography, wetland morphology, wetland substrates, etc.) affect the amount and quality of materials that are transported from land to water. Aquatic connections determine how materials and organisms are transported among wetlands.

### 1.4.2 Hydrological landscapes framework

The hydrology, chemistry, and biology of aquatic ecosystems reflect the features of the landscape that contribute water to a 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).

A watershed can consist of multiple landforms, each with distinct hydrogeological characteristics. This is particularly true of Alberta, where the surficial geology consists of a thick layer of vertically and horizontally variable glacial drift. The concept of hydrological landscapes was created to cope with this complexity (Winter, 2001). The hydrological landscape framework considers the complete picture surface and groundwater movement and interaction. It recognizes that movement of water is determined by physical principles. Within a climatic region, these principles reflect two components: the form of the land surface (shape, size, slopes of the earth’s surface) and its hydraulic properties. Once these characteristics are understood, so too will the hydrology of the landform of interest.

Moreover, areas in different locations that have 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., 2012). Thus, once individual FHLUs have been fully characterized and catalogued, they can be inserted into a nested characterization of the landscape. The hydrology of the landscape can then be described using simple concepts. The hydrological landscape framework is a useful tool, particularly when a practitioner needs to make sense of the hydrological behaviour of an area with numerous landform configurations. The framework is also the backbone of landform research focused on characterizing FHLUs for the six types of landforms in the region (see Chapter 2).

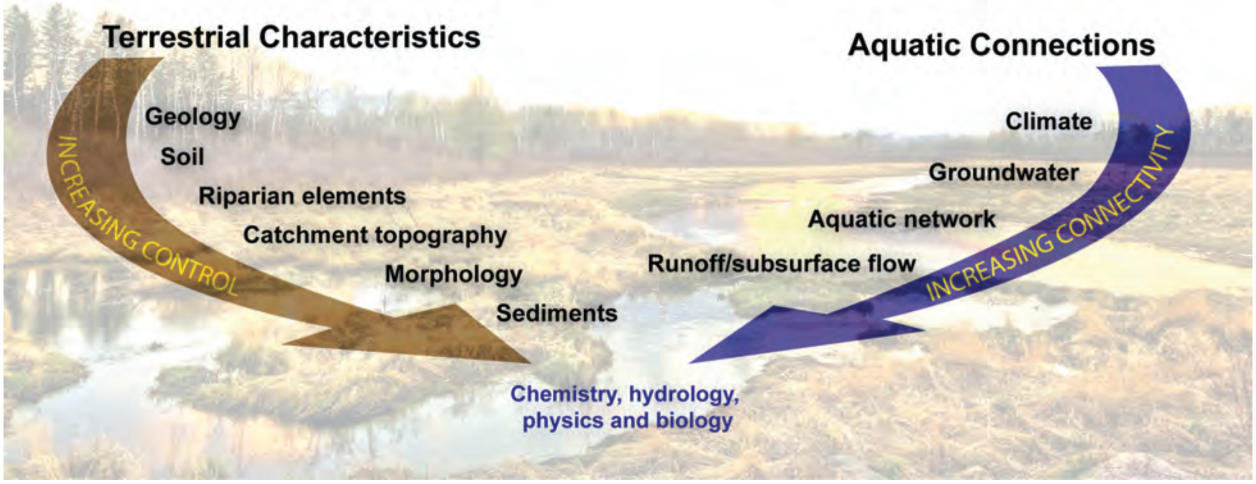


**Figure 1-8. Wetland landscape elements. Modified from Serrano et al., (2009).**

### 1.4.3 Adaptive management

Environmental management involves uncertainty and the potential for unanticipated adverse environmental and social impacts. Adaptive management acknowledges that understanding of an ecosystem will always be incomplete. But as the science improves, so too will the accuracy and reliability of the design, construction and operation of a wetland. Decisions about the wetland should be considered opportunities to improve our understanding of the ecosystem. The results of any wetland “intervention” should be assessed in a timely manner and the experience used to inform subsequent decisions. Adaptive management is a central theme and strategy in this guide, as displayed in Figure 1-9 and detailed in Chapter 8.

Revising designs or operation implies that at least some decisions and actions can be changed, and that there are practical, reasonable, affordable, and timely interventions that have already been assessed and documented. A lack of such planning and assessment often undermines adaptive management (Appendix D of CEMA, 2012).

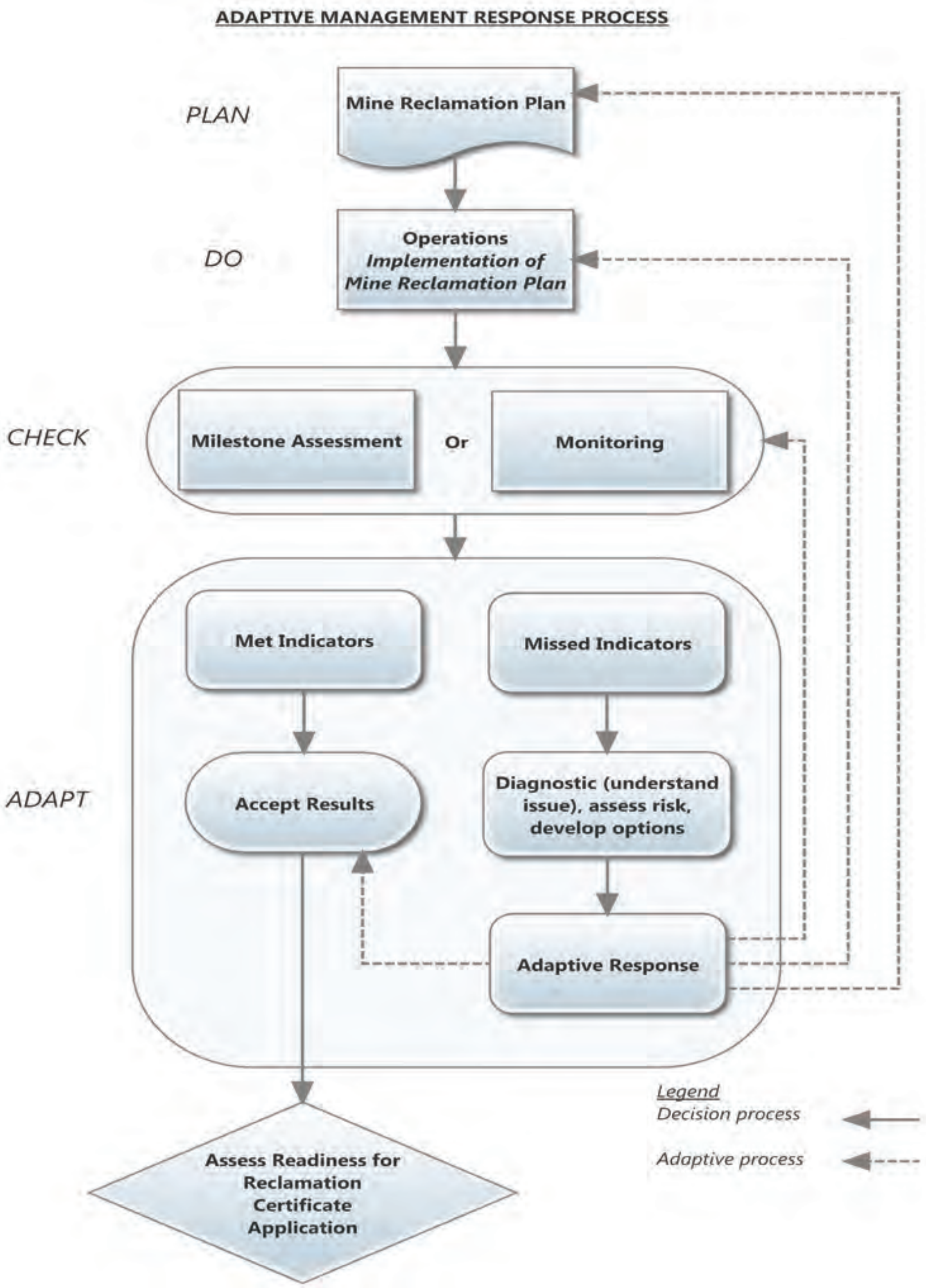


**Figure 1-9. Example of the use of adaptive management within the process of reclamation certification in Alberta.**

#### 1.4.3.1 Minimum ecological management framework

The Minimum Ecological Management Framework (MEM) emerged from experience with marsh restoration projects run by Ducks Unlimited Canada (NPS, 2011). Over the last 30 years, DUC has learned that the main objective in constructing new wetlands is the minimization of management interventions.

The focus is on actions that lead to the long-term sustainability of hydrological cycles most appropriate for the intended wetland type. As detailed in Chapter 8, MEM includes a series of essential steps:

Identification and clear definition of measurable project goals

Creation of a solid reclamation project plan based on adaptive management

Ensuring that enough attention is paid to hydrology and that it is approached strategically

Creation of a solid monitoring program with a documentation process that can feed the adaptive management cycle

## 1.5 Regulations and expectations

### 1.5.1 Regulatory and regional planning context

The reclamation planner must respect legislation regarding water management and environmental protection. Regional and sub-regional plans and strategies are in place and/or are being developed. This section distils this information down to four main categories of regulation, planning and assessment:

Binding legislation – laws that must be followed throughout the project approval, operation and closure of mines, and for which adherence is assessed prior to reclamation certification;

Management strategies – non-binding policy used to guide planning of mining and reclamation activities;

Regional planning – plans intended to direct the development of the region over coming decades; and

Multi-stakeholder strategic planning – non-binding strategies developed by communities working with government to address priority information needs.

#### 1.5.1.1 Binding legislation (laws governing reclamation goals)

The Alberta government and the Alberta Energy Regulator (AER) are largely responsible for regulating oil sands development and reclamation (Responsible Energy Development Act, 2013). Should an issue cross boundaries or have national significance for fisheries or biodiversity, it then falls under joint or federal jurisdiction. Relevant federal legislation includes the Canada Water Act (2005), the Canadian Environmental Protection Act (CEPA, 1999), the Migratory Birds Convention Act (1994), the Species at Risk Act (2012), and the Fisheries Act (1985). See Howlett and Craft (2013) for more information on federal legislation.

In Alberta, Alberta Environment and Sustainable Resource Development leads policy development. The Oil Sands Conservation Act (2000), the provincial Water Act (1999) and the provincial Environmental Protection and Enhancement Act (EPEA, 1993) are the most relevant pieces of legislation for wetlands reclamation. Responsibilities under these Acts are addressed during the mine application process, and specifically, during preparation of environmental impact assessments (when mitigation and reclamation measures must be described) and during operations as EPEA Approvals are created and renewed.

The government can establish conditions in the EPEA approval reflecting the proponent’s commitments made in the EIA. Such commitments (and approval conditions) can include specific mitigation measures or the preparation of conservation or reclamation plans. Under the Oil Sands Conservation Act (and its Oil Sands Conservation Regulations), oil sands mine applications are made, public hearings on these applications are held, and regulations with respect to construction, operation and abandonment of landforms are set. The Act specifically prohibits “waste of oil sands resources” and stipulates “maximum recovery of crude bitumen,” provisions that substantially affect reclamation.

A fundamental component of the EPEA and its Conservation and Reclamation Regulation (1993) is the reclamation objective of returning disturbed landscapes to “equivalent land capability.” This concept recognizes that, while only some reclaimed ecosystems may be identical to pre-mining conditions, the acceptable standard for end land use and environmental integrity is high. The Regulation outlines the provisions for returning the specified land to an equivalent land capability, supplies the roles and responsibilities of reclamation inspectors, and sets the requirements for an application for a reclamation certificate.

In February 2009, the ERCB (now part of the AER) issued new tailings management regulations (Directive 074), which established aggressive criteria for managing tailings. Operators are required to reduce tailings and provide target dates for closure and reclamation of tailings ponds. The Directive also lays out timelines for operators to process fluid tailings at the same rate they produce them, which aims to eliminate growth in fluid tailings. To this end, companies must implement plans that significantly reduce growth in fluid tailings by consolidating fluid tailings and forming deposits of consolidated tailings that are ready for land reclamation. The directive requires annual mine and tailings plans to be submitted. The province is also developing a Tailings Management Framework to deal with pre-existing (legacy), current and forecast tailings. Performance criteria will be aimed at reducing the impact of tailings storage and encouraging reclamation of legacy tailings. Tailings regulations have the potential to greatly affect wetlands reclamation since many wetlands are planned to be built on in-pit and out-of-pit tailings disposal areas.

#### 1.5.1.2 Management strategies (with water conservation objectives)

In 2003, Alberta Environment (now Alberta Environment and Sustainable Resource Development (ESRD)) introduced a “Water for Life” strategy, which recognized three goals: safe, secure drinking water; healthy aquatic ecosystems; and reliable, quality water supplies for a sustainable economy (AENV, 2003). The strategy gives wetlands, as fundamental components of watersheds, a high priority for conservation and makes development of a wetland policy and supporting action plan a major objective. The Alberta Wetland Policy received Cabinet approval in September 2013. It is provincial in scope and the goal of the wetland policy is to “conserve, restore, protect, and manage Alberta’s wetlands to sustain the benefits they provide to the environment, society, and the economy.”

This policy is based on wetland value, which is determined by relative abundance on the landscape, biodiversity, ability to improve water quality, capacity for flood reduction, and human uses. Wetlands are to be assigned an overall wetland value, which will be used in compensation schemes. Where permanent wetland loss is incurred, wetland replacement is required and the amount of replacement is dictated by the calculated value of the wetland, which will be assessed in the field using a standardized methodology currently under development by ESRD. “In cases where development that results in wetland loss is subject to a reclamation plan, replacement requirements will be adjusted accordingly, taking into account the area and value of both wetlands lost and wetlands constructed under the reclamation plan” (AENV, 2003). Types of replacement include restoration/reclamation and “non-restorative replacement,” which includes a variety of methods that advance the state of wetland science and management. An implementation plan for the Green Area, which includes the mineable oil sands region, is due in late 2015.

The Water for Life Strategy, created by the Alberta government in 2003, also led to the establishment of Water Planning and Advisory Councils (WPACs) for the Athabasca watershed. WPACs will develop watershed management plans, and it is expected that the structural and functional health of reclaimed wetlands will be considered within a landscape-scale framework.

#### 1.5.1.3 Regional planning (addressing sustainable development)

The Land-use Framework, authorized under the Alberta Land Stewardship Act (2010), created seven new land-use regions and calls for the development of a regional plan for each one. They are to use a cumulative effects approach to manage the impacts of existing and new activities. In August 2012, the province approved the Lower Athabasca Regional Plan (LARP), which is a product of three years of consultation with Albertans, First Nations, Métis, and experts on social, economic and environmental issues. The following excerpts from LARP are relevant to wetland reclamation:

> LARP’s strategic directions of “encouraging timely and progressive reclamation of disturbed lands” and “inclusion of Aboriginal peoples in land-use planning;”
>
> LARP sets out the development of a Tailings Management Framework, which is a plan to deal with legacy tailings;
>
> The direction to reclaim as quickly as possible is an important concept;
>
> LARP recognizes the importance of using reclaimed lands to help achieve the region’s desired economic, environmental and social outcomes.

#### 1.5.1.4 Strategic planning and research (problem-solving issues)

As regulatory direction has increased over the past decade, a number of multi-stakeholder (e.g., CEMA, RAMP, WBEA, AWC-WPAC) and industry (e.g., CONRAD and COSIA) initiatives have been launched. Multi-stakeholder groups contain representatives from the oil industry, provincial and federal government, Aboriginal peoples, and sometimes forestry interests, academics and consultants. The common objectives are the identification and filling of information gaps that impede reclamation work or environmental management. Subsequent recommendations to government can become binding if incorporated into project approvals.

Oil sands operators are required, through EPEA Approval conditions, to participate in CEMA to produce recommendations and management frameworks pertaining to the cumulative impact of oil sands development. Recommendations from CEMA are submitted to Provincial and Federal government regulators, which may then be included in EPEA Approvals. Through this process, CEMA is a key advisor to governments committed to inclusive dialogue on cumulative environmental effects of regional development on air, land, water, and biodiversity. CEMA membership includes representatives from the oil sands industry, provincial and federal governments, Aboriginal groups, and non-profit organizations such as environmental advocacy groups and educational institutions.

CEMA’s Reclamation Working Group produces and maintains guidance documents that provide recommendations and best practices to ensure that oil sands reclaimed landscapes meet regulatory requirements, satisfy the needs and values of stakeholders, and are environmentally sustainable. A key deliverable of the group is to produce the Wetlands guide, which is reviewed every 5 years and updated as necessary. Advances in wetland reclamation for the oil sands region are largely driven by the EPEA approval conditions which require operators to ‘undertake construction of pilot wetlands and their watersheds to provide opportunities for monitoring, model validation, and incorporation of the findings’ into the update of the Wetlands guide. Operators are also required to submit a 5-year Wetland Research Plan, the findings of which must be incorporated into the update of the Wetlands guide. The EPEA approval conditions also require operators to submit a Wetland Plan periodically (approximately every 5 years), which “shall comply” with the Wetlands guide.

### 1.5.2 Regulatory objectives for reclamation

EPEA’s Conservation and Reclamation Regulation defines equivalent land capability as “similar to the ability that existed prior to an activity being conducted on the land, [recognizing that] the individual land uses will not necessarily be identical.” Land capability is further defined as “the ability of land to support a given land use, based on an evaluation of the physical, chemical and biological characteristics of the land, including topography, drainage, hydrology, soils and vegetation.”

Broad environmental components will be examined to evaluate reclamation performance. The *Criteria & Indicators Framework for Reclamation Certification* (*C&I Framework*; CPPENV, 2012) recommends specific objectives to define “equivalent land capability.” (Table 1-7). It identifies a common reclamation goal, which is prescribed in EPEA mine approvals: “The reclaimed soils and landforms are capable of supporting a diverse self-sustaining, locally common boreal forest landscape, regardless of the end land use.” The content of the *C&I Framework* defines the conditions to determine successful reclamation, meaning that a site is on track toward the reclamation goal. Table 1-7 presents the Goal-Objectives-Criteria in the *C&I Framework*. The *C&I Framework*, although not a regulatory document, collates performance criteria and indicators prescribed in EPEA mine approval conditions and CEMA reclamation guideline documents. A draft Record of Progressive Reclamation, as referenced in LARP, was developed in 2013 and is aligned with the objectives and criteria of the *C&I Framework*.

Oil sands wetlands are currently designed to meet the regulatory expectation of self-sustainability. That is, after an initial monitoring and maintenance period (envisioned to last from 3 to 10 years) wetlands fall under the scenario of an absence of any human intervention. There is great debate as to the achievability of this expectation, but nonetheless this is the basis for all designs. Self-sustenance is discussed further in Section 8.1.1.

**Table 1-7. Reclamation goal, objectives and criteria from the *Criteria & Indicator Framework for Reclamation Certification* (CPPENV, 2012).**

| **Goal: Reclaimed soils and landforms are capable of supporting a diverse, self-sustaining, locally common boreal forest landscape, regardless of the end use.** | |
|---|---|
| **Objective 1: Reclaimed landscapes are established that support natural ecosystem functions.** | |
| **Criteria** | a. Landforms are integrated within and across the lease boundaries. |
| | b. Landforms have a natural appearance. |
| | c. Landscape and landforms incorporate surface drainage, lakes and wetlands. |
| | d. Landforms have geotechnical stability. |
| | e. Reclamation materials are placed appropriately to the landform. |
| | f. Terrestrial and aquatic vegetation appropriate to the boreal forest is established. |
| **Objective 2: Reclaimed landscapes are established that support natural ecosystem functions.** | |
| **Criteria** | a. Reclaimed landforms have the required water quality. |
| | b. Reclaimed landforms have the required water quantity. |
| | c. Nutrient cycling is established on the reclaimed landscape. |
| | d. Reclaimed ecosystems display characteristics of resilience to natural disturbances. |
| **Objective 3: Reclaimed landscapes are established that support natural ecosystem functions.** | |
| **Criteria** | a. Reclaimed landscape provides for biodiversity. |
| | b. Reclaimed landscape provides commercial forests. |
| | c. Reclaimed landscape provides fish and wildlife habitat. |
| | d. Reclaimed landscape provides opportunities for traditional use. |
| | e. Reclaimed landscape provides opportunities for recreational use. |

### 1.5.3 Aboriginal expectations for wetland reclamation

Aboriginal residents of the Regional Municipality of Wood Buffalo use wetlands for subsistence hunting and trapping, food and medicinal plant collection, and spiritual well-being. Recent studies (Garibaldi Heritage and Environmental Consulting, 2006; O'Flaherty, 2011; CEMA, 2012) have found that indigenous values address all of the broad forms of wetland function identified in this guide (e.g., hydrology, water quality, provision of animal habitat, land use, and other ecosystem functions).

Cultural values, in addition to ecosystem values, should be recognized in the design of the reclaimed landscape. It is important to incorporate cultural values and experiences of the First Nations into the reclaimed landscape. Due to the availability of published studies, some of this discussion is focused on the cultural values and traditional knowledge of the Fort McKay First Nation.

The significance to First Nations of living off the land cannot be overstated (Fort McKay Industry Relations Corporation, 2010). The hunting and trapping of a wide variety of animals, fishing in lakes and rivers, and gathering a broad range of berries and other plants is important economically, culturally and socially. Most Aboriginal communities believe that reclamation should restore wetland plants and animals that have been used for harvest and consumption (O'Flaherty, 2011; AENV 2008, Appendix F). Rat root (sweet flag, *Acorus calamus*) is an example of a culturally significant wetland plant, used regularly as a natural remedy for a number of aches, pains, colds and flus (Fort McKay First Nation, 1996; Garibaldi Heritage and Environmental Consulting, 2006). Rat root, an important medicinal wetland plant, is also recognized by some members of the community as having two different forms. The habitat (wetland type) in which the rat root occurs, and the colour of the rhizomes, are believed by some to influence the medicinal effectiveness of the plant (Garibaldi, 2006). Waterfowl and fur-bearing species, such as ducks and muskrat, are among many culturally significant species.

For residents of Fort McKay, as with many other communities, hunting and harvesting are central to their way of life; they reaffirm the continuing vitality of Aboriginal culture and strengthen the kinship links through which harvesting is organized and wild food distributed (Fort McKay Industry Relations Corporation, 2010). Indeed, in a study of wetlands, O'Flaherty (2011) stressed that Fort McKay wetland values are not merely object-oriented but also include the experiential benefits of being on the land, reinforcement of social ties, and transmission of traditional ecological knowledge and culture to new generations. O'Flaherty suggests that Fort McKay people believe that in addition to providing habitat for animals being harvested, wetlands support the individual and family needs of other animals, which are as important as those of Fort McKay people. He concluded that in Fort McKay's view, ecological values of wetlands are intrinsic; their importance does not rely on being valued by people.

In Fort McKay's framework, four primary cultural components describe the ways in which people experience culture: self, community, land and creator. These four cultural components are linked with community values of tradition, self-reliance, self-determination, cooperation, caring, cohesion/bonding, connectedness, purpose, peace, rootedness, rhythm of nature and respect. Selected traditional activities considered to be indicators of cultural values include: hunting, fishing, trapping, berry-picking, wage employment, education, visiting and raising children (Fort McKay Industry Relations Corporation, 2010).

"Intangible cultural values" (O'Flaherty, 2011), such as broader ecological values, cultural values, and social processes associated with how Aboriginal peoples use wetlands must also be considered. Some communities support reclamation approaches that would restore opportunities for socially and culturally meaningful activities. For example, Aboriginal peoples from the region once lived in small, isolated family units and survived by trapping muskrat and beaver in the winter. Trap lines still lie at the heart of the connection of the people with the land. They may be handed down from generation to generation, linking the young with elders in a practical and spiritual sense. The lines also provide year-round circuits to hunt, fish, collect plants and educate youths about the natural environment.

The disappearance and fragmentation of traplines (Tanner et al., 2001) is an enormous concern. It is believed that the “culture is changing because the landscape is changing” (J. Fraser, pers. comm.). Spirituality for these people springs from their interaction with the land (AENV 2008). The Fort McKay community relies on access to healthy landscapes and wildlife populations to maintain its way of life and culture; it is critical to this community that the reclaimed landscape provides these attributes after mining is completed.

The replacement of appropriate types of wetlands and their extent in the reclaimed landscape are both highly important factors in the incorporation of FN cultural values. Muskeg (organic wetland) is recognized by the Fort McKay First Nation as an integral component of the boreal forest landscape. Cecilia Fitzpatrick, a daughter of the last hereditary chief of the Fort McKay First Nation, related that her father told her of the importance of muskeg: “*that muskeg is why the earth breathes – the body is like the earth, we need a heart to live and the muskeg is your heart, the mountains are your brain and the creeks and rivers are blood vessels”* (Fitzpatrick, 2003). In the past, moose meat was stored in naturally cold muskeg, where the frost never retreated. Moss was collected and dried for toilet paper, diapers, mattress stuffing and house insulation. This integrated view of the landscape and recognition of the importance of muskeg is particularly relevant to reclamation landscape planning.

Another important concern for Aboriginal communities (O’Flaherty, 2011; CEMA, 2012) is aquatic connectivity and the need to consider wetland design at the landscape level (Figure 1-10). This reflects the role of wetlands in the storage and delivery of water across the land surface or underground connections. Water quality is a key indicator. It is seen as a result of water moving through the land, with wetlands and creeks playing a primary role. In a study of wetlands,

O’Flaherty (2011) stressed that for Fort McKay the importance of maintaining connectivity is believed to apply not only to the linking of wetlands but linking the animals and people who use wetland values to both the wetlands themselves and to the other parts of the landscape. Wetlands provide good travel routes during the winter and thus provide connectivity for Fort McKay people across the landscape. The results of the O’Flaherty study indicate that the travel routes linking sites are as important as the values associated with the sites themselves.

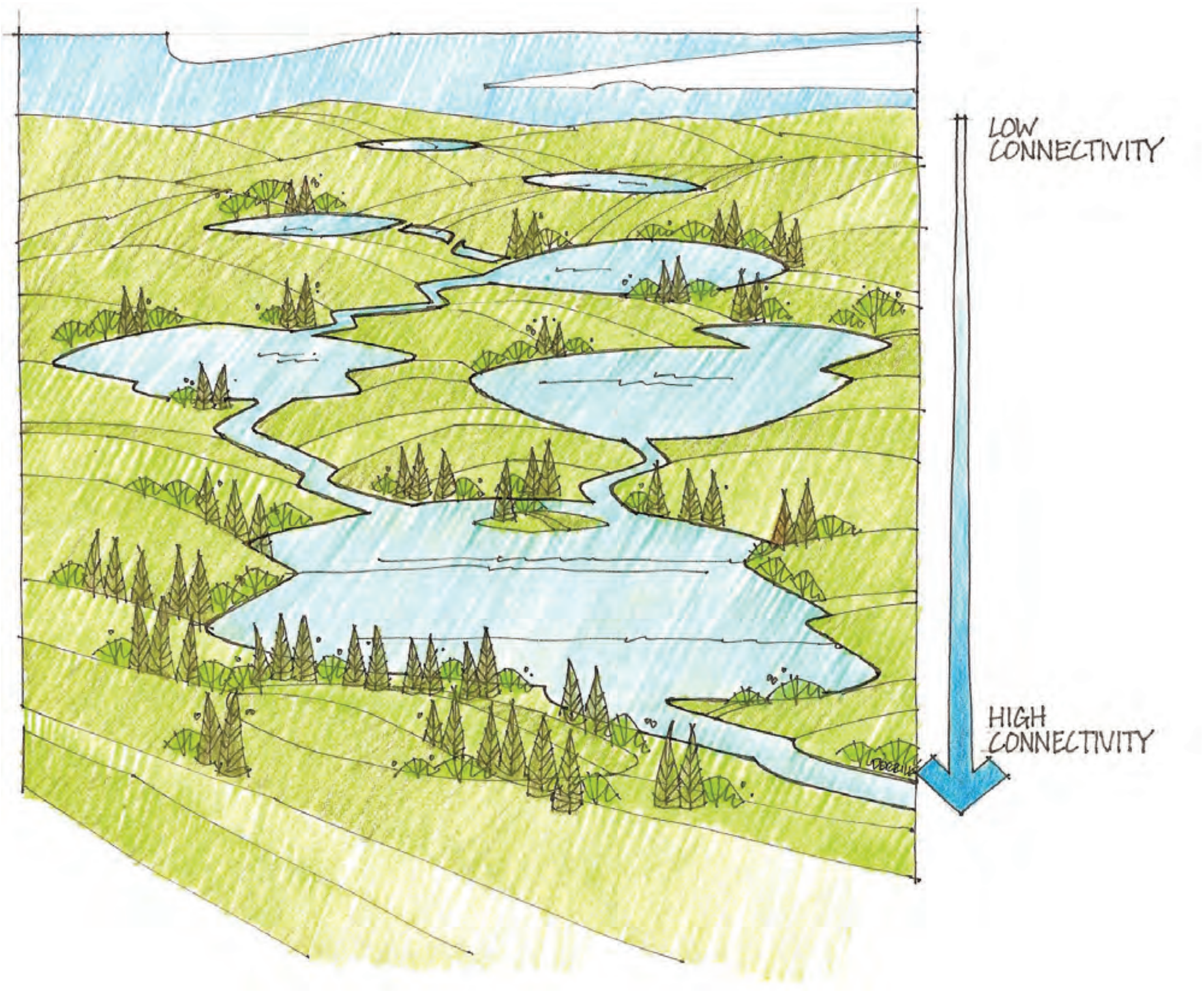


**Figure 1-10. Connectivity of aquatic systems on the landscape highlighting different hydrologic types (e.g., perched, headwater, flow-through).**

O'Flaherty (2011) suggests that because Aboriginal people tend not to speculate about future conditions that are unknowable, the evaluation of the integrity of reclaimed wetlands could best focus on comparisons with natural analogues. Additionally, O'Flaherty made some suggestions for qualitative yet measurable criteria to evaluate the extent to which Fort McKay values are being returned to the land:

People are able to harvest plants and animals that they believe meet their customary use requirements;

Animals (especially beaver, moose and bear) are successfully raising healthy families;

People are able to move freely on the land to access reclaimed wetlands;

Site-specific wetland values are functionally connected with a range of other wetland and non-wetland values; and

> People are able to identify personal and family history on the land and value this history as positive, including by passing it on to their children.

Due to the long-term nature of many of these criteria, this assessment will not be appropriate for isolated reclamation sites. It will require mature, interconnected wetlands in a larger final reclaimed landscape.

An important consideration is the distribution and proportion of these wetland units on the reclaimed landscape, since it will likely be a greatly changed landscape from the pre-mining condition. Current closure and reclamation plans reduce the amount of wetlands in the final landscape, replacing them with upland forests and large scale end-pit lakes, which significantly change the reclaimed landscape from that which existed before oil sands development (Buffalo et al., 2011).

Garibaldi (2009) suggests that one useful approach for focusing efforts in restoration is to target species that are both foundational to cultures and offer meaningful ecological targets for landscapes. These cultural keystone species (CKS) permeate the culture and represent much more to the community than food or sources of raw materials. The list of CKS for Fort McKay includes moose, cranberries, blueberries, ratroot and beaver. The CKS model, when applied to reclamation, offers a mechanism to jointly address social, spiritual, and ecological values of people with connections to the modified landscape. Garibaldi suggests that for reclamation efforts to be meaningful for local people, such efforts must take into consideration more than ecological functionality and address the linked social and spiritual factors. The CKS model provides aboriginal communities an opportunity to use language and symbols that resonate with the community and changes the reclamation structure from one that is externally imposed to one that is internally valid and meaningful.

Garibaldi (2009) indicates that one of the key advantages of the CKS model is its effectiveness at translating cultural landscape information in a way that is understandable to Western researchers. Both Western reclamation practitioners and Fort McKay community members have indicated that focusing on CKS facilitated more meaningful ongoing communication about reclamation.

The CKS model is not directly related to an ecological keystone species role in the food chain; rather it is a social model influenced by ecological theory (Garibaldi, 2009). While the reclamation of habitat for CKS will also support the reclamation of habitat of associated species, the application of this model does not replace the development of ecosystems that can support a range of species. Nevertheless, many of the CKS identified by Fort McKay naturally occur in muskeg wetlands and the re-establishment of healthy populations of these species on functional wetlands within the reclaimed landscapes could be fundamental to reclamation success.

In closing, Elders and others actively practicing a traditional lifestyle have a vast store of knowledge about the wetland of the oil sands region, and the life histories of the culturally significant species that inhabit them. Recent reports have recommended the inclusion of Aboriginal participation at every stage of wetland reclamation, from planning to building to monitoring (O'Flaherty, 2011; CEMA, 2012; SENES Consultants Ltd., 2011). In addition to providing meaningful opportunities for elder input, the participation of youths in wetland reclamation may help strengthen cultural integrity. CEMA is currently developing a Traditional Knowledge Framework that will provide community engagement guidance for reclamation in the municipality.

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# Chapter 2
# Watershed Hydrogeology and Geochemistry

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Water quality and quantity objectives should be defined for each hydrological building block. As well, connectivity between components needs to be considered early in design to achieve water supply and redistribution criteria from landform to landscape.

An important hierarchy for the establishment of engineered wetlands exists. For example, designers need to recognize the overriding influence of climate, and understand both the intra- and inter-annual variability and the specific context of the design timeframe. They must reconcile the impact of climate change on water budgets. They need to determine the quantity, timing and duration required for each component of the landscape through time, using the water budget as a tool. In the oil sands, an accurate conceptual model focusing on evapotranspiration, soil storage, and groundwater, rather than on precipitation and runoff, is key for designing reclamation wetlands.

Planners need to identify and assemble engineered landforms based on material type and hydrologic tendency. They should determine the appropriate arrangement and connectivity of HUs overlain on HRAs, and construct them with features for water conservation and redistribution for the desired hydrological response.

Geotechnical material characterization is important for determining the movement and storage of water. Equally important is the geochemical characterization of materials. Mining materials will influence water quality and our understanding of how they will interact with other materials (e.g., peat). It is important to consider how mining materials will influence future reclamation efforts, while recognizing the unique properties of peat and its significance in wetland hydrology.

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# Table of Contents

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## 2.1 Context

Successful closure designs for wetlands will rely on the interaction of climate, geology, hydrology, vegetation succession, and topography. Wetland occurrence is governed by the amount of water available, storage trends and residence time of water on the landscape, which in turn is partially controlled by the regional climate. The primary climate parameters (precipitation and temperature) are not static but subject to constantly changing values of mean and variance over long periods, making climatic variation a key consideration.

### 2.1.1 Climate in the region

Climate is the overarching controlling factor for hydrology on the Western Boreal Plain (WBP) (Devito and Mendoza, 2006; Devito et al., 2005b). Climate dictates the balance between precipitation and evapotranspiration (ET), as well as the vegetation that enhances ET. In the WBP, the potential exists for a soil water deficit to occur in most years because potential ET (PET) often exceeds precipitation. Seasonal soil water deficits in forestlands may develop in summer, and water stored in the wetland will be important for sustaining wetland processes through dry periods. Evaluation of water resources should occur annually to coincide with the growing season and not vary from year to year. The previous year’s snowfall is an important factor to vegetation for a particular spring to autumn period, with snowfall considered as seasonal storage, less sublimation losses. Water budgets can be evaluated from November to October, while accounting for storage from previous years. Precipitation after senescence of vegetation or after average daily temperatures reach freezing should be carried forward to the following year, as these resources supply water for the following summer. The 12-month year can be evaluated yearly based on air temperature or photosynthetically active radiation (PAR) or remain static throughout the investigation (i.e., November to October).

An understanding of interactions of the dynamic water budget, basin storage properties, and geologic setting is required for an assessment of wetland hydroperiod (Section 2.2.1). This understanding will also determine the form and function of the wetland (Kennedy and Mayer, 2002). Combinations of the above properties, along with the influence of vegetation increasing through time, will produce a hydroperiod that will eventually lead to a specific wetland type.

### 2.1.2 Variability

Sub-humid regions such as the Athabasca Oil Sands are characterized by long-term potential water deficit (P PET) and are modulated by seasonal and decadal wet-dry cycles. Changes in the actual net atmospheric fluxes, the difference between precipitation and actual evapotranspiration (AET) lead to dry (cumulative water deficit), moderate (net water balance near zero), or wet (water surplus) conditions (Bothe and Abraham, 1993); however, P can vary significantly, while AET remains relatively stable from year to year. Average annual precipitation and ET data are of little use in landscape design and performance modelling. More valuable are probabilities of achieving design criteria and performance markers on different timescales (seasonal and decadal).

Designs must anticipate variability in hydrologic response to global climate cycles (i.e., Pacific Decadal Oscillation, El Niño/La Niña) to accommodate periods of extreme water surplus or deficit. However, there is a need to better quantify these cycles and to evaluate their interacting effect on wetland sustainability (Mwale et al., 2009). Distinct cycles of varying duration and frequency are present in historical climate records. Identifying each discrete wetting/drying cycle within the record provides valuable information that will be pertinent to construction timeframes. Within each historical climate record, repeating cycles are evident with unique frequencies.

Climate cycles themselves are variable in frequency, with minor temporal variations from one cycle to the next. These major cycles in the Fort McMurray region repeat every 50, 13, 6, and 3 years, corresponding roughly to the Atlantic Multi-decadal Oscillation, Pacific Decadal Oscillation (PDO), El Niño and La Niña cycles, respectively (Figure 2-1). Similarly, Mwale et al. (2009) showed statistically significant periodic cycles for precipitation of 25, 11, 8 and 4 years, with the 25-year cycle being most dominant for northern Alberta. Identifying cycles in the historical records and forecasting likely conditions relevant to the construction timeline will provide a powerful tool for wetland planners. The effects of large-scale climate anomalies could lead to either an unusually dry or wet climate, in most cases accruing a cumulative net water deficit on the landscape punctuated by short periods of more intense precipitation (Figure 2-1). An in-phase effect could result either in extreme climate (flood or drought) because of mutual strengthening by coinciding amplitudes. Alternatively, “normal” climate may arise from off-phase interactions, creating a cancelling effect. By identifying periods where multiple climate oscillations act to amplify dry periods or wet periods, planners may better be able to place the initiation of reclamation into the overall climate cycle. This may better help allocate water resources into the future. Planners also need to understand that well-documented climate cycles may change in response to climate change (Collins et al., 2010; Fedorov, 2000).

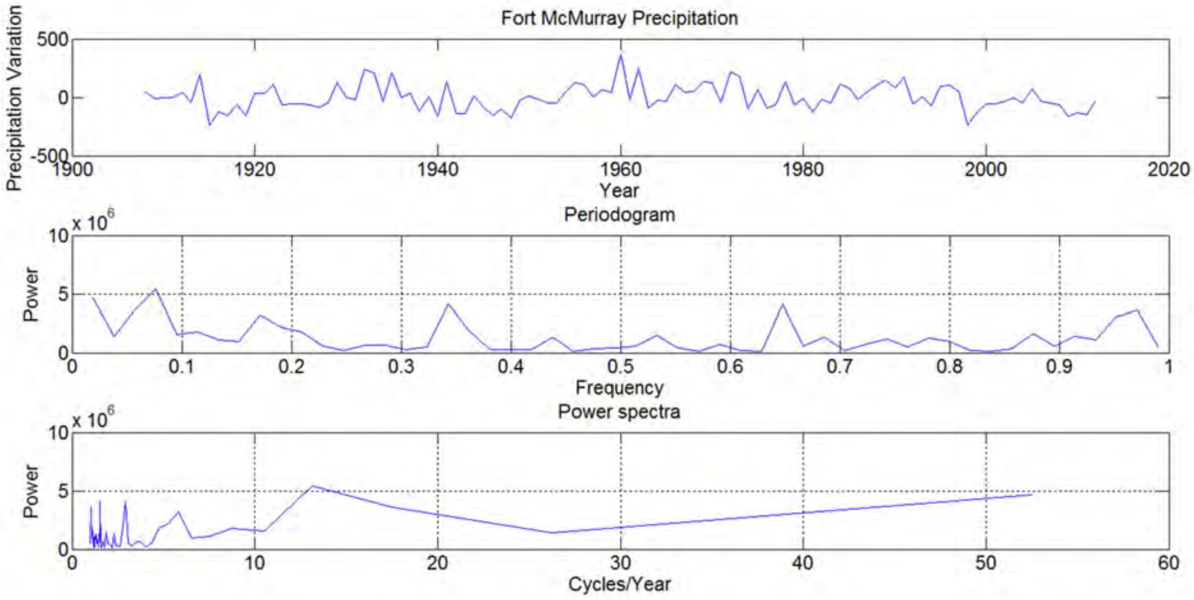

**Figure 2-1. Climate analysis of the Athabasca Oil Sands Region.**

### 2.1.3 Climate change

The trajectory of future climate change trends has been projected according to current socio-economic drivers, in addition to other scenarios (Bernstein et al., 2007). Temperature and precipitation are the primary variables that are most pertinent to wetland design. General circulation models (GCMs) excel at capturing trends in global temperature and resulting forecasts come with a high degree of confidence. But they are less successful at simulating historical trends and spatial distribution of precipitation. GCMs are complex but a grossly simplified representation of the global atmosphere. Despite their shortcomings, they are the best tool available to make future projections for temporal distributions and changes. In a region characterized by potential annual water deficit punctuated by periodic surplus, the frequency and magnitude of precipitation will have large implications on available water resources in the Western Boreal Plain (WBP).

North America is very likely to warm during this century with the annual mean warming likely to exceed global mean warming in most areas (Bernstein et al., 2007). Warming is expected to be greatest in winter in northern regions. Likewise, annual mean precipitation is very likely to increase in much of Canada (Barrow and Ge, 2005). Projected warming is expected to be accompanied by an increase in atmospheric water qux as a consequence of the temperature dependence of the saturation vapour pressure in the atmosphere (Qualtiere, 2011). With increasing temperature, increases of greater than 5°C imply a lengthening of the growing season and increases in ET losses from both wetlands and forestlands (Barrow and Ge, 2005; Seely and Welham, 2010; Welham, 2010). Although the trends are less uncertain than absolute changes in T and P, the effect of feedback mechanisms associated with warming are unclear. Frequency, magnitude, and timing of the precipitation events will be of greater importance to future projections than annual precipitation totals, with implications for interception (Section 2.2.1.2), runoff (Section 2.2.1.3) and groundwater flow (Section 2.2.1.5).

The degree to which increases in temperature-driven evaporation will offset increases in precipitation is unknown. Studies by Keshta et al. (2011) on watersheds in the AOSR utilized down-scaled GCM projections to understand the impact of future changes in precipitation on maximum soil moisture deficits in a probabilistic approach. Although the canopy in the study was assumed to be static, the forecasted maximum moisture deficit was calculated to slightly decrease due to precipitation surplus, whereas evapotranspiration in the study sites is expected to increase (Keshta et al., 2012). Changes in permafrost and ground ice can be expected with increasing minimum temperature, affecting water availability, likely in the form of increased AET, throughout the growing season (Barrow and Ge, 2005). The vulnerability of wetlands to a changing climate depends on the degree to which they rely on groundwater for hydroperiod maintenance. Newly constructed ombrotrophic wetlands that are largely dependent on precipitation are most vulnerable to changes in climate. Wetlands created to utilize discharge from regional groundwater flow systems or process-affected water are likely least vulnerable during initiation before internal conservation feedback mechanisms can establish. Wetlands with groundwater inputs have the buffering capacity of regional groundwater flow systems, though precipitation inputs as recharge to groundwater systems will decline depending on corresponding changes to ET or runoff. Therefore, a lag in climate change-induced stress on wetlands may manifest as decreased groundwater inflows (Herrera-Pantoja et al., 2011). Although ombrotrophic natural systems arguably have a greater resilience to climate-induced desiccation, the differences between natural and constructed systems will play a role. Newly constructed systems will likely have reduced capacity to buffer climate effects due to the negative conservation feedbacks attributed to an established vegetation structure (Waddington et al., 2014).

## 2.2 Hydrology

Hydrology remains fundamental to the success of reclaimed wetlands, just as it does in natural systems. Water inputs to wetlands may come from precipitation, surface runoff, groundwater, or from mine facilities, such as process-affected wastewater in end pit lakes. Water movement through the region contrasts strongly with that of the Boreal Shield (Bell, 2010) and other regions. Surface runoff is minimal compared with soil storage and groundwater flow. Vertical movement of water dominates over horizontal movement in the coarse-grained hydrological resource areas (HRAs) of the WBP. Examining hydrology not only allows planners to budget water resources over the landscape, it also helps them understand trends in water quality, carbon sequestration and vegetation growth.

Interaction of a wetland’s water budget, potential water storage and HRA properties creates a hydrological signature of the seasonal pattern of water depth, duration and frequency of flooding, known as the hydroperiod. The unique signature of each wetland results from the differing water storage potentials, input of water and sediment properties. Therefore, wetland hydrological units (HUs) with similar vegetation-soil-atmospheric interactions may interact with differing underlying geological properties to produce similar hydroperiods (Devito and Mendoza, 2006). Hydrological units are defined in Devito et al. (2012), but generally the region can be divided into:

1. Wetland HUs: Units with long-term average surplus moisture, characterized as potential sources of water to the watershed. Typically characterized by dynamic water tables near the surface due to soil layering, promoting saturated conditions. Storage is limited but the area of exposed open water greatly affects the hydrologic regime due to differences in vegetation and soil processes.

2. Forestland HUs: Units of deeper, drained soils, where ET can be significant due to considerable depth potential. During periods of extended soil water deficits, Forestland HUs can have large water storage potential and act as water sinks on the landscape.

Designers can manipulate vegetation, basin morphometry and geological setting for a range of climate and water-balance scenarios to create sites with a range of hydroperiods necessary to support wetland function, though there are often practical limits at a watershed scale (often driven by economics).

### 2.2.1 Water budget

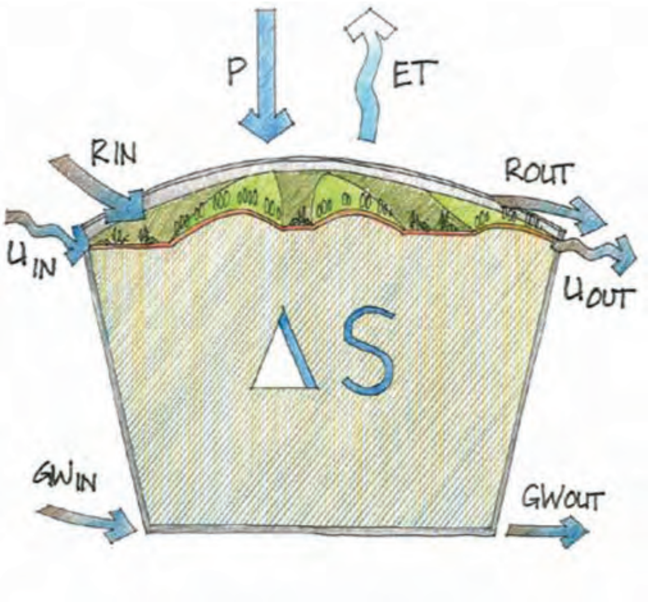

Figure 2-2. Elements of a water balance equation.

The water budget equation devised by Devito et al. (2012) provides the best basis for understanding water allocation in the WBP, where the focus is on storage (Figure 2-2). The water budget equation is used as a tool for understanding and designing for climate, geology and their interaction at differing scales. Identifying patterns of water storage is integral to understanding the hydrologic and ecosystem response on reclaimed landscapes.

Each component of the water budget will differ due to seasonal and decadal climate variability from year to year as well as vegetation succession. All components of the water balance will be affected directly or indirectly by changes in vegetation over time. Managers will need to balance the use of vegetation on the closure landscape for upland flood and erosion control early on with the need to limit plant uptake of soil moisture storage in subsequent years. The hydrological building blocks are connected by plant roots, surface and near surface water, and groundwater.

$$! S = P - ET + (R_{in}-R_{out}) + (GW_{in}-GW_{out}) + (U_{in}-U_{out})$$

Where the primary focus is ! S = change in storage; P= precipitation, ET = evapotranspiration, $R_{in}$ = runoff flowing into a system and $R_{out}$ = runoff flowing out of a system; $GW_{in}$ = groundwater flowing into a system, $GW_{out}$ = groundwater flowing out of a system, and $U_{in}$ = Uplift moving into a system and $U_{out}$ is uplift out of a system.

#### 2.2.1.1 Precipitation

Precipitation varies spatially from 10s to 100s of km, while total annual rainfall amounts can range from 200 mm to approximately 1,200 mm throughout Alberta (Barrow and Ge, 2005). Understanding climate regimes is therefore fundamental for any water budget. The form of precipitation (snow, sleet, hail, rain, and fog) greatly influences temporal dynamics of hydrology (Woo and Winter, 1993). Accumulation of snow reduces inputs to wetland surfaces during the winter, redistributing several months' precipitation into a small number of melt events during spring. Much of this water may never contribute to storage due to the presence of ground ice. In the Fort McMurray region, snow accumulation typically accounts for less than 30% of annual precipitation, with accumulations of less than 100 mm. During winter, drifting can redistribute snow from large areas into wetland depressions, increasing annual snow inputs by an order of magnitude (Hayashi et al., 1998). This may or may not hold true for the Boreal Plain with forests. Indeed, while drifting snow can represent a major source of water to wetlands (Winter and Woo, 1990; Woo and Winter, 1993), moderate vegetation growth, as that which follows successful revegetation, may eliminate drifting (van der Kamp et al., 2003).

### 2.2.1.2 Net Precipitation/Throughfall

Net precipitation ($P_n$) reaching the wetland surface is a function of total precipitation in an open area (P), less rainfall intercepted (I) by vegetation. Intercepted P evaporates, with no contribution to wetland water balances. Interception can be as high as 65% for small rain events or 15% for larger events in black spruce wetlands (Buttle et al., 2000). The amount intercepted is also a function of rainfall magnitude and intensity. Inputs to the wetland surface through $P_n$ may decrease in each year following wetland construction due to increased interception with re-vegetation. Major precipitation events often occur when vegetation demand for water is high. Additionally, a decreased potential for $P_n$ exists as 92% of rainfall events total less than 10 mm (Fort McMurray Airport Environment Canada climate data). Depending on canopy architecture and antecedent soil water content, forests can remove an average of the first 5 to 10 mm of many precipitation events (Buttle et al., 2000).

Snow interception and subsequent sublimation during cold and dry winter conditions can represent water losses of up to 30% (30 to 40 mm annually) of accumulated snow depths (Buttle et al., 2005). Hedstrom and Pomeroy (1998) showed snow interception to be upwards of 65% on black spruce canopies. Furthermore, water that is able to penetrate vegetation canopies will have to penetrate the litter layer of forestland HUs. Depending on the forest type and development of the soil, storage capacity of the forest floor is approximately 15 mm of water for the nominal 7-cm duff layer (Redding and Devito, 2010; Wagner, 1987). Accounting for the development of vegetation and soils over time is therefore required to ensure adequate water supply in the future. Total interception will vary among HUs because of vegetation structure or duff development. Interception can vary temporally, predominantly in areas with deciduous vegetation (Buttle et al., 2000) and with vegetation succession. Interception terms also must include water losses during winter.

### 2.2.1.3 Runoff

All landscapes can generate storm runoff. However, runoff relies on antecedent conditions and precipitation quantities. In addition, the quantity and rate of runoff versus infiltration are dependent on the permeability of the surficial geologic materials. For example, rainfall in excess of 20 to 25 mm is needed before any runoff or soil infiltration will occur in forested areas of the Boreal Plain but will vary according to material permeability (AENV, 2008). However, precipitation data from Fort McMurray indicate that reaching 25 mm of rainfall occurs less than 2% of the time (Devito and Mendoza, 2006; Woo and Winter, 1993). Runoff and P are not necessarily directly correlated because of the transient soil storage component of the water budget (Devito et al., 2005b). Large soil water storage manifests in the low runoff numbers (< 30%) reported by Woo and Winter (1993) for regional-scale watersheds and in the less than 20% reported in the Utikuma Research Study Area (URSA) and AOSR (Devito and Mendoza, 2006). In addition, Devito et al. (2005a) showed that during and after a single wet year that followed two dry years, the runoff coefficient for the basin was less than 1%, with rainfall converted to soil water storage. Major precipitation periods are synchronized with evapotranspiration and the amount of water stored as snow tends to be small. On average, there tends to be a high demand for water at the same time that it becomes available, providing limited opportunity for overland flow and runoff (Devito et al., 2005a).

Moreover, runoff can occur in wetlands according to dynamic water storage capacity. The common misconception that wetlands have the ability to attenuate floods is true only if they are not at maximum water storage capacity. In reality, wetlands with large groundwater inputs often have a smaller dynamic storage range, and remain nearly saturated. Precipitation inputs in saturated systems will typically generate increased runoff depending on connectivity (Bay, 1969; Roulet, 1990). Conversely, wetlands with a larger dynamic storage capacity can store much of the water delivered by a storm and not generate runoff when hydrologically isolated.

#### 2.2.1.4 Evapotranspiration

Evapotranspiration rates are often reported as potential evapotranspiration (PET), which is the rate at which water can be removed from a free water source (Eaton and Rouse, 2001; Roulet, 1990). Actual evapotranspiration (ET) can be much less than PET if water availability is restricted. Conversely, ET can be more than PET as a result of local surface heating or wind turbulence, although the most common reason is attributed to vegetation (Roulet, 1990). ET:PET is a useful measure for managers of wetland systems, and understanding how ET varies spatially and temporally helps explain wetland function and is another mechanism that reclamation planners can use to guide wetland function.

The difference between P and ET represents the quantity of water available to wetlands, as well as recharge for surface and groundwater inputs. In the WBP, a soil-water deficit exists in most years when using PET in calculations. PET is used as it is easier to compare regions based on climate without the confounding effects of vegetation. ET may be higher over shallow-water wetlands compared with vegetated wetlands, leaving a smaller annual surplus (Lafleur, 1990). ET is typically the dominant output of wetland water balances in continental western Canada (Devito et al., 2005a; b).

Several studies have quantified AET from HUs in the WBP (Brown, 2010; Brown et al., 2013; Petrone et al., 2007). Humphreys et al. (2006) demonstrated that average midday ET was similar across several peatland types, while average daily ET covered a small range from 1.7 to 2.5 mm per day for an open extreme-rich fen in Saskatchewan and low-shrub bog in Ontario, respectively. It was suggested that differences in daily or midday ET among peatlands were a function of the response of specific functional plant communities to environmental controls rather than peatland type or water table depth. ET was shown to be slightly less than PET, suggesting physiological vegetation controls were present at all sites (Sonnentag et al., 2010).

Site morphology also plays a critical role in ET rates, in some cases more than vegetation differences. For instance, locations sheltered by large trees or hills may experience up to 30% less summer ET and winter sublimations than those that are more exposed (Petrone et al., 2007; Reba et al., 2012). Water exchange with the atmosphere continues during winter, where sublimation rates can reach 4 mm per day of snow water equivalent (SWE) in parts of the Boreal (Hedstrom and Pomeroy, 1998). Water losses through sublimation may not be as high as during summer AET but they have the ability to accumulate significant losses over the prolonged winters of the WBP.

The rate of ET can change dramatically with the succession of plant communities. The type and age of vegetation can having a large influence on ET:PET, and subsequently on the wetland water budget (Roulet, 1990). Plants are able to restrict the movement of water in several ways — through shading evaporative surfaces and increasing stomatal resistance as a water conservation mechanism. In addition, each plant species will react differently to environmental variables through varying water-use efficiencies (WUE). For example, transpiration rates are greater for bryophytes than emergent macrophytes. Therefore, it is more meaningful to determine ET rates for similar vegetation communities and structure than it is to compare wetland types. Furthermore, although considered a loss due to the presence of vegetation, the addition of the terms $U_{in}$ and $U_{out}$ to the water balance equation is used to stress the importance of root translocation on water balances. Uplift is considered auxiliary to ET as it is hypothesized that, devoid of wetland HU input, forestland vegetation stress would increase, subsequently lowering ET rates (Devito et al., 2012).

The success of wetland hydrological function hinges on vegetation feedbacks conserving water during prolonged water deficits. Sonnentag et al. (2010) found no significant differences in total ET (~316 mm per year) across wet and dry years in an open, moderately rich fen in the Boreal Plain. The majority of variation in ET was explained by net radiation (67%), with the contribution of depth to the water table just 33%. Water table depth controls the contribution of different land surface components of ET, which resulted in similar ET regardless of hydrological conditions (Sonnentag et al., 2010). In wet conditions, ET PET, but during dry conditions, ET rates are significantly lower, likely because of differences in surface conductance. Still, ET rates will depend on the vapour pressure gradient that exists between the surface and atmosphere. Surface vapour will be largely dependent on surface moisture content, which relies on the hydraulic conductivity of the substrate. Internal conservation feedback mechanisms will further confound these broad generalities and may also change temporally as a result of vegetation (Admiral et al., 2006). Due to the complex interplay of water table depth, surface conductance and vegetation, ET from fens and bogs during droughts decreased in Brown’s (2010) study.

The effect of vegetation on reclaimed landscapes will vary with the seasonal synchronization of precipitation and vegetation growth. Two time scales are applicable: seasonal followed by long-term succession. The majority of annual precipitation occurs as rainfall during mid-summer, when ET rates are highest. Synchronization of rainfall with maximum water demand by vegetation and evaporation limits direct P and runoff inputs to wetlands due to interception by canopies (Carey and Woo, 2001; Devito et al., 2005a). As closure landscapes develop, water budgets will reflect successional processes and responses to climate cycles.

#### 2.2.1.5 Groundwater

Groundwater recharge is water entering the saturated zone, available at the surface of the water table. Conversely, groundwater discharge is the removal of water from the saturated zone across the water table surface. Groundwater flow occurs at a variety of scales; flow in the region occurs predominantly at the local to intermediate scales, driven by comparatively low rates of recharge (Devito et al., 2012). Groundwater flows at much smaller velocities than surface water. Timescales pertinent to groundwater processes are therefore much longer, with residence times of subsurface water ranging from less than a year to centuries (Hatton, 1998) depending on spatial scale, topography, and permeability. Although groundwater movement is slow, the area of interaction with groundwater can be large, resulting in large volumes of water entering or leaving a wetland system (Tóth, 1999). Even in low permeability silts groundwater can contribute almost 100 mm of water to the wetland per year. In coarser deposits or in areas of increased water deficit, $GW_i$ can be as much as 700 mm and can easily dominate the water balance of a wetland relative to precipitation (Devito and Mendoza, 2006). When conceptualizing the influence of groundwater flows on water budgets, the source area must be considered, as small movement of groundwater from large areas can account for large volumes of water flow.

Groundwater recharge is linked to flushing of salt and other compounds. It is therefore critical to map and model how water will move through the reclaimed soils and aquifers to assess their potential for water supply. Wetland reclamation design for areas that do not receive substantial precipitation should include a groundwater system that can provide reliable inflows to sustain the hydrological, biogeochemical, and ecological processes and functions.

For continued groundwater inputs to wetlands, groundwater can be recharged throughout the landscape, or from localized, focused recharge from heterogeneous materials or topography (Devito et al., 2012). The patterns of groundwater flow from recharge to discharge areas form flow systems, which form a framework for understanding recharge processes. Vital aspects of a conceptual model that incorporate recharge processes must determine:

1. The components of the landscape contributing to groundwater recharge;
2. If recharge areas are transient in nature;
3. If topographic catchment coincides with groundwater catchment;
4. What controls recharge rates spatially; and
5. The relevance of lateral redistribution of runoff and shallow through-flow to recharge downslope (Hatton, 1998).

Potentially, recharge from adjacent hill slopes will localize to nearby depressions. Local groundwater flows respond faster to precipitation events, seasonal soil moisture dynamics, and dilute chemistry compared to longer pathways. Recharge from forestland bypassing adjacent depressions acts as intermediate flow systems into regional lowlands. Groundwater interactions between HUs are potentially important for all wetlands. The volume of groundwater inputs and outputs dominate compared with surface water, with groundwater inputs acting to moderate water table fluctuations in wetlands (Winter, 2001; Winter and Woo, 1990). The groundwater connection of forestlands (erroneously referred to as uplands) and wetlands HUs is fundamental in the maintenance of both systems and a key mechanism in the movement of water between the two units.

#### 2.2.1.6 Forestland-wetland connections

For groundwater recharge from forestlands to be of benefit to wetlands or from wetlands to forestlands (Section 2.2.1.5), a connection between the two must be established. These connections may be transient and can change flow direction in certain instances (Devito et al., 1997). The particular recharge or discharge function of a wetland influences its susceptibility to desiccation through water table variations and water chemistry. These in turn largely depend on the geologic setting (Section 2.3). When the water table in the adjacent hill slope is above the wetland, the wetland is in a groundwater discharge region, and gains groundwater. Alternatively, external water could come either from shallow or deep groundwater flow systems, which may originate beyond a watershed defined by topography.

Studies have further shown that groundwater flow direction can be extremely dynamic, reversing from recharge to discharge on a daily, seasonal, or annual cycle in response to local vegetation water demands or regional groundwater recharge (Devito et al., 1997; Hayashi et al., 1998; Price et al., 2005). In many wetlands, forestland species such as willow and aspen can pull water from nearby wetlands into forestlands (Hayashi et al., 1998; Meyboom, 1966). Although not directly affecting AET of surface water, losses from the wetland via lateral groundwater movement are attributed to gradients induced by adjacent transpiration rates (U) in the water budget equation. This appears to be an important process in coarse-grained materials, but only if the wetlands are topographically low in the flow system (Smerdon et al., 2005). Devito et al. (2005a) demonstrated that fens are often located in groundwater discharge zones or forestlands, given an adequate supply of nutrient-rich water. Water slowly infiltrates over a large area focused into a narrow discharge zone supplying adequate and consistent flows for peatland formation. Focused zones of groundwater discharge may be candidate locations for some wetlands. Modelling would be needed to identify how the landform would alter the hydrology of the existing landscape, potentially rendering the discharge zone null.

#### 2.2.1.7 Mined landscape

Research on natural analogues indicates that groundwater discharge to wetlands is a major source of water, especially for those wetlands situated in topographic lows on coarse-textured outwash (Goodbrand, 2013). However, the topography of mine landscapes exhibits greater relief than the surrounding natural landscapes, especially in areas of out-of-pit sand or clay overburden deposits. The increased gradients that result from large volumes of waste deposits may lead to interruptions or redirections of groundwater flow and will influence where wetlands can be created. Groundwater seepage from constructed landforms are addressed in chapters 5 and 6. 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, groundwater levels eventually reach a new equilibrium. Water movement through altered environments may be dramatically different than it was pre-disturbance and may continue to evolve during mining practices and after mining ceases (CEMA, 2012). Groundwater flow modelling may provide valuable insight to help inform future decisions.

#### 2.2.1.8 Water storage

Maintaining adequate quantities of water in constructed wetlands will be the primary use of the water budget method of calculation for the landscape. The water balance is a mass balance with a net value of zero. There can be a positive water storage change over a particularly wet period, or, for places like Fort McMurray, it can be negative during a soil-water deficit in the summer. More important is the available storage capacity. Systems may have large storage capacities, but relatively small dynamic ranges of storage. Fens are largely saturated, compared with systems with large dynamic storage capacity, such as swamps, which can range from flooded to dry in summer. Water table variability differentiates different wetlands types. There are many ways to achieve each desired hydroperiod and thus wetland type.

As hydroperiod is simply the interaction of water budget, potential water storage, and material properties (Devito and Mendoza, 2006), changing the materials can directly change storage properties as well as the water table response to water inputs. Similarly, by changing the proportions of HUs on the landscape, differing hydrological responses will occur in wetlands. However, not all combinations of materials, HU arrangement, and orientations will produce a suitable hydroperiod. This method serves as a tool to identify plausible hydrological regimes given the available materials and engineering constraints that will support a particular type of wetland. Planners must understand that although changing the materials, storage potentials, and proportions of HUs on the landscape may create the desired hydroperiod, these changes may also affect the long-term “memory” of the system and other closure objectives.

In the Western Boreal Plain, a change in water storage does not need to reset at the end of each annual cycle, as the change is generally not near zero. Therefore, constraining water budgets to an annual timeframe may not be useful. The landscape and its hydrologic components have a memory of the length and intensity of climate cycles, particularly drought. Water memory and soil water content vary with storage capacity and differ substantially between wetland and forestland HUs. Wetland HUs typically have short-term water memory of one to two years and reach maximum storage thresholds more quickly in response to short-term deviations in water surplus relative to most forestland HUs (Devito et al., 2012). By contrast, forestland HUs have a much longer water memory due to deep available storage capacity. The response to term events in forestlands is usually buffered by 20 to 30 years. The required large water surpluses fill available storage, spill to adjacent HUs, and increase connectivity (Devito and Mendoza, 2006). The memory must be accounted for, as it influences the timing and intensity of how that landscape responds to events.

An important difference between natural analogues and reconstructed oil sands landscapes is the initial moisture conditions of the reconstructed landforms (HRAs). Landforms placed dry by truck-and-shovel method may take several years or decades to reach hydrological equilibrium. Assessment and timelines for reclamation certification of landscapes must consider this history because reclaimed landscapes have varying mixes of materials at different periods in climate cycles. Components of the climate cycle are repetitive (Section 2.1.2), in contrast with initial moisture conditions, which are only relevant until they come to equilibrium with the landscape.

While a designer and manager have no control over climate cycles, they can exert some control over water balance and landscape connectivity. The landscape must be able to tolerate drought conditions, but also store and transmit appropriate proportions of excess water during water surpluses. To assess the potential antecedent water content of the soil, landform, or landscape within a climate cycle, the land designer and manager need to interpret the data within both the year of observation and the context of longer-term climate cycles.

#### 2.2.1.9 Ice

Ice is a critical contributor to the conservation of water and the creation of conditions suitable for wetland HU maintenance. Ice lenses can form in all soils, though the thermal properties of wetland soils make ice even more influential. The distribution and persistence of ice can greatly influence water storage and transmission dynamics. Recently, evidence suggests that ground ice may be why peatlands, especially bogs, can persist in relatively dry climates such as Fort McMurray's (Petrone et al., 2008). A seasonal frost table allows perched water to accumulate closer to the surface than it otherwise would. Seasonal frost sustains water supplies required by moss and vascular plants during early periods of evaporative demand. In wetlands, thick organic deposits help insulate thick ice deposits, maintaining water storage longer into the summer than in forestland or ephemeral draws.

Forestland HUs frequently have low antecedent water storage during the fall, and therefore soils freeze in a permeable state. These frozen permeable soils result in infiltration and storage of spring moisture. Conversely, wetland HUs have higher water content in the fall, and can freeze as impermeable slab ice. Freezing stores significant quantities of water that are not released until summer. Ice facilitates a rapid runoff response to melting ice and snow and to spring and early summer rains. Lateral water flow along the top of the ice lenses through the surface-active layer is an important transmission mechanism. When wetland HUs are connected, porous organic surface layers can transmit substantial amounts of water in a non-erosive way.

Periods of increased atmospheric demand serve to enhance the preservation of ice through a negative feedback in which less conductive, dry moss layers retard the transfer of energy to the ice layer. Only water that melts from the top portion of the ice lenses is available for plants during the high demand period of the early and mid-growing season. Additionally, water cannot drain deep in the soil profile or down to the water table. Thus, ice lenses store water and release it upon melting later in the year than in the absence of ice. The delayed release provides water to maintain saturated soils later in the growing season. These thermal dynamics must be considered in conjunction with hydrology, as both are coupled through several mechanisms and feedbacks. Understanding the thermal properties of construction materials used in wetland reconstruction, in particular the use of developing ice layers, may prove helpful in maintaining hydrological functions of wetlands in colder climates and in the face of climate changes (MEND, 2012).

### 2.2.2 Peat hydrology

A key feature in the maintenance of a wetland is the accumulation of carbon over time. Maintaining high rates of accumulation relative to decomposition relies on the maintenance of peat-forming mosses, while limiting rates of decomposition (Clymo, 1984). Decomposition rates are thought to be minimized through low soil temperatures and perennially saturated conditions (Frolking et al., 2002) and this will apply to constructed wetlands with placed peat. Moreover, research has suggested the accumulation of humic acids, phenols and dissolved inorganic carbon provides a negative feedback to decay through increased groundwater residence times (Mitsch and Gosselink, 2000; Morris and Waddington, 2011).

Maintaining a net carbon-accumulating wetland, often used as a measure for restoring wetland function (Lucchese et al., 2010), requires the growth of key peat-forming species such as *Sphagnum*. A key determinant for growth of *Sphagnum* is matric potentials above -100 mb, corresponding to readily accessible water (Price and Whitehead, 2001). The -100 mb threshold has been shown to correspond to 30% volumetric water content (VWC) in natural sites and 33% VWC in an experimental transplanted wetland surface, suggesting that the matric potential–volumetric water content (  c–"c) relationship is species- and peatland-specific (Cagampan and Waddington, 2008). Although peat will likely be placed onto the landscape initially, favourable conditions will need to persist as the landscape evolves.

While much of the peat soil is saturated, large portions of peatland ecosystems, such as hummocks and some bogs, are seldom saturated. Rather, there is a need for a water table near the surface for much of the year, or for feedback mechanisms that can sustain the active layer through dry periods. Peat soils can be thought of as more dynamic and self-regulating compared with typical mineral substrates. The surface portion of wetland soils is often living, allowing soils to react with changing environmental conditions, spatially and temporally through multiple feedback mechanisms. In natural peatlands, the large pore structure of the near surface contributes to a high water-storage capacity (Boelter, 1968), particularly specific yield, which aids in limiting water table fluctuations to the near surface and so maintains critical wetness (Price, 1996). Furthermore, high storage capacity of surface layers acts as a regulatory function as peat can shrink and swell (Price and Schlotzhauer, 1999).

Changes in peat compression (i.e., vertical displacement) result from water table fluctuation (Price, 2003) and flow processes both seasonally and long-term (Whittington and Price, 2006). Higher hydraulic conductivity ($K_{sat}$) near the surface (Boelter, 1965) aid in drainage under high flow situations in a non-erosive way. Decreased pore size, a result of drying, will retard flows when near-surface soil moisture deficits exist (Cagampan and Waddington, 2008). Compression affects the main hydraulic properties of peat, including its bulk density, hydraulic conductivity, and specific yield (Chason and Siegel, 1986; Hogan et al., 2006). Compression of the peat surface in response to the lowering water table during dry periods will decrease hydraulic conductivity and specific yield while increasing bulk density (Hogan et al., 2006; Whittington and Price, 2006).

The presence of *Sphagnum* guarantees wet ground surface conditions over a wide range of water table depths due to increased capillarity. Moist surface conditions reduce ground surface resistance (Sonnentag et al., 2010). Conservation feedbacks such as these create systems able to buffer changes in climate through time. Although knowledge of natural peat-forming systems is important, peat used in a reclamation context comes with distinct features. Reclamation peats may have undergone significant degradation, alteration and mixing with other overburden substrates. It is therefore important to utilize and modify reclamation materials to mimic the hydrological functionality of natural systems.

#### 2.2.2.1 Peat disturbances

Disturbances such as peatland drainage and peat extraction can have a large effect on the hydrophysical properties of peat (Silins and Rothwell, 1998). The largest discrepancies between natural and stockpiled peat are associated with the stripping of overburden material and accelerated decomposition. Peat is salvaged in the oil sands for placement in future closure plans and throughout this process peat soils are often mixed with other overburden materials, and left stockpiled to dewater until needed.

Peat-mineral mixtures can provide an enhanced growth media in upland reclamation. Peats are often mixed with tailings sand or with glacial deposits to improve the physical, chemical, and growth supporting characteristics of the tailings sand. Peat-mineral mixtures have been intensively studied to determine optimal peat-to-sand ratios because growth on pure sand requires costly irrigation and fertilizer application (Middleton et al., 2011). Like mineral soils, peat varies greatly in both physical properties and suitability for reclamation efforts. Middleton et al. (2011) found growth was poorest on reclaimed areas when using deep, mesic peat or marl compared with shallower mesic peat in peat-mineral mixtures. This was due to differential rates and magnitudes of mineralization products. For reclamation of wetland systems, peat-mineral mixtures may not be desirable as they act to decrease moisture retention, a property inherent to wetland function (Walczak et al., 2002; Moskal et al., 2001).

Peatlands are drained prior to overburden removal and subsequent stockpiling. Drainage is associated with severe shrinkage and decomposition of peat. Shrinkage occurs because, as the pore water pressure decreases with drainage, the peat structure collapses, causing bulk density to increase by up to 63% in the upper 40 cm within a few years (Silins and Rothwell, 1998). The subsidence is associated with the collapse of readily drainable macropores (Silins and Rothwell, 1998) which are ordinarily important pathways for runoff generation in peat (Baird, 1997; Holden et al., 2001). Subsidence accelerates with the mineralization of organic matter and further decay of organic structure (Egglesmann, 1975). Stockpiled peat may continue to sit, draining in long windrow storage facilities through drying and wetting cycles and continuing to decompose at higher rates (Lieffers, 1988).

Once peat reaches a critical dryness, it can become hydrophobic and lose potential saturation capacities upon re-wetting (Eggelsmann et al., 1993; Hillman et al., 1997; 1990; Rovdan et al., 2002; Schwärzel et al., 2002). Rovdan et al., (2002) and Baisley (2012) also show decreases in moisture retention associated with drained peat soils at more advanced stages of decomposition. Subsidence and irreversible drying have been noted following drainage in many studies (Bowler, 1980; Hillman et al., 1990; 1997; Holden et al., 2001), with permanent structural changes possible. Schwärzel et al., (2002) showed the development of wetting inhibitory surfaces during peat desiccation. The development of hydrophobic surfaces led to abnormally high wetting resistance in strongly earthified peat layers. Plant waxes in peat also account for water repellence in reclaimed peat-mineral mixes (Visser, 2011).

#### 2.2.2.2 Peat use in reclamation

Although reclamation in the oil sands may be different than reclamation efforts after peat extraction, several parallels between the two exist. Research from the Peatland Ecology Research Group (PERG) provides relevant information on the processes and links between hydrology, vegetation and reclamation success. More importantly, PERG research provides an understanding of feedback mechanisms relevant to AOSR reclamation, in particular many negative feedbacks between vegetation, carbon partitioning and hydrology. Research has confirmed peatland development following peat placement is possible with remnant peat in the case of restoring degraded peatlands but has yet to be confirmed a proven method in the AOSR. Lucchese et al. (2010) suggested that *Sphagnum*-dominated peatlands can be considered functionally restored when organic matter thickness prevents the mean water table position for a drought year from extending into the underlying formerly cutover peat surface. The simple carbon accumulation model was used in combination with an ecohydrological model to assess peatland restoration success.

Although restoration differs from reclamation, the process-based understanding from restoration efforts in these studies may prove valuable for the initiation of peat in unfavourable locations. Though the use of direct placement of peat in AOSR may prove impractical, scheduling of overburden material removable and reclamation efforts may present opportunities for more realistic peatland creation. Rather than using a homogeneous stockpiled peat for peatland creation that has undergone several transformations (Section 2.2.2.1), wetlands could be constructed from the bottom up to best replicate natural systems. Decomposed dense peat layers on the bottom serve to retain water better than disturbed mixtures, also providing better connectivity to surface layers for moisture through capillarity rise. Abrupt contrasts between peat layers have been cited as an issue for maintaining surface moisture when water table position drops below the interface (McCarter and Price, 2014). McCarter and Price (2014) also suggest structural growth, decomposition and consolidation in combination with higher water tables will be required for a cutover site to recover into a net carbon sequestering system.

Constructed wetland systems will likely require these elements also. However, designers have the ability to construct wetlands from a confining layer up, rather than from an existing position in the organic layer profile, as in restored cutover systems. Newly constructed system moss growth will likely be similar to restored cutover sites, with mosses devoting resources to sustain fast growth (vertical) over structural growth (Waddington et al., 2011). Low bulk density, high porosity, higher specific yield and limited soil water retention will be by-products of fast vertical growth. Rapid vertical growth of the active layer may create stark textural contrasts within the profile, between well-decomposed stockpiled peat and the newly forming layers. The large pores of the rapidly growing active layer restrict capillarity from the basal peat to the new moss layer. Characterization of peat prior to placement should ensure this effect is minimized by employing an intermediate layer to bridge differences in pore sizes (McCarter and Price, 2014). The textural differences in peat layers can be marginalized by keeping water tables above the interface until sufficient decomposition of the newly growth layers has occurred. Segregating peat materials through scheduling — as is done for waste materials — may yield better reclamation success. Heavily decomposed peats should be placed at the bottom of the constructed wetland profile and hydrological connectivity from deeper layers should be a design element. Characterization of peat materials will be important for the creation of newly constructed peat forming systems (McCarter and Price, 2014).

Transplanting peat blocks can damage the internal peat structure. Cagampan and Waddington (2008) quantified the change in surface peat transplanted directly onto a cutover peat surface. Minimal structural changes within the peat matrix led to nearly identical soil-water retention, porosity and bulk density. Moreover, low soil-water tensions were maintained well above the laboratory-measured critical *Sphagnum* threshold of 33% (-100 mb) VWC, further indicating favourable conditions for *Sphagnum* survival and growth. The direct peat placement method was shown to be successful in preserving the moisture retention, porosity, and bulk density while also limiting hauling costs. Reclamation efforts in the region may be more successful with initial peat layers to initiate the reclamation. If peat can be established in wetlands, it may stabilize the water budget by moderating water storage and reducing ET (AENV, 2008). Placing peat is not the same as growing it, but ultimately the goal of any reclamation project is to create a self-sustaining system.

## 2.3 Hydrogeological setting

### 2.3.1 Geological deposits

Although climate influences the wetland water balance, wetland geology will influence the storage capacity, groundwater flow, and runoff properties. Geological setting is largely static several years after reclamation efforts and influences wetland basin geometry, substrate properties, and storage potential development. It also interacts with climate to influence the dominance of water balance components, such as surface water versus groundwater interactions (CEMA, 2005; Winter, 2001). Geological materials have been described in depth as part of the *End Pit Lakes Guidance Document* (2012). As such, readers are asked to refer to Section 5.2 of that guidance in addition to the cross-section provided in Figure 2-3.

Potential for deep overburden deposits consisting of silt-to clay-rich glacial tills creating large soil storage terms is what distinguishes the Athabasca Oil Sands Region. Overburden can be thick and varied in texture and chemistry (Devito and Mendoza, 2006). Oil sands mining results in large quantities of stripped and stockpiled overburden. Fine- to medium-grained tailings sands coupled with finer secondary tailings fraction are also produced. Till, sand, and non-processed oil sand are all used in construction projects. Soft tailings are intermediate in texture and grain-size (CEMA, 2005). Differing hydraulic properties of fine- and coarse-textured materials lead to a varied capacity for subsurface storage and transmission, as well as complexity in surface-water/groundwater interactions. Construction should focus on characterizing the hydrological properties for overburden materials and their spatial arrangement, as they can range greatly. For example, coarse-grained materials encourage flow-through, while fine-grained materials act as horizontal or vertical barriers to water flow.

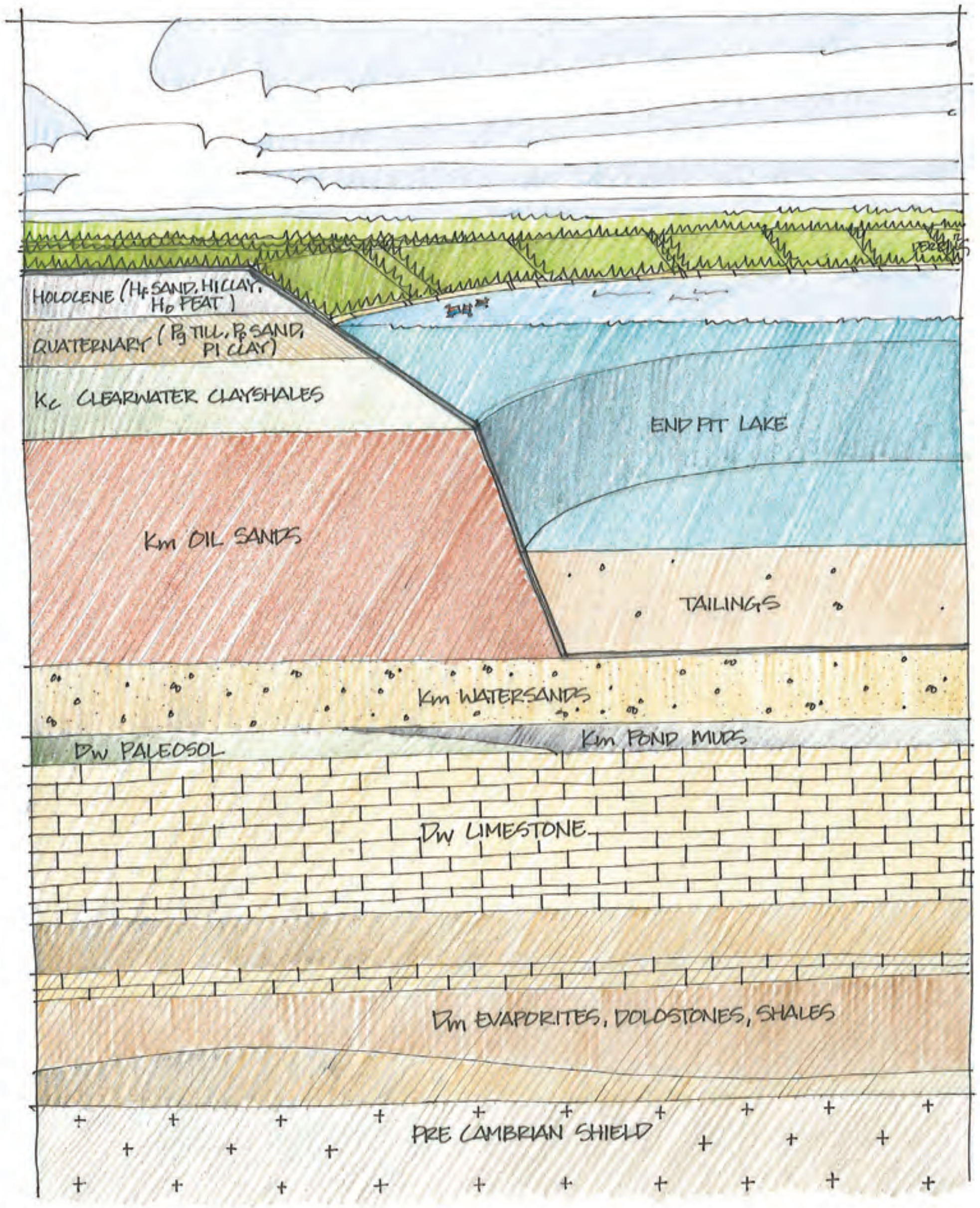

**Figure 2-3. Typical stratigraphy of the oil sands.**

### 2.3.2 Topography

Undisturbed topography of the region is generally flat to gently rolling (40 m elevation variation) with the exception of the Birch Mountains and Muskeg Mountain. Slopes are gradual (<15%; <300 m long) with hummocky, rolling, or flat terrain (MacMillan et al., 2006). Generally, mined landscape topography exhibits greater relief than the surrounding natural landscape, particularly where high sand and marine shale overburden deposits are formed. Overburden waste and tailings sand storage deposits tend to be steeper and more abrupt and uniform in composition than the existing landscape. As a result, the source and flow paths of groundwater on the post-mining landscape may be dramatically different compared with pre-disturbance and will influence where and how wetlands can be created. Increased hydraulic gradients and changes to groundwater-shed boundaries need to be carefully evaluated, as they have the potential to change after reclamation with continued mining elsewhere in the watershed.

On a smaller scale, micro-topography can play an important role in how the hydrological regime of an HU interacts within an HRA. Subtle design elements, such as micro-topographical relief, can be incorporated during construction that can make a particular landform behave differently. When combined with textural contrasts, the hydrology of such landforms often exhibits poor surface connectivity that impedes surface runoff and leads to accumulation of water in wetland depressions, potentially allowing the formation of wetlands on terraces or benches. In this way, many smaller wetlands may be created throughout forestland HUs and act similar to “opportunistic” wetlands.

Accumulation of water in hummocky terrain is largely dependent on the amount of relief as well as the temporal characteristics of water input (Devito et al., 2012). At a smaller scale, micro-topography (hummocks and hollows) within wetlands creates a broad range of hydrological conditions needed to support a variety of wetland species ranging from open-water to hummock-dwelling species. Typically, upland landform reclamation produces steeper gradients than pre-disturbance landscapes. Designed landforms on upland landscapes include features that mimic drumlins, eskers, flutings, kettles, dunes, gullies, river valleys with flood plains and terraces, and undulating and hummocky complexes with depression wetlands.

To build wetland systems on closure landscapes, landforms elevations, slopes, and aspects should fall within the normal ranges for the region. Wetlands should also be designed and constructed on topographic highs such as plateaus, depressions on gentle slopes, or on lowlands, depending on material properties. Closure landscapes should maintain aesthetics (McKenna et al., 2011) and meet several hydrological objectives, such as reduced ET and decreased sedimentation (Devito and Mendoza, 2006). Slope angle and length has been shown to influence sedimentation rates and infilling of wetlands to a lesser extent than upland vegetation cover (Tajek et al., 1985) in circumstances where runoff dominates. However, slope angle and length will likely be dominant determinants of sediment input rates to wetlands during early years of vegetation establishment if runoff processes dominate (Tajek et al., 1985).

## 2.4 Spatial and temporal scales

Important processes operate over a range of temporal and spatial scales, from diurnal plant scales to decadal landscape evolution. The long-range planning time for oil sands operators and regulators is decades. Wetlands, forests, and soils will continue to evolve over centuries in response to changes in climate and succession. Landscapes may evolve toward less runoff and more storage as soils and vegetation develop over decades. Consequently, groundwater recharge may decline depending on the current position in the climate cycle as well as initial soil water contents.

Assessment and timelines for reclamation of landscapes must consider this history as well as the timescales of operating processes. Landscapes are reconstructed and reclaimed with varying initial material conditions during different positions in the climate cycle. Landform materials used in construction are often placed dry, taking years to decades to reach equilibrium within the landscape. Initial moisture conditions of reconstructed landforms will likely exhibit behaviour that is different from that of natural analogues for this reason. Conversely, landforms such as tailings may take multiple years to dewater. Initial moisture conditions must be considered for each building block given the initial water contents for a given landscape position within the climate cycle.

Spatial scales will vary from microscopic vapour exchange at leaf stomata to catchment processes ranging from 10s to 100s of hectares in size. To combine processes operating on vastly different scales, hydrological frameworks are employed that break the watershed into principal components, or building blocks. These building blocks represent the aggregation, or response, of all sub-watershed processes operating simultaneously and allow planners to reconstruct landscapes with the desired hydrological response.

### 2.4.1 Building blocks of the landscape

Classifying climate, geology, and wetland distribution is required for generalizing dominant hydrological processes such as surface water and groundwater processes (Buttle et al., 2005; Sivapalan, 2003; Sophocleous, 2002; Winter, 2001). To connect processes across differing scales on the landscape, a hydrological framework must be used that employs a hierarchical approach for examining the controls on processes that move water through a catchment within a given region (Devito et al., 2005b). The hierarchical sequence in order of decreasing hydrological control is 1) climate, 2) bedrock geology, 3) surficial geology, 4) soil depth and type, and 5) topography and drainage network. The framework enables users to define the interaction scale and create an appropriate conceptual model to understand the source flow paths and fate of water throughout the landscape. What differentiates this approach from other frameworks such as the one employed by Buttle (2006) is the inclusion of climate controls.

The hydrological landscape framework encompasses the complete hydrological system, which includes the movement and interaction of surface and groundwater components. The movement of water through these hydrological compartments is controlled by fundamental 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 geology. Under the framework, individual hydrologic units have characteristic soil properties resulting in distinct soil-vegetation-atmosphere interactions. The HUs enhance differences in responses of the hydrological response areas (HRAs), over which they lay, to climate cycles. An HRA is an area of any scale in the landscape with similar soil texture, permeability and the size and proportion of HUs within it that yield a characteristic water storage, as well as scale and type of flow processes. Once HUs have been identified and parameterized, they can be combined to characterize the response in conjunction with the landscape while also understanding connection from one HU to another. The hydrological landscape framework is a practical tool when determining hydrology of an area with varying landform configurations. Delineating the landscape into functional building blocks will facilitate the calculation of the water balance at multiple scales, but it is important to understand HUs and HRAs will likely extend beyond lease boundaries.

### 2.4.2 Wetland catchment ratios

Considerable caution should be used when predicting appropriate catchment-to-wetland ratios as runoff coefficients are transient and can vary largely with particle size of substrate (Devito et al., 2005a; b). Furthermore, the concept does not consider the maintenance of forestland HUs by wetland water resources nor whether the catchment area is defined topographically or hydrologically. In some years wetland HUs may be drawn upon to satisfy demands for water in forestland HU and in some cases given a separate component in the water balance (Devito et al., 2012). An assessment of the demand of water through the succession of forestland is needed.

The prevalence of peatlands on the WBP is close to 65% and the ratio between upland and fen wetland is close to 1:1 (Price et al., 2010). The notion of a wetland:catchment area ratio in a reconstructed wetland is misleading if adopted without consideration. For example, detailed mapping of the 50 RAMP lake watersheds by Bloise (2009) showed that wetland spatial coverage varies from 0 to 100%. Research in northern Alberta reported ratios that varied from < 1:1 to 10:1 (Devito et al., 2012). Modelling demonstrated that the upland source area ratios in reconstructed wetlands were sensitive to hydraulic conductivity of the liner and aquifer materials (Price et al., 2010).

Clearly, the ratio is directly related to the HUs involved, as well as the type of HRA on which they are situated (Devito et al., 2005b). A particular wetland:catchment area ratio depends on geology, water storage capacities, and the HRAs and HUs that are combined for a particular wetland HU (Devito et al., 2012). Furthermore, the groundwater contributing area may extend beyond the topographic surface watershed boundary, particularly in coarse-textured HRAs (Goodbrand, 2013). Knowledge of the extent of contributing area is critically important in applying the water balance approach to estimate groundwater flow to various sizes of constructed wetlands.

### 2.4.3 Hydrological connectivity

Connectivity and long-term flow direction are controlled by differences in storage between and within HUs. Connectivity of surface water may facilitate the continuity of habitat, organisms, or nutrient redistribution. Furthermore, wetlands with a groundwater connection tend to exhibit moderated water-level changes during wet-dry climate cycles, sustaining hydrologic function (Amon et al., 2005). The hydrological connectivity between wetland and forestland HUs is often critical to maintaining a supply of water from wetlands to moderate deficits in forestland HUs (Devito et al., 2012). Wetland source water has the potential to maintain forest growth depending on the arrangement of moisture deficits, while also being a source of baseflow in drier years (Devito et al., 2005a).

By designing at multiple scales of interconnections between wetland and forestland units, dual functionality may exist, where landscapes are more likely to be sustained during extended dry periods as well as periods of extreme surplus. To design at multiple scales on the landscape, one must first understand the water balance of each landform component and identify dominant processes (Section 2.2.1; Figure 2-5). Each of the water balance components may operate at a differing spatial extent and if they are needed to connect the supply of water between landforms, the spatial scale must first be determined.

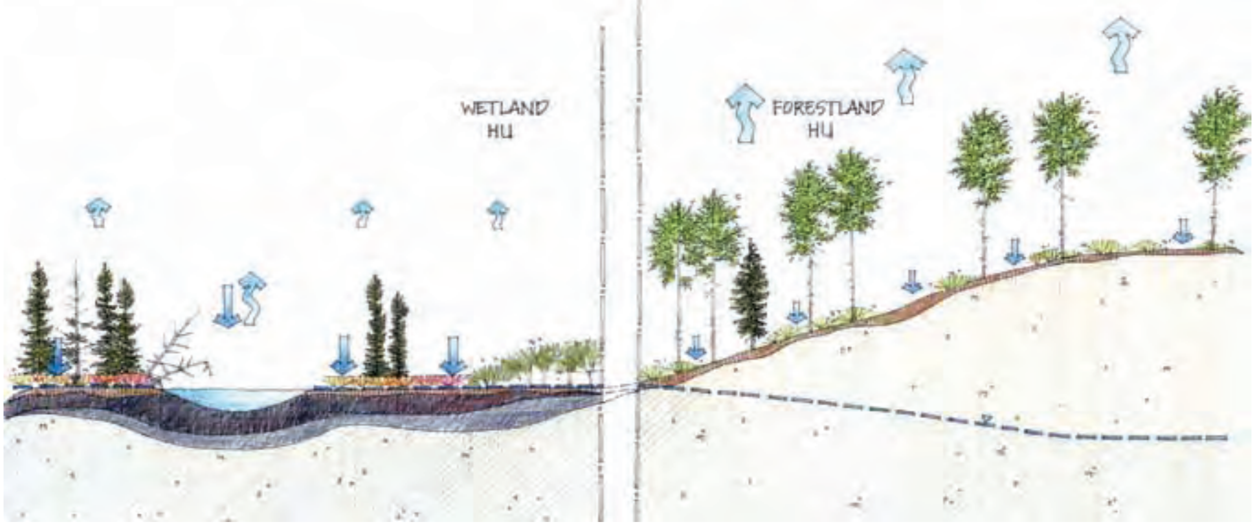

**Figure 2-5. Comparison of typical vegetation structure, soil layering, water levels, and atmospheric exchange in wetland and forestland hydrological units (Devito et al., 2012).**

HUs have a “memory” of the length and intensity of the seasonal and decadal pattern of wetting and drying, which results in varying connectivity within and between HUs (Devito et al., 2012). The change in water storage through time is known as antecedent storage, which differs from initial storage. Wetland HUs reach storage thresholds more quickly and respond more rapidly to short-term deviations in climate cycles than most forestland HUs; a concept referred to as short “water memory” (Devito et al., 2012). The effectively small storage capacity of layered wetland HUs can “fill and spill” more readily than deeper forestland HU buckets (Devito et al., 2012). Similarly, in areas of the WBP where low topographical relief dominates a particular HU, surface and/or groundwater levels in lower topographic settings frequently fill and spill to adjacent HUs that may be at higher surface elevations. This results in flow reversals driven by hydraulic gradients when storage is exceeded.

Surface-water connectivity may also play an important role in the redistribution of water depending on antecedent moisture conditions and soil texture. During drought periods, wetland HUs may become disconnected on the landscape through the absence of surface water connections. However, during several subsequent years of water surplus, HUs fill and connect at multiple scales. Maximum connectivity between HUs occurs when storage is near maximum potential. During periods of water surplus, connections supply runoff to lakes and depressions that may be otherwise poorly connected to Wetland HUs. Water quantity, quality, and the timing of water flow in the WBP are regulated by this intermittently linked network of wetland and forestland HUs. Designers can anticipate the hydrological response of a landform and landscape trajectories by conceptually manipulating the arrangement, distribution, and connectivity of the HU and HRA characteristics in the reconstructed landscape to mimic the functional assortment of natural landscapes. As previously discussed, HUs on the landscape will connect at multiple scales, each scale being important under different scenarios (Figure 2-7). The amount of connectivity and movement of water will also largely depend on the proportion of wetland to forestland HUs (Section 2.3.2; Figure 2-6).

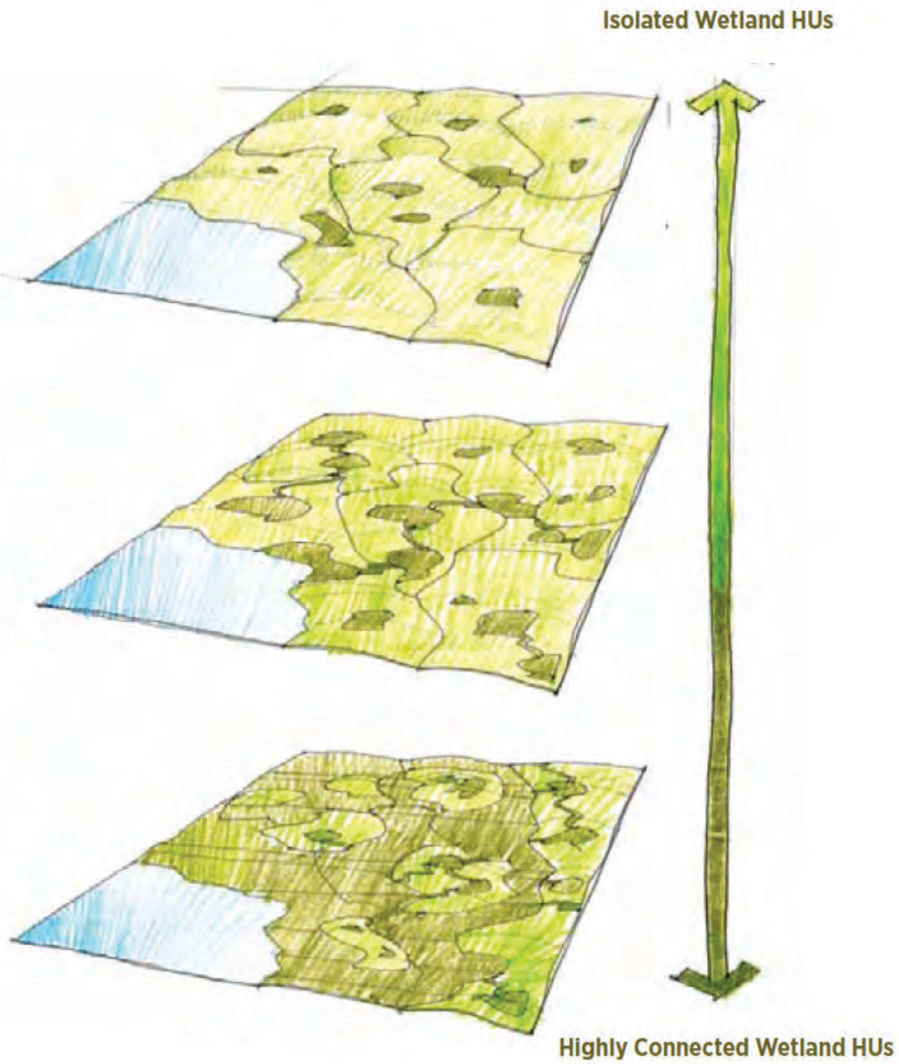

**Figure 2-6. Range of combinations of wetland and forestland HUs on a landscape. The light green represents forestland HUs and the dark green and blue represent layered and open-water portions of Wetland HUs. No scale or slope is implied. This range of spatial arrangement of HUs could occur on no relief or sloping away from or towards the larger open-water system. It could occur over a 100x100 $m^2$ or 10x10 $km^2$ area. Top:** small isolated wetland HUs. The dominant water movement is from wetland HU to forestland HU. The landscape is dominated by the forestland HU water balance,

with a wet moisture deficit with large soil storage or groundwater recharge. Landscape scale flow is via “fill and spill” from forestland HUs to wetland HUs or to the open water at the bottom and this occurs infrequently (every two to three decades)**. Middle:** increasing proportion and connectivity of wetland HUs. Redistribution of water from both wetland HUs to forestland HUs as well as to adjacent connected wetland HUs (often via ephemeral draws). The landscape water budget is roughly balanced between the two HUs. **Lower:** large expanses of well-connected networks of wetland HUs. The dominant water movement is between connected adjacent wetland HUs. The landscape is dominated by a wetland water balance with net moisture surplus, limited storage, and larger and consistent surface flow (runoff) at the landscape scale (Devito et al., 2012).

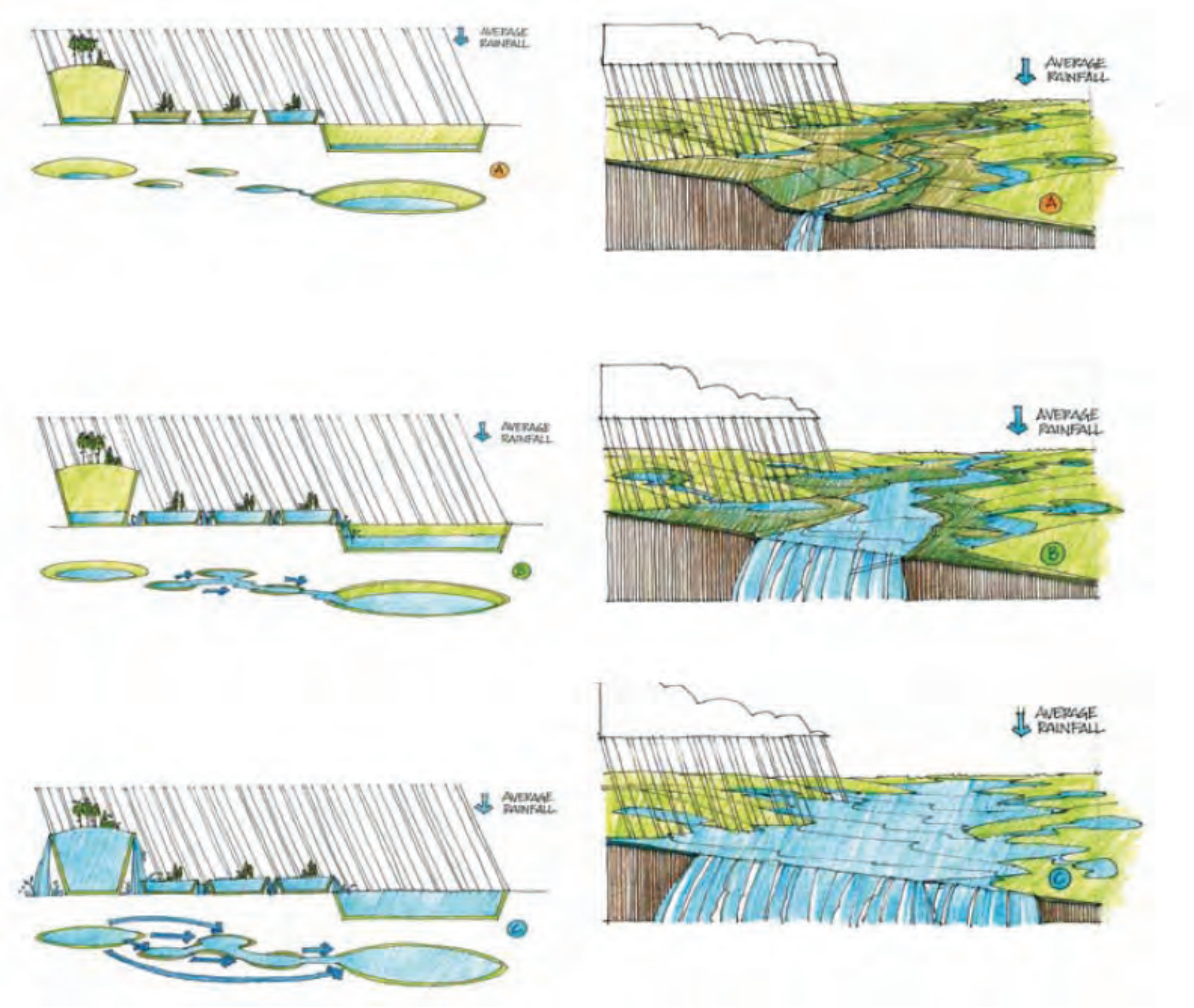

**Figure 2-7. Influence of variability in water memory and antecedent soil moisture in hydrologic response and landscape-scale connectivity (Devito et al., 2012).**

Wetland HUs may be isolated or occur as a spectrum of wetland complexes from open-water systems to deep- and terrestrialized shallow-layered wetlands. Within wetlands, peat tends to form in water-saturated areas. The hydraulic properties of peat impede flow; peat accumulation can stabilize volumetric moisture contents of the soil, creating additional wet areas in which more peat can form on the surface (McCarter and Price, 2014). Water impeding positive feedback mechanisms influences local hydrology and can influence local and regional topography through the formation of domed bogs. The surface flow systems associated with these wetland types need to act independently of the underlying mineral terrain (Devito and Mendoza, 2006). Stream drainage networks can be poorly developed in the low-relief WBP landscape.

Due to the width of the flow area and the porous active layer that modulates surface flow, water is transmitted non-erosively as near-surface runoff within the network of connected “active layers” characteristic of the fens, bogs, thicket swamps, and ephemeral draws that make up the larger interconnected wetland HU. Current landscape models equate wetland flow networks with stream channel networks. Even in the absence of streams, the effective surface-water catchment area for a wetland HU, and in most years for the entire landscape, is the total area of connected wetland HUs, which includes ephemeral draws (Devito et al., 2005b).

Ephemeral draws and riparian areas possess adequate soil structure, layering, and storage dynamics to promote surface saturation within the landscape, thus distinguishing them from forestland HUs (Figure 2-8). Ephemeral draws are often extensions that connect wetland HUs and forestland HUs. Due to the arrangement of ephemeral draws on the landscape, they act as connectors between wetland and forestland HU types (Devito and Mendoza, 2006). Due to frequently saturated soil, ephemeral draws are important but often overlooked sources and conduits of runoff water. Their importance is largely due to shallow depths to confining layers with low storage, and the presence of persistent frost that allows for rapid transmission of overland runoff while subtle gradients allow for the movement of water in a non-erosive way.

Ephemeral draws are important connectors of forestland wetland HUs, particularly during spring melt or decadal wet cycles, and they are easily incorporated into the reconstructed landscape by examining natural systems. The scale of connectivity can be designed or estimated based on understanding soil textures of building blocks, relative position of the building blocks, and their arrangement. Understanding that climate cycles will change the type, strength, and direction of hydrological connection between HUs is imperative for landform construction and highlights the uniqueness of wetland:catchment area ratios required in each landscape configuration.

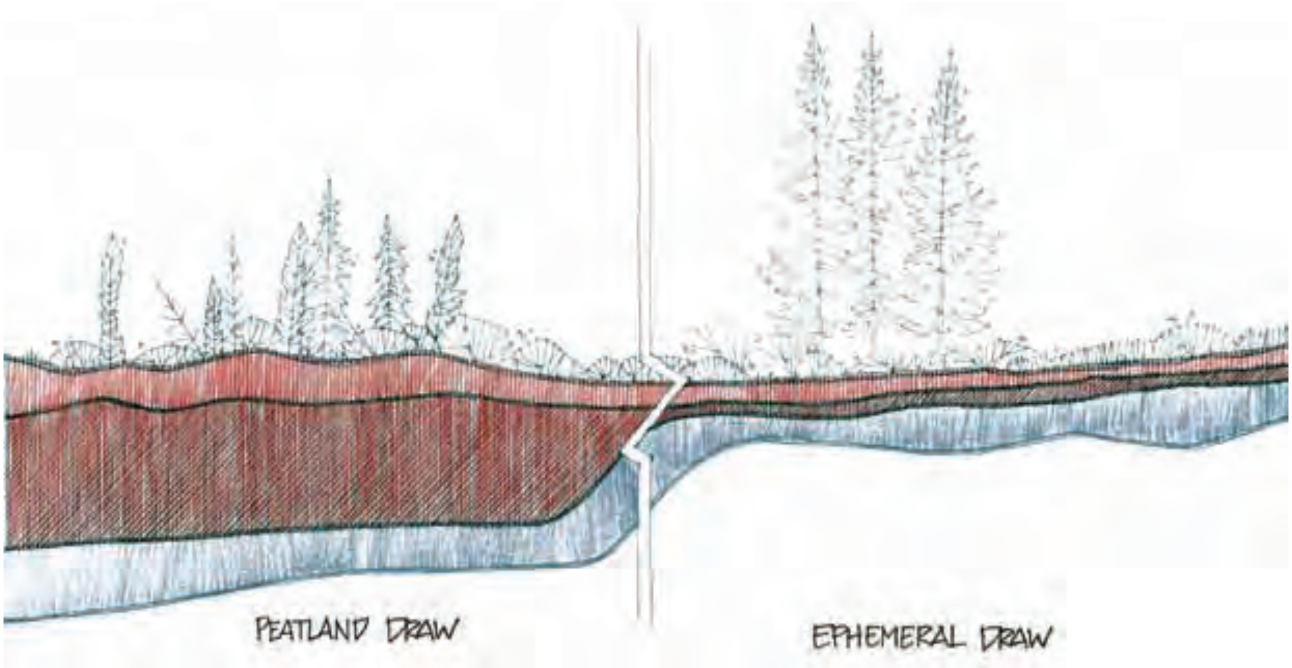

**Figure 2-8. Range in type, depth, and properties of soil layering in wetland HUs typical of the Boreal Plains. Wetland HUs typically have 1) an underlying fine-textured (clay) or confining layer, overlain by variable depths of 2) compacted or partially decomposed organics and 3) surface organic materials, referred to as the active layer. These layers play a large role in the hydrologic function of wetland HUs. Peatlands and ephemeral draws represent the spectrum of wetland HUs. Peatlands have the thickest organic layers and ephemeral draws have the thinnest organic layers (Devito et al., 2012).**

## 2.5 Mining materials and geochemistry: Implications for water quality

Many of the materials available for reclamation of landscapes and wetlands are by-products of oil sands extraction. Oil sands processing produces large quantities of diverse materials, each with a unique set of challenges. The interaction of hydrology and particular process-affected materials will yield water quality issues that need to be understood and accounted for.

### 2.5.1 Mining material properties and tailings

Materials available for use cover a spectrum of physical properties (Table 2-1). Wetland designers will have a diverse palette of materials at their disposal. Materials can be broadly classified as salvaged overburden or by-products. Many of the materials stripped prior to oil sands extraction are salvaged and stockpiled for use in closure-engineered earthworks. Peats and glacial deposits (till, fluvial, lacustrine) are most common, with residual materials (Clearwater and McMurray Formations) also utilized to a lesser degree.

Peat materials are classified as overburden, though they represent significant value to reclamation efforts. During removal of peat for stockpiling, the collection of glacial overburden often occurs due to overstripping. Overstripping may be intentional to create peat mineral mixtures for growth mediums. Glaciolacustrine (Pl) is clayey overburden material of glaciolacustrine or moraine origin, which can be used as subsoil in conjunction with a peat-mineral mix surface treatment. If its organic carbon content is high enough, it may be used as both surface soil and subsoil. Glaciofluvial (Pg) overburden is sandy material used similarly to Pl with the same organic carbon restrictions. Pg is coarser texture than Pl and classified as loamy fine sand to sandy loam. Glacial materials have variable texture, which is related to their permeability (Table 2-1).

Generally, permeability decreases with increasing clay content and increasing density of the McMurray Formation overburden samples (Table 2-1). Some materials however will physically change with time or altered moisture content. Disturbed Clearwater Formation materials occur as a mass of “flakes” and “lumps” of dry fine-textured sodic shale, which are permeable. However, once moistened, clays in the shale expand until they are dispersed and rearranged into an impermeable configuration with greater density. Subsidence occurs in the process and structural integrity diminishes.

Tailings sand consists of remnant fine sand after hydrocarbon removal. Tailings sand is a structureless, rapidly permeable, non-compacted material. Salts may be present in low concentrations and tend to be flushed through the permeable sands in 1 to 3 years in the upper metre (AENV, 2000). Although low in concentration, the volumes of salts will be determined by local hydrology. Wetlands developed using coarse-textured substrates may have difficulty maintaining sufficient water depth when the water table is deep due to lowered water retention and capillary. Consequently, low conductivity materials can be used to reduce percolation and maintain water levels.

To facilitate the production of trafficable landscapes, consolidated/composite tails (CT) are formed by adding a coagulant (e.g., gypsum) to a mixture of fluid fine tails (FFT) and sand to form a non-segregating slurry (i.e., fines contained within the sand pores) that will rapidly dewater upon deposition. Composite tailings saline in composition that interact with water are likely to produce saline groundwater due to leaching. Fine sands with high silt and clay content lead to moderate to slow permeability of CT.

During watershed design, rates of groundwater recharge and discharge can be managed by placing finer-textured, less-permeable clay, or a sandy, permeable material and altering slope geometry. By changing the materials used, surface runoff rates and watershed size requirements can be altered to create the desired hydrological function. Compaction of materials further extends the range of properties available to engineer landscapes (Table 2-1).

**Table 2-1. Mining material properties.**

| Description | % <0.002 mm | % 0.075-0.002 mm | Sand % | Gravel % | Dry density (kg/m$^3$) | Specific gravity | Porosity (%) | AEV (kPa) | Field capacity (% vol) | Wilting point (% vol) | Hydraulic conductivity (m/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Mineral/process materials** | | | | | | | | | | | |
| Pleistocene glacial till | 50 | 37 | 13 | 0 | 1518 | 2.60 | 0.42 | 12.1 | 0.4 | 0.33 | 1.0E-10 |
| Pleistocene Sand silt overburden | 0 | 0 | 97 | 3 | 1545 | 2.73 | 0.43 | 16.33 | 0.45 | 0.07 | 1.0E-05 |
| Pleistocene fluvial PF4 composite | 5 | 95 | 0 | 0 | 1453 | 2.60 | 0.44 | 0.48 | 0.04 | 0.02 | 1.0E-03 |
| Pleistocene fluvial PF4A composite | 0 | 3 | 95 | 2 | 1572 | 2.69 | 0.42 | 0.567 | 0.06 | 0.02 | 1.0E-03 |
| Lean oil sands (compacted) | 3 | 21 | 76 | 0 | 1754 | 2.90 | 0.40 | - | - | - | 1.0E-10 |
| Lean oil sands (lightly places) | 3 | 21 | 76 | 0 | 1261 | 2.90 | 0.57 | - | - | - | 5.0E-02 |
| Tailings sand | 0 | 7 | 93 | 0 | 1355 | 2.63 | 0.48 | 0.55 | 0.042 | 0.018 | 5.0E-03 |
| Mature fine tailings | 2 | 88 | 10 | 0 | 1113 | 2.31 | 0.52 | 9.8 | 0.45 | 0.21 | 1.0E-06 |
| Fine coke | 0 | 13 | 87 | 0 | 903 | 1.63 | 0.45 | - | - | - | 1.0E-06 |
| Coarse coke | 0 | 6 | 94 | 0 | 982 | 1.63 | 0.40 | 2[1] | 0.1[1] | - | 1.0E-06 |
| Very coarse coke | 0 | 1 | 68 | 31 | 1021 | 1.39 | 0.27 | 0.6 | 0.1 | - | 1.0E-02 |
| **Peat/mineral mixtures (vol)** | | | | | | | | | | | |
| 1:9 PF5A:HO2 | | | | | 454 | 1.97 | 0.77 | 2.79 | 0.38 | - | 1.0E-05 |
| 3:7 PF5A:HO2 | | | | | 746 | 2.43 | 0.69 | 0.35 | 0.28 | 0.15 | 5.0E-05 |
| 1:1 PF5A:HO2 | | | | | 901 | 2.41 | 0.63 | 0.29 | 0.28 | - | 5.0E-03 |
| 9:1 PF5A:HO2 | | | | | 1158 | 2.60 | 0.55 | 0.3 | 0.11 | 0.04 | 1.0E-03 |
| 9:1 PF5A:HO2 | | | | | 1389 | 2.56 | 0.46 | 0.35 | 0.07 | 0.04 | 1.0E-02 |
| 1:9 PF4:HO2 | | | | | 367 | 2.02 | 0.82 | 0.3 | 0.5 | 0.32 | 1.0E-04 |
| 3:7 PF4:HO2 | | | | | 588 | 2.10 | 0.72 | 0.59 | 0.32 | 0.18 | 5.0E-04 |
| 1:1 PF4:HO2 | | | | | 981 | 2.53 | 0.61 | 0.92 | 0.19 | 0.13 | 1.0E-02 |
| 7:3 PF4:HO2 | | | | | 1195 | 2.66 | 0.55 | 0.96 | 0.12 | 0.09 | 5.0E-02 |
| 9:1 PF4:HO2 | | | | | 1360 | 2.69 | 0.49 | 1.01 | 0.08 | 0.04 | 1.0E-05 |
| **Peat** | | | | | | | | | | | |
| Aurora mesic/fibric HO2 | | | | | 2.52 | 2.01 | 0.87 | 1.110 | 0.48 | 0.2 | 1.0E-04 |
| Aurora mesic HO2 | | | | | 237 | 1.90 | 0.88 | 0.900 | 0.47 | 0.18 | 5.0E-03 |
| Aurora wet humic HO2 | | | | | 722 | 2.12 | 0.66 | 1.540 | 0.38 | 0.17 | 5.0E-05 |
| *Sphagnum* peat living[2] | | | | | 10 | 1.41 | 0.99 | 0.003 | 0.15 | 0.03 | 5.0E-04 |
| *Sphagnum* peat moderately decomposed[2] | | | | | 52 | 1.41 | 0.96 | 0.020 | 0.35 | 0.1 | 1.0E-06 |
| Woody peat moderately decomposed[2] | | | | | 137 | 1.39 | 0.90 | 0.060 | 0.55 | 0.15 | 5.0E-05 |
| Herbaceous peat moderately decomposed[2] | | | | | 156 | 1.63 | 0.90 | 0.100 | 0.75 | 0.18 | 1.0E-07 |
| Well-decomposed peat[3] | | | | | 261 | 2.59 | 0.90 | 0.070 | 0.75 | 0.22 | 5.0E-08 |

[1] (Fenske, 2012) [2] (Boelter, 1968) [3] (Rovdan et al., 2002)

### 2.5.2 Water quality

The water quality issues associated with wetland design and construction are most influenced by mining and tailings fills. Across these materials, extensive variability exists between the parent source lithology as well as the operations that evolve the materials. The information in this section is based on material within the variability. Water quality issues on the mine site can be divided into two primary groups:

1. **Process-affected water:** water with an altered chemical composition resultant of oil sands mining activities. Examples include; raw tailings water, dyke seepage, process water, and water released from tailings.

2. **“Dirty Water”:** water that has been altered through interaction with mined areas within the clean water diversion systems, and water from reclaimed overburden areas.

Extraction of bitumen from oil sands using an aqueous process produces oil sands process-affected water (OSPW) and tailings containing trace metals, sulphates, salts, phenolics and other organics. Water quality studies have characterized water from the Athabasca River, local groundwater as well as runoff from overburden seepage with a suite of OSPW constituents (AXYS Environmental Consulting Ltd., 2005). Geochemical characterization of all construction materials will need to be conducted to identify potential water quality concerns. With sulphate concentrations approaching 48 mg/L (MRM, 2012), metals including nickel, copper, and zinc will form insoluble sulphides resulting in lower metals concentrations before reaching the wetlands. Vanadium and other metals will occur at higher concentrations in more alkaline pH waters derived from OSPW (Puttaswamy et al., 2010). Geochemical interactions between construction materials and differing water sources is thus critical and will vary across reclamation projects. Further reactivity or remobilization of these products will need to be assessed during periods of drought. Additionally, trace metals released from weathering are expected to be sequestered within peat, as are other potential low-concentration constituents. Wetland-facilitated removal of phenolics is not expected at the low concentrations (7.5 µg/L) (Kadlec and Wallace, 2008), and minor plant uptake is anticipated. However, organics are expected to degrade in wetlands with high microbial activity and in marshes exposed to ultraviolet radiation. All wetlands have the functional capacity to provide improvements in water quality depending on water residence times, constituent concentration, and specific chemical properties such as diffusion and adsorption rates. While many wetlands constructed on the reclaimed landscape may not be designed as treatment wetlands, they will provide some benefit to improving water quality through biogeochemical cycling.

High levels of nitrogen and phosphorus are found in tailings and OSPW. High levels of nutrients may provide additional resources to emerging vegetation, but also pose eutrophication risks to wetlands. Nitrogen and phosphorus are expected to be cycled internally and stored in living and dead organic material (Daly et al., 2012). High demands of nutrients can be expected during the establishment of the vegetation including peat growth. Furthermore, a supply of nutrients may further augment water devoid of nutrients, giving rise to fens.

OSPW will seep from sand dykes, soft tailings and mature fine tailings for an undetermined number of years (AENV, 2000). Process water may supplement natural sources during the establishment of wetlands during dry years, though the initial design must also plan for the eventual disappearance of this mining water source released off-site (Daly et al., 2012). Further, increased cation exchange capacity of fine-textured materials, in particular clays, has the potential for greater solute exchange with groundwater (Devito and Mendoza, 2006). Therefore, geology should not only be characterized for hydraulic properties, but geochemically as well.

### 2.5.3 Peat interactions

The interaction of OSPW within wetlands may offer reclamation possibilities for the maintenance of wetlands as well as the landscape as a whole. Flow and transport in peat soils depend on the chemical characteristics of the solute (Hill and Siegel, 1991), microbiological processes (Todorova et al., 2005), and the physical characteristics of the peat porous matrix (Ours et al., 1997). Both sodium and naphthenic acids (NAs) are strongly adsorbed by organic matter (Ho, 2000; Janfada et al., 2006). Peat has a high buffering capacity, adsorbing many substances found in OSPW and retarding the transport of sodium and NAs (Scott et al., 2005).
Sorption of sodium and NAs in OSPW on fen peat from Alberta was tested by Rezanezhad et al. (2012a). Field values of OSPW of ~40 mg/L NAs and 385 mg/L sodium were produced by evaporation from mosses and evapotranspiration from vascular plants. The high concentrations of contaminants remained detrimental to the moss health, but not the vascular plants (Rezanezhad et al., 2012b). Ninety-four percent of NAs and 84% of sodium in OSPW was absorbed by 1 kg of peat (Rezanezhad et al., 2012b). Therefore, transport of sodium and NAs in peat is retarded to the plant-rooting zone. Dispersion in the peat also reduces the concentration of potentially toxic compounds in the plant-rooting zone. Retardation before reaching full contamination potential of the plant-rooting zone may provide sufficient time for reintroduced plant communities to isolate themselves from the underlying contaminants with the accumulation of thicker organic layers (Daly et al., 2012). An understanding of the migration and persistence of sodium and NAs in the rooting zone of peat is still needed, as these factors will control toxicity thresholds in wetlands.

This research highlights the need to design wetlands with thicker peat layers (~2 m) to disperse and delay contaminants to the rooting zone (Daly et al., 2012). Thicker peat layers may delay contaminants several years before any effect of OSPW on plants is detected (Rezanezhad et al., 2012a).

### 2.5.4 Salinity

In the natural state, low concentrations of salts exist at the surface due to leaching and vertical accumulation of peat. Early in the mining process, overburden is stripped to expose underlying bitumen. Overburden may be coarse-grained (sand) or fine-grained (silt, shale and clay), and non-saline, saline, or sodic depending on its origin. During mining the peat is removed and the underlying sands are processed. The resulting tailings are returned to site, stratifying the soil with saline sands exposed at surface.

Saline and sodic leachates are a challenge for wetlands reclamation, in that many boreal wetland plants show sensitivity to elevated conductivity and sodium (Crowe et al., 2002; Howat, 2000; Purdy et al., 2005). Subsurface flow from overburden, in general, demonstrates an influent chemistry with salinity that ranges from freshwater to brackish water (MRM, 2012). Salt concentrations are expected to be generally tolerable for salt-sensitive plants depending on inundation times. However, initial weathering and extended dry periods may lead to salt accumulation during wetlands establishment. One of the many unknowns with salinity is how concentration is linked to hydrology, a product of a variable climate in the region. Evaporative concentration and subsequent recharge may enhance salt contents in the absence of local flow systems (Tóth, 1999). All weathering-related subsurface flow constituents are expected to show decreasing concentration over time, depending on precipitation, infiltration rates, and type of subsurface material (MRM, 2012). Nevertheless, these early-elevated salt concentrations will coincide with early establishment of vascular plants and bryophytes.

Some moss species common to northeastern Alberta may be tolerant to salt concentrations typical of post-mined oil sands landscapes (Trites and Bayley, 2008). Furthermore, salt concentrations in OSPW are likely not high enough to disrupt photosynthesis (Wilcox, 1984). Tested species would likely survive periodic inundations in OSPW, as may occur during spring snowmelt or after heavy rains when significant quantities of freshwater provide dilution. However, constant growth in salt concentrations equal to 30% of concentration in OSPW was detrimental for mosses, reducing the number of new shoots (Daly et al., 2012). Persistent inundation with OSPW should be avoided if a moss carpet is an objective.

Reclamation goals related to initial water chemistry might coincide with initial hydrological function of the landform. A lack of vegetation cover early in the life of the landform may enhance the runoff of freshwater, flushing and diluting potentially detrimental contaminants. Flushing through regular or sporadic connections across the landscape may concentrate salts in low-energy environments and provide more treatment options. If wetlands are designed with a treatment function as a design objective, managing the quantities of water and connectivity throughout the landscape will help mitigate the effects of salinity on the landscape.

### 2.5.5 Sedimentation

Excessive erosion of forestlands contributes to sedimentation in wetlands and can be detrimental to wetland function. Sedimentation has been shown to impair seed emergence in prairie marshes (Ignacio Galinato and Van Der Valk, 1986). With time, high sediment loads can quickly infill wetland depressions, impairing propagation of wetland species.

Sedimentation from forestland to wetland systems can be expected if construction materials fail to meet design criteria, or if design criteria fail to capture the magnitude of extreme storm events. Within the AOSR, erosion and sedimentation rates vary as a result of soil texture of reclamation material, slope angle, slope length, and vegetation cover (AENV, 2000). Potential erosion is calculated using the Universal Soil Loss Equation (Tajek et al., 1985) for different vegetation covers. The establishment of good vegetation cover on upland areas places potential erosion below the severe category even with steep slope angles of 2.5H:1V and 200-m extents (AENV, 2000). Therefore, the risk of sedimentation is expected to be highest during the early phases of reclamation while vegetation is absent or in the early stages of establishment. Wetland creation should coincide with adequate upland vegetation establishment. Furthermore, the silts and clays from tailings streams may eventually form bottom substrates for shallow-water wetlands or marshes (MRM, 2012).

The development of riparian zones bordering wetlands may provide protection from early sediment loading and periods of large moisture surplus. Simple slope contours, clay tills, and young vegetation on reclaimed landforms may increase the risk of channelling and slumping, while water flows away from young forest stands (MEND, 2012). Therefore, a balance is needed for management strategies between soils capable of delivering water to emerging upland stands and the prevention of slope erosion and sedimentation of wetlands. Numerical models can be used to highlight potential areas of concern. Erosion models will also highlight how uncertainty associated with climate and material properties may affect landform evolution (Evans et al., 2000).

## 2.6 Summary

When considering desired wetland function during the design process, a good understanding of the influence of interactions between the dynamic water budget, material storage properties, and the geologic setting is required to assess the hydroperiod of the wetland. Designers can manipulate these properties to produce the required hydroperiod for the specific wetland type. Although combinations of water budget, storage properties, and geologic setting may produce similar wetland types, the connectivity of these wetlands to the existing landscape may differ, resulting in a divergence in hydrological or geochemical function over time with succession.

The mosaic of wetlands and forestlands in the Boreal Plains is superimposed on and interacting with a heterogeneous landscape of varying material properties. Each superimposed unit of interaction produces a unique hydrology. Units exist as building blocks, which can be used to conceptualize processes on a site-by-site basis. There is no universal prescriptive approach for wetland reclamation. Instead, one must follow a framework similar to Devito et al. (2012) to create wetlands that will persist for the designed lifespan while continuing to function as designed under all evolutions of climate.

# Chapter 3
# Natural Wetlands in the Region

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Much of the knowledge on natural systems gathered over the past century can be applied to reclamation in the oil sands, with the objective of maximizing the wildlife and ecological processes common to the boreal forest. Reclamation can be guided by a sound understanding of the way the basin of a wetland slopes at the edges, its depth in the middle, and how it determines the emergent plant communities and the types of wildlife that are likely to use a site. This knowledge also helps set targets in terms of expected species composition and ecological functions for a reclaimed wetland. Natural wetlands tend to be relatively small. Peatlands in the oil sands region are mostly smaller than 1 $km^2$ in size, have a perimeter ranging from 0.3 to 0.8 km and range from circular to elliptical in shape. Permanent marshes are mostly less than 0.07 $km^2$ in size. Designs should include wetlands that range in size, but focus on smaller wetlands.

Wetlands should be designed to support a community, rather than simply specific species. Where specific species are desired, or where regulations stipulate that habitat for specific species must be created (e.g., for a species at risk), practitioners should identify the additional management steps necessary (e.g., provision of overwintering habitat) after designing the wetland to support a functional community. Providing habitat for some species will require a landscape-scale approach, rather than just the reclamation of a single wetland.

Successful wetland reclamation depends heavily on zones of emergent vegetation. All wetlands should be bordered by a riparian zone of trees and shrubs to provide sediment and nutrient interception, nesting and foraging sites. As well, wetland hydrology will often dictate whether reclamation achieves it objectives. The hydroperiod is unique to each type of wetland. Water depth and duration of flooding and drawdown are important considerations.

At a landscape scale, a variety of wetland types that possess a range of hydroperiods is necessary, as this approach supports more biotic communities and increasing regional biodiversity. As well, the landscape position is a key determinant of wetland function and hydrology.

Connectivity between wetlands in the region is also important. Multiple wetlands placed in close proximity (less than 1 km apart) provide the ecological stepping stones needed to increase colonization rates and thereby stabilize populations. Biodiversity is best achieved by maximizing diversity within a single wetland and from wetland to wetland. Within-wetland diversity can be maximized by incorporating hummocks, hollows, pools, coarse woody debris, high shoreline complexity, variable basin profiles, and islands. A reclaimed landscape should include ephemeral and permanent wetlands juxtaposed with upland forest stands and patches of emergent and shrubby vegetation.

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## 3.1 Introduction

Natural wetlands have been studied extensively over the past 100 years. Some of this knowledge on natural systems, in particular the drivers of their form and function, can be applied to reclamation with the goal of maximizing ecological processes and wildlife common to the boreal forest (CEMA 2012; Eaton and Fisher, 2011). An understanding of wetland depth profile — the way the basin of the wetland slopes at the edges, how deep it gets in the middle, and how it influences the development of emergent plant communities and the kinds of wildlife that will likely use a site — can guide reclamation. This knowledge also helps set targets in terms of expected species composition and ecological functions for a reclaimed wetland.

This chapter provides background on wetlands properties, their basic physical, chemical, and hydrological characteristics, the general types of biotic communities they support, and the types of wetlands in boreal Alberta. It also covers the ecological principles that can affect the success of wetland reclamation and the importance of spatial and temporal scales. Many of the basic principles are also invoked in the design chapters. While not all aspects of natural wetlands are addressed in this chapter, an overview of the critical points related to wetland reclamation in the Alberta oil sands region has been included. More detailed information can be obtained from the references cited herein.

## 3.2 Wetland properties

### 3.2.1 General wetland functions and ecosystem services

Society's interest in wetlands is based largely on the benefits of their natural functions (Barker and Maltby, 2009). These ecosystem services have provided essential resources throughout our evolutionary history (Ehrlich and Wilson, 1991). Like any other ecosystem, wetlands are complex. Interactions among their species and environment govern the movement of materials and the composition of their biotic communities (Barker and Maltby, 2009). From a cultural perspective, wetlands provide many marketed and non-marketed benefits to humans, from supplying food and recreational opportunities to fulfilling spiritual and inspirational needs (O'Flaherty, 2011). Wetlands help improve water quality and storage, mitigate flooding and drought events, moderate water flow, stabilize shorelines, and act as centers for groundwater discharge and recharge. Their high productivity makes them proficient at nutrient recycling, sediment retention and organic matter accumulation. Water purification is particularly evident in wetlands with herbaceous plant species, such as cattails (*Typha latifolia*), sedges (*Carex* spp.) and bulrushes (*Schoenoplectus* spp.). The accumulation of carbon in the sediments is of significance, particularly in bogs and fens. On local and regional scales, wetlands help moderate weather and climate, in addition to processing and sequestering greenhouse gases.

Wetlands' high biological productivity and aquatic component provide wildlife habitats that exhibit high diversity and are completely unique from all other landforms and land-covers (Gibbs, 2000; Gopal, 2009; Ramseier et al., 2009). In northern Alberta, some wetlands provide key rearing and overwintering habitat for fish (Nelson and Paetz, 1992; Mallory et al., 1994; Paszkowski and Tonn, 2000), but are also primary habitats for waterbirds (Semenchuk, 1992), amphibians (Russell and Bauer 2000), aquatic arthropods (Merritt and Cummins, 1996), aquatic plants (Raab et al., 2013), beavers (Martell et al., 2006; Eaton et al., 2013), mink, muskrats, and otters. Wetlands provide important supplementary habitat for moose, caribou, songbirds and arthropod assemblages.

### 3.2.2 Wetland structural and functional properties

Wetlands are found in areas where water collects on the surface or close to the soil surface (National Wetlands Working Group, 1997). They are characterized by poorly drained soils, hydrophytic vegetation and various kinds of biological activities that are adapted to a wet environment (National Wetlands Working Group, 1988). For mineral-based wetlands, their geomorphic, climatic, hydrologic, biotic or edaphic (factors related to soil) setting results in little or no organic matter or peat accumulation in the soil. Such soils are often classified as gleysols, or gleyed/peaty phases of other soil orders in the Canadian System of Soil Classification (Soil Classification Working Group, 1998). Wetlands with organic soils are more simply referred to as peatlands. Peatlands contain more than 40 cm of peat accumulation on which organic soils (excluding folisols) develop. Classification of landforms suggests that the majority of the entire Alberta mineable oil sands region is peatlands. Rooney et al. (2012), using data from AESRD, showed that 64% of the area is peatlands, two-thirds of which are forested fens.

The water table in a wetland sits close to, at, or above the soil surface for most of the growing season. The persistence of water and activity of anaerobic bacteria generate unique soil structures and features. Organic wetland soils differ from mineral wetland soils in their level of organic matter, bulk density and porosity, hydraulic conductivity, nutrient availability, and cation exchange capacity (CEC). Distinctive characteristics in organic wetland soils are related to the origin of mosses, herbaceous material, and wood and leaf litter in the wetland. Mineral wetland soils, in comparison, develop redoximorphic features. These result from the reduction, translocation or oxidation of manganese and iron oxides under hydric conditions. The type and extent of redoximorphic features indicate the degree and duration of hydric conditions.

Hydrophytic vegetation, which thrives in wet conditions, is also a key component of wetlands (Mitsch and Gosselink, 2007). The diversity and types of vegetation in any one location depends on the type of wetland, its soils, regional climate, duration and depth of inundation, soil and water chemistry, light availability, interspecies competition, and landscape positioning of the wetland itself.

Wetlands vary by size, shape, basin morphology, substrate topography, substrate type, hydrology, vegetation and wildlife communities, amount of open water, and depth (Mitsch and Gosselink, 2007). Because they occur across a gradient of moisture levels and landforms (Figure 3-1), with concomitant differences in physical structure, chemical characteristics, and habitat types, it is impossible to describe a “standard” wetland. Appendix B describes and compares key structural and functional attributes of wetlands that should be considered for reclamation.

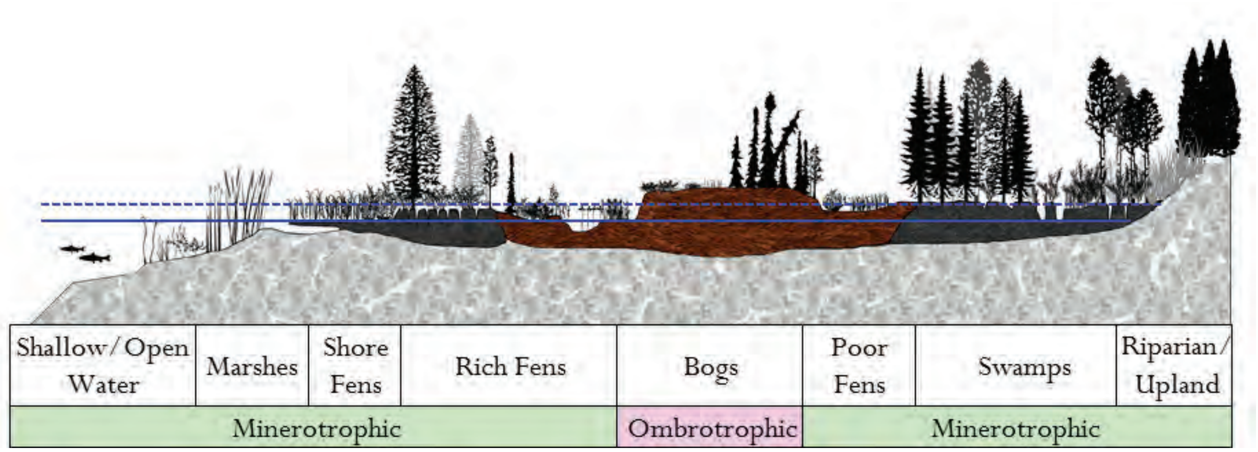

**Figure 3-1. Landscape cross-section of Boreal Plains wetlands showing variation in soil and peat deposits, water depth/saturation level, and general vegetation types (adapted from Smith et al. 2007b). The dashed blue line is the high-water level, and the solid blue line is the low-water level. The light grey is mineral soil, the dark grey is woody peat, and the brown is sphagnum peat.**

Some wetlands, such as treed fens or bogs, may possess little standing water and support vegetation similar to that found in upland habitats. At the other end of the spectrum, lacustrine wetlands that form at the edge of lakes support many aquatic plant species, as well as aquatic and semi-aquatic wildlife species.

Many wetlands possess a series of zones, defined principally by water depth and vegetation. A typical depressional wetland (i.e., marshes and shallow-water wetlands — the two most common reclaimed wetland types planned on oil sands mine leases) could include a series of aquatic zones, as well as adjacent riparian and upland zones (Figure 3-2). The upland is characterized by a range of vegetation communities, which may be dominated by herbaceous, shrub, and/or tree species; it is not usually influenced directly by elevated water tables. Although there are many definitions of “riparian zone,” the one used here is the terrestrial environment adjacent to the wetland where vegetation is influenced by elevated water tables, flooding, and the water-holding capacity of the soil (Naiman and Décamps, 1997); this zone may also include a variety of vegetation types. The aquatic zone includes those areas flooded long enough to exclude terrestrial plants. In depressional wetlands, the aquatic zone is further divided into a wet meadow zone characterized by a variety of herbaceous species, often arrayed in discernible bands related to soil saturation around a wetland. These often include an emergent zone of cattails, rushes and similar species that are rooted below the water but emerge above its surface; a submerged/floating-leaved zone in which plants are rooted below the water and are either entirely submerged or have leaves that float on the surface of the water; and an open-water zone where few or no rooted plants are found but which may support unrooted species such as duckweed. Not all wetlands have every zone, and the relative size of each zone can vary widely. Physical habitat characteristics have an important influence on the wildlife in a wetland.

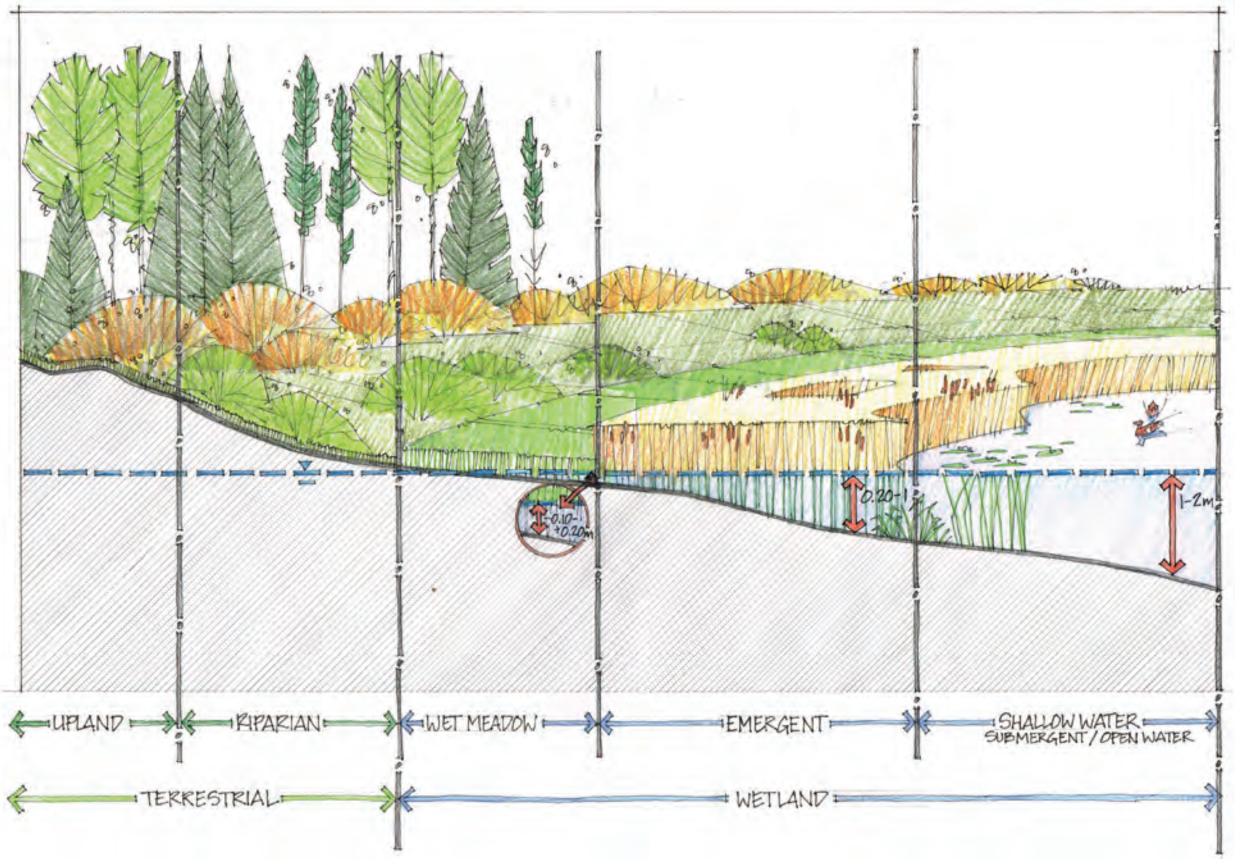

**Figure 3-2. A conceptual description of wetland zones for marsh and shallow-water wetlands.**

In boreal Alberta, marshes and shallow-water wetlands have the highest habitat complexity and support the widest array of wildlife, including waterbirds, snakes, amphibians, and a range of semi-aquatic mammals; diverse communities of terrestrial birds and other mammals occur in the adjacent riparian and uplands. In contrast, fens and bogs sometimes lack any significant areas of open water, and therefore support fewer large wildlife species (National Wetlands Working Group, 1988). In marshes and shallow-water wetlands, a variety of habitat types are required to support the food web. A greater variety of habitats and niches will reduce competition between wildlife species and increase biodiversity (Figure 3-3).

Although all zones are important, the shallow-water emergent zone is particularly important as it provides important habitat for benthic macroinvertebrates and relatively warm areas for amphibians in northeastern Alberta to deposit their eggs. Because the developmental rate of amphibian eggs and larvae is directly related to ambient temperature, shallow water that warms quickly in the sun, particularly in the spring, may be critical to the ability of amphibians to colonize wetlands. Emergent plants themselves provide habitat for macroinvertebrates and birds, and substrate for algal growth (periphyton). Emergent vegetation may provide food for semi-aquatic mammals, nesting habitat for birds, and escape cover and foraging habitat for a variety of aquatic and semi-aquatic organisms. Wetlands with a higher abundance of macrophytes can support more macroinvertebrates (Hornung and Foote, 2006) and duck broods (Longcore et al., 2006); the growth rate of ducklings is also related to the abundance of macroinvertebrates in some systems (Cox et al., 1998).

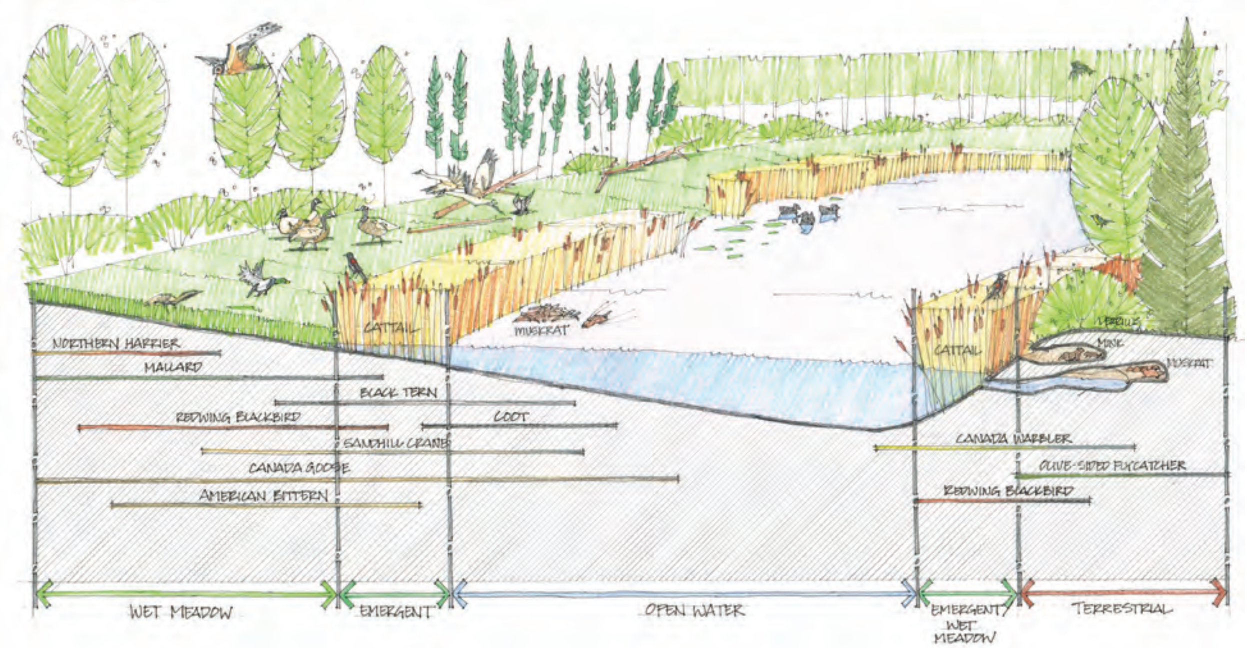

**Figure 3-3. Potential habitat use by bird and mammal species in a wetland. The figure is a generalized representation, and does not illustrate the full suite of species that use wetlands, or temporal or fine-scale differences in habitat use. (Adapted from Weller and Spatcher, 1965).**

**Key Message for Design**

Zones of emergent vegetation are an important component of many wetland types, and designs for these types (e.g. swamps, marshes) should include provisions for the development of such zones. Specific design considerations for these zones are supplied later in this chapter and elsewhere in this guide.

All wetlands should be bordered by a riparian zone of trees and shrubs to provide sediment and nutrient interception, nesting and foraging sites.

To allow important wetland functions to occur, wetlands should be bordered by natural vegetation within at least 250 m of the wetland edge. This border should include vegetation characteristic of local riparian zones.

### 3.2.3 The Importance of hydrology

Mitsch and Gosselink (2007) referred to hydrology as the “single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes.” The hydrology of a wetland creates the hypoxic conditions necessary for soil development and the conditions to which specialized vegetation is adapted. These conditions determine the type of wetland to be established and influence the trajectory it will take as the system matures (Winter and Woo, 1990; Winter, 1992). The importance of hydrology as the principal driver of wetland ecosystem functioning is explored below and in Appendix B.

Wetlands represent the aquatic edge of terrestrial habitats and the terrestrial edge of permanent water habitats (Figure 3-4; Mitsch and Gosselink, 2007). Because they often contain elements of both types, even small changes in hydrology can significantly affect the chemical and physical properties of a wetland. These properties include nutrient availability, degree of substrate anoxia, soil chemistry, sediment properties, and pH (Mitsch and Gosselink, 2007). Similarly, when hydrology changes even slightly, biota can respond with major shifts in species composition, richness and ecosystem productivity (Murkin and Ross, 1999; 2000). Depending on the type of wetland, some changes may cause ecosystem productivity to decline (Mitsch and Gosselink, 2007), while other changes will enhance productivity (van der Valk, 2000). One of the biggest threats to the long-term productivity of freshwater wetlands is long-term hydrological stability. In essence, hydrological patterns can act as either a limitation or a stimulus to the presence or absence of a species and total species richness, depending on the wetland type and its need for intermittent disturbances (Mitsch and Gosselink, 2007).

**Figure 3-4. Shallow-water wetland aquatic bed state, showing floating and submerged vegetation dominating the open-water zone. Photo courtesy of Ducks Unlimited.**

Water enters wetlands via stream/river/lake flows, runoff, precipitation and groundwater discharge. These flows can be extremely variable and the variations can be stochastic in nature (Kadlec and Wallace, 2009). Wetlands lose water via connectivity to other waterways, groundwater and evapotranspiration (ET). Water loss via ET can be considerable in certain systems since it is driven by solar radiation and plant productivity. This is true for wetlands in the Athabasca Oil Sands Region (Devito et al., 2012). The hydroperiod for all wetlands may be defined as the depth, length of time, and the portion of the year a basin holds water either above, or close to, the soil surface. It is often referred to as the hydrological “signature” of each wetland type (Mitsch and Gosselink, 2007). Hydroperiod defines the rise and fall of a wetland’s surface and subsurface water and the speed with which these processes occur. For wetlands that are not permanently flooded, the time a wetland has water standing on the surface is called the flood duration, and the average number of times that a wetland is flooded in a given period is known as its flood frequency. Great variability can be seen from year to year in many wetlands as a result of current climatic circumstances and previous conditions.

Hydroperiod (particularly water depth and duration of flooding and drawdown) has critical impacts on the establishment and survival of wetland plant species (Figure 3-5; Budelsky and Galatowitsch, 2000; Miller and Zedler, 2003; see Appendix B), and may need to be controlled in the first few years of reclamation to encourage the development of native plants. Variability in hydroperiod also has strong implications for the biogeochemical functioning of wetland ecosystems (Verhoeven, 2009). Hydroperiod is generally defined slightly differently by wildlife ecologists, and corresponds to the flood duration (Pechmann et al., 1989; Brooks and Hayashi, 2002; Boven and Brendonck, 2009). Many aquatic or semi-aquatic animals rely on standing water for egg and larval development, foraging and overwintering habitat, predator avoidance, and other needs. Natural wetlands typically exist along a hydroperiod gradient that determines the predator communities. Short hydroperiod wetlands — those that dry every one or two years — lack vertebrate predators such as fish, and may even lack many larger invertebrate predators such as dytiscids (diving beetles) (Wellborn et al., 1996; Brooks, 2005). These systems support unique invertebrate faunal communities compared with wetlands with longer hydroperiods (Tarr et al., 2005). Wetlands with intermediate hydroperiods, or those that dry approximately once every five years, accumulate invertebrate predator populations. They typically lack aquatic vertebrate predators, although semi-aquatic bird and mammal predators may utilize these wetlands. More permanent wetlands, particularly those connected at least periodically to other systems via surface water flow, may support fish (Wellborn et al., 1996), and even small-bodied fish may affect amphibian (Eaton et al., 2005) and macroinvertebrate populations (Zimmer et al., 2000). However, in northern Alberta most permanent wetlands lack fish because of overwinter anoxia (Conlon, 2002; Norlin et al., 2005, 2006; Cobbaert et al., 2010). Refer to Appendix B for an expanded discussion on flooding duration.

**Figure 3-5. Marsh wet-dry cycle proposed by van der Valk and Davis (1978).**

The hydroperiod for each wetland type is unique and must be considered key to the design and construction of all wetlands. At a landscape scale, it is important to establish a variety of wetland types that possess a range of different hydroperiods, as this approach supports a variety of biotic communities, thereby increasing regional biodiversity. Wetland hydrology is to some degree conceptually understood (Mitsch and Gosselink, 2007), but modelling and understanding wetland hydrology on reclaimed landforms is perhaps the greatest challenge in wetlands reclamation. Indeed, it is the main variable that can lead to the failure of a reclaimed wetland (D’Avanzo, 1989). Consequently, in the oil sands region, a tremendous amount of effort has been spent on understanding natural and reclaimed landform hydrology and deriving best practices for re-establishing hydrology on reclaimed lands (see Chapter 2). Ross (2009) provides guidance for the application of water depths in wetland designs.

**Key Messages for Design**

Wetland hydrology is the most important control on wetland ecosystems and will often dictate whether reclamation achieves its objectives. Appendix B and Chapter 2 provide considerations related to hydrology. Ross (2009) provides guidance for the application of water depths in wetland designs.

Hydroperiod for each wetland type is unique and is key to the design and construction of all wetlands. Water depth and duration of flooding and drawdown must be considered. At a landscape scale, a variety of wetland types that possess a range of different hydroperiods are necessary, as this approach supports a variety of biotic communities, thereby increasing regional biodiversity.

Some disturbance events (e.g., wet-dry cycles) are normal in wetlands and can enhance species richness; they should be considered as positive events, if they are within the natural range of variation for the region.

## 3.3 A functional wetland classification approach

There is a diverse array of wetlands in Canada and classification has at times been problematic. Some classification systems depend on structure, while others concentrate on function. The key to understanding which system to apply depends on a user's familiarity with the systems and the limitations of each approach in the region.

Three of the most commonly used wetland classification systems in North America are the *Classification of Wetlands and Deepwater Habitats of the United States* by Cowardin et al. (1979), released by the Fish and Wildlife Service of the U.S. Department of the Interior; the *Classification of Natural Ponds and Lakes in the Glaciated Prairie Region* by Stewart and Kantrud (1971), specific to the North American Prairie Pothole Region; and the *Canadian Wetland Classification System* (CWCS) by the National Wetlands Working Group (NWWG, 1997), developed by the University of Waterloo and Environment Canada's Canadian Wildlife Service. A new wetland classification specifically for Alberta wetlands is being developed.

### 3.3.1 The Canadian Wetland Classification System

The Canadian Wetland Classification System recognizes five major classes or types of wetlands: bogs, fens, marshes, swamps, and shallow-water wetlands; these are the general classes used in oil sands mine reclamation (see Table 5-3). The five classes are grouped into organic wetlands (peatlands) and mineral wetlands. Organic wetlands include fens and bogs while mineral wetlands include the other three. Both peatland and mineral wetlands have gradients in richness and wetness that produce a number of sub-classes (e.g., thicket swamp and conifer swamp).

The CWCS promotes holistic and ecological management, use and conservation of Canadian wetlands (Adams et al., 1997). While the CWCS is self-described as a scientific system, it was not developed for regulatory or planning purposes. The classification hierarchy consists of five classes, 49 forms, 72 subforms, and eight types. Classes are designated on the basis of the origin of the wetland ecosystem and the nature of the wetland environment. Forms are specific to each of the five classes and are differentiated on the basis of surface morphology, surface pattern, water type, and morphology of underlying mineral soil. Types are classified by vegetation physiognomy. Constructed wetlands “for habitat enhancement and wastewater treatment” are excluded for the classification system. A central focus of the CWCS is the recognition of the importance of peatlands.

The CWCS references common vegetation types within the general description of each class, but they are not the central distinguishing criteria. As a result, the CWCS is not particularly helpful for informing wetland designers positioning or establishing plant communities. It does, however, provide useful information on landscape positioning, hydrology, and hydrological connectivity. One challenge is that a significant amount of prior knowledge is required to apply the system to wetland reclamation design. Ecologists with extensive scientific knowledge of wetlands report having difficulty working through the CWCS classification hierarchy to the desired outcome of wetland identification on the ground, because it is based more on hydrological parameters and landscape positioning than on characteristics that are readily observed in the field (Bayley and Mewhort, 2004).

Each classification system provides benefits to wetland designers. But to ensure uniformity in terminology throughout the guide, the nomenclature described in the CWCS will be used.

### 3.3.2 Oil sands reclaimed wetland classification system

The development of wetland site types depends on a number of factors, including external climatic, hydrological, and chemical drivers as well as internal ecosystem processes that function to move the development of wetlands along a successional gradient. From a functional point of view, these natural wetland classes (bog, fen, marshes, swamps, and shallow-water wetlands) form a set of development “grades.” These grades are achieved by crossing a series of environmental thresholds (Figure 3-5), and these same thresholds must also be crossed in the reclamation of wetlands.

These thresholds are additive and as the more complex wetland grades are achieved a significantly greater number of thresholds must be crossed, making reclamation of some grades more difficult than others. Among the thresholds, a few are especially noteworthy.

1. Bogs and fens form deep layers of peat; marshes and swamps generally do not form layers of peat as deep as bogs and fens.
2. Bogs differ from all other wetlands in receiving only ombrogenous (originating from precipitation) water.
3. Many bogs in the northern Alberta area have discontinuous permafrost that is actively thawing.

4. Fens have a moss-dominated ground layer and a minerogenous water source, whereas marshes have few mosses.
5. Poor fens are acidic and *Sphagnum*-dominated, while rich fens are alkaline and true moss-dominated.
6. Saline fens have high sodium values and few or no mosses in the ground layer.
7. In Alberta, bogs are always wooded (presence of a tree layer with open canopy), while fen vegetation is variable, ranging from wooded to treeless and the presence of a well-developed shrub layer, to no trees and shrubs present and dominated by sedges and mosses.
8. Marshes are dominated by a field layer (the zone that lies above the ground layer and bellow the shrub layer), while swamps are forested (closed canopy).

These thresholds are used as the criteria for a functional wetland classification. Although this functional classification mostly reflects the CWCS, it differs in the use of thresholds as the defining features. The classification utilizes the “site type” concept similar to that in Beckingham and Archibald (1996).

### 3.3.3 Peat-forming wetlands (Bogs and fens)

Peatland form and function depend on peat accumulation and the pattern of loss or gain of carbon. Peat accumulation is determined by the input produced by photosynthesis. This organic matter accumulates first in the upper, aerobic peat column (or acrotelm), where relatively rapid rates of decomposition occur. The rate at which this partially decomposed organic matter is deposited into the water-saturated, anaerobic peat column (the catotelm, where decomposition through methanogenesis and sulfate reduction is extremely slow) largely determines the amount of carbon that will accumulate. In many soil classifications, peatlands soil is greater than 30% organic matter and forms deposits at least 30-40 cm in depth. Non-peat-forming wetlands such as swamps typically accumulate less organic material and no carbon-rich peat.

Peatlands vary greatly in vegetation structure. They may be forested (closed canopy), wooded (open canopy), shrub-dominated, or sedge-dominated. Ground layers may be moss-dominated, lichen-dominated, or bare. Finally, peatlands vary according to their position in the landscape. They can be associated with streams, lakes, springs, and seeps, or are isolated at higher elevations. Peatlands often occur on the landscape as “complex peatlands,” where several distinctive types occur together. Perhaps the most common classification combines aspects of hydrology, vegetation, and chemistry into a functional system of peat-forming wetlands. This approach considers hydrology fundamental to peatland function and recognizes two peatland types, fens and bogs. Fens receive water, nutrients, and minerals from the surrounding uplands, from groundwater, and from precipitation. Bogs receive water, nutrients and minerals only from the atmosphere. Both have stable water-table fluctuations (generally less than 30 cm of drawdown over the growing season. Bogs and acidic fens occur on oligotrophic substrates and must cross many more thresholds during their development than alkaline fens, which have fewer constraints (see Figures 3-6a and 3-6b). Water chemistry tables for peatlands in northern Alberta can be found in Halsey (2007).

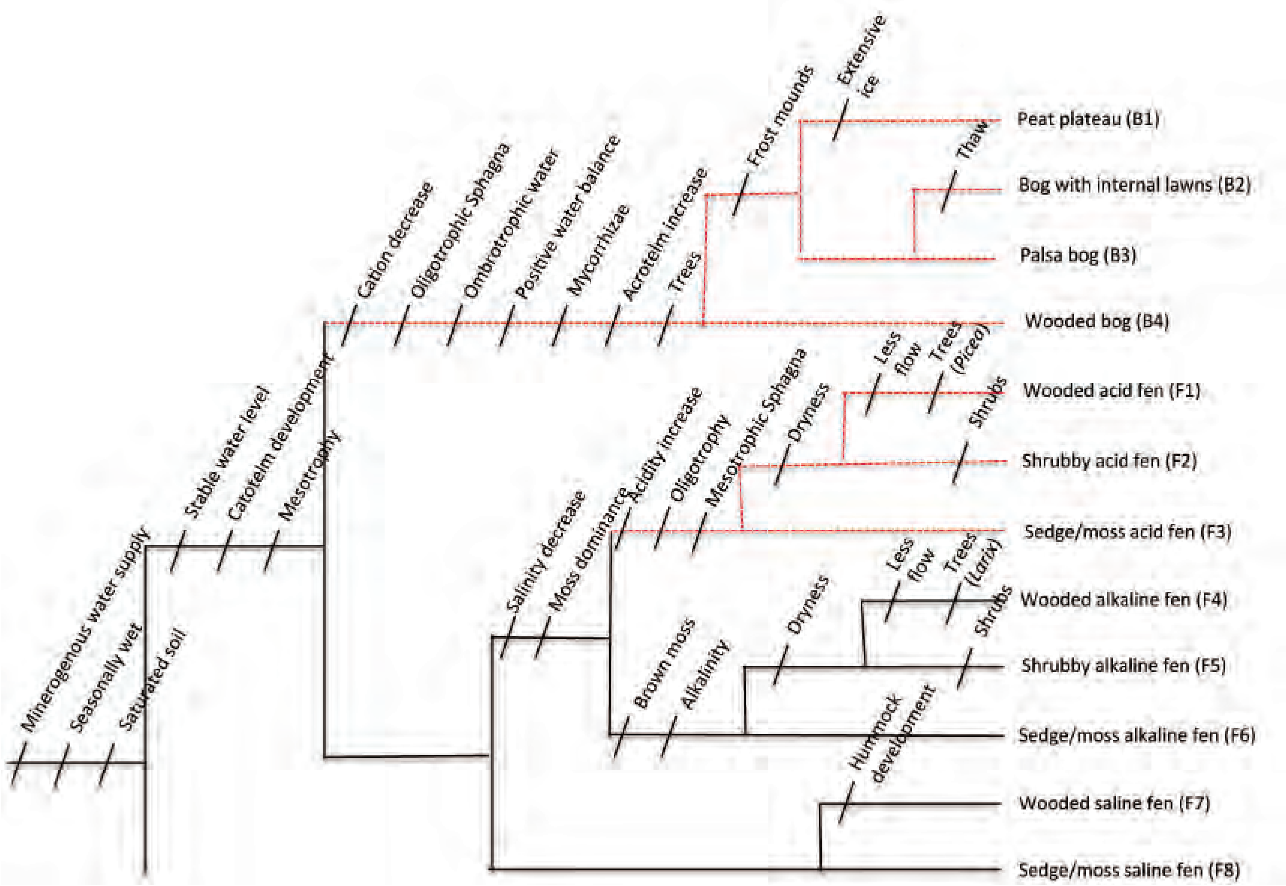

**Figure 3-6a. A dendrogram of functional peatland of wetland types in the oil sands region. Wetlands form related grades of successional development each characterized by thresholds (slanted bars). These “lineages” of wetland types translate to a wetland classification of three site types (bogs, fens, and non-peat forming wetlands), each with a series of ecosite types. Dotted red lines indicate lineages for which our ability to reclaim particular wetland types is less certain.**

**Figure 3-6b. A dendrogram of non-peatland wetland types in the oil sands region. Wetlands form related grades of successional development each characterized by thresholds (slanted bars). These "lineages" of wetland types translate to a wetland classification of three site types (bogs, fens, and non-peat forming wetlands), each with a series of ecosite types. Dotted red lines indicate lineages for which our ability to reclaim particular wetland types is less certain.**

### 3.3.3.1 Bog (AWI Class: B)

Bogs receive their nutrients, minerals, and water from the atmosphere (ombrogenous). They are acidic (pH 4.0-4.9 or less) and mineral-poor (reduced conductivity 43-89 S/cm, sometimes less). Surface water calcium ranges from 5-12 mg/L and sodium from 3-5 mg/L (Table 3-1). A relatively large aerobic zone (the acrotelm) positioned above the anaerobic catotelm is occupied by a small number of oligotrophic species of *Sphagnum*. Sedges (*Carex* spp.) are absent or nearly so. Nearly all of the vascular plant species are woody and have associations with mycorrhizal fungi.

Alberta bogs have an open tree canopy of *Picea mariana* (Figure 3-7). Microrelief of raised mounds (hummocks) and depressions (hollows) is generally well developed. Bogs are limited in distribution to areas where precipitation exceeds potential evapotranspiration, although the oil sands region does have some bogs. This may be because the bogs were formed in wetter, colder times and persist by actually modifying their hydrology. Key indicator species are *Rubus chamaemorus*, and an abundance of hummocks of *Sphagnum fuscum*. Bogs in Alberta have been described by Belland and Vitt (1995).

**Figure 3-7. Wooded bog dominated by *Picea mariana*. Photo courtesy of D. Vitt.**

Four ecosite types of bogs occur in the oil sands region:

> **Peat plateau (AWI wetland type: BTXC):** When bogs develop a continuous layer of permafrost, they are peat plateaus. Peat plateaus are characterized by relatively large and dense groves of *Picea mariana*, a drier ground layer dominated by feather mosses and lichens, along with extensive high hummock development. Small round areas of wet lawns are either collapse features (collapse scars) or areas that have never had permafrost. In either case, the surrounding peat surface is one metre or so higher than the collapse scar surface. Peat plateaus are described by Tarnocai (1970), Zoltai and Tarnocai (1975), and Horton et al. (1979).
>
> **Bog with internal lawns (AWI wetland type: BTXI, BTXR):** Bogs with intermittent permafrost (frost mounds) and areas without permafrost as well as irregular wet areas (internal lawns) that have formed in the recent past from permafrost thaw are common in northern Alberta. They are further characterized by a hummocky feather moss/*Sphagnum* ground layer, usually 10-50 cm above the lawn surface. They are described by Vitt (1994) and Beilman et al. (2000).

**Palsa bog (AWI wetland type: BTXN):** Bogs with intermittent permafrost but no evidence of thaw are uncommon in the region. True palsas form when water in the peat column is abundant, and in these cases large, peaty, ice-filled mounds form that are many metres high. The lack of abundant water in western Canadian bogs prevents large palsas from forming; however, large frost mounds that have not thawed may be present in some northern sites. These sites are best characterized by extensive, but localized hummock development associated with ground layers of lichens and feather mosses.

**Wooded bog (AWI wetland type: BTNN):** Bogs with no permafrost or permafrost thaw features (Figures 3-8 and 3-9) are dominated by an open, uniform canopy of *Picea mariana* and abundant hummocks of *Sphagnum fuscum* (or occasionally *S. capillifolium*). The complete absence of *Betula* and *Salix* and almost complete lack of *Carex* species are key features. See Belland and Vitt (1995) for more details on regional differences.

**Figure 3-8. Oblique aerial view of permafrost thaw creating patchy wet areas (internal lawns) within a wooded bog without permafrost. Photo courtesy of D. Vitt.**

**Figure 3-9. Oblique aerial view of wooded bog (including evidence of past wildfire) ringed by a narrow wet marginal fen. Photo courtesy of D. Vitt.**

**Figure 3-10. Ground layer of *Sphagnum fuscum*, typical of wooded bogs. Photo courtesy of D. Vitt.**

### 3.3.3.2 Fen (AWI Class: F)

Water quality (chemistry) is the main factor controlling fen type and flora, but water quantity (flow) controls vegetation structure and surface topography. Fens receive water, nutrients, and minerals from the surrounding uplands, groundwater, and from precipitation, and have higher amounts of base cations and associated anions than bogs. They vary in acidity and alkalinity and also in amount of flow and in nutrient supplies. Unlike high microrelief of hummocks and hollows in bogs, fens feature a more level topography of extensive carpets and lawns dominated by *Sphagnum* or true mosses. In general, fens lack a well-developed acrotelm due to water levels at or near the surface of the peat. As water flowing through the fen increases, the surface vegetation develops a reticulation of wet pools and carpets separated by slightly raised ridges. Further increase in water flow directs the patterns into linear pools (some filled with floating vegetation (carpets or flarks), alternating with linear ridges (strings). These pool/string complexes are oriented perpendicular to water flow, with smaller pools always upstream from larger ones. Sedges are abundant, but vegetation development is highly variable, ranging from sites that are moss-dominated, or sedge-dominated, to those having canopies of either shrubs or trees. Vitt and Chee (1990) reviewed chemical and floristic characteristics of fens in Alberta.

**Acid fen (AWI Wetland type: FO, FT (in part)):** Acid fens have pHs of 4.6 to 5.0 and are *Sphagnum*-dominated *(S. angustifolium, S. fallax*, & *S. majus*). They are nutrient poor (oligotrophic) and have few base cations (surface water: reduced EC=44-77 S/cm, calcium 3-7 mg/L, and sodium 3-5 mg/L). Alkalinity is less than 3 mg/L, but often approaches zero. Microsites within these fens consist largely of carpets and lawns, and if flow is sufficient, longitudinal pools (flarks) and ridges (strings) may be present. Acid fens have been studied by Vitt et al. (1975), Vitt and Bayley (1984), and Nicholson and Vitt (

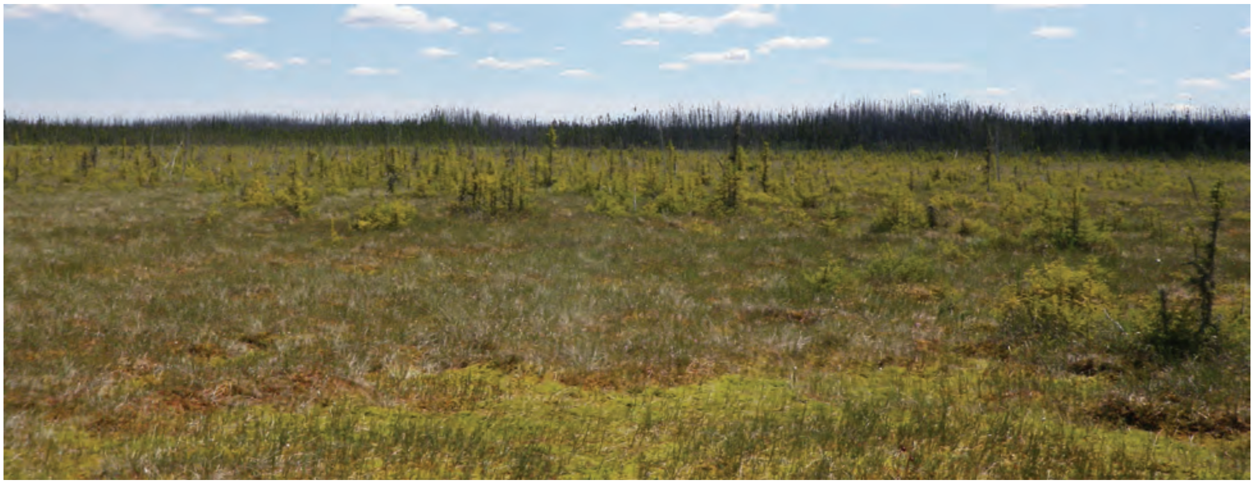

**Figure 3-11. Sedge-moss (*Sphagnum*)-dominated acidic fen (*Sphagnum angustifolium* in foreground). Photo courtesy of J. Hartsock.**

As flow decreases owing to vegetation development, vegetation changes. Wet fens (**Wetland type FONG)** are sedge and/or moss-dominated, with numerous lawns and carpets. Small pools may be present. Drier fens with less flow may be invaded by shrubs **(Wetland type FONS).** Shrubs consist of *Chamaedaphne calyculata*, *Andromeda polifolia*, and species of shrub *Betula*. Low hummocks of *Sphagnum angustifolium* and *S. magellanicum* are present. Even drier sites support abundant trees (*Picea mariana*); these wooded acidic fens **(Wetland type FTNN)** are rare, but do occur in transitional areas from shrubby acidic fens to wooded bogs.

**Alkaline fen (AWI Wetland type: FO, FT (in part):** Alkaline fens have pHs from 6.2 to 7.7 or higher and are dominated by true mosses (often called “brown mosses”). Mesotrophic species of *Sphagnum* (*S. teres, S. warnstorfii, S subsecundum,* and *S. obtusum*) may be present in sites with lower pH. Alkalinity is variable and ranges from 106-220 mg/L; surface water has reduced EC ranging from 115-629 S/cm with calcium values from 25-629 mg/L and sodium values recorded from 3-120 mg/L. Water levels are variable and associated with vegetational differences. Alkaline fens have been described by Slack et al. (1980) and Chee and Vitt (1989). Historically, these fens have been divided into “moderate rich fens,” with pHs from 6.0 to 7.0 and “extreme rich fens” with pHs above 7.0.

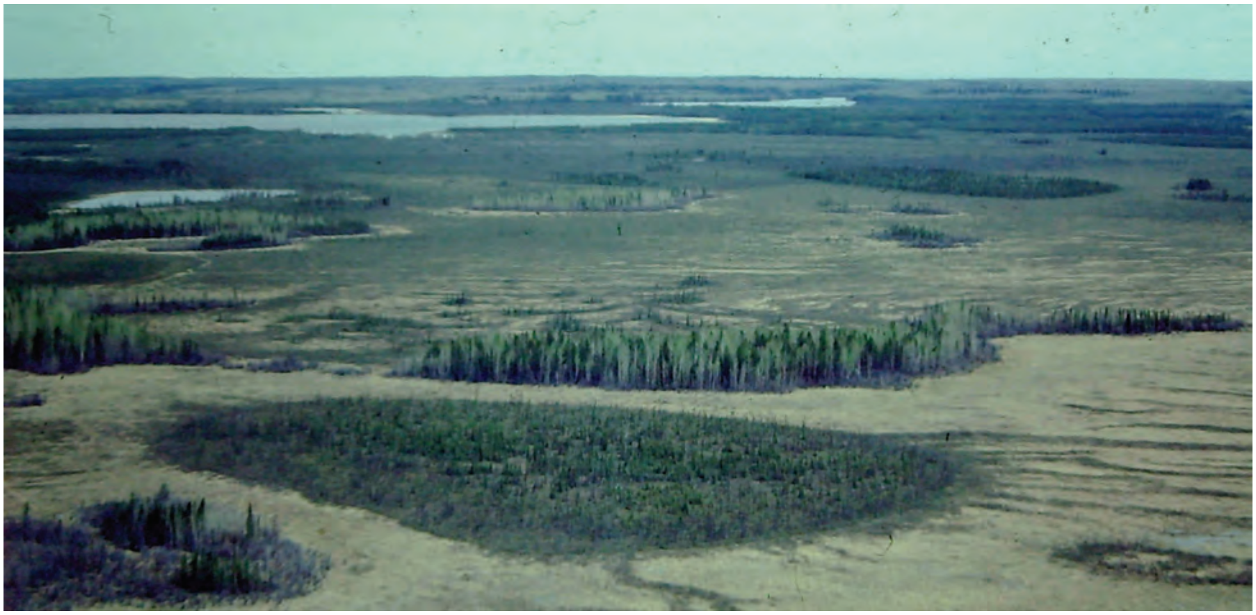

**Figure 3-12. Oblique view of patterned sedge-moss (true moss)-dominated alkaline fen surrounding a wooded bog island. Photo courtesy of D. Vitt.**

Wet alkaline fens with water close to the surface are dominated by true mosses (*Hamatocaulis, Drepanocladus*, and *Scorpidium*) and/or sedges (*Carex lasiocarpa, and C. diandra*) (**Wetland Type FONG**); drier fens have an abundance of shrubs (shrub *Betula* and *Salix* species) (**Wetland type FONS),** while even drier sites support hummock development by true mosses (*Tomenthypnum nitens*) and development of a tree canopy (*Larix laricina* or *Picea mariana*) (**Wetland type FTNN)**.

**Saline fen (AWI: not treated):** The abundance of the base cation, sodium, characterizes these fen types. The abundance of Na$^+$ is associated with a lack of mosses in the ground layer and an abundance of sedges. Salt-tolerant species are evident (e.g., *Triglochin* spp.*).* The pHs are basic and the nutrient status is mesotrophic. Wet sites are dominated by species of *Carex* (especially *C. aquatilis*, *C. atherodes*, and *C. utriculata, along with Calamagrostis stricta*), whereas drier sites have individuals or groves of *Larix laricina* and occasional shrubs (*Salix* species). Saline fens occur along a gradient of sodium concentrations. Fens with ECs of less than 500 µS/cm are most influenced by calcium ions (alkaline fens), those with ECs of 500-2000 µS/cm have been termed sub-saline, while those having ECs above 2000 µS/cm are saline (S. Bayley pers. comm.). Saline fens have been examined by Purdy et al. (2005) and Trites and Bayley (2009).

**Table 3-1. Minimum and maximum means of surface water chemistry for sites across western Canada for the four different peatland types. From Halsey (2007). Poor fens = acidic fens. Rich fens = alkaline fens. Bogs and poor fens are *Sphagnum*-dominated, rich fen types are true-moss dominated. Variance measures in Halsey (2007).**

| | Bog | Poor fen | Moderate-rich fen | Extreme-rich fen |
|---|---|---|---|---|
| pH | 4.0 – 4.9 | 4.6 – 5.1 | 6.2 – 6.4 | 7.3 – 7.7 |
| Conductivity(µS/cm) | 42.6 – 88.9 | 44.3 – 77.3 | 114.8 – 255.6 | 150.3 – 629.1 |
| Ca$^{++}$ (mg/L) | 5.1 – 11.6 | 3.3 – 7.3 | 25.2 – 45.0 | 42.0 – 83.4 |
| Mg$^{++}$ (mg/L) | 1.2 – 4.6 | 2.8 – 3.2 | 10.2 – 15.6 | 15.0 – 25.0 |
| Na$^+$ (mg/L) | 2.6 – 5.4 | 2.7 – 4.7 | 3.5 – 22.0 | 3.6 – 119.7 |
| K$^+$ (mg/L) | 1.0 – 1.8 | 0.9 – 1.2 | 1.1 – 2.0 | 0.9 – 1.7 |
| NH$^+_4$ (µg/L) | 57.6 – 193.3 | 58.4 – 253.9 | 34.3 – 432.7 | 24.0 – 63.8 |
| NO$^-_3$ (µg/L) | 14.4 – 16.0 | | 4.8 – 20.4 | |
| NO$^=_2$ and NO$^-_3$ (µg/L) | | 18.0 – 32.8 | 21.1 – 229.3 | 39.0 – 63.8 |
| TDN (µg/L) | | 1083.1 | 1059.4 – 4782.6 | 1562.9 |
| TKN (µg/L) | 2918.0 – 2942.0 | 2131.8 – 3614.0 | 2113.1 – 3246.0 | |
| P (mg/L) | 0.4 | | | |
| SRP (µg/L) | | 5.3 | 13.7 – 93.9 | 29.9 |
| TP (µg/L) | 281.6 – 443.6 | 282.9 – 324.6 | 0.1 – 141.7 | 0.0 |
| TDP (µg/L) | 0.0 | 15.1 – 81.0 | 7.9 – 80.0 | 30.6 – 42.0 |
| DOC (mg/L) | | 37.9 | 0.3 – 35.9 | 0.5 |
| Cl$^-$ (mg/L) | 0.6 | 0.4 | 1.3 – 170.3 | 1.0 – 41.2 |
| SO$^=_4$ (mg/L) | 1.0 | 0.2 | 0.8 – 11.1 | 58.0 – 155.8 |
| Alkalinity (mg/L CaCO$_3$) | | 2.9 | 106.1 – 166.8 | 220.6 |
| Bicarbonate (mg/L) | | 3.6 | 140.5 – 203.4 | |

### 3.3.4 Non-peat-forming wetlands

According to the National Wetlands Working Group, non-peat forming (mineral) wetlands occur in areas on the landscape where surface water exists, but little (<40 cm) or no organic matter or peat has accumulated above the mineral soils. However, some mineral wetlands on the Boreal Plains are known to have 1 m or more of peat (Bayley and Mewhort, 2004; Nicholson et al., 2006). Factors such as position in the landscape, geology and soils, hydrology, and climate all influence the formation of mineral-based wetlands. They occur as wet areas in mineral soil drainages and seepages, floodplains with sedimentary mineral soils, shallow water areas of palustrine, lacustrine, or riverine systems, and many other areas in the landscape where water collects on mineral soils.

Mineral wetlands receive water, nutrients, and minerals from the surrounding uplands, groundwaters, and from precipitation. Because of this, they are generally alkaline, with neutral to basic pH (Adams et al., 1997). Nutrient availability is enhanced by periodic aeration, as well as by shallow depths, surface water and groundwater loading, and high rates of productivity and decomposition (Thormann et al., 1999). Because of these factors and the naturally phosphorus rich mineral soils, mineral wetlands in Alberta are typically eutrophic (Bayley et al., 2007).

The hydroperiod of mineral wetlands is controlled mainly by the difference between precipitation and evapotranspiration (where P PET in the Boreal Plains (Devito et al., 2005)), groundwater interactions, and, to a lesser degree, surface runoff. Surface runoff in the region is low due to flat topography, soil storage, and evapotranspiration (Smerdon et al., 2005). Seasonal and annual variability in the Boreal Plains climate influences short- and long-term cycles in water levels (Mwale et al., 2011). Vegetation responds to these fluctuations in water depth and hydroperiod (Weller and Spatcher, 1965; van der Valk, 1978). Vegetation zones can undergo cycles of flooding that lead to the degeneration of emergent plants and succession in favour of submersed communities. Likewise, drawdown conditions coincide with the rapid succession of annual species, germination of emergent seeds, and a regeneration phase as water levels begin to rise again (Figure 3-5).

#### 3.3.4.1 Marsh (AWI Class: M)

Marshes are mineral wetlands that experience variable inundation regimes that vary from periodic to seasonal to annual fluctuations in water levels. This is a key difference between marshes and peat-forming fens and bogs. It is this water level variation in marshes that drives productivity. Water inputs to marshes include surface runoff, groundwater discharge or seepage, and direct inputs from precipitation. These inputs, in addition to the geology of each system, determine the variability of the water table (from surface flooding to drawdown). Under certain circumstances the substrate may be alternately exposed and flooded depending on the hydrodynamics of the marsh (Figure 3-5). Like fens, marshes generally have a water source in addition to direct precipitation. The resulting diversity of dissolved mineral inputs and aeration give rise to high productivity and decomposition of vegetative material. Common vegetative species include reeds, sedges, and grasses, broad-leaved emergents, floating-leaved and submerged aquatic vegetation, algae, and other herbaceous and forb species. In many areas in the Boreal Plains, marshes typically occur as smaller (10 to 100+ metres wide) rings of vegetation around basins, but they can also occur as large expanses, particularly in the nutrient-rich inland deltas or alluvial fans of major river systems (e.g., Peace/Athabasca Delta and Saskatchewan Delta).

A diversity of soil substrates in marshes is also common given the diversity of marsh wetland types. Mineral soils are commonly found in marsh wetlands and organic soils are typically present as sedimentary peat (surficial layers humic or limnic peat). The depth of this peat can vary depending on where the marsh exists in relation to other wetlands, such as fens. Therefore, mixtures of both mineral and organic soils can be common in marshes. Soil types range from mineral gleysols (humic and rego) to organic humisols and mesisols (Soil Classification Working Group, 1998).

> **Wet Meadow Marsh (M1):** The terminology for wet meadow marsh varies from vernal pools, ephemeral wetlands, intermittent wetlands, and hog wallows. While the nomenclature varies among specialists and across regions, what is known is that these landscape features are as permanent as rivers, lakes, marshes, and bogs (Zedler, 2003). In Britain, many small temporary wetlands are thought to be in excess of 8,000 years old. In California some ponds date back at least 50,000 years (Martin 1990). While ponded water may come and go during the year in these habitats, it is present in most years for at least a short time. This predictability allows a distinctive community of flora and fauna to develop.
>
> The pH of wet meadow marshes is generally basic, ranging from 6.5 to 8.5; pH is partly determined by the amount of peat present (Bayley and Mewhort, 2004). Nutrient status is often eutrophic. Dominant vegetative species in wet meadows include emergent aquatic macrophytes, chiefly graminoids such as rushes, grasses, sedges, herbs and shrubs (Table 3-2). The plant communities are a reflection of both the duration and depth of flooding. Generally, the communities that develop in wet meadow marshes are incapable of withstanding water deeper than 30 cm for more than one growing season. They tend to position themselves based on their flood-depth tolerance. The variety of species that develop is also usually linked to the frequency with which bottom sediments are exposed to air and light, allowing seed germination to occur.
>
> Wet meadow marshes are usually circumneutral to highly alkaline owing to the presence of dissolved minerals such as calcium, potassium carbonate, or potassium bicarbonate. They tend to be quite fresh, but they can become saline depending on the substrates over which they form. Natural landscape features that determine the spatial distribution of soil salinization in catchment areas include parent material, topography and associated groundwater flow systems (Salama et al., 1999). The water in saline marshes can be high in dissolved salts from water losses that result in the accumulation of sulphates and chlorides of sodium and magnesium near, or at, the soil surface. In highly saline marshes, vegetation development and diversity can be hampered because of the salt toxicity to plants. In sub-saline to saline marshes, plant assemblages will change, although there should be some overlap of marsh species since many species are tolerant of salinity. Indicator species in saline wet meadow communities include *Puccinellia nuttalliana*,

*Triglochin maritima*, and *Schoenoplectus tabernaemontani* (Raab and Bayley, 2012; Wong et al., 2007)*,* whereas *Carex rostrata* and *C. atherodes* were found only in low salinity areas (Raab and Bayley, 2013).

In general, wet meadow marshes can be the most complex marsh systems to design hydrologically and to maintain. This is because they require shallow depths where soils are exposed on an almost annual basis.

**Emergent Marsh (M2):** More permanent marshes have water above or at the land surface in most years and may have deeper basins and more constant supplies of groundwater than wet meadow marshes (Figure 3-13). The pH of emergent marshes is neutral. Nutrient status is often eutrophic and conductivities of the surface waters may be somewhat higher than wet meadow marshes, particularly if the time between drawdowns is longer (i.e., one year of drawdown every 10 or 15 years). This reflects the evaporative transport of ions and interactions with sediments over time (Ross, 2009). Marsh vegetation is organized along water level gradients to form distinct communities or assemblages. Vegetative species in emergent marshes often include many of the same species observed in wet meadow marshes, such as rushes, reeds, grasses, sedges, herbs and shrubs. However, they also include an additional community of more flood-tolerant wetland species that are suited to growing in deeper-flooded conditions. These species include *Typha latifolia*, *Schoenoplectus spp*., floating leaved and submerged vegetation, and algae (Table 3-2). Table 3-5 includes water chemistry for emergent marshes in Boreal Alberta.

**Figure 3-13. An emergent marsh. Photo courtesy of Duck Unlimited Canada.**

**Table 3-2. Vegetation classes in various marsh types in the Boreal Plains region.**

| Vegetation type | Description | Examples |
|---|---|---|
| **Wet meadow** | An upright plant rooted in substrate beneath the water or exposed to seasonal flooding but emerging above water surface; differs from emergent species below in its inability to handle deep flooded environments (i.e., greater than 30 cm). | *Carex aquatilis, Carex rostrata, Senecio congestus, Carex atherodes Epilobium leptophyllum, Carex utriculata, Cicuta maculate, Mentha arvensis, Petasites frigidus, Galium trifidum, Calamagrostis canadensis, Sium suave, Potentilla palustris, Salix* spp. |
| **Emergent** | An upright plant rooted in substrate or exposed to seasonal flooding but emerging above the surface; does not include plants with flowering parts above the surface but are otherwise entirely under water. These species tend to handle deeper flooding than wet meadow species (i.e., > 30 cm). | *Scirpus* spp., *Zizania palustris, Typha* spp., *Sparganium* spp., *Acorus calamus, Schoenoplectus lacustris, Schoenoplectus acutus.* |
| **Open-water: Floating** | Rooted or free-floating, leafed plants with leaves normally floating on the water surface. | *Nuphar* spp., *Brassenia schreberi, Nymphaea* spp., *Spirodela polyrhiza*, *Lemna spp., Polygonum amphibian, Potentilla palustris, Alisima* spp., *Calla palustris, Sagittaria cuneata, Menyanthes trifoliate.* |
| **Open-water: Submergent** | Plants normally submerged under water. Some species may have flowering parts that break the water surface. Species such as *Potamogeton* have floating as well as submerged leaves; however, the submerged leaves represent a larger part of the plant and the genus is submergent. | *Potamogeton* spp., *Ceratophyllum demersum, Elodea canadensis*, *Utricularia vulgaris, Ranunculus gmelinii, Myriophyllum spicatum, Callitriche verna.* |
| **Open-water: Algal** | | Phytoplankton, Metaphyton |

Not all wet meadow marshes exist where emergent marshes occur, but most emergent marshes transition into wet meadow marshes as their outer edges grade nearer toward their upland edges (see Figure 3-2). Water depths are usually 30 cm or deeper. Deeper flooded areas of emergent marshes often support floating leaved and submerged aquatic communities such as *Petasites frigidus* and *Comarum palustre*.

#### 3.3.4.2 Shallow-water wetlands (M3)

Shallow-water wetlands, also known as shallow open-water wetlands, differ from both emergent and wet meadow marshes in the length of time they remain flooded and the flooding depths in the most central portions of the basin. They feature a semi-permanent or permanent water table, with open standing water in the central portion of the wetland for much of the growing season in most years (Figure 3-14). While the CWCS indicates that the central open-water portion be no deeper than 2 m, their open-water component can only form if they've been flooded with more than 1 m of water for longer than two years. Shallow-water wetlands tend to have chemical characteristics similar to emergent and wet meadow marshes. The dominant central open-water section generally covers at least 75% of the wetland. This open-water area can support a variety of submerged and floating vegetation or algae, depending on whether it exists in a clear or turbid state. The outer edges of shallow-water wetlands often support communities of both emergent and wet meadow plant species.

Water depth is an important determinant of the state of shallow-water wetlands. In deeper wetlands, nutrients are diluted; this results in lower phosphorus and a reduced likelihood of phytoplankton dominance (Cobbaert et al., 2014). If the depth is shallow enough (< 175 cm), a submersed aquatic vegetation (SAV) community will dominate. In drier years, nutrients are concentrated, with higher TP and TN, and phytoplankton can respond rapidly, leading to algal domination. If the depths are shallow enough, with sufficient light penetration, then SAV can also grow, leading to a rich community of both phytoplankton and SAV. These are highly productive systems.

As in emergent and wet meadow marshes, the substrate of shallow-water wetlands is mineral or shallow organic soil. Organic substrate is composed of soft, unconsolidated sedimentary material formed beneath standing water and made up of a mixture of mineral material and well-decomposed organic material. The material is soft, oozy, and semi-suspended. Mineral substrates can include or be composed of sands, gravel, rock, bedrock, or gleysols.

**Figure 3-14. A shallow-water wetland, open-water state. Photo courtesy of Ducks Unlimited.**

Surveys of these shallow habitats are rare in the region, although these wetlands are numerous (Bayley and Prather, 2003; Bayley et al., 2007; Sass et al., 2007). They are often embedded in fen/bog complexes or surrounded by marshes or upland forests (Halsey et al., 1997; Bayley and Prather, 2003). In boreal Alberta, shallow-water wetlands can be small to large ponds that can occasionally become very shallow during periods of drought. Bayley (pers. comm.) has measured a 1.5-m change in water depth in ponds in the Utikuma region during droughts compared with normal years. Nicholson et al. (2006) found that some ponds were formed over a peat substrate (and hence were not mineral wetlands), and the fringe vegetation was characterized by marsh species (although some *Drepanocladus* (a moss) was present in some plots).

The primary productivity of shallow-water wetlands is characterized by mixed populations of phytoplankton and SAV in the open water (Bayley and Prather, 2003, Bayley et al., 2007). Some of the most common SAV species include *Potamogeton richardsonii*, *Myriophyllum exalbescens* and *Chara* spp. (Bayley and Prather, 2003). Norlin et al. (2006) provide a more detailed list of the vegetation they found in shallow-water wetlands. Unlike eastern boreal lakes on shield bedrock, which are typically oligotrophic, shallow-water wetlands situated on thick glacial till are often eutrophic (Prepas et al., 2001; Bayley and Prather, 2003). They also tend to be high in DOC, dark in color with neutral pHs (Bayley and Prather, 2003; Norlin et al., 2005). As with marshes in general, high productivity and decomposition results in low oxygen levels during the winter. Lack of oxygen, and occasional freezing to the bottom, reduces small fish populations (i.e., stickleback), allowing zooplankton communities to flourish (Norlin et al., 2005; 2006). Waterfowl, zooplankton and macroinvertebrates, and amphibians benefit from the lack of fish in most of these systems.

> **Disturbed marsh/beaver ponds (M4):** Disturbed marshes indicate a change in state with respect to flooding regimes. For beaver ponds, it means either the creation of an entirely new wetland site following the building of a dam or a fundamental change in overall plant diversity due to the long-term stabilization of water levels. Depending on location, beaver pond depths can range from 0.25 m to more than 2 m (Roulet et al., 1997). Depth of flooding dictates the plant communities that survive once stabilization has occurred. Generally, disturbances such as changes in flooding regime or beaver dams result in a mix of M1 and M2 plant communities, depending on the hydroperiod and the depth of flooding that occurs in a particular location. Table 3-3 provides parameters for the likelihood of beavers occurring at a site. Appendix D presents more information on beaver ponds.

**Table 3-3. Parameters related to increased likelihood of beavers. Adapted from Eaton et al. (2013).**

| Characteristic | Parameters |
|---|---|
| **Primary factors** | |
| Stream gradient | <6% |
| Valley floor width | Wide (>25 m) |
| Channel width | Narrow (3 to 4 m) |
| Stream depth | Shallow to moderate |
| Area of watershed | Moderate (500 to 5,000 ha) |
| Stream flow rate | Moderate |
| Stream velocity | High |
| **Secondary factors** | |
| Riparian vegetation | Deciduous (especially aspen), shrubs |
| Soil | Poorly drained |
| Stream substrate | Sediment |
| Abundance of predators | Low |

**Table 3-4: Chemical properties of selected permanent and semi-permanent natural marshes on the Boreal Plain. Table adapted from Bayley et al. (2014).**

| | All marshes[1] | | Freshwater[2] | | Sub-saline[3] | | Saline[4] | |
|---|---|---|---|---|---|---|---|---|
| Parameter | Mean | 90% CI | Mean | 90% CI | Mean | 90% CI | Mean | 90% CI |
| **Water** | | | | | | | | |
| Conductivity ( S/cm) | 1341 | 288 | 228 | 20 | 1107 | 108 | 3666 | 347 |
| Total dissolved solids ( g/L) | 0.94 | 0.22 | 0.21 | 0.02 | 0.73 | 0.08 | 2.55 | 0.25 |
| Chloride (mg/L) | 114 | 57 | 1.3 | 0.4 | 51 | 15 | 474 | 108 |
| Sulfate (mg/L) | 444 | 257 | 11.9 | 4.7 | 230 | 45 | 1731 | 557 |
| Sodium (mg/L) | 159 | 59 | 7.4 | 1.5 | 88 | 16 | 596 | 96 |
| Potassium (mg/L) | 22 | 7.2 | 5.6 | 1.1 | 22 | 2 | 44 | 16 |
| Magnesium (mg/L) | 86 | 39 | 9.6 | 1 | 117 | 50 | 96 | 20 |
| Calcium (mg/L) | 50 | 5.7 | 27 | 2 | 52 | 4.7 | 75 | 7.3 |
| Ammonia ( g/L) | 168 | 68 | 125 | 29 | 105 | 5.8 | 423 | 136 |
| Nitrate/nitrite ( g/L) | 2.8 | 1.1 | 2.9 | 0.5 | 1.6 | 0.4 | 6.2 | 2.1 |
| Total dissolved nitrogen (mg/L) | 2.9 | 0.46 | 2.1 | 0.23 | 2.9 | 0.18 | 4.4 | 0.89 |
| Total nitrogen (mg/L) | 3.8 | 0.82 | 2.4 | 0.23 | 3.4 | 0.31 | 7.1 | 1.6 |
| Total phosphorus ( g/L) | 269 | 117 | 135 | 19 | 177 | 43 | 750 | 229 |
| Total suspended solids (mg/L) | 11 | 2.1 | 8.5 | 2.1 | 11 | 2.1 | 11 | 2.3 |
| Proportion Secchi depth | 78 | 5.3 | 78 | 5.1 | 74 | 5.7 | 88 | 4.1 |
| **Sediment** | | | | | | | | |
| Water content (%) | 65 | 5.0 | 68 | 6.2 | 61 | 5.0 | 76 | 2.3 |
| Total phosphorus (mg/g) | 0.9 | 0.1 | 0.8 | 0.1 | 0.9 | 0.1 | 1.3 | 0.1 |
| Total nitrogen (%) | 2.0 | 0.2 | 2.2 | 0.2 | 1.9 | 0.2 | 2.2 | 0.2 |
| Total carbon (%) | 26 | 2.7 | 30 | 3.0 | 23 | 2.8 | 31 | 1.8 |

[1]N = 39 marshes on the Boreal Plain from Rooney and Bayley (2010), [2]N = 10 marshes on the Boreal Plain with EC < 500 S/cm from Rooney and Bayley (2010), [3]N = 22 marshes on the Boreal Plain with EC = 500 - 1,000 S/cm from Rooney and Bayley (2010), [4]N = 7 marshes on the Boreal Plain with EC = > 2,000 from Rooney and Bayley (2010).

#### 3.3.4.3 Swamp (AWI Class: S)

Swamps blur the lines between mineral and peatland wetland types, and can occur in widely different landscape settings from mineral soil floodplains to more peat-dominated soils in the case of conifer swamps (Figure 3-15). For this reason, swamps have traditionally been harder to identify than other wetland types and are often confused or grouped with other wetland classes. Swamps are distinguished from other wetland types in that they are wooded (treed or shrubbed) wetlands that are in contact with minerotrophic water in either mineral or shallow peat soils (Smith et al., 2007a). An important distinction is that woody vegetation dominates swamps, with canopy coverage normally greater than 50%. Because of the improved nutrient availability and aerated soils, swamps tend to have greater canopy coverage and taller trees than fens. The abundance of woody material in swamps provides another important distinction in that the peat is primarily composed of decomposing wooded material (shrub and tree) rather than the *Sphagnum* or sedge-dominated peat types that comprise the organic layer in fens and bogs. Furthermore, peat soils in swamps are fairly well decomposed compared with soils in peatlands.

**Figure 3-15. A conifer swamp, showing hummocky peat on the ground (characteristic of swamps in general) and black spruce-dominated tree cover. Photo courtesy of Duck Unlimited Canada.**

Generally, boreal swamps in Canada are poorly understood. Little information is available on the basic hydrological and physical parameters of swamps and what does exist provides little hydrological guidance for reclamation purposes (see Table 3-5). As a result, our ability to reclaim these systems is limited.

**Black spruce swamp (S1):** Wetlands with soils dominated by fibric or woody-based shallow peat accumulation. *Picea mariana* dominate the tree layer with tree heights >10 m and canopy closures exceeding 60%. Often located on hummocky terrain with small pools of surface water present during mid-summer months. The rooting zone is often in contact with mineral-rich water. Aside from general (National Wetlands Working Group, 1997) and boreal (Smith et al., 2007a,b; Halsey et al., 2004) wetland classification systems, boreal swamp systems - including boreal conifer swamps, and black spruce swamps - have been poorly described in the literature. Common tree, shrub, forb/herb and graminoid species found in black spruce swamps are listed in Appendix A.

**Tamarack swamp (S2):** *Larix laricina* is common to wooded swamps and fens throughout the Boreal Plains and is associated with wet, more nutrient-rich soils than those supporting black spruce. Depending on nutrient availability and hydrology, *Larix* ranges from heights of 1-2 m tall, thin-foliaged, shrub-like stunted trees in poorer fens to 25–30 m tall dense-foliaged trees in true tamarack swamps. Generally, sites supporting *Larix* with heights >10 m that possess dense canopies and moist soil indicators are considered swamps (Figure 3-16); tree height is a reliable and defining feature to determine whether a system is a tamarack swamp (tree height > 10 m), or a tamarack fen (tree height < 10 m). Factors influencing the distribution of vegetation in these systems include distance from shore, canopy cover, substrate nitrate concentration, substrate pH and substrate conductivity (Girardin et al., 2001). Depth, pH, and carbon concentration of the water table are also found to be factors related to species distribution. Appendix A provides a list of species commonly found in tamarack swamps.

**Figure 3-16. A tamarack swamp. Photo courtesy of Ducks Unlimited Canada.**

**Shrubby swamps (S3):** Shrubby swamps are usually underlain by mineral soils with relatively little peat accumulation. The vegetation is dominated by tall (> 2 m) shrubs (e.g., willows (*Salix* spp.), *Cornus sericea var. sericea = C. stolonifera*, *Alnus* spp., *Betula occidentalis*., over a species-rich graminoid/forb understorey. Some of the more common herbaceous species include *Equisetum* spp., *Petasites frigidus var. sagittatus*, *Parnassia* *palustris*, *Carex* spp. and *Calamagrostis canadensis*. Mosses may cover large parts of the ground when the water table drops below ground level, but fluctuating water levels prevent the accumulation of peat. In gently sloping sites, the transition from shrubby swamp to shrubby upland can be difficult to delineate (Figure 3-17). Many shrubs that grow along the outer edges of swamps are also capable of growing on well-drained slopes above the water table. Two of the most common are *Cornus sericea var. sericea* and *Corylus cornuta*. However, many shrubs cannot tolerate prolonged flooding, and help make the distinction between wetland and upland. Noticeable upland species include *Corylus cornuta*, *Prunus pensylvanica*, *Prunus virginiana*, *Amelanchier alnifolia*, *Symphoricarpos albus* and *Rosa spp* (see Appendix A).

**Figure 3-17. A shrub swamp. Photo courtesy of Duck Unlimited Canada.**

**Hardwood Swamps (S4):** Hardwood swamps have at least 25% tree cover (although most stands have closed canopies). More than 80% of the trees in these swamps are broad-leaved (Figure 3-18). In Alberta, most hardwood swamps occur in transitional areas between permanent marsh and fen wetlands and uplands. The vegetation of these wetlands is distinctive: *Betula neoalaskana* and *B. papyrifera* are the most common trees, but *Populus balsamifera* sometimes dominates in hardwood swamps on floodplains. *Acer negundo* and tree-sized willows (Salix spp.) are common in swampy, human-modified environments. Tall (> 2-m) shrubs are usually abundant in the understory; the most common are *Salix* spp., Cornus sericea var. *sericea*, and *Alnus* spp. (Appendix A). The ground surface in hardwood swamps is often irregular, with networks of small channels and pools persisting throughout the growing season. This creates a variety of microhabitats, which support many moisture-loving forbs (e.g., *Caltha palustris*, *Chrysosplenium iowense*, *Impatiens* spp., *Viola palustris*), graminoids (e.g., *Calamagrostis canadensis*, *Carex* spp.) and pteridophytes (e.g., *Equisetum* spp., *Dryopteris* spp.).

**Figure 3.18. A hardwood swamp. Photo courtesy of Ducks Unlimited Canada.**

**Mixedwood swamps (S5):** In Alberta, mixedwood swamps are usually located between hardwood swamps and coniferous swamps. Trees cover at least 25% of the site, but are usually denser (Figure 3-19). Most have closed canopies. Broadleaf and coniferous trees are abundant, with each group accounting for 20-80% of the canopy. The dominant hardwood is *Betula neoalaskana*, and the most common softwood species are tamarack and black spruce. Tall shrubs are usually abundant in the understory. The most common shrubs are willows (*Salix* spp.), red-osier dogwood, and speckled alder (*Alnus incana*). Many of the forbs and graminoids found in hardwood swamps are also found among the hummocks and depressions of mixedwood swamps, but mixedwood systems tend to be slightly poorer in overall plant communities and less diverse as well.

**Figure 3.19. A mixedwood swamp. Photo courtesy of Ducks Unlimited Canada.**

**Table 3-5. Summary of depth to water table recorded in the literature for swamp systems. Means across swamps surveyed are presented (where given), with ranges in brackets.**

| | Roy et al. (1999)[1] | Locky and Bayley (2006)[2] | Warner and Asada (2006)[3] | Dunn et al. (2009)[4] |
|---|---|---|---|---|
| **Depth to water table (cm)** | [a] (20 – 58)<br>[b] (14 – 51) | 13.1 (10 – 20) | >0 - >50 | >0 - >35 |

[1] Roy et al. (1999) water table depths are from forested wetlands of Quebec, with [a] being ranges from mineral substrates and [b] the ranges from organic substrates.
[2] Locky and Bayley (2006) water table depths presented are from black spruce swamps of Manitoba.
[3] Warner and Asada (2006) present a range of water table depths observed in Canadian peatlands.
[4] Dunn et al. (2009) present water table depth from a boreal black spruce wetland in Manitoba.

**Key Messages for Design**

It is important to understand the characteristics of the wetland types that are being planned/designed. These characteristics should drive the designs. This chapter summarizes the main characteristics of different wetland types of interest, which can be used for design.

## 3.4 Additional wetland properties that can inform design

The information in this section focuses on form, but most has been empirically related to function. Thus, the information supports the ecological functioning and natural appearance of wetlands by presenting data that can be used to emulate the physical structure of natural wetlands. The focus on peatlands is meant to answer the question “How big and what shape is a peatland?” from a conceptual perspective. The information on marshes is divided into a) locations of marshes on the landscape that can inform closure planning, and b) a summary of research conducted by Bayley et al. (2014), making recommendations on physical characteristics to support the establishment of a healthy vegetative community. The guidance in this section does not stand alone; it must be considered along with the biodiversity and wildlife guidance presented in Section 3.4 and hydrological information presented in Chapter 2.

### 3.4.1 Peatland size and shape

Size is important when emulating natural peatlands. Natural peatlands in the oil sands area have a distinct size and perimeter range, with few outliers. Bloise and Vitt (unpublished data) delineated and analyzed wetlands in 50 lake watersheds that were part of the RAMP (Regional Aquatics Monitoring Program) in the mineable oil sands region. The majority (~95%) of the wetlands in these watersheds were peatlands, two thirds of which were fens. This analysis tells us that peatlands in the region are mostly less than 1 $km^2$ in size and have a perimeter ranging from 0.3 to 0.8 km (Figure 3-20). Also, in general, they range from circular to elliptical in shape.

**Figure 3-20. Area and perimeter for 12,906 wetlands in 50 watersheds surrounding RAMP lakes in the oil sands region. (Data from Bloise & Vitt, unpublished).**

## 3.4.2 Marshes

### 3.4.2.1 Landscape position

Marshes tend to occur in areas with flat or shallow sloping topography (Figure 3-21) and form in flat, kettle, morainal, and other basins. Marshes may be connected with lakes (lacustrine marshes) or rivers (riparian marshes), or they may be isolated or connected with other wetlands (basin marshes). Isolated marshes, however, are only isolated in the sense that they have no permanent surficial connections; they often are connected to local and regional groundwater sources or have intermittent surficial connections that flood every decade or so. Recharge, discharge or flow-through marshes may occur on the landscape.

Within each marsh form (basin, lacustrine and riparian) are several subforms. Of the basin marshes, discharge basins lie in topographic lows below the water table and are fed mainly by groundwater discharge (National Wetlands Working Group, 1997). Isolated basins also rely on groundwater discharge and lack surface channels, but they are smaller and shallower than discharge basins. Linked marshes are often found in intermediate topographic positions and are periodically linked to channelized inlets and outlets. Basin marshes may be fresh to saline, although saline marshes are less common in northern Alberta (Rooney and Bayley, 2011b).

**Figure 3-21. Forms of isolated marshes on hummocky terrain within the hydrological landscape. Adapted from Winter (2001).**

Lacustrine marshes are located near permanent, inland water bodies such as lakes and deltas (National Wetlands Working Group, 1997). Bay marshes are situated in offshore zones and bays adjacent to lakes that are prone to sediment filling and drawdowns. They tend to have dramatic fluctuations in water levels. Lagoon marshes form in semi-closed basins behind barrier beaches or bars. Shore marshes are situated in near-shore to littoral zones and have fairly stable water levels.

Riparian marshes occupy valleys and drainage channels with or without flowing water (National Wetlands Working Group, 1997). Stream marshes are situated on embankments, channels, islands, and streambed materials of streams and rivers. They form on alluvial deposits in sheltered areas away from strong currents. Meltwater channel marshes form in abandoned channels in broad spillway valleys and alluvial and outwash plains. They receive water mainly from intermittent or discontinuous sources of groundwater discharge and surface runoff. Delta marshes form in active or abandoned glacial deltas with rivers or streams flowing over them and are associated with interfluvial basins, levees, shorelines, channels and lagoons. Floodplain marshes develop on aggraded alluvial plains and terraces bordering perennial streams and are associated with swales, levees, oxbows, and meander scars.

Other types of isolated marshes include hummock, slope, and spring marshes, which are all closely associated with groundwater upwelling or seepage (National Wetlands Working Group, 1997). Hummock marshes are fed by upwelling and are above the water table. They tend to have a quaking surface in depressions or on slopes. Slope marshes are fed by groundwater seepage. Spring marshes are associated with point source discharge of springs and tend to form near streams and rills.

Marshes may lie below or at the groundwater table, or may be perched on a low-permeability soil lens above the groundwater (Alberta Environment, 2008). The Boreal Plains are mainly flat outwash plains and plains till, although post-reclamation landscapes will resemble morainal or hummocky topography. Although less common than glacial till and outwash, natural moraine terrain (e.g., moraine deposits in Utikuma) and boreal transition zone (e.g., Beaver Hills moraine) areas do exist. Figure 3-21 illustrates basin marsh forms in hummocky terrain.

**Key Messages for Design**
Wetlands are located in a variety of positions on the landscape. Landscape position is a key determinant of wetland hydrology and function and should be specifically considered in design. Chapter 2 expands upon this concept.

#### 3.4.2.2 Permanent marsh size and shape

Based on Bayley and others (Rooney and Bayley, 2010; 2011a; 2011b; 2012; Raab and Bayley, 2012; 2013; Bayley et al., 2014), simple design criteria that imitate the physical structure of the natural wetlands will maximize ecological functioning of constructed marshes. Constructing marshes similar in structure to natural marshes will increase the likelihood that constructed marshes are self-sustaining, natural in appearance, and healthy and resilient to disturbances. The following messages for marsh wetland design are adapted from Bayley et al. (2014).

Permanent marsh sites studied by Bayley et al. (2014) were generally small, averaging 5.5 ha in size (Table 3-6). Yet there is a broad range in marsh size (I. Creed and S. Bayley, unpublished data). Efforts should be made to generate a diversity of sizes and shapes on the landscape, with an initial emphasis on the construction of smaller marshes.

Slope and depth are important for the establishment of marsh vegetation. Vegetation zones fluctuate according to flooding and hydroperiod. Marsh zones are seasonally (emergent zone) to periodically (wet meadow zone) flooded, and retain waterlogged or hydric soils to which marsh plants are specifically adapted (Mitsch and Gosselink, 2007). On average, some 76% of the area of permanent marshes on the Boreal Plains is vegetated (Bayley et al., 2014; Table 3-6). In these marshes, the wet meadow and emergent zone widths averaged 19 and 29 metres, respectively. Large marsh areas support higher habitat diversity and complexity for many aquatic species (Wilson and Bayley, 2012).

**Table 3-6: Physical and hydrological properties of selected permanent and semi-permanent natural marshes on the Boreal Plain. OWZ = Open water zone, EM = emergent marsh zone, WM = wet meadow zone. Table adapted from Bayley et al. (2014).**

| | **All marshes**[1] | | **Freshwater**[2] | | **Sub-saline**[3] | | **Saline**[4] | |
|---|---|---|---|---|---|---|---|---|
| **Parameter** | Mean | 90% CI | Mean | 90% CI | Mean | 90% CI | Mean | 90% CI |
| Total Area (ha) | 5.5 | ±1.3 | 6.7 | ±0.4 | 5.0 | ±1.3 | 6.6 | ±1.7 |
| Area OWZ (ha) | 2.4 | ±1.0 | 3.4 | ±1.1 | 2.1 | ±1.0 | 2.7 | ±0.9 |
| Area EMZ + WMZ (ha) | 3.5 | ±0.9 | 4.4 | ±0.4 | 2.9 | ±0.6 | 5.9 | ±1.9 |
| Width WMZ (m) | 19 | ±5.9 | 15 | ±2.6 | 12 | ±1.5 | 56 | ±14 |
| Width EMZ (m) | 29 | ±5.2 | 21 | ±3.0 | 31 | ±4.3 | 39 | ±10 |
| Width EMZ + WMZ (m) | 45 | ±9.6 | 36 | ±4.6 | 43 | ±4.6 | 68 | ±21 |
| Proportion marsh area | 76 | ±5 | 80 | ±3.8 | 74 | ±5.1 | 82 | ±5.9 |
| Maximum depth (m) | 1.1 | ±0.1 | 1.2 | ±0.1 | 1.2 | ±0.1 | 0.8 | ±0.1 |
| Amplitude (m) | 0.19 | ±0.01 | 0.17 | ±0.01 | 0.19 | ±0.02 | 0.18 | ±0.01 |

[1]N = 39 marshes on the Boreal Plain from Rooney and Bayley (2010), [2]N = 10 marshes on the Boreal Plain with EC < 500 S/cm from Rooney and Bayley (2010), [3]N = 22 marshes on the Boreal Plain with EC = 500 - 1,000 S/cm from Rooney and Bayley (2010), [4]N = 7 marshes on the Boreal Plain with EC = > 2,000 from Rooney and Bayley (2010).

Part of the reason for the large width and relative area of wet meadow zones in natural marshes is their shallow-graded slopes (Figure 3-23). Shallow shorelines have more gradual elevation gradients, thereby allowing for the development of wider marsh zones. Shallow slopes buffer vegetation against rapid changes in water depth, thereby increasing resilience against a wide range of precipitation and subsequent water levels (Forrest, 2010; Wilson and Bayley, 2012). The slope of natural marshes sampled in the boreal transition zone averaged 2.3% (Bayley et al., 2014). This is equivalent to a 43:1 slope ratio (for every 1 metre vertical drop in elevation there is a 43-metre horizontal run). When the slope is less than 20:1, there is a significant loss of vegetated marsh area (Bayley et al., 2014). However, the shallower the slope, the more intensive the management necessary to promote the establishment of desired plant species while minimizing invasive and weedy upper-slope species.

**Figure 3-22: Vegetation zones in a natural marsh in the oil sands region. Vegetated (marsh) zones (emergent and wet meadow) add up to about three quarters of the total surface area of the wetland. Photo courtesy of S. Bayley.**

Seasonal water-level fluctuations are essential in the establishment of a marsh, and effort must be put into mimicking conditions that will bring about the flooding regimes necessary for wetland processes and marsh vegetation growth. Table 3-7 presents ranges in seasonal water amplitude for permanent marshes that can guide hydrological modelling.

Wetland water depth should be less than 2 m (Adams et al., 1997). The average maximum depth of permanent marshes sampled in the Boreal Plains was approximately 1 metre. Basin morphology of these marshes tended to be a flat shallow pan (possibly with a few deeper holes) rather than bowl-shaped. If a rich community of SAV is desirable, then flat, shallow basins with a few deeper holes permit the growth of SAV in water roughly 50 cm to 1.5 m deep (Bayley et al., 2013). As a result of light limitation, the maximum depth for growth of SAV in Alberta marshes is approximately 1.75 m, but light limitation may occur at shallower depths in more turbid waters (Cobbaert et al. 2014).

**Figure 3-23. Basin marshes have shallow shoreline slopes, which in turn increases the marsh area. Constructed marshes should be developed with similar shallow slopes to allow natural flooding and drawdown of water levels. Created based on data from Bayley et al. (2014).**

**Key Messages for Design**

Natural wetlands tend to be relatively small. Peatlands in the oil sands region are mostly smaller than 1 $km^2$ in size, have a perimeter ranging from 0.3 to 0.8 km and range from circular to elliptical in shape. Permanent marshes are mostly less than 0.07 $km^2$ in size. Designs should include wetlands that range in size, but focus on small wetlands.

The vegetated zones (emergent + wet meadow) of permanent marshes should add up to about three quarters of the surface area of the wetland. To accomplish this, shoreline slopes for depressional wetlands (marsh and open water wetland) should be low: < 20:1.

Hydrology is the single most important determinant of wetland function. To build functional wetlands, design to the natural hydroperiod of wetlands. Water amplitude for permanent marshes is about 20 centimeters.

### 3.4.2.3 Intermittent/seasonal wetlands (meadow marsh)

Intermittent/seasonal wetlands (classified as “meadow marsh” in this chapter) are generally small, form reliably (except perhaps in the driest years) in a permanent basin, and dry reliably so that a large portion of the basin has a level of moisture as dry as that of the surrounding uplands (Zedler, 2003).

**Landscape position:** While ephemeral wetlands may lie near other water bodies, they generally remain unconnected to flowing waters or permanently flooded water bodies. They most often exist as small isolated pools.

**Size and depth:** These wetlands tend to be small in area and shallow (  1 m). Wetlands in cleared areas within forested landscapes tend to be warmer than pools under forest canopies and also dry out more frequently.

**Figure 3-24. Vegetation in a meadow marsh. Photo courtesy of Ducks Unlimited.**

**Hydrology:** Intermittent wetlands fill seasonally, usually reaching their maximum depths after spring snow melt or following large summer precipitation events. They tend to dry up and expose substrate annually.

Studies in Europe and in North America emphasize that temporary wetlands supply biologically important habitat, renowned both for their specialised assemblages and the considerable numbers of rare and endemic species they support (Bratton, 1990; Baskin, 1994; Kalettka, 1996; King et al., 1996). They play an essential role in supporting a wide variety of species that depend on shallow flooded areas. They can be biodiversity hotspots, acting as donor sites of biota and seeds for more permanent, newer wetland habitats. They can also reduce habitat fragmentation between newly constructed wetlands (Homan et al., 2004). Intermittent marshes tend to be important for groundwater recharge and connectivity (Winter and LaBaugh, 2003; van der Kamp and Hayashi, 1998).

Intermittent wetlands can form almost anywhere. All that is needed is water, a depression and, for a surface-fed pool, some silt to stop the water draining immediately (Biggs et al., 2010). Biggs et al., (2010) recommend taking advantage of the hydrological functions of intermittent wetlands by incorporating them into reclamation plans. Such waterbodies, which are common on the pre-disturbance landscape, naturally buffer runoff from catchments and can store water and release it slowly.

Three variables determine the communities that inhabit intermittent wetlands: (1) the time of year the soils became moist enough to promote germination (month); (2) the amount of time between moistening of the surface soils and the beginning of inundation (onset); and (3) the duration of inundation (length) (Bliss and Zedler, 1998). Of the three, a month of inundation appears to exert the most influence on what species are found in ephemeral pools. Inundation keeps terrestrial species out, but if it continues for too long it can stress the wetland and decrease biodiversity (Bliss and Zedler, 1998).

**Key Messages for Design**

Plan for a diversity of wetland types, including small (<1 ha) and shallow (<1 m) isolated pools that will dry up annually.

## 3.5 Biodiversity and wildlife

### 3.5.1 Framework for reclaiming wetlands for wildlife

Wetland reclamation should include provisions for high-quality habitat for multiple species. One of the regulatory criteria for wetland reclamation is there be no net loss in habitat for species at risk. Moreover, reclamation should serve the needs of Aboriginal peoples by re-establishing habitat for culturally important species, such as moose and beaver. Fifty-three sensitive, at-risk (see Table 3-7) and culturally important species in the mineable oil sands region of Alberta have been identified at this time (see Appendix D). Although the number of species that falls within these categories will change over time (e.g. as the status of additional species is assessed by government agencies), efforts should be made to maximize the probability that suitable habitat for all are present on the post-reclamation landscape. Meeting this goal does not necessarily entail lists of site-specific enhancements for each species, for a number of conceptual and practical reasons.

Re-establishing a species in an area first requires reclamation of all the components needed to satisfy that species' life-history requirements: food, thermal shelter, predation refugia, mating/rearing habitat, and overwintering sites, (Carroll et al., 2001; Paquet et al., 2001). However, the detailed habitat requirements for many species are largely unknown.

**Table 3-7. National and provincial definitions of species at risk.**

| Jurisdiction and category | Definition |
|---|---|
| **National**[1] | |
| **Endangered** | Species faces imminent extinction or extirpation (extinction of species in Canada, but still occurs elsewhere) |
| **Threatened** | Species is likely to become endangered if limiting factors not reversed |
| **Special Concern** | Species may become threatened or endangered because of a combination of biological characteristics and identified threats |
| **Provincial**[2] | |
| **At Risk** | Species known to be at risk after formal detailed status assessment and legal designation as Endangered or Threatened in Alberta |
| **May Be At Risk** | Species that may be at risk of extinction or extirpation |
| **Sensitive** | Species that are not at risk of extinction or extirpation but may require special attention or protection to prevent them from becoming at risk |

[1] Committee of the Status of Endangered Wildlife in Canada (COSEWIC) status; http://www.cosewic.gc.ca/eng/sct5/index_e.cfm.

[2] Alberta Environment and Sustainable Resource Development (AESRD) general status of wildlife; http://esrd.alberta.ca/fish-wildlife/species-at-risk/albertas-species-at-risk-strategy/general-status-of-alberta-wild-species-2010/default.aspx.

In their review of the state of existing knowledge of wetlands and wildlife in boreal Alberta, Eaton and Fisher (2011) highlight massive knowledge gaps about even well-studied species such as caribou (*Rangifer tarandus*). Much of the available information is based on natural history studies or Habitat Suitability Index (HSI) models. HSIs representing the major environmental variables are believed to influence a species' occurrence, but these models perform poorly at prediction (Cole and Smith 1983; Bart et al., 1984 in Morrison, 2006) because they are not based on field data and do not consider interactions between environmental variables (see also Muir et al., 2012). Eaton and Fisher (2011) offer an empirical approach to designing wetlands that may maximize the chances a focal species will recolonize a reclaimed wetland, through extensive analysis and design recommendations tailored for each species. Currently, these exist only for select species in Alberta. However, even with knowledge of the full suite of habitat requirements for each target species, it would remain impractical to design reclaimed wetlands to explicitly meet each species' needs, as designing a wetland for one species might make it unsuitable for another, equally desired, species.

The problem of designing reclaimed wetlands for specific species is also one of scale. For most species in Table D-1, Appendix D, wetlands are but one component of their total habitat requirements. Many species use habitats at spatial scales beyond those captured in reclaimed wetland design. Notable examples include whooping crane, bison, moose, and caribou populations (Wallace et al., 1995; Fortin et al., 2003; Dussault et al., 2005; Dussault et al., 2006; Boyd et al., 2008). Indeed, no wetland design can fix regional-scale problems, such as loss of functional habitat due to increased predation (Wittmer et al., 2005; Wittmer et al., 2007; Sorensen et al., 2008; Latham et al., 2011; Whittington et al., 2011).

An alternative framework for wildlife habitat design in wetlands involves a practical, holistic, community-based approach that seeks to maximize the chance that diverse communities will recolonize a reclaimed landscape. "Wildlife" here refers to all the biota that inhabit a wetland, including microbes, fungi, plants, and animals, as all of these components are needed for ecosystem function. The goal is a functional wetland with high structural complexity, heterogeneity, and biodiversity (Zedler, 2000; Zedler and Kercher, 2005; Reich et al., 2012). Reclaimed wetlands that emulate these characteristics are more likely to support local wildlife populations; they are also expected to increase chances of colonization by sensitive and at-risk species. Community-scale recommendations should not exclude sensitive or at-risk species from reclaimed habitats. In fact, by emulating natural wetlands, the probability of species-at-risk and culturally important species recolonizing these wetlands should be markedly greater (Eaton and Fisher, 2011). In theory, reclaiming diverse, functional wetlands is reclaiming potential habitat for these focal species. The best wetland design recommendations for the most sensitive, aquatic-dependent species are generally the same as those recommended for maximizing biodiversity as a whole. These recommendations focus on the landscape scale because many wetland-dependent species rely on additional habitat types such as upland forest for foraging habitat and overwintering sites — an ecological phenomenon known as landscape complementation (Dunning et al., 1992).

### 3.5.2 Framework for reclaiming wetlands for biodiversity

Increased biodiversity provides functional redundancy and hence resilience to perturbation (Peterson et al., 1998; Folke et al., 2004). Wetland biodiversity can be measured in several ways (Whittaker,1972; Whittaker et al., 2001; Magurran, 2004). The total species diversity in a landscape (gamma diversity) is determined by the species diversity in patches at a local scale (alpha diversity) and the differences in species among those patches (beta diversity). One of the goals of a reclamation plan must be to maximize total (gamma) diversity by maximizing both local wetland (alpha) and among-wetland (beta) diversity.

A diversity of wetland and upland patches or types supports a whole suite of species that depend on wetlands directly or indirectly at some point in their life cycle, increasing beta diversity. The selection of a marsh, peatland, or ephemeral pond as the reclamation target for a site will be limited by site characteristics and hydrology, but these conditions vary greatly in the boreal forest, providing opportunities for constructing different wetland types. Each has a different ecological community, and a different expected species assemblage. In the oil sands region, for example, alpha diversity of individual marshes (especially those that are saline) is often low, but the gamma diversity can be quite high because there are large differences between the communities that inhabit different marshes (Trites and Bayley, 2009).

At a smaller spatial scale (alpha diversity), hummocks, hollows and pools within an individual wetland each support a variety of flora and fauna (Gopal, 2009). Fens may be classified based on richness versus poorness, and fresh versus saline, depending on nutrient and chemical status. In marshes, elevation gradients subtly divide plant communities into unique zones or groupings; within each zone, plants are capable of withstanding similar hydrological, physical and chemical stresses. Variations in the hydrological influences and plant species between zones mean each zone may possess unique physical structure in the water column, and unique chemical properties of its water and soils. This results in variations in bacteria, fungal and algal communities, invertebrates, water birds, and mammals.

Each species of wildlife occupies a niche and has unique habitat requirements; that is, not all species respond to the same habitat patches and conditions. For example, although most amphibians require forested land around ponds, other species avoid such areas, and instead require large areas of emergent vegetation (e.g., horned grebes *Podiceps auritus*) (Kuczynski et al., 2012). However, there are some commonalities in habitat associations among species in that increased physical and vegetative structural complexity leads to increased biodiversity (Burnett et al., 1998, Tews et al., 2004). Wetland-level (alpha) biodiversity can be increased by creating a complex wetland shape that maximizes the length of shoreline per unit area and provides more habitat for more wetland species (Attum et al., 2008). Coarse woody debris provides habitat for aquatic invertebrates (Alsfeld et al., 2009), which are important prey items for wildlife species and important to wetland function. Islands provide important refuge areas for waterbirds, and local irregularities in the contour of the wetland bottom will increase habitat heterogeneity (Alsfeld et al., 2009). A variety of depths should be constructed, including deeper water to provide overwintering habitat for semi-aquatic mammals and small-bodied fish. Suitable basin profiles, high connectivity (Section 3.5.3.1), and high vegetation complexity also foster alpha diversity, as does providing a juxtaposition with upland forest types.

Alpha, beta, and gamma biodiversity change through time. Ecological succession is a natural process wherein species are replaced over time by other species as site characteristics change (Connell et al., 1977). Succession generally builds stability and diversity. The species that are introduced or naturally colonize a site now may not be the species that occupy a site decades later. Our ability to predict successional trajectories remains limited, and so does our ability to design a "new" early-successional wetland. The best option for designing wetland wildlife habitat is to maintain ecological processes by emulating natural wetland systems.

## 3.5.3 Landscape/watershed considerations

### 3.5.3.1 Connectivity

Traditionally, wetland restoration and conservation has viewed wetlands as isolated, unique entities (Amezaga et al., 2002). But this does not reflect how natural wetlands and their associated biota interact. Natural wetlands are generally highly connected to each other and to their upland surroundings (Attum et al., 2008), both in terms of hydrology and the movement of species. The degree to which wetlands are functionally linked — their connectivity (Tischendorf and Fahrig 2000a, b) — plays a key role in determining how wetlands are colonized, how they function, and what wildlife they support (Amezaga et al., 2002). The importance of connectivity between wetlands, and between wetlands and uplands, has been highlighted in work on Traditional Knowledge in northern Alberta (O'Flaherty, 2011).

Wetlands are patches of highly diverse, specialized habitat that share characteristics with both terrestrial and fully aquatic systems, but differ from both in a myriad of ways. They are typically embedded within a matrix of upland habitats, and rely on functional connectivity to exchange individuals and species. The first microorganisms that arrive at a wetland establish quickly and maintain their dominance in the community, thereby shaping that wetland's function thereafter — the "monopolization hypothesis" (De Meester et al., 2002). Fish species may actively disperse into ponds and their presence in one wetland is primarily dictated by the surface hydrological connectivity to others (Baber et al., 2002). In contrast, protozoa, plankton, and plant propagules – the biological building blocks of wetlands – rely on passive dispersal to colonize wetlands. They are carried by wind, water, insects, and birds from one wetland to another; waterbirds are particularly important dispersal vectors (Figuerola and Green, 2002; Green et al., 2002; Green and Figuerola, 2005). Small mammals, reptiles, and amphibians disperse through water or over land. Hydrological connectivity (via streams) allows species to colonize new habitats, leading to high species richness (Cunningham et al., 2007). Overland, these species use forests as travel corridors (Roe et al., 2004), which makes the landscape important in providing connectivity between wetlands (Attum et al., 2008). For amphibians, connectivity affects population viability (Cushman, 2006). In fact, almost all amphibians disperse through wetlands (Rothermel, 2004), seasonal migrations, or as a response to stochastic disturbances such as periodic drought (Roe and Georges, 2007).

### 3.5.3.2 Proximity

In general, hydrological connectivity is considered to be surface-driven, but this is not necessarily true for wetlands and watersheds in the Western Boreal Plains (see Chapter 2 of this Guide). Actually, surface connectivity between wetlands in the region can be limited (Devito et al., 2012). Even in the absence of surface hydrological links, physical placement on the landscape in particular is a key factor in determining connectivity (Amezaga et al., 2002). For volant (flying) species and those relying on passive dispersal, connectivity decreases with increasing distance between wetlands (Charalambidou and Santamaría, 2002). For non-volant species, connectivity depends on the land cover of the intervening terrestrial uplands. Roads and other barriers will also decrease wetland connectivity (Carr and Fahrig, 2001; Roe et al., 2006; Beaudry et al., 2008; Eigenbrod et al., 2008).

A landscape with multiple wetlands in close proximity to one another, with a minimum of terrestrial barriers and an intact forest buffer zone, fosters ecological connectivity (Attum et al., 2008). Semlitsch and Bodie (1998) argue that the local and regional distribution of wetlands is critical to maintaining ecological connectivity between physically separated wetlands. Others suggest that wetlands covering the entire hydroperiod spectrum are required to protect groups such as amphibians (Snodgrass et al., 2000; Paton and Crouch, 2002; Brown et al., 2012). Small wetlands play an especially critical role in connectivity, as stepping stones that allow individuals to move between populations and to recolonize wetlands following local extinctions (Semlitsch and Bodie, 1998; Gibbs, 2000).

How close wetlands have to be to each other to provide connectivity has not been well researched, but several factors are involved. For passive dispersers, waterfowl migration patterns are important (Lurz et al., 2002; Viana et al., 2012); for active dispersers, density and type of terrestrial barriers and intactness of adjacent forest are critical (Cushman, 2006; Attum et al., 2008). Forest structure provides cover, connectivity for species dispersal, nesting sites, and hibernacula for a variety of species (Baldwin et al., 2006a, b; Beier and Noss, 1998; Gilbert-Norton et al., 2010).

Appendix D recommends a maximum distance between adjacent wetlands of 1 km to accommodate amphibians. In addition, suitable habitat for terrestrial activities of amphibians must be provided (see below).

### 3.5.3.3 Juxtaposition

Wetlands are also connected to the surrounding uplands. Wetlands influence landscape-scale diversity, and the landscape in turn affects wetland diversity. Therefore, the juxtaposition of aquatic, riparian, and terrestrial habitats will profoundly affect the biodiversity and ecological function of a wetland (Wiens, 2002). Juxtaposition is important for all wetland species, as most rely to some degree on the surrounding upland matrix.

Landscapes are composed of several patch types, and most vertebrate and macroinvertebrate species use multiple patches at some point (Wiens, 1976; Kotliar and Wiens, 1990; Wiens et al., 1993). When the resources in these patches are substitutable, the use of multiple patches can increase population sizes and maintain stability; this is called landscape supplementation (Dunning et al., 1992). When different patches provide unique, non-substitutable resources, landscape complementation can allow the species to persist, but only if those patch types occur in close proximity (Dunning et al., 1992, Fisher and Merriam, 2000). Semi-aquatic species such as beavers and otters, and species with biphasic lifecycles (e.g., amphibians), which require aquatic habitats for breeding and terrestrial habitats as adults, are particularly dependent on landscape complementation and habitat juxtaposition to survive.

Though little work has been done on amphibian populations in the oil sands, a radio-tracking study of Canadian toads (n=29) in northeastern Alberta found that individual toads moved an average of 461 m (± 353) from their breeding site to upland, forested habitat. Three toads were tracked to putative overwintering sites 654-1,386 m from the breeding lake; these overwintering sites had sparse tree cover and firmly packed sandy soil (Constible et al., 2010). This suggests that suitable habitat for terrestrial activities of amphibians, including foraging and overwintering, must be provided if these animals are to successfully colonize reclaimed wetlands and persist in the local area. In Ontario wetlands, amphibian species richness and abundance was positively correlated not only with wetland area, but also with forest cover and the amount of wetlands in the adjacent landscape (Houlahan and Findlay, 2003), suggesting that wetlands in diverse, forested landscapes had a higher probability of being sustained long-term.

### 3.5.4 Riparian zones

The upland habitat adjacent to wetlands – the riparian zone – is a habitat type in its own right, with unique hydrology (Vidon and Hill, 2004), vegetation composition and structure (Harper and Macdonald, 2001), and wildlife communities (Darveau et al., 1995, Darveau et al., 2001; Hannon et al., 2002; Kardynal et al., 2009). Riparian zones regulate nutrient and organic inputs into wetlands from the surrounding landscape. They contain plants associated with both wetland and upland environments, so are particularly diverse. Riparian zones are more than just buffer zones; they are core habitats for semi-aquatic species and those with biphasic lifecycles (Semlitsch and Jensen, 2001; Semlitsch and Bodie, 2003). As well, they facilitate hydrologic and ecological connectivity between the aquatic and terrestrial components of the landscape.

**Key Messages for Design**

Nature is variable; embrace that variability in design and outcomes for wetland reclamation.

Wetland systems should require minimal maintenance, and feature general resilience to perturbation. Increased biodiversity provides functional redundancy and hence resilience to perturbation. Total biodiversity can be maximized by maximizing both within-wetland and among-wetland diversity. Different plant and animal communities occur in different wetland classes; a diversity of wetland types across the landscape will therefore maximize among-wetland biodiversity. A reclaimed landscape should include ephemeral and permanent wetlands juxtaposed with upland forest stands and patches of emergent and shrubby vegetation. Within-wetland diversity can be maximized by incorporating hummocks, hollows, pools, coarse woody debris, high shoreline complexity, variable basin profiles, and islands.

At a landscape scale, reclamation strategies should plan for landscape complexity and connectivity among wetlands, and between wetlands and their terrestrial matrix. It is important to plan not only the wetland itself, but also the terrestrial matrix in which it is embedded.

Wetlands should be designed for functional connectivity to source populations. Connectivity and the availability of source populations are critical for the biotic communities that develop at reclaimed wetlands, and the rate at which this occurs. Surface connectivity between wetlands in the region can be limited (Devito et al., 2012). Without this strong surface connection, the proximity of reclaimed wetlands to one another is an important design consideration. Multiple wetlands should be placed in proximity as they provide ecological stepping stones that increase connectivity between wetlands, lowering extinction rates and increasing colonization rates, thereby increasing population stability (Levin 1974; Forman 1995). The recommended maximum distance between adjacent wetlands is 1 km, with wetlands designed as complexes rather than isolated units.

Design wetlands to support a community, rather than simply specific species. Where specific species are desired, or where regulations stipulate that habitat for specific species must be created (e.g. for a species-at-risk), identify what *additional* management steps are necessary (e.g. provision of overwintering habitat) after designing the wetland to support a functional community first. Providing habitat for some species will require a landscape-scale approach, rather than just the reclamation of a single wetland.

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# Chapter 4

# Lessons from Oil Sands and International Wetland Reclamation and Restoration Projects: A Selective Literature Review

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The available information on wetland reclamation for mining is limited, and little literature exists on the construction of watersheds to support wetlands. However, designers and operators can refer to publications from other wetland creation and restoration efforts. The published literature, and in particular the available case histories, are useful sources of information for all involved in oil sands wetland reclamation. A huge wealth of textbooks and technical papers has been produced on wetland restoration.

At the same time, some significant differences exist between oil sands wetland reclamation and wetland restoration. For example, oil sands wetland reclamation generally involves construction of the entire watershed, its substrates, soils and wetlands through placement of mine waste using truck and shovel or through tailings activities. The details of watershed construction are as important as wetland construction. As well, for decades or centuries, much of the water reporting to a typical reclaimed oil sands wetland has elevated salinity and toxicity – runoff and seepage from tailings and dumped overburden. Some wetlands are designed to dilute these waters (with seepage and overland flow from natural areas) and to biodegrade organic acids from disturbed areas. Moreover, oil sands reclaimed wetlands are meant to meet reclamation certification criteria, which are as yet undefined.

One of the key lessons from wetland restoration is the importance of establishing a set of goals specific to the intended site. They should be measurable, achievable, reasonable and complemented by a realistic time frame. Many wetlands fail to meet their intended goals. Having reasonable and clearly defined goals is critical to success.

Operators need to take care in setting goals for reclaimed wetlands relative to natural wetlands. The ecological trajectory of reclaimed oil sands wetlands is complex. Given the inherent uncertainty of these novel ecosystems, developing simple rather than complex methods of setting goals and evaluating success should be considered.

The HEAD program’s study of the Utikuma wetlands 250 km west-southwest of Fort McMurray provides a wealth of useful information on the functions of natural wetlands in the boreal forest. Designers are encouraged to use the HEAD synthesis document for closure planning and landform-level designs in oil sands reclamation. The wetland history has been tracked over decades in response to climate variation and logging/disturbance activities on the land. Most of the wetland processes studied in the program will be important in the performance of reclaimed wetland in the oil sands.

Benefits could be derived from completing an inventory of all natural wetlands in the oil sands region that are currently being studied, as well as those that have been constructed through highway and mining reclamation. Mapping these wetlands and assessing their performance would lead to a valuable set of “lessons learned” for the oil sands mining wetland reclamation.

## Table of Contents

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## 4.1 Introduction

Dozens of textbooks and hundreds of technical papers deal with restoring wetlands. Many relate to restoring wetland function in agricultural areas where wetlands were drained decades or centuries previously. The literature on wetland *reclamation* is more limited, and little deals with construction of watersheds to support wetlands. This chapter explores international and oil sands wetland reclamation experience with a focus on case histories and the lessons learned from the design and operation of these wetlands.[†] While the chapter and the guide draw on wetland restoration experience, the focus is on reclamation, which will be the predominant form of wetland construction in the Athabasca Oil Sands Region.

Several research teams have studied reclaimed and natural wetlands in the region. This chapter draws upon the work of Cooper (2004), Daly (2007), Gupta (2009), Hersikorn (2009), Legg (2009), Morrison (2009), and Devito et al. (2012). Section 4.6.1 and Appendix G provide an overview of the findings under the ongoing Carbon Dynamics, Food Web Structure, and Reclamation Strategies in the Athabasca Oil Sands Wetlands (CFRAW) Project. There is an opportunity for a regional database and synthesis.

The chapter is organized by the sequence required for oil sands wetland reclamation (planning and design, surface water and hydrology, substrates and water quality, construction, revegetation, and monitoring and maintenance). Lessons from the review were used to develop and write the design chapters (Chapters 5 through 8) in this guide. The select case histories provide a valuable source of information for designers.

As described in Chapter 1, there are a few significant differences between oil sands wetland reclamation and wetland restoration that dominates the literature that are important in the context of this manual. Five of the most significant differences are as follows:

Oil sands wetland reclamation generally involves construction of the entire watershed, its substrates, soils, and its wetlands through placement of mine waste using truck and shovel or through tailings activities. Details of watershed construction are as important as those of the wetland construction.

For decades or centuries, much of the water reporting to typical reclaimed oil sands wetlands has elevated salinity and toxicity — runoff and seepage from tailings and dumped overburden. In some cases, the wetlands are designed to dilute these waters (with seepage and overland flow from natural areas) and to biodegrade organic acids from disturbed areas.

Oil sands reclaimed wetlands are designed to meet reclamation certification criteria, which are as yet undefined and are presently inferred.

To meet regulatory approval conditions, the wetlands must be self-sustaining – capable of meeting criteria in the absence of ongoing monitoring or maintenance.

The regional landscape already contains dozens of reclaimed wetlands and will contain hundreds of reclaimed wetlands. The first wetlands were reclaimed decades ago, the last ones many decades from now.

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[†] Note that the classification of some of the wetland examples described in this chapter may differ from that used for other chapters in this manual.

## 4.2 Wetland planning and design

### 4.2.1 Importance of goal-setting (various U.S. wetland restoration programs)

Dozens of studies have found that wetland creation and restoration efforts have low success rates (see Environmental Law Institute, undated). Success is often measured by the number of hectares meeting permit conditions and is often focused on herbaceous cover. Some assessments are based on wetland function, which is more difficult to both achieve and measure. For example, FERC (2004) reported that 35% of surveyed constructed wetlands failed to meet the federal definition, most often due to having less than 80% cover by native plant species. Kihslinger (2008) reports success rates of 13 to 96%, with many studies reporting compliance success rates of 40 to 70%. Ambrose (2000) reports that in one region (riparian mitigation projects in Orange County), none of the constructed wetlands met their function goals.

| | |
|---|---|
| **Lesson:** | *Many or most wetlands fail to meet their intended goals. Having reasonable and clearly defined goals is a critical element of success.* |
| **Opportunity:** | *Creation of a set of wetland goals that are specific to the intended site, measurable, achievable, reasonable and have a time frame that can be reached. This would allow overall integrated landscape reconstruction for oil sands, and allow greater certainty in design and reclamation certification.* |

### 4.2.2 Establishing fens (Québec peat mining restoration projects)

Oil sands closure plans call for building large peatlands, typically fens. There has been some success in restoring fens after peat mining in eastern Canada (Cobbaert et al. 2004); but no large-scale fens have been reclaimed. In the oil sands, Syncrude Sandhill Fen and Suncor Nikanotee Fen are the first such attempts. Bog reclamation is not currently being attempted. Experience from Eastern Canada, the US or Europe provide useful lessons, but because there are large differences in climate, substrates, and scale of disturbance the application of peatland restoration or reclamation literature and lessons from other regions to reclamation of peatlands in the Oil Sands region is limited.

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| **Lesson:** | *While we can learn from fen restoration work, development of fens for oil sands reclamation is largely outside of precedent.* |
| **Opportunity:** | *Sandhill and Nikanotee fens are excellent research opportunities to understand fen reclamation and several large tailings plateaus provide opportunities in the next several years to commercialize fen reclamation.* |

### 4.2.3 Hydrological modelling and watershed design (Suncor Nikanotee Fen, Syncrude Sandhill Fen)

Recent analyses of a numerical hydrologic model (Price et al., 2010) outlined the feasibility of creating fen hydrological and geomorphological regimes in northern Alberta.

Construction of the Suncor Pilot Fen, later named Nikanotee Fen, was completed in 2013. The design includes a watershed to provide surface and groundwater inflow to a fen basin. A liner was used to move precipitation falling on the watershed toward the fen (Pollard et al., 2012). The upland watershed is approximately twice the size of the fen and constructed using tailings sand to form an aquifer that overlays the liner. At the lower end, a basin above the aquifer is filled with 2 m of peat from a local donor site. Fen vegetation is being established on the peat surface. The Price et al. (2010) model suggests that annual precipitation will be adequate to recharge and infiltrate the watershed, maintain saturated conditions, and sustain fen vegetation.

Similarly, a site investigation and modelling were employed for the conceptual and permit-level designs of the Syncrude Sandhill Fen and its watershed (Wytrykush et al., 2010; Pollard et al., 2012). The fen was located in a seepage discharge area above sand-capped composite tailings. Tailings sand hummocks and uplands were designed and constructed to enhance infiltration to supply the fen area, located in the lowest elevation part of the watershed, with steady seepage and bank storage. Reclamation prescriptions were adjusted to maximize net percolation in some areas to enhance water reporting to the fen area. Transient soil-water-atmosphere cover modelling was employed to estimate net recharge and three dimensional transient and steady state seepage modelling was employed to design the watershed and fen. The design watershed water balance was based on the interaction of seepage and precipitation water and was central to design and initial operation of the wetland.

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| **Lesson:** | *Many wetlands will require surface water and groundwater modelling as part of conceptual and detailed design. The model is not the design, just one step in the design process, and further design, reporting, and construction blueprints are required for designed oil sands wetlands.* |
| **Opportunity:** | *Calibration of existing models and development of surface-water/groundwater tools for modelling at the wetland scale for design would aid the design of the next large commercial wetlands and allow simpler exploration of various design options with respect to watershed configuration, topography, substrates, and water quality.* |

### 4.2.4 Wetland placement locations: Terraces (various oil sands landforms)

Some of the constructed landforms in the oil sands region have terraces or benches on their slopes that have allowed wetlands to develop. It has also been noted that at many mine sites in the oil sands and internationally, ponding on benches often lead to slope erosion (e.g., McKenna, 2002; Golder, 2004) when the ponds overtop their containment during snowmelt or storms. In some cases, ponding water and erosion can trigger slumping.

If geotechnical/erosional issues are addressed, trapping small quantities of water on terraced slopes can play an important role in creating a suitable hydrologic regime in reclaimed landscapes, providing long linear wetland conditions that also support adjacent upland vegetation (see Devito et al., 2012) as well as diversity.

In peatlands with a significant surface slope, and in rather dry sites, bunds and terraces may offer important advantages. Bunds constructed along contour lines can reduce surface water runoff. When prepared in conjunction with site grading, they can produce level terraces that support a shallower and more widely distributed water table and suitable moisture conditions for wetland plant establishment. The efficient water retention at bunded peatlands may favor hydrophilic species and inhibit those adapted to dryer conditions. Erosion and sedimentation problems can also occur during inundations (Price et al., 2003), but *Eriophorum vaginatum* and other species have been introduced to stabilize the surface.

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| **Lesson:** | *Building marshes or fens on narrow bench terraces may provide a major opportunity for reclamation diversity in the oil sands but increases risks of water overtopping the wetland banks causing erosion and deposition downstream.* |
| **Opportunity:** | *Recognize that there are risk tradeoffs. Construct berms and channels to have lateral gradients and to have deeply incised channels to reduce potential for overtopping.* |

### 4.2.5 Creating microtopography (North Carolina)

Bruland and Richardson (2005) investigated the responses of hydrology, soils, and vegetation to microtopographic variation on a non-riverine mineral soil flat wetland in North Carolina. Microtopography was created by configuring hummocks (mounds) and hollows (depressions) on otherwise level terrain of intermediate elevation. The microtopography triggered a variety of hydrologic, edaphic and vegetation responses over the growing season. The authors conclude it is worthwhile to use hummocks and hollows that are consistent with the microtopography of nearby wetlands of the same hydrogeomorphic setting.

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| **Lesson:** | *Microtopography (mounds 1 to 5 m in diameter) is used in mine reclamation to change the hydrologic performance of slopes and plateaus and provide microsites for ecological function.* |
| **Opportunity:** | *Use this technique in wetland reclamation as a research trial and develop design and construction guidance for oil sands.* |

### 4.2.6 Importance of documentation (various oil sands and non-oil sands wetlands)

There is a need for an inventory and description of reclaimed wetlands. Papers describing wetland restoration and the construction of highly engineered water treatment wetlands dominate the wetland construction literature. There is limited information available on wetland reclamation. Most of the (sparse) mining reclamation wetland literature has focused on bioremediation of acidic-rock/heavy-metal drainage. Through international mining and reclamation organizations, there is an opportunity to create a network of practitioners, researchers, and regulators involved in wetlands for mine reclamation.

Numerous reports and theses explore the biological performance of the several dozen reclaimed wetlands in the oil sands region. Unfortunately, the literature suffers from some ambiguity in identifying the names and locations of these wetlands, and lacks detailed explanations of the history and hydrologic regime of these sites. There are also differences in operational definitions of the terms “natural wetlands” and “reference wetlands,” reflecting differences in the objectives of the various wetland studies. Additional uncertainty stems from a lack of standardized knowledge of which wetlands are influenced by process-affected waters from tailings and which are affected by runoff and groundwater from overburden fill.

**Lesson:** *Publication of case histories is one of the most valuable sources of information for wetland designers but the mine wetland reclamation literature is limited.*

**Opportunity:** *Publish individual case histories in oil sands reclamation and a periodic compendium of performance. Create a common industry inventory of constructed wetlands and those natural ones being studied and always reporting the geographic coordinates of research sites to aid communication. Establish an international group involved in mine wetland reclamation.*

## 4.3 Surface water and groundwater hydrology for wetlands

The physical hydrology (groundwater and surface water) is a central theme in wetlands reclamation and restoration as demonstrated by the case histories in this section. (Water quality is explored in Section 4.4).

### 4.3.1 Channel design and bank stabilization (various U.S. sites)

After placer mining in Alaska along Nome Creek, the Bureau of Land Management (BLM) reconstructed a stream within a single channel. They eliminated unstable debris piles and settling ponds that contributed to excessive runoff, and stabilized and revegetated the floodplain (Kostohrys, 2007). The bank-full discharge (two-year flood event) was used to determine the channel dimensions. But after erosion events the channel was widened to the dimensions closer to a five-year flood. The BLM team cautioned that while overestimating the channel dimensions can cause braided channels and increased construction costs, underestimating the required channel capacity can result in “channel failure and catastrophic floodplain damage.” Repeated flood events, considerable lateral channel erosion and the formation of braided channels destroyed the riparian willow plantings. Managers learned that similar problems could be minimized by creating a wider channel with flatter meanders on inside channel bends.

Laub et al. (2013) compared two methods of bank stabilization in Maryland: (1) a designed channel approach; and (2) the planting of a riparian buffer. They compared soil attributes such as bulk density, soil organic matter and root biomass at sites that had undergone each treatment with control sites. Bulk density and root biomass at 10-20 and 20-30 cm below the surface at both recent (< 10 years old) and older sites (> 10 years old) at designed channels were significantly different than controls, with higher bulk density and lower root biomass. Bulk density exceeded values known to restrict root growth. The researchers concluded that the compaction of riparian soils from the use of heavy machinery during the creation of a designed channel can have lasting consequences. In contrast, the soil properties of the riparian buffer planting sites were not significantly different than controls. The authors suggest that planting of riparian buffers is preferable to creation of designed channels when soil compaction is a concern.

The U.S. National Park Service reclaimed placer mined reaches of Glen Creek in Denali National Park and Preserve. Researchers used techniques developed by the Bureau of Land Management to design a more stable channel. The channel design was based on stream capacity to contain a 1.5- to 100-year flood. This required an estimation of flood flows, ranges of channel configurations, and determination of stream slope stability and sinuosity based on drainage area (Karle and Densmore, 1994). The floodplain was stabilized using alder brush bars installed perpendicularly to the channel to slow water and trigger deposition. Small circular depressions created by bulldozers to capture sediment and bank plantings of willow and alder were completed. A moderate flood event when the project was near completion caused significant channel changes, including bank erosion, channel widening and migration. Post-flood, the researchers concluded that stream channel design must account for changes in bed particle size diameter. In addition, slope changes were attributed to bed material changes. The alder brush bars provided some floodplain protection and sediment capture. The bulldozer tracks trapped sediment, but they would not be able to control erosion during large flow events.

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| **Lesson:** | *Adequate channel design is critical. Inlets and outlets and the wetlands themselves need to be designed to withstand floods without damage.* |
| **Opportunity:** | *The oil sands will have hundreds of permanently flowing watercourses in the reclaimed landscapes. There is an opportunity at some sites to create and monitor these watercourses, and their related riparian and wetland areas, to learn through design, construction, reclamation, and through performance monitoring. There is also an opportunity to continue to test and report on success and failure of engineering efforts in oil sands reclamation, eventually leading to a CEMA guide on its more general use.* |

### 4.3.2 Water level management (coastal U.S. wetlands)

Artificial stabilization of water levels tends to reduce marsh area and vegetation diversity (Keddy and Reznicek, 1986) and can severely affect water quality (Coops and Hosper, 2002). The use of dyke and control structures isolates coastal wetlands from the lakes and converts them to inland wetlands (Wilcox and Whillans, 1999). Restoring the hydrological regime of a littoral wetland requires: 1) restoring the natural variation in lake levels if the wetland is connected to a regulated lake and, 2) restoring the connections between wetland and lake if these connections have been altered. Because lakes have other uses, restoring a completely natural level of variation is not always achievable. Coops and Hosper (2002) suggest two possibilities to restore a more natural level of variation of a lake: expand the critical limits between which the water level is allowed to fluctuate annually, within the permissible limits; and/or highly managed water-level manipulations aimed at a specific process, such as incidental water level recession to trigger the colonization of the lake bottom by emergent vegetation. Wilcox and Whillans (1999) describe narrow bridges built into road beds that cross portions of a marsh causing water to slow and excessive sediment deposition. To alleviate these issues, the authors suggest increasing the width of the bridge spans or adding additional bridges or culverts to the roadbed.

**Lesson:** *Design the wetlands and their outlets to allow for variation in water levels.*

**Opportunity:** *Develop experience in oil sands wetland reclamation to both manage water levels in the short term and design to allow natural variation in the long term.*

### 4.3.3 Hydrological design (Suncor Wapisiw marsh)

Suncor Wapisiw Marsh occupies 2 ha of the 220-ha Wapisiw Lookout plateau (formerly known as Pond 1). It was designed and reclaimed between 2007 and 2010 and is instrumented for monitoring (Russell et al., 2010; Daly et al., 2010). The marsh is a long distance from the crest of Tar Island Dyke to allow de-licensing of a dam. It receives water from overland flow and seepage through the shallow reclaimed tailings sand. It also receives some seepage return water from the dyke toe. The marsh was designed using the second edition of the CEMA wetland guide and includes shallow slopes, small islands, and a pumped sump vault outlet. Performance thus far is good, but it is affected by the quality and quantity of the pumped water.

**Lesson:** *Small wetlands can sometimes be designed into structures that are geotechnically sensitive by ensuring adequate offsets from dump or dyke crests.*

**Opportunity:** *Recognize the value of creation of small wetlands throughout the reclaimed landscape.*

**Figure 4-1. Suncor Wapisiw Lookout (Suncor photo).**

### 4.3.4 Opportunistic Wetlands (Syncrude Bill's Lake)

Bill's Lake is a 0.7-ha opportunistic marsh that formed on Syncrude's SW 30 Dump in the late 1990s and has been the subject of intensive study (Syncrude, 2004; Kessler et al., 2010). An important finding from Bill's Lake is that opportunistic wetlands can form in low areas of constructed slopes or those areas with settlement. There will be numerous similar features in the reclaimed landscapes in the oil sands.

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| **Lesson:** | *Opportunistic wetlands will form on reclaimed areas in areas of blocked drainage or settlement.* |
| **Opportunity:** | *Develop methods to encourage opportunistic wetlands and develop semi-designed wetlands. Develop methods to better predict the amount and type of opportunistic and semi-designed wetlands to better describe future landscapes even at the closure planning level. Inventory and model opportunistic wetlands and semi-designed wetlands as they form.* |

**Figure 4-2. Bill's Lake (Canadian Association of Petroleum Producers photo).**

### 4.3.5 Ditch blocking (various wetlands)

Ditches are constructed landforms that convert peatlands and other wetlands to agricultural or industrial uses. The efficacy of drainage is related to the depth of ditching, distance between ditches, and the hydraulic conductivity of the peat or mineral substrate. The drawdown is greatest near the ditch, and often diminishes quickly with distance (Price et al., 2003). Ditches can be blocked with peat at regular intervals and water can be diverted onto the peat surface (Schimelpfenig et al., 2013). The choice of material depends on slopes and water flows. The standard method, when available, is to remove peat from areas in or adjacent to the ditch and packed as a plug. One option is to fill in the entire ditch with peat (or mineral soils, in the case of marshes, meadows, and riparian zones). More intrusive but less expensive options include plywood or wooden planks, heather or straw bales or sheet metal (Cooper et al., 1998). On slopes, extra effort is made to ensure blocked ditches are not eroded, undercut, or washed out.

Ditch blocking usually extends the full depth of the ditch and reaches the ground surface. However, many damaged blanket peat areas have extensive peat pipe systems underground, either in the upper horizon of the peat body, or running along the interface with the mineral surface beneath. Where the density of peat piping is high, the blocking of drainage channels alone may not fully rewet a site (Lunt et al., 2010). In addition, water table depth increases with the distance from the ditch (Hedberg et al., 2012).

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| **Lesson:** | *Ditch blocking may be a desirable form of semi-designed wetlands that could be incorporated into reclamation design practice where it is desired to have long linear wetlands to provide ecological value.* |
| **Opportunity:** | *Development of semi-designed wetland techniques and experience in ditch blocking.* |

### 4.3.6 Beaver activity (Syncrude S4 Beaver Pond)

As part of construction of the S4 Dump (now known as Gateway Hill) Syncrude included a long, linear, north-south toe ditch to catch runoff from dump activities. Beavers, which come and go from this site, moved in, damming the south end of the ditch and flooding much of the surrounding area.

This opportunistic marsh illustrates the dramatic role of beavers in the reclaimed landscape. In this case, beaver impact was anticipated and no specific accommodation was made for beavers, as their activities are considered beneficial (Eaton et al., 2013).

**Figure 4-3. Syncrude S4 Beaver Pond.**

**Figure 4-4. Beaver pond at Syncrude Gateway Hill (Google Earth, May 2011).**

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| **Lesson:** | *Beavers will dam oil sands watercourses soon after areas are reclaimed and where willow and/or aspen are available for food and building materials (or where these water courses are located near undisturbed areas).* |
| **Opportunity:** | *Design watercourses and wetlands to accommodate beaver activity and confirm methods to predict the density and size of such beaver ponds in the reclaimed landscape.* |

### 4.3.7 Watershed design using natural analogues (HEAD Program)

The HEAD program's study of the Utikuma wetlands (Devito et al., 2012) 250 km west-southwest of Fort McMurray provides a wealth of useful information on the functions of natural wetlands in the boreal forest. This guide has been greatly influenced by its work. The wetland history has been tracked over decades in response to climate variation and logging/disturbance activities on the land. Most of the wetland processes studied will be important in the performance of reclaimed wetland in the oil sands.

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| **Lessons:** | *The full list of applicable lessons is too numerous to summarize here. The reader is strongly encouraged to read Devito et al. (2012). A few of the key lessons:*<br>*Wetlands show major responses to variation in climate on decadal cycles, especially through wet and dry periods.*<br>*The watershed design is at least as important as the wetland design.*<br>*A variety of shoreline configurations (from shallow to steep, from clayey to sandy) support different wetland functions.*<br>*Wetlands are often perched well above the water table even in sandy materials. The hydrologic processes are often complex.*<br>*It is usually not useful to distinguish between classical surface water and groundwater – they are all part of an integrated system with the substrates and the vegetation communities.*<br>*Ephemeral draws are a common feature of boreal wetlands.* |
| **Opportunity:** | *Use of the HEAD synthesis document by designers for closure planning and landform-level designs of wetlands in oil sands reclamation. Ongoing work in the Utikuma watersheds with the aim at developing better numerical models to handle the surface-water/groundwater/vegetation response to climate variations. Annual technical tours for designers and regulators.* |

## 4.4 Substrates, reclamation materials and water quality

This section describes case histories where lessons from studying substrates, reclamation materials, and water quality have important implications for oil sands wetland reclamation.

### 4.4.1 Processed-material-influenced wetlands (Suncor CT ponds and natural wetland)

A 4-metre-deep consolidated tailings (CT) demonstration pond was created in 1999 at Suncor's Waste Area 11. The area was filled with sand and CT (Daly et al., 2009). Pond 5 tailings process water was pumped from an upstream area. Some of the area was amended with peat (poor trafficability restricted access to the rest of the area). The experimental program was designed to test direct revegetation of consolidated tailings and to measure the natural biodegradation of naphthenic acids in process-affected waters.

**Figure 4-5. Suncor CT's natural wetland (Golder Associates photo).**

Results indicate that biodegradation of the labile naphthenic acids occurs rapidly (within 8 to 10 months) but the larger, chained naphthenics degrade more slowly. Stands dominated by *Typha* spp. (cattails) and *Scirpus* spp. (bulrushes) developed within three years following construction on peat-amended areas, but more slowly in areas without peat. Relatively little submerged aquatic vegetation colonized (perhaps due to the shallow water), whether or not peat was applied, and deep areas were sparsely vegetated by one species, *Stuckenia pectinatus (*fennel pondweed*)*, 13 years after construction.

The Suncor Natural Wetland was a reclaimed forest ecosystem but became an opportunistic wetland with inputs of precipitation and dyke seepage water. The area has been studied extensively (Daly, 2007) and provides useful information on the impacts of process-affected waters.

**Lessons:** *Wetlands can be successfully reclaimed OSPW-dominated environments. Peat-amended areas have faster rates of plant colonization. Colonization by submerged aquatic vegetation is slower than hoped. Bioremediation is effective with one-year water retention times but not for long-chained molecules.*

*Salinity is a significant geochemical limitation both to plant establishment and to the persistence of aquatic organisms in the region. Most plants will be stressed by water containing more than 600 mg/L of sodium, or an electrical conductance of > 4,000 µS/cm. Therefore, plant selection must focus on species with moderate to high salt tolerance. Work to understand water-quality impacts is ongoing. However, aquatic invertebrate community composition and amphibian abundance and distribution are affected at conductivities as low as 1,000 µS/cm.*

**Opportunity:** *Ongoing monitoring, and development and trial of techniques for tailings wetland reclamation. Designs to reduce the concentrations of dissolved salts and organics in waters supplying wetlands are a major opportunity, through dilution by runoff or natural waters, or through reduction in the concentrations of process-affected waters used to slurry tailings.*

### 4.4.2 Soil placement (Alberta and Florida)

**Figure 4-6. Reclamation of an oil pad at year 4 (Photo courtesy of Dale Vitt).**

Vitt et al. (2011) experimented with planting *Carex aquatilis (water sedge)* and *Salix lutea* (yellow willow) on mineral soil at a drill pad reclamation site near Peace River, Alberta. These species established well without peat soil. In addition, the application of fertilizer reduced the performance of planted species. It might be possible to initiate peatland formation using vascular plant introductions on mineral soil without placing peat, or any additional treatments such as fertilization.

In an effort to recreate forested wetlands following phosphate mining in Florida, Miller et al. (1985) created a perched water table on a 2:1 sand-clay mix from mine tailings and phosphatic clay. The sand-clay mixture was sprayed two feet deep, dewatered over three months to create an impermeable layer, and then topped with overburden. In this case, reclamation of marsh and wet meadow sites required the creation and maintenance of proper soil conditions. Wetland soils have distinctive features, such as mottling and other redoximorphic features that result from seasonal or perennial inundation and soil anoxia. These features indicate that suitable hydrogeochemical conditions are present. Vepraskas et al. (1995) were interested in the time required for wetland soil features to develop. Using created marshes that had water pumped in at a rate of 11 cm/week, they determined that soils constructed in and near the edge of the marsh had characteristics of hydric soils within 30 cm of the ground surface within 3 years. Some redoximorphic features (reduction and dissolution of iron) can occur during short periods of inundation when soil organic matter content is greater than 3%.

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| **Lesson:** | *The design of the soil cover requires a multidisciplinary approach. In areas where the cover is designed mainly for vegetation establishment and growth, planting on mineral soils (without the placement of peat) may be an option.* |
| **Opportunity:** | *Develop techniques for designing soil covers in wetlands in a multidisciplinary nature (construction and access, erosion, water quantity and quality, vegetation establishment and growth, wildlife) and look for opportunities to conserve peat stockpiles where planting into mineral soils may suffice.* |

## 4.5 Vegetation establishment and community

This section describes case histories that have implications for vegetation establishment, growth, and the development of wetland communities. The lessons are summarized at the end of this section.

### 4.5.1 General importance of vegetation establishment (Ireland)

In a cutaway peatland converted to a shallow-water wetland, Higgins and Colleran (2006) observed that the lack of recolonizing vegetation at recently abandoned sites made some new lakes vulnerable to nutrient runoff and algal blooms. The embryonic lakes and wetlands were characterized by rudimentary food chains, in which higher trophic levels were absent and micro-biota played an elevated role. Site age influenced both the degree of revegetation by macrophytes, which provided a valuable buffering effect in older lakes against external nutrient inputs and excessive phytoplankton growth, and food web dynamics by increasing the colonization time for macroinvertebrates and higher trophic groups. Longer-term monitoring of cutaway lakes is required in order to ascertain the processes and time scales involved in the establishment, development and eventual stabilization of these ecosystems.

### 4.5.2 Importance of connectivity (Colorado and Ohio; Wyoming)

Fifteen years after creation, Gutrich et al. (2009) found that marshes in Colorado and Ohio had lower species richness and fewer native species than natural analogues. They concluded that created marshes did not resemble natural marshes largely due to their isolation from natural marshes and propagule sources. Hydrologic stabilization is known to reduce species diversity (Keddy and Reznicek, 1986). Marshes created for waterfowl habitat in the western U.S. have homogenized and support large mono-specific stands of *Typha* spp. and *Scirpus* spp.

In the absence of planting, reclaimed wet meadows and marshes may have long delays in vegetation establishment. In Wyoming, more than 1,500 wetlands have been created in former bentonite mining sites and many have not developed submerged or aquatic plant communities due to their isolation (McKinstry and Anderson, 2005). To examine the role of isolation in vegetation establishment, McKinstry and Anderson (2005) studied 12 wetlands within 5 km of each other: six wetlands served as controls and six had salvaged wetland soil spread 10-15 cm thick. The use of salvaged soil increased the number of native species, total vegetation percent cover, and total plant biomass, when compared with control wetlands. The species pool in the salvaged soil, however, was limited to only 10 species.

### 4.5.3 Using soil seed banks (Japan)

The use of soil seed banks has also been studied on artificial lakeshores in Japan (Nishihiro et al., 2006). In 2002 a pilot study evaluated revegetation of lakeshores using soil seed banks. Lake sediments containing seed banks were spread 10 cm in thickness on the surfaces of artificial lakeshores, constructed of concrete. The constructed lakeshores had micro-topographic variations, ranging from -0.8 to 0.3 m relative to the annual mean lake level, which was important for the restored vegetation, as species sorted themselves based on the microtopography. Several invasive species were manually removed, as part of collaboration among citizens, scientists and lake management officials.

### 4.5.4 Planting (Olentangy River Wetland Research Park, Ohio)

In the Olentangy River Wetland Research Park, Ohio, two experimental 1-ha riverine wetlands were created in 1993 with the construction of a river water delivery system (river water was pumped continuously for the duration of the experiment). One wetland was planted with more than 2,400 rootstock and rhizome plant propagules of 13 species typical of midwestern marshes. The other wetland remained unplanted. Both received the same amount and quality of pumped river water and maintained essentially identical hydroperiods between 1994 and 2003.

The aim of the experiment was to test the influence of planting on ecosystem succession and on the development of a wetland when it is created on formerly non-wetland soil. Of particular interest, Mitsch et al. (2012) show that the vegetation composition of the two wetlands (one planted, the other left to “self-design” through natural invasion) converged within about 15 years.

The unplanted wetland was dominated by *Typha* spp. for the first six years, but in 2002 *Typha* coverage was only 9% of the total area (compared with 5% in the planted wetland). After 10 years, the planted wetland continued to support more diverse vegetation cover. However, the unplanted wetland had higher productivity. The authors suggest that there are desirable values from both “diverse” and “high productivity” marshes. Plant diversity and species differences led to some differences between basins in macrophyte productivity, carbon sequestration, water quality changes and nutrient retention. Both wetlands continued to retain nitrogen (as nitrate) and soluble reactive phosphorus 10 years after creation. However, there were signs that sediment and total phosphorus retention were diminishing after 10 years of river flow.

The two experimental wetlands on former non-wetland soil allowed researchers to observe the morphological and geochemical features of hydric soil development within 2-3 years of wetland creation. Most changes occurred in near-surface soils (0-8 cm depth) where sedimentation and organic matter accumulation were most rapid. Over the first decade, soil organic matter increased by 63% in the upper 8 cm of soils to an average of 8.6%. On average, soil organic matter increased by 1% every 3 years in this created marsh (Mitsch et al., 2005).

**Figure 4-7. The Olentangy River Wetland Research Park.**

### 4.5.5 Role of drawdown (Cache la Poudre River, Colorado)

A 17-ha riparian wetland was created on a former gravel mine along the Cache la Poudre River in Colorado (Roelle and Gladwin, 1999). The pit was filled with a mixture of sand, gravel, cobble and clay. A drain culvert equipped with a screw gate allowed water levels to be manipulated. Subsurface flows are derived from river seepage. Two years prior to wetland creation, mature, seed-producing cottonwoods and willows growing upstream were monitored to determine timing of seed production. Water tables were drawn down at 1 cm/day to expose bare mineral soil at the timing of highest seed rain. Establishment was variable year to year and with maximum densities of 182 seedlings/m$^2$ for cottonwood and 344 seedlings/m$^2$ for willows (comparable to densities in natural areas). These researchers concluded that vegetation reclamation from natural seed sources is a viable option, with the proper water level management.

### 4.5.6 Soil amendment (Nome Creek and Birch Creek, Alaska)

Two thousand willow cuttings planted following placer mining along Nome Creek in Alaska had a mean survival rate of 87% (Kostohrys, 2007). However, the most labor-saving, cost-effective revegetation resulted from fertilization, not from additional willow plantings. For several years after reclamation, fertilizer was applied to encourage the recruitment of native plant species. The group used 450 kg/ha, 50% 20-20-10 (N-P-K) and 50% 20-10-10. Willows are flourishing along the creek and are 1-2 m in height.

Along placer-mined streams in interior Alaska, Cooper and Haveren (1994) found that willows established from natural aerially dispersed seed onto sites that had supplemental watering for 1 or 2 years. Topsoil application reduced seedling survival after one year.

### 4.5.7 Role of tussocks (Japan)

Koyama and Tsuyuzaki (2010) examined the ability of two tussock-forming species, *Carex middendorffii* and *Eriophorum vaginatum*, to facilitate the establishment of other species in a formerly *Sphagnum*-dominated wetland in Japan. They concluded that tussocks facilitated plant establishment in the edge microhabitat by providing litter cover and enhancing seed accumulation, seed germination and seedling survival. However, *Sphagnum* spp. did not establish in the study sites, and the resulting vegetation differed strongly from reference areas where peat mining had not taken place.

### 4.5.8 Importance of *Carex aquatilis* (Suncor Nikanotee Fen, Alberta)

The water sedge *Carex aquatilis* is a key species for fen reclamation as it tolerates a wide range of geochemical conditions, including a pH from 3.0 to 9.2, electrical conductivity up to 8,820 S/cm, and 0.27 to 1,022 mg/L $Na^+$ (Koropchak et al., 2012). It also thrives in a wide range of water levels and both mineral and organic soils. Of the 11 vascular species seedlings planted in the treatment cells, *Carex aquatilis* survived better and outperformed all others, regardless of treatment (Vitt et al., 2013). *C. aquatilis* occurs in all fen types and does not associate with any wetland or peatland species. It is most abundant in water tables ranging from 20 cm below the soil surface to 20 cm of standing water (Vitt et al., 2013). For these reasons it is a key vascular plant introduced into the Nikanotee Fen.

### 4.5.9 Peat salvage depth (Québec peat mining restoration projects)

Salvage depth can greatly influence available propagules and seed banks as well as substrate quality and plant establishment. In peatland, the quality of the peat substrate improves establishment. Shallow depths reduce the amount of incorporated underlying mineral horizons and retain the high organic carbon content and quality of available nutrients (MacKenzie, 2011). The effects of salvage depth are also applicable to non-vascular species. Rochefort et al., (2003) reported significantly greater establishment of *Sphagnum* from harvesting the top 0 to 10 cm of the peatland surface compared with spreading deeper layers.

### 4.5.10 Revegetation from seed (Suncor Nikanotee Fen, Alberta)

Germination trails have been conducted to examine stratification procedures for 10 local wetland plant species (Vitt et al., 2013): *Potentilla palustris*, *Carex aquatilis*, *Betula glandulifera, Carex paupercula*, *Scirpus validus*, *Beckmannia syzigachne*, *Picea mariana*, *Smilacina trifolia, Triglochin maritima*, and *Triglochin palustris*. Treatments included length of stratification (30, 60, and 90 days), moisture treatment (wet and dry), light treatment (dark and light), and temperature treatment (ambient, 2 °C, and -20 °C). For best results, species should be stratified independently as each differs in responses to stratification time. All species responded similarly or better in wet conditions compared with dry, dark compared with light, and at cold (2°C) temperatures. In general, they found that a wet and dark stratification at 2°C for 30 days produced optimal seed germination. A number of vascular plant species seeds were stratified and introduced to the Nikanotee Fen by hand in experimental plots, and there appears to be good germination of Triglochin maritimum and several other species.

### 4.5.11 Transplants (Europe)

Vegetation transplanted to newly created wetlands may reach stable states, although the species composition may differ from the natural wetland vegetation that was the source of the plants, even after 20-30 years. Klötzli (1987) reported on one of the first large-scale transplantation experiments in Europe, where mesotrophic fen and fen-meadow vegetation was transplanted to an artificially constructed wetland to make room for an airport near Zürich. He found that many native species present in small numbers in the original sward — among them *Carex hirta, Eupatorium cannabinum* and several *Juncus* species — expanded rapidly after some time. After varying in abundance for many years they reached a state of relative stability. Such invasions or rapid expansion of dominant species can be decisive for further ecosystem development. A single species may develop very high cover and inhibit development of the target community anticipated at the start of this project. Such “arrested succession” (Niering and Goodwin, 1974) may persist for decades (Van der Valk, 1981; Van der Valk and Jolly, 1992). Cattail (*Typha* spp.) invasion of newly reclaimed marshes is a common example (e.g., Ralston et al., 2007).

### 4.5.12 Transplants (Syncrude Sandhill Fen)

Vitt et al. (2013) conducted greenhouse and field experiments to better understand plant community establishment and responses to environmental factors likely to be encountered in post-oil sands mining constructed wetlands, such as the Syncrude Sandhill Fen Reclamation Project (Pollard et al., 2012). They analyzed key species to determine their rates of germination and tolerance to salinity.

After four years, 99 species were found growing in their experimental cells, including 65 species of vascular plants, 33 bryophytes, and one lichen. These species were either introduced in the live transplanted peat blocks and as propagules or in the seed bank, or arrived from airborne propagules. The live transplanted peat cells were more species-rich, but stockpiled peat cells were more species diverse and had variable composition. Dominant species were *Typha latifolia, Beckmannia syzigachne, Carex aquatilis,* and *Calamagrostis canadensis*. Frequently occurring species were *Taraxacum officinale, Salix lutea, Bryum pseudotriquetrum, Rumex* *occidentalis*, and *Carex canadensis.* The stockpiled cells were dominated by *Typha latifolia*, *Carex aquatilis*, *Salix lutea*, and *Calamagrostis canadensis*, with *Beckmannia syzigachne* being dominant in most of the cells. Fen species persisted in live transplants and recruitment of additional fen species occurred. The stockpiled peat was rapidly colonized, and had a high frequency of mosses, but was dominated by *Typha latifolia*, *Carex aquatilis, Salix lutea*, *Calamagrostis canadensis*, and *Beckmannia syzigachne.*

Salt-tolerant species including *Triglochin maritima* and *Juncus tenuis*, and the dominant colonizers in all cells *Typha latifolia, Beckmannia syzigachne, Carex aquatilis,* and *Calamagrostis canadensis* were able to colonize stockpiled peat supplied with process-affected water. Wetland plants began to exhibit negative effects at salinity levels exceeding 300 mg/L $Na^+$, or an electrical conductance of 2,000 uS/cm. They recommend that source water not exceed 600 mg/L $Na^+$, or about 4,000 S/cm, as most species studied were highly affected above this level. Experimental cells fed process water had fewer species than freshwater cells. *Carex aquatilis* and *Beckmannia syzigachne* were most tolerant of process water.

### 4.5.13 *Sphagnum* establishment (Québec peat mining restoration projects)

Establishing mosses is crucial to the peat-forming process for many boreal ecosystems (Rochefort, 2000). *Sphagnum* has been a keystone genus for bog reclamation in eastern Canada. It has not been found to recolonize degraded peatlands unaided (Poulin et al., 2012), but can be successfully introduced (Lunt et al., 2010).

Necessary conditions include a stable water table and the elimination of degrading factors (burning and trampling, low pH (< 3.5), high inputs of nitrogen and phosphate from receiving waters and/or nitrogen from atmospheric deposition). Sliva and Pfadenhauer (1999) found that *Sphagnum* re-introduction was only efficient after vascular pioneer species were established on their study sites. Ongoing research is exploring the use of *Sphagnum* and vascular plant species transplants, including *Eriophorum angustifolium, Erica tetralix* and *Empetrum nigrum* (Lunt et al., 2010). The simultaneous introduction of vascular plant (*Carex aquatilis*, *Juncus balticus, Calamagrostis inexpansa, Triglochin maritimum, Betula pumila*) and bryophyte species introductions is being tested at the Nikanotee Fen, Alberta.

Once site prerequisites of a high water table are achieved, three key interventions are required: reintroduction of moss diaspores; a protective mulch cover; and a saturated peat surface (Rochefort, 2000). Manually or mechanically spreading moss diaspores over the bare peat provides the propagules from which *Sphagnum* individuals can regenerate (Rochefort et al., 1995). As described by Quinty et al. (1997), moss diaspores can be harvested from a donor site to a depth of 5-10 cm, preferably in a long narrow strip. The ratio of harvested area to reclamation area is recommended to be 1:10, or even 1:20. The regeneration potential of moss fragments stockpiled for use diminishes with time.

### 4.5.14 Invasives management (Québec peat mining restoration projects)

Invasive species commonly establish in restored peatland sites (Poulin et al., 2012). Obligate wetland species, such as *Typha latifolia* (cattail), facultative wetland species such as

*Calamagrostis canadensis*, and ruderal species such as *Equisetum arvense* are able to colonize immediately following restoration activity. Eight years after restoration, the abundance of ruderal species decreased, although they still contributed 15% of the species richness compared with < 1% on the reference sites. Despite their establishment, invasive species did not deter peatland species and their abundance may diminish over time in areas where *Sphagnum*-induced acidification and/or Ericaceous shrub cover increases (Poulin et al., 2012).

### 4.5.15 Invasives management (Central Europe)

Depending on the target community, a desirable species in one site can become invasive in another. Klötzli and Grootjans (2001) cite the example of a wetland project with the goal of establishing basiphilous (basic pH) wetland communities, but *Sphagnum* species dominated after sod cutting. *Eriophorum vaginatum* can be considered a nurse species facilitating the establishment and growth of other plants, particularly *Sphagnum* spp. However, this species can become invasive and occupy all available space, prohibiting the re-establishment of *Sphagnum* species that are important to peat formation. Eriophorum may impede progress and greenhouse gas emissions may increase (see next section on succession blockage). For these reasons, Lavoie et al. (2005) suggest that whenever possible, *Sphagnum* diaspores should be spread on bare peat instead of using *E. vaginatum* for bog reclamation. However, when sources of *Sphagnum* diaspores are scarce (in Europe in particular), *E. vaginatum* remains a useful option.

### 4.5.16 Vegetation management (Hungary)

In Hungary, Timmermann et al. (2006) tested different levels of rewetting to favor natural colonization of peat-forming plants and repress the invasive species, *Solidago gigantea*. After seven years, significant spread of potentially peat-forming plants was largely restricted to long-term shallow inundated sites. The authors concluded that although *Phragmites* and *Carex* spp. were present in a certain area where the hydrologic regime was optimal (long-term shallow inundation), strong competition from *Glyceria maxima* and *Typha spp.* would either make their large-scale expansion take decades or fail entirely.

When the level of disturbance is low, and hydrological, hydrochemical and soil conditions are adequate, natural colonization may occur. If natural colonization does not occur, the addition of desired plants is necessary (Lunt et al., 2010). But before deploying costly planting or seeding efforts, the factors that may be preventing natural plant colonization should be identified and removed. Dispersion limitations or seed availability of desired species, for example, can prevent natural colonization of bare peat. Invasive or undesired species, meanwhile, can outcompete desired species.

**Lesson:** *Revegetation strategies include natural invasion, seeding, and planting; many projects use multiple approaches. Laboratory work on germination requirements for vascular plant species is an essential element of revegetation design and methods for key boreal wetland species are being developed. Natural invasion may take decades to recreate the designed vegetation communities and in some cases will tend towards monocultures. Control of invasive species is commonly required. Water level management is commonly required during establishment.*

**Opportunity:** *A plethora of revegetation techniques are applicable to the oil sands region and a concerted work plan over the next decade to establish proven and economical methods for marsh and fen reclamation would help operators and regulators agree upon a standard suite of methods and approaches.*

## 4.6 Wetland performance, monitoring and management

### 4.6.1 Wetland performance assessment (CFRAW program)

The CFRAW project[‡] began in 2005 as a collaboration among five researchers who had worked together on wetland-related projects for several years. The objectives were to:

1. Track the movement of carbon to describe the dynamics and food web structure in constructed wetlands of differing ages and material additions;
2. Assess the effects of mine process materials and their interactions in constructed wetlands on the environmental condition of selected components of wetland food webs; and
3. Document the qualitative changes in the distribution of carbon, relative abundance and dispersal of potentially toxic elements/compounds in constructed wetlands.

Team members studied 16 “focal” wetlands, representing a factorial suite of contrasting age since formation, including younger (< 7 year) and older (> 8 year) sites, the use or absence of OSPW and/or tailings in construction, and the presence vs. absence of sediment amendments with a carbon-rich capping layer of terrestrial or hydric origin. Supplemental observations were made from a larger suite of up to 40 wetlands within and adjacent to the oil sands lease areas. Appendix G provides a synthesis of this work.

### 4.6.2 Marsh vegetation index of biotic integrity

Plants are valuable indicators of wetland function and condition and can be used to determine the success of reclamation when compared to reference sites. A vegetation-based Index of Biotic Integrity (vIBI) was developed by Raab and Bayley (2012) to evaluate the health of reference and reclaimed wetlands in the oil sands. Advanced (AvIBI) and a basic (BvIBI) assessment tools were developed by correlating vegetation community metrics collected in the field to physiochemical stress gradients (Rooney and Bayley, 2012). The assessment tools differ in the time and experience required by the scientist to conduct the survey.

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[‡] http://web2.uwindsor.ca/cfraw

The BvIBI tool includes metrics of total above-ground biomass, vegetation zone width, and proportional total vegetation cover. The AvIBI tool requires more advanced botanical training and involves evaluating the adjusted floristic quality assessment index (Miller and Wardrop, 2006), relative diversity of dicot species, and relative cover of invasive species. The two-tiered approach is valuable for rapid monitoring through the BvIBI and more in-depth assessments with the AvIBI required as they can be used in tandem to track health through time. The stress-range gradient method was selected as the most appropriate scoring method and was used to categorize sites into good, fair or poor classes. The AvIBI method had greater correlation to the stress-gradient matrix compared with BvIBI. Both tools classified 14 out of 20 reclaimed wetlands as being in poor health. The developed vIBIs may be a valuable method for practitioners and regulators to evaluate the floristic metrics of reclamation success in the oil sands region (Raab and Bayley, 2012).

An IBI has also been developed for submerged and floating aquatic vegetation (SAV) to assess reclaimed wetlands in the oil sands region (Rooney and Bayley, 2012). This vegetation community can serve as a relatively good indicator because it is sensitive to environmental conditions and plays an integral role in wetland health through water sediment and nutrient filtration and oxygenation. The SAV community metrics were compared with physiochemical stress gradients and scored using the continuous-reference range method. Five metrics were correlated to wetland stress, including richness of floating species, relative abundance of alkaline species, percent cover of floating leaf species, relative abundance of *Ceratophyllum demersum* and a minimum *Potamogeton* species relative percentage of 0.12. Of the 25 sampled reclaimed wetlands that included tailings and tailings-free designs, all were significantly below the biological integrity of the 37 sampled reference wetlands. The SAV IBI can be used to assess the health of reclaimed wetlands and serves as a guideline for practitioners in developing target outcomes of successful projects (Rooney and Bayley, 2012).

**Lesson:** *Reclaimed wetlands in the oil sands have numerous similarities and differences when compared with natural reference wetlands in the region and care needs to be taken in setting goals for reclaimed wetlands relative to reference wetlands. The ecological trajectory of reclaimed oil sands wetlands is complex and tools to understand these trajectories are emerging. Given the inherent uncertainty of these novel ecosystems, simpler rather than more complex methods for setting goals and evaluating success should be developed.*

**Opportunity:** *Develop a simple list of goals for wetland performance and continue to develop models to help understand these systems and their trajectories to influence future designs and future editions of the guide. Development of wetland goals that recognize the differences between reclaimed and natural wetlands is critical. Development of methods to allow reclaimed wetlands to be more similar to reference wetlands will be an ongoing process.*

### 4.6.3 Use of adaptive management (Wyoming)

Reclamation of a gravel pit complex in western Wyoming (Cooper, unpublished data 2008 gravel mine reclamation in Grand Teton National Park) included regrading the land surface to be in contact with a shallow, natural groundwater table. Several years of research was needed to determine the source and direction of groundwater flow and its seasonal elevation variation. A project goal was to establish a dense stand of tall willows (*Salix* spp.) from aerially dispersed seed. Willow seeds require bare and wet mineral soil for germination. The site was designed so that the water table would be just below the ground surface in late June to facilitate naturally dispersed willow seed germination. A water table map was created for late June and the proposed land surface topography mimicked the water table with a variance of ±30 cm. The new land surface required removing 2-3 m of sediment to reach the proposed elevation, and the sediment was pushed into large gravel pit lakes, reducing their depth. This required moving more than 200,000 $m^3$ of sediment.

The site was designed so that natural willows were preserved around the site to facilitate seed dispersal to all parts of the site. In addition, several hundred thousand nursery grown sedges, grasses and spike rushes were grown and planted along the hydrologic gradients built into the plan. Willow establishment was heavy in the first year, and seedlings survived well. Several problems with this program arose. First, the commercial nursery that propagated seedlings delivered and planted more than 100,000 *Carex feta* plants, a species that is not native to the Rocky Mountains, and was considered an exotic plant when discovered. The nursery had been provided locally collected *Carex* seed, but for unknown reasons *Carex feta* was provided. Because the project was in Grand Teton National Park, and *Carex feta* had flowered and fruited before it was identified, the research team concluded it had formed a soil seed bank. Therefore the site soil was scraped, and the removed soil stockpiled in a landfill. The site then had to be replanted, a process that took nearly five years.

| | |
|---|---|
| **Lesson:** | *Wetland reclamation is a multi-year process, especially if new techniques are being developed during commercial reclamation. Chain of custody should be implemented when collecting seed and having them propagated in a commercial nursery to ensure that the correct species are planted on site.* |
| **Opportunity:** | *To adjust reclamation schedules to embrace the multi-year nature of wetland reclamation while at the same time looking for ways to confine major efforts to the first few years as an optimization of the process.* |

### 4.6.4 Highway 63 oil sands borrow pits

Numerous borrow pits along Highway 63 and other roads in the oil sands region have been partially reclaimed to shallow-water wetlands (e.g., EBA, 2002). For most of the older sites, water depths are generally too great for emergent vegetation and side slopes too steep to support more than a fringe of cattails and bulrushes. To date there has been no published inventory or description of these wetland sites, though formal monitoring of new wetlands created by recent Highway 63 road construction is underway (e.g., Legaree, 2014).

Soil characteristics, slope geometry, and water depth are critical to elements of wetland reclamation and small changes in design can influence project success. Where there is some soil and the water table is shallow, cattails will prosper (Figure 4-8). The CFRAW study provides additional information and findings.

**Figure 4-8. Cattails in a borrow pit near Fort McMurray.**

| | |
|---|---|
| **Lesson:** | *Where productivity and emergent vegetation is desired, keep wetlands shallow.* |
| **Opportunity:** | *Inventory the borrow pit wetlands and develop a list of learnings for use in mine reclamation.* |

## 4.7 Summary

The published literature, and in particular the case histories, is an important source of information for this guide and for all those involved in oil sands wetland reclamation. While there is limited information available on wetland reclamation for mining, the lessons from other wetland creation and restoration and the publications on oil sands wetland experience and performance provide learning opportunities for designers, operators and regulators.

There is a major opportunity to complete the inventory of all natural wetland in the oil sands region that are under study and those that have been constructed through highway and mining reclamation. Furthermore, mapping of these wetlands and assessment of their performance would lead to a valuable set of lessons.

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# Chapter 5
# Wetland Design For Mine Closure Plans

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All oil sands mines have mine closure plans that provide the design basis for the closure landscape and conceptual level designs for all mining landforms and the lease-wide surface drainage system. “Design for reclamation certification” is focused on meeting regulations and approval conditions. Wetlands are a key component of this landscape level design. Progressive reclamation takes many decades and the closure plans are updated every five to 10 years.

The wetland design has nested spatial components (regional, landscape, landform, patch, and microsite). This chapter focuses on the landscape scale, with an eye to the regional and landform scales).

The design of the watershed is at least as important as the design of the wetland. Considerable effort goes into each watershed and wetland even at the closure planning level. Before each landform is constructed, a more detailed landform design is completed and then updated during construction. Wetlands are a major focal point of this level of design. Wetland reclamation requires a detailed design, which is done when the mining earthworks are largely completed. The detailed design includes landform grading, coversoil placement, and revegetation. An operation, monitoring, and maintenance (OMM) manual is developed at this time. Semi-designed and opportunistic wetlands don’t go through this formal design process, but may be anticipated in the closure plan. A method of estimating their occurrence is provided.

At the closure planning level, wetlands are usually designed as shallow-water wetlands, marshes, or fens. Guidance for designing swamps and bogs is in progress.

Developing the design basis by setting goals and objectives in consultation with the mining company, regulators, stakeholders, and First Nations is too often overlooked but is critical to guiding design, construction, operation, and ultimately reclamation certification. Guidance in developing goals and objectives is provided.

Landscapes and landforms are part of complex environmental systems and their performance is difficult to predict. Design and operational strategies to overcome this uncertainty are presented.

While numerical models are used for design, the initial wetland designs are done using rules of thumb, which are provided for the common wetland types and locations in the closure landscape. Designs are later refined with additional analysis.

Beavers are likely to modify the wetlands considerably and repeatedly. Guidance on designing wetlands to anticipate and accommodate beaver dams and canal building is provided.

Each specialist in the design team (which includes mine and tailings planners, geotechnical engineers, surface water hydrologists, soil scientists, vegetation and aquatics scientists, wildlife biologists, and traditional knowledge experts) has an important role to play throughout the various design iterations, construction, reclamation, and operation of the wetlands. Closure planning level design guidance for each expert is provided.

Wetland designs are assessed against the design basis and an engineering risk assessment is conducted. Schedules, volumes, and borrow sources are developed.

Some wetlands may be redesigned a dozen times or more with each interaction of the mine closure plan, depending upon the degree of change (in mining, tailings performance, land use decisions, technology, etc.), and whether the wetland is constructed early or towards the end of a mine life. Each time, the closure plan is created to enough detail to allow good operational decision-making by the mine and its regulators. A good closure plan, kept current, also provides direction on the design of individual landforms (and their wetlands), which is the topic of the following chapter.

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## 5.1 Introduction and background

Progressive reclamation is integral to oil sands mining and has been a continuous activity since oil sands mining began in the 1960s. It is required in each mines' operating permit and is central to the primary goal of achieving reclamation certification. The mix of desired land uses continues to evolve (e.g., Oil Sands Mining End Land Use Committee, 1997; Doran, 2013) and in recent years there has been a specific focus on reclamation to wetlands as part of the reclamation to a "locally common boreal forest," which includes wetlands as a key component.

The main focus of oil sands reclamation is to allow operators to receive a reclamation certificate from the Alberta government, and in doing so, relinquish control and some of the residual liability of the land back to the Crown (see Section 8.6). Yet the criteria for this certification (and hence the design goals) remain unclear (e.g., Powter and Polet, 2012; Creasey, 2012). Chapters 5 through 8 guides designers to declare their goals and objectives (their design basis) and then set about drawing up plans, designs, schedules, and field activity schedules to create wetlands to meet these objectives in a way and over a timeframe acceptable to regulators and other stakeholders, including the company shareholders (McKenna, 2002). Thus these chapters embrace the strategy proposed by Cowan et al. (2013) to "Design for Relinquishment" or as adapted to the Alberta jargon, "Design for Certification" and are set in the broader context of the framework of sustainable mining (e.g., Abbott and McKenna, 2012).

Life-of-mine planning started in the oil sands in the 1970s and closure planning became a formal activity starting in the 1990s (McKee and McKenna, 1997). All applications for new oil sands mines require a closure plan and most recently, all operating oil sands mines were required to submit updated closure plans to Alberta Environment (December 2011) and on a nominal five-year basis. Wetlands are a key component of the lease drainage system and land uses in these closure plans.

A rich literature on wetland construction is available (Chapter 4), but most relates to restoration of existing natural (or agriculturally affected) watersheds, with little on wetland reclamation in a mining context or in northern climates. Oil sands wetland reclamation and performance are the subjects of many academic papers.

Wetland development in the oil sands occurs over many decades, from the first designs at the closure planning scale through landform design and construction, reclamation, operation and monitoring, and finally certification. Four consecutive phases are shown in Tables 5-1 and 5-2, from large landscape-scale mining watersheds, which will contain dozens of wetlands, to landform-scale watersheds with one or several wetlands, to construction and operation of individual wetlands.[1]

Wetland design is governed by the interplay of geotechnical, surface water, groundwater, soils, vegetation, wildlife, operational, schedule, and economic considerations (Chapter 1 and McKenna, 2002). Wetlands are but one component of a complex reclaimed landscape and their design is both dictated by and to some degree governs reclamation activities throughout the

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[1] Temporal and spatial scales are based on work in progress by Brian Eaton and Jason Fisher (of AITF) and Gord McKenna (of BGC) for OSRIN.

lease (Figure 5-1). Other guidance documents provide design direction on landforms (Millennium EMS Solutions, 2010), soils (MacKenzie, 2011), forest vegetation (Alberta Environment, 2010), riparian reclamation (Geographic Dynamics Corp., 2011) and end pit lakes (CEMA, 2012a).

As this chapter explains, the design of the watershed is as important as the wetland design. Both involve integrating biophysical systems across spatial and temporal scales and across teams.[2] Teams involved with mine and tailings planning, closure planning, landform and wetland design, mine and tailings operations, reclamation operations, along with regulatory and public affairs, are working to generate self-sustaining reclaimed wetlands and their watersheds to meet societal expectations over a century-long design and construction process. Watershed and wetland design at the lease/closure planning scale is one element of this work.

### 5.1.1 Phases of design

The level of wetland design complexity escalates with each design phase as individual wetlands are planned, designed, and constructed. If the initial closure planning — which must start even before mining begins — is sound, the process has great potential to bring about the desired wetland assemblages and values desired by stakeholders, government, and the mining companies themselves (see Section 1.5).

The first and highest level of oil sands wetland design, planning, and scheduling is done at the landscape scale as part of mine closure planning (e.g., ICMM, 2008; An et al., 2013). Most of the major decisions regarding watershed and wetland design are made at this level. A closure plan is a formal regulatory submission, prepared by a mine operator before mining begins and updated approximately every five years throughout mine operations. It describes the reconstruction and reclamation of the entire mining lease area, including the 10 to 20 landforms that will be created, and the dozens of watersheds and wetlands on and adjacent to these landforms that will be built over the 50- to 100-year life of the mine. This chapter provides guidance on conceptual designs for wetlands and their watersheds for closure planning.

Among the typical steps in closure planning design are goal-setting, watershed and wetland designs, and methods to assess the design. The guidance provided here leans heavily on the reclaimed wetlands already constructed over the past 20 years in the region (see Chapter 4) and the research into regional wetlands in the University of Alberta HEAD Program (Devito et al., 2012, and summarized in Chapter 2). It also draws on experience from the closure plans produced by mine operators in the region in 2011.

Table 5-3 presents the wetland types to be considered for design. It is consistent with the classification system described in Section 3.3.

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[2] Based on work in progress that is part of the COSIA Land EPA-led “Integrated Landscape Reconstruction.”

**Table 5-1. Phases of wetland design and construction**

| | Overall description | Design activities | Field activities | Monitoring |
|---|---|---|---|---|
| **Closure planning**<br>**Chapter 5** | Closure planning and design of all wetlands on a lease | Development of a closure plan before mining (EIA) with five-year updates<br>Working at the landscape and regional level | Predevelopment geological investigations<br>Mining activities elsewhere on the lease | Baseline environmental data collection for EIA<br>Ongoing climate monitoring<br>Monitoring of analogs and other constructed wetlands as part of adaptive management activities |
| **Landform design**<br>**Chapter 6** | The initial landform design followed by 5 to 30 years of landform construction by the mining operations, large mining equipment and full-scale tailings deposition, working towards a roughed-in watershed and wetland | Landform scale design within the framework of the closure plan completed just before disturbance of the landform footprint<br>Monitoring of progress, and adjustment of designs as needed | Site investigation prior to disturbance<br>Mining, fill placement, tailings operation to construct the landform/watershed, rough in the wetland location | Monitoring and guiding landform construction by mine and tailings operations staff |
| **Wetland reclamation**<br>**Chapter 7** | The site is transferred from the control of the mining/tailings operations staff to reclamation staff, smaller equipment is used for landform grading and construction of various landform elements (such as the wetland inlet, outlet, perched wetlands, swales), reclamation material is placed, and the initial vegetation is planted | Reclamation design – landform grading, design of the elements, monitoring during reclamation activities<br>Monitoring and tweaking of design | Site characterization<br>Landform grading<br>Construction of elements<br>Reclamation material placement<br>Initial revegetation<br>Establishment of hydrology | More detailed hydrology monitoring<br>Monitoring and guidance of construction, reclamation, and revegetation activities |
| **Operations, monitoring, and certification**<br>**Chapter 8** | The wetland is operated to guide establishment of the targeted ecosystem, monitored and maintained until certification and relinquishment to the Crown | Finalization of an operation guide, preparation of an application for reclamation certification | Adjustment of water level and water quality, subsequent revegetation, wildlife management, maintenance as required | Monitoring of wetland and watershed performance |

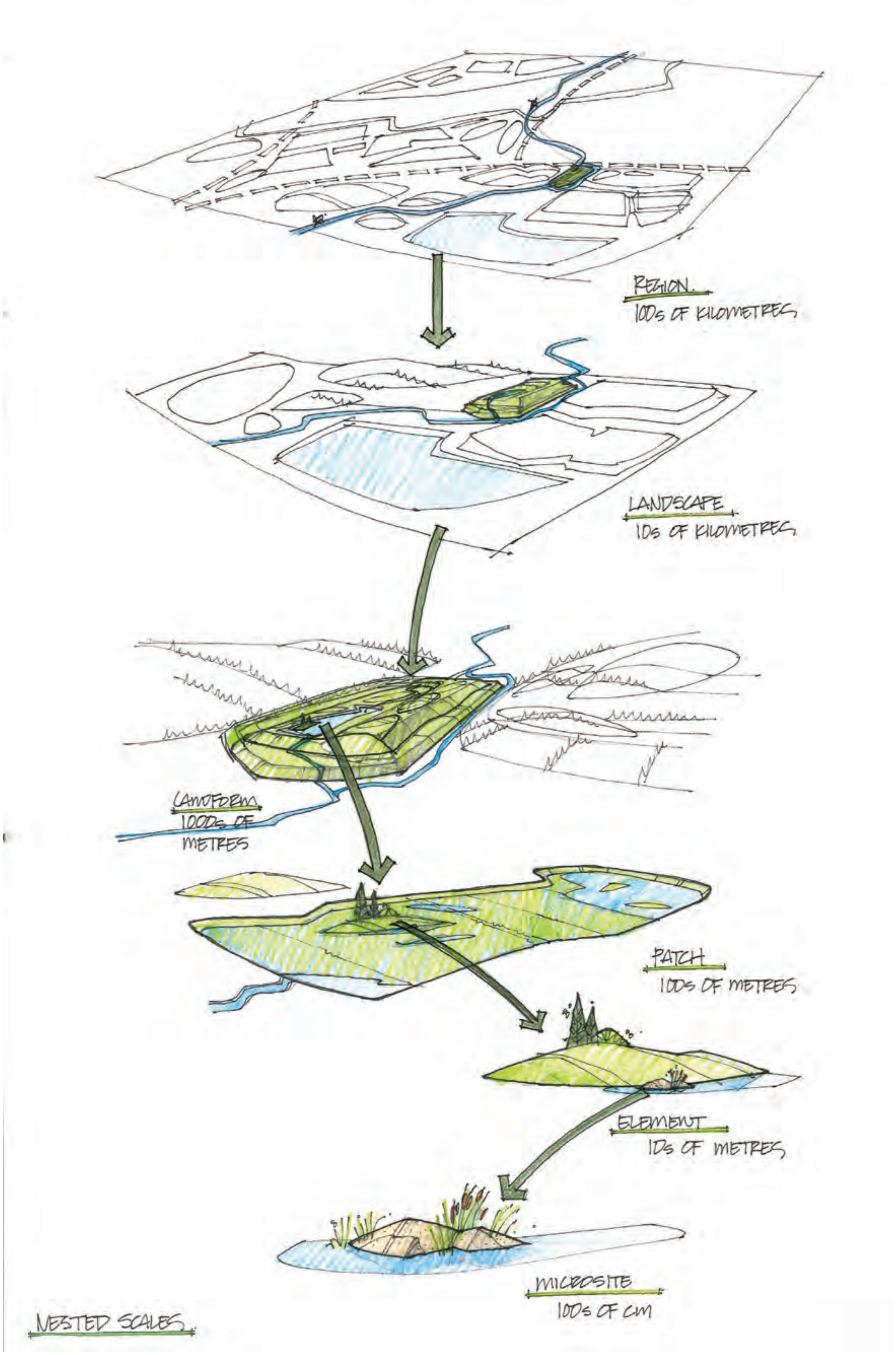

Figure 5-1. Nested scales for oil sands closure planning and landform design.

**Table 5-2. Spatial scales for wetland design**

| Scale | Description | Typical size | Design significance |
|---|---|---|---|
| **Region** | A collection of landscapes that function together to deliver ecosystem services (e.g., surface water drainage, climate) and support human values (e.g., Aboriginal uses, transportation, development, forestry, mining) at a large scale. Indicative scale is 50,000 to 100,000 km$^2$.<br>The region can be taken as the Lower Athabasca Region. | 93,212,000 km$^2$<br>9.3 million hectares | Largely confined to connectivity of wetland for some wildlife species. |
| **Landscape** | A collection or mosaic of landforms that fill one's frame of vision, typically including an oil sands lease and adjacent areas. | 100 to 1,000 km$^2$<br>10,000 to 100,000 ha<br>Each closure plan or mining lease is essentially a landscape. | Closure planning level scale.<br>Creation of watersheds that supply the quality and quantity of water to support the wetlands, connectivity for wildlife within and between watersheds (both natural and artificial), and to ensure downstream ecosystems have suitable water quality and quantity. |
| **Landform** | Landform scale – individual mining landforms (such as dumps, external tailings facilities, in-pit tailings facilities, gravel pits, etc.) typically involve one or more watersheds at the scale of 50 to 3,000 hectares (0.5 to 30 km$^2$).<br>A collection of patches that is topographically defined and is the major unit of specific design for mines. Patches need to interact to create an ecosystem that supports wildlife. | 1 to 25 km$^2$<br>(100 to 2,500 ha) | Design of substrates, topography, surface water, groundwater, soils, and vegetation to support and connect wetlands. |
| **Patch** | Patch scale – reclamation planning units, one wetland etc. Often in the 1 to 50 ha scale. | 0.01 to 0.1 km$^2$<br>0.1 to 50 ha | Vegetation plans are represented at this scale, as are some design elements which provide natural appearance and diversity in the landscape (islands, shoreline configurations) |
| **Microsite** | Microsite – log, rock, small hollow or mound, 1 m$^2$. | 0.1 to 100 m$^2$ | Individual diversity and wildlife enhancement elements, not usually marked on blueprints. |

### 5.1.2 Wetland types

Table 5-3 shows the five types of reclaimed wetlands that can be designed at the closure planning stage, as developed by CEMA representatives and wetland manual authors for this edition of the CEMA wetland guide. This chapter provides design at the landscape/lease scale; subsequent chapters provide guidance at greater levels of detail.

**Table 5-3. Wetland types and schedules. AWI = Alberta Wetland Inventory.**

| Closure planning phase | Landform design phase | Construction/ reclamation phase | Comment |
|---|---|---|---|
| **Type** | **Sub-type** | **Vegetation target** | |
| **Shallow-water wetland (AWI class: M3)**<br>1-2 m water depth in persistent open-water zone; maximum water level 1 m in vegetated zones<br>No trees | **Shallow-water wetland**<br>Periphery vegetation includes graminoids, forbs, herbs<br>Dominantly mineral soils<br>Drawdown 1 in 20 years | **Aquatic bed**<br>Various emergent, submergent, and floating vegetation species<br>Grasses, rushes, reeds<br>Fishless | Shallow-water wetlands will be common in the reclaimed oil sands region.<br>Waterbodies with substantial areas with water depths greater than 2 m are termed “reclamation lakes” and are not covered by this manual. |
| | | **Open-water state**<br>Phytoplankton algae dominates open water<br>May have fish present | |
| | | **Mudflats**<br>Dry/exposed substrate | |
| **Marsh (AWI class: M)**<br>-0.1 to 1 m water depth<br>Standing water present in most years for at least a short period of time.<br>Nutrient rich | **Persistent marsh**<br>0.2 to 1 m water depth<br>Drawdown 1 in 5 years; nearly always flooded<br>Dominantly mineral soils | **Emergent marsh (Ecosite L)**<br>Herbs, forbs, sedges and grasses<br>No trees | Marshes will be common in tailings areas, especially where settlement is expected. Some marshes will be designed for water polishing and flood attenuation. Beavers will form marshes and open water wetlands in many riparian areas. |
| | **Intermittent marsh**<br>-0.1 to 0.2 m water depth<br>Drawdown 1 in 2 years<br>Flooded seasonally<br>No trees | **Meadow marshes (Ecosite L)**<br>Flooded in most years for at least a short period of time.<br>Dominated by sedges and grasses<br>Herbs, forbs, graminoids. | Many intermittent marshes will form opportunistically or be semi-designed wetlands.<br>Meadow marsh environments likely to fringe many marshes on tailings.<br>Vernal pools are a type of intermittent wetland – small pools that appear during high water periods (spring melt /rainstorms) in depressions. |

| Closure planning phase | Landform design phase | Construction/ reclamation phase | Comment |
|---|---|---|---|
| **Type** | **Sub-type** | **Vegetation target** | |
| **Swamp<br>(AWI class: S)**<br>Water depth not well known.<br>Trees (   10m high), Shrubs (   2m high). Canopy coverage    50%.<br>Mineral soils, but some peat present. Hummocks present.<br>Dominated by woody plants (trees and shrubs) | **Coniferous swamp**<br>Closed canopy of conifers<br>Thicker peat | **Black spruce swamp** | Suncor and Ducks Unlimited have done work on swamps for oil sands reclamation. Beckingham and Archibald did not single out swamps in their ecosite classification system.<br>The current state of practice has not advanced sufficiently to recommend targeting these types of wetlands for construction. Future research is proposed to guide decisions to determine how best to establish these ecosystems. |
| | | **Tamarack swamp** | |
| | **Deciduous swamp**<br>Woody overstory vegetation with rich understory<br>Thinner peat | **Shrubby swamp** | |
| | | **Hardwood and mixedwood swamp** | |
| **Bog<br>(AWI class: B)**<br>Slightly raised above water table<br>Treed<br>Stable water table<br>Organic substrate | **Bog**<br>Low pH and alkalinity, dominated by precipitation, positive water balance | **Wooded bog**<br>(Ecosite I1) | Bogs typically have very little watershed and are dominated by precipitation water.<br>The current state of practice has not advanced sufficiently to recommend targeting these types of wetlands for construction. Future research will inform decisions to determine how to establish these ecosystems if they are indeed practical to construct. |
| | | **Shrubby bog**<br>(Ecosite I2) | |
| **Fen<br>(AWI class: F)**<br>Water table near the peat surface (approximately 0.2 m below peat surface)<br>Range of pHs<br>Dominated by runoff and seepage<br>Organic substrate | **Saline Fen**<br>Salinity greater than 2000 uS/cm | **Wooded Saline Fen**<br>Hummock development<br>Treed | Likely to form where oil sands process-affected water is expressed to surface.<br>Likely to be common on wet areas of overburden dumps.<br>Fens may form opportunistically or may be designed. |
| | | **Sedge/Moss Saline Fen**<br>Graminoid species, no hummocks | |

| Closure planning phase | Landform design phase | Construction/ reclamation phase | Comment |
|---|---|---|---|
| **Type** | **Sub-type** | **Vegetation target** | |
| | **Alkaline Fen**<br>Slightly basic pH (> 7.0)<br>High alkalinity<br>Salinity < 2000 uS/cm<br>Moss dominance, particularly brown moss | **Wooded rich fen**<br>(Ecosite K1) | |
| | | **Shrubby rich fen**<br>(Ecosite K2)<br>Less flow<br>Shrubs | |
| | | **Moss/Sedge rich fen**<br>(Ecosite K3)<br>Graminoid species | |
| At the closure planning level, one would design and specify one of these three (or five) types of wetland. | At the landform design level, one would design the geometry and hydrology and substrates for one of these sub-types for each wetland (with an eye to the vegetation type). | During construction phase, designs for the vegetation would be completed. Management to encourage the species assemblages will be applied. | |

This guide focuses on creation of specific landform types, but wetland complexes will be common. A mix of shallow-water wetlands, marshes, and fens, they will be controlled largely by groundwater discharge conditions, salinity, and water depths. Some swamps and bogs will form opportunistically regardless of design intent, but perhaps only over extremely long timeframes. Wildlife habitat varies with different wetland ecosites and ecosite phases (see Section 3.5)

Some will argue that we may not be able to create natural wetland ecosystems, especially fens, but instead should be planning for similar but different “novel” ecosystems (Hobbs et al., 2013) – ecosystems that exist without historical precedents. The authors of the guide have chosen not to make such a distinction, but recognize that it may be decades or centuries before the reclaimed wetlands become indistinguishable from natural ones, if ever.

And as highlighted by Devito et al. (2012) and many others, wetlands are not always wet, and the extents change seasonally and through decadal cycles. Section 3.4.2.3 provides additional guidance on ephemeral wetlands.

Table 5-3 is a cornerstone to the structure of this wetland guide. However there are other design approaches at the closure planning stage currently practiced in the oil sands region that also have merit:

> Simply declare wetlands as “wetlands” – that is, don’t specify the type, subtype, or vegetation target. This approach is expedient, reflects the real uncertainty in planning and design, avoids the ambiguity of declaring time periods for various wetland types to form, and avoids creating unrealistic expectations. It misses an opportunity for early planning for different types of wetlands and misses an opportunity to communicate the expected long-term landscape conditions.
>
> Specify the ecosite phase (the wetland vegetation target). This approach has the merit of facilitating commonly used wildlife habitat suitability models and communicates the designers’ opinion of the closure landscape. But this level of detail is premature given our current state of knowledge and might be seen by some as unreliable or overly optimistic.

The advice to closure planners is to adopt a transparent process and highlight the uncertainties.

## 5.2 Designing watersheds and associated wetlands

Reclaimed mine landscapes and their closure plans will include several dozen new watersheds. The design of the watershed is as important as the design of an individual wetland. Unlike designing constructed wetlands in natural watersheds, where the geography of the watershed is mature, closure planners must design entire watersheds to support a variety of goals and ecosystems. As yet, there is no watershed design manual. Watershed design is significantly constrained by the mine and tailings plan, local geology, and the requirement for self-sustaining landscapes with no intervention after an operating and monitoring period.

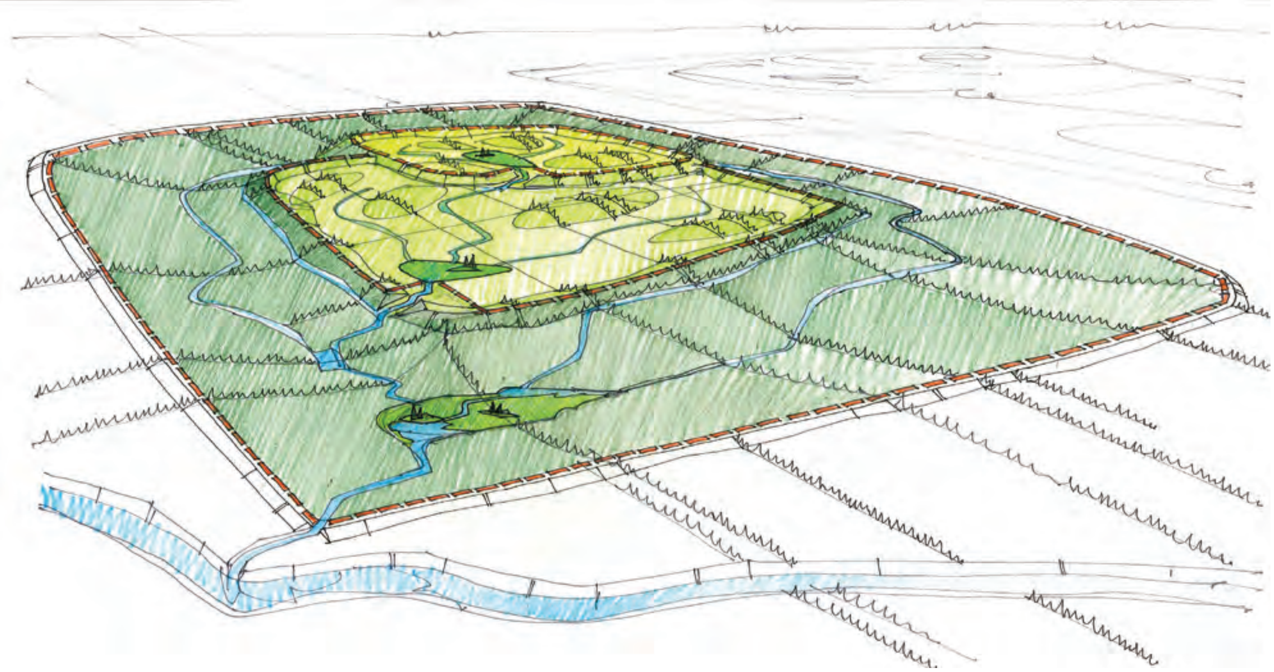

**Figure 5-2. Nested watersheds on a reclaimed oil sands landform.**

A watershed is defined here an area with surface water that drains to a location/outlet at a lower elevation where the waters join another water body or course, natural or constructed. Watersheds are separated by drainage divides. See Sections 2.3 and 2.4 for more detail.

Mining landforms are usually headwater areas comprised of nested watersheds (Figure 5-2). Most oil sands closure landscapes will have one to three main watersheds, each with one to 10 mining landforms with surface water drainage to the Athabasca River or one of its tributaries.

### 5.2.1 Overview of the closure planning process

Closure plans are living documents. They are modified at least annually, with formal designs generated every five years. They take a team of people about 12 to 18 months to develop. They are detailed enough to allow for good communication and robust decision-making but conceptual enough to allow the team to draft each landform design in a few days or weeks and modify them with time.

The closure plan:

- Allows input from all interested parties including First Nations and Métis communities, regulators, and other stakeholders (Section 5.2.3)
- Defines objectives and performance targets for the integrated closure landscape (Sections 5.2.4 and 6.2.6)
- Divides a landscape into landform units based on shape, construction substrates, the timing of reclamation, and intended end uses. Individual units can be tracked separately through each stage of development: initial disturbance, operations, reclamation, monitoring, and certification.
- Demonstrates how the closure landscape can be constructed and reclaimed to achieve the specified objectives
- Highlights key mining and tailings constraints necessary to achieve an acceptable closure landscape (to guide year-to-year decision-making by short- and long-range planners)
- Addresses material balances for landform construction and reclamation materials (Section 5.5)
- Evaluates and communicates risks and develops contingency plans
- Allows informed regulatory review (An et al., 2013)

An operator’s first closure plan supports an environmental impact assessment (EIA) before mining. As individual landforms are completed during mining, the closure plan becomes more detailed and informed. By the time the final plan is developed, many landforms may already be complete, and some certified.

The timing of mining and reclamation activities is driven primarily by the rate of mine development and tailings technology (e.g., CEMA, 2012b). The closure landscape is constrained by mine and tailings plans, as they define the size and location of any operational features, such as the final pit wall and the volumes of mine byproducts. A consistent planning approach and assumptions, geotechnical constraints, integrated closure topography and landscape units are the essential elements that link construction, reclamation and closure.

Mining byproducts do not always provide ideal construction materials. Leaching of contaminants from tailings and poor trafficability of soft tailings, for example, provide challenges to landscape reconstruction. Experience, data, models, and engineering judgment are used to predict how mining materials will behave, how to design the landforms and landscape to accommodate both the expected behaviour and uncertainty, and to forecast future landscape function.

The closure landscape includes well-integrated landforms that form a functional analogue of the pre-disturbance boreal forest and other adjacent or nearby operations. Physical integration of topography will ensure landscape continuity. Other considerations include reconstructed watershed boundaries, water transport, and variation in water quantity and quality across lease boundaries (see Stantec, 2010).

### 5.2.2 Closure planning steps

Closure planning is performed differently by different teams, given that each site and each team is unique. Listed below is a typical process, somewhat simplified and idealized (An et al., 2013):

Establishing the closure planning team
Developing and executing stakeholder and regulatory action plan
Providing high-level input into development of the mine plan
Establishing specific closure objectives
Developing conceptual-level design of each landform
Identifying lease-wide design issues
Determining volumes, schedule, sequencing
Developing a monitoring and maintenance plan for all areas of the lease
Performing an engineering risk assessment
Finalizing and communicating the closure plan
Supporting the closure plan, answering queries, adjusting to new conditions
Scheduling development of the next closure plan

### 5.2.3 External input in closure planning and wetland design

Many mines take advantage of the closure planning process to engage First Nations, local stakeholders, and regulators in the decision-making process and this is common in the oil sands. *“Effective closure planning involves bringing together the views, concerns, aspirations, efforts and knowledge of various internal and external stakeholders to achieve outcomes that are beneficial to the operating company and the community that hosts it . The process of engagement may not result in full consensus on closure outcomes, but it should be considered successful if it leads to fully informed decisions.”* (ICMM, 2008). Mines and their external stakeholders will choose the level of engagement. Wetland design, construction, and operation will benefit from these interactions and usually generate a high degree of interest.

### 5.2.4 Setting goals

The closure goals vary by operator and evolve with the iterations of closure plans. At the highest level, closure planners generally attempt to create a plan that will:

- Meet the conditions set out in the operator's EPEA approval;
- Maintain ecosystem function and biodiversity (terrestrial and aquatic);
- Deliver landscape capability suitable for defined end land uses;
- Address and attempt to meet expectations of the company, regulators, First Nations, and other stakeholders;
- Speed the rate of reclamation while minimizing costs;
- Reduce corporate liability; and
- Facilitate reclamation certification and relinquishment of parcels of reclaimed land and their reclamation liability to the Crown.

Oil sands operator approvals generally state: "The approval holder shall reclaim the land so that the reclaimed soils and landforms are capable of supporting a self-sustaining, locally common boreal forest which is integrated with the surrounding area" (e.g., Alberta Environment, 2011). It is expected that the mines will create a significant number of wetlands covering a significant area of the landscape, though it is recognized that total area of reclaimed wetlands will be less than in the pre-mining footprint.

Table 5-4 provides a list of suggested wetland design and performance goals at the closure planning level developed by the authors for this document. Designers and operators can adapt these goals to suit specific situations. Millennium EMS Solutions (2010) provides additional design information.

**Table 5-4. Suggested goals for wetland design at the closure planning scale.**

| Category | The closure planning design for each wetland shall formally . |
|---|---|
| **Planning/ management/ operation** | Maintain human and wildlife health and safety |
| | Meet goals for targeted land uses including meeting equivalent capability targets |
| | Meet applicable regulations, agreements, and corporate objectives for each phase of construction, reclamation, operation, monitoring, and certification, specifically addressing EPEA approval conditions |
| | Specify tailings water quality constraints with respect to wetland performance (state the range of acceptable tailings water quality with respect to downstream wetland performance) |
| | Support (avoid interfering with) the ongoing operation of the mine |
| | Be self-sustaining |
| | Have natural appearance and function |
| | Integrate with the landform, lease, and regional scales, especially with respect to water and wildlife |
| | Provide access for reclamation, operation, maintenance, and monitoring |
| | Indicate the required substrates at each location |
| | Include Aboriginal participation |

| Category | The closure planning design for each wetland shall formally . |
|---|---|
| **Land use** | Provide traditional uses |
| | Support lease-scale and regional wildlife habitat / movement goals |
| **Geotechnical** | Design for geotechnical stability; avoid potential for catastrophic breaching |
| | Constrain and accommodate settlement |
| | Provide suitable trafficability for reclamation equipment and future land uses |
| | Avoid situations where dams are created or cannot be delicensed |
| **Surface water, groundwater, and topography** | Create a positive water balance and supply enough water for downstream needs |
| | Meet water-quality criteria within the wetland and exiting the wetland |
| | Create a suitable range of water depths and topographic profiles |
| | Accommodate erosion and deposition, even under extreme events |
| | Accommodate beaver activity |
| | Provide adequate residence time/biodegradation and/or dilution where wetland is required for water polishing |
| **Soils** | Specify soil profiles, quality, and volumes to meet approved reclamation prescriptions for various target ecosystems/land uses |
| | Make efficient use of reclamation material |
| | Accommodate groundwater recharge/discharge/seepage zones |
| **Vegetation** | Specify revegetation with native species that supports the intended land uses |
| **Infrastructure** | Plan for infrastructure decommissioning (haul roads, light vehicle roads, trails, weirs, pipelines, powerlines, pumps, etc.) |

### 5.2.5 Partitioning water in the landscape

As detailed in Sections 2.1 and 2.2, the Western Boreal Plains has relatively low annual precipitation. Potential evaporation slightly exceeds average annual precipitation, and runoff occurs mainly in snowmelt and otherwise infrequently, if at all, through the year.

Much of oil sands closure planning revolves around partitioning and transmitting surface water and groundwater at the landscape/lease scale to minimize erosion and physical instability, and meet four sometimes-competing land use objectives:

Provide topography and soil covers to store water through the summer to allow trees on reclaimed lands to have growth and yield curves that at least match those of similar natural areas in the region.

Manage water tables to minimize risks of salinization and provide a unsaturated zone deep enough for upland plants to thrive.

Provide sufficient water for reclaimed and natural wetlands and streams to maintain water levels within acceptable ranges and have acceptable water quality

Provide sufficient water for the end pit lakes to maintain water levels within acceptable ranges and have acceptable water quality.

These goals should be achieved as the reclaimed landscape matures and goes through the decadal climate cycles (Devito et al., 2012) and climate change. Every closure planning and landform design decision affects the site-wide water balances and water quality. Many of these decisions have significant impacts on reclamation costs (especially having wetland in difficult areas or avoiding wetlands in groundwater discharge areas).

Design engineers embrace these tradeoffs, as well as uncertainty in properties, performance, and models, as a central part of their trade (e.g., Petroski, 1992). As indicated in these design chapters, wetland design is highly constrained, even at a closure planning scale. The amount, location, and types of wetlands are dictated by mining, materials, and the climate. A central task of the closure planning and landform/wetland design teams is to create designs that partition the scarce water resource to meet the closure goals.

### 5.2.6 Managing uncertainty through design and adaptive management

Wetland reclamation is rapidly maturing in the oil sands region. Currently, the major uncertainties in oil sands wetland reclamation are as follows:

**Reclamation certification criteria**: Lacking criteria, how will the success of the wetland be judged? In the near absence of agreed-upon criteria, this guide advocates setting design goals and objectives (Sections 5.2.4 and 6.2.6) to overcome this uncertainty.

**The watershed and wetland water balance**: We currently know enough to design wetlands that will generally have a large positive water balance. But what are the upper limits for the percentage of wetlands in a reclaimed watershed based on water quantity and hydroperiod? See Chapters 2 and 3 for discussion of natural hydrology and wetlands. See Sections 5.3.3 and 6.4 for current design solutions.

**Water quality**: How does water quality affect wetland performance? What are the limits for various ecosystem functions? (See Sections 2.5 and 5.3.3)

**Reclamation materials**: How much, and of what type of reclamation, is optimal (ecologically and economically) in various wetland positions? See Section 5.3.4.

**Revegetation**: What is the optimal (ecologically, operationally, and economically) strategy for revegetation of various types of wetlands. Chapter 7 provides details.

**Wildlife**: How can wetlands be designed to optimize wildlife habitat value at various spatial and temporal scales? See Section 5.3.6 and Appendix D.

**Cost**: How can the costs of wetland reclamation be optimized and the reclamation process be made more efficient to the point where it becomes routine?

The value of progressive reclamation, combined with adaptive management (CEMA, 2012a; Chapters 1 and 8) for wetlands in particular, is to ensure there is a “learn by doing” approach, and that experience from the design, construction, reclamation, and monitoring of each wetland carries forward transparently to each future closure plan and wetland project. Ongoing research and development of manuals complement this process.

Part and parcel with this approach is acceptance of wetland performance that may be less than desired in historic wetlands, but with a track record of improvements in performance of newer wetlands built with increased experience. Historically, the reclamation certification process has recognized this approach. A major concern among miners in Canada and internationally is that they will build landscapes that are largely acceptable to shareholders and the public, but fail to receive the endorsement of regulators and some stakeholders (McKenna, 2002). A common understanding and a more transparent sharing of risks among operators and regulators is needed (Morgenstern, 2012).

Engineering risk assessment (e.g., Pate-Cornell, 2007) and contingency plans are becoming common in closure planning elsewhere (An et al., 2013) and go a long ways to embracing, addressing, and communicating uncertainty.

### 5.2.7 Initial design of wetland location, type, and size

One of the earliest designs in a closure plan is the surface water drainage network, which includes wetlands. First, locations where wetlands are likely to form are indicated. The wetland area is sketched and one of the feasible wetland types (marsh, shallow-water wetland, fen) is assigned. The type of wetland assigned is governed by substrate, expected groundwater conditions, and expected settlement. If a wetland is expected to form, it should be indicated and designed.

Next, locations where water polishing is required are determined. Wetlands can be designed to have adequate retention times to degrade organics and allow mixing of waters for dilution. Areas where opportunistic wetlands are likely to form are also indicated (see Figure 5-23 for methods of estimating the locations, size, and frequency of opportunistic wetlands).

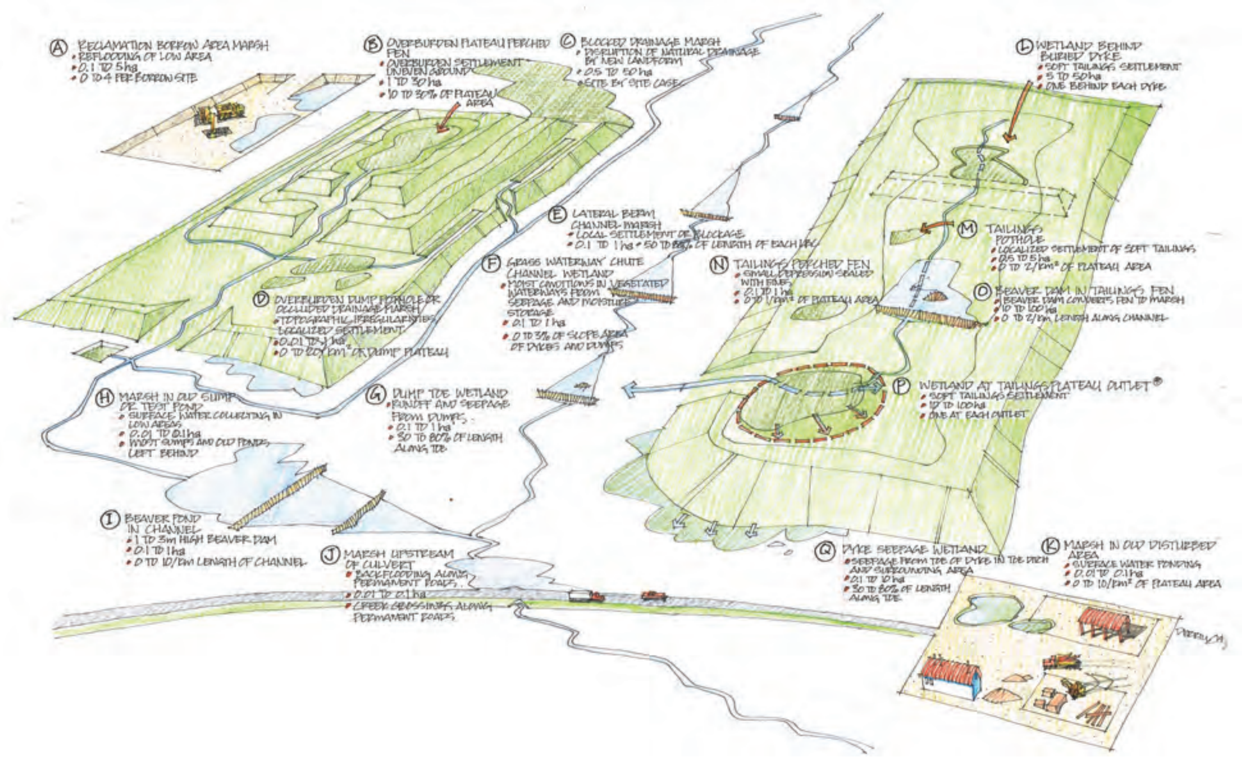

**Figure 5-3. Guide to estimating the locations, sizes, and frequency of opportunistic wetlands in the closure landscape.**

Finally, and if there is a desire for more wetlands area than indicated after the design landscape is reviewed, and if other tradeoffs and constraints allow, more wetlands are added to the plan by adjusting watershed topography and substrates. Selecting suitable locations of wetlands in the closure landscape is tightly constrained. Some areas require wetlands, and others will eschew them, particularly where geotechnical requirements dictate that slopes have low groundwater tables for stability.

The landform conditions (wetland types, substrates and landscape positions; Figure 5-4) comprise most of the wetland/substrate pairings that should be considered for design and construction. As a first iteration, these wetland locations are marked on closure plans. For example:

> For tailings plateaus for both in-pit and out-of-pit landforms, fens with small marshes are drawn in low areas where seepage water will discharge. Areas of settling soft tailings at the outlet of tailings plateaus may be designed to be shallow-water wetlands fringed with marshes. Care is taken not to impound so much water that geotechnical stability (breaching) could be an issue. Beavers are likely to enhance and influence wetland performance in these areas.
>
> Wetlands can be designed at the toes of dumps, where stability permits, and there may be an opportunity for small marshes on stable plateaus with enough catchment.
>
> Gravel and borrow pits that intersect the water table can be reclaimed to shallow-water wetlands and marshes as a component of their reclamation.
>
> The surface water drainage system will create riparian zones that may be designated as wetlands, or beaver activity will create wetlands.
>
> Areas that need retention time for polishing of process-affected water that cannot report to an end pit lake may employ a polishing wetland, often constructed on original ground.
>
> Many areas will be designed to avoid impounding water (e.g., on slopes or upper beach areas on tailings plateaus) to reduce the risk of wetland development and potential geotechnical instability (e.g., Oil Sands Tailings Dam Committee, 2014).

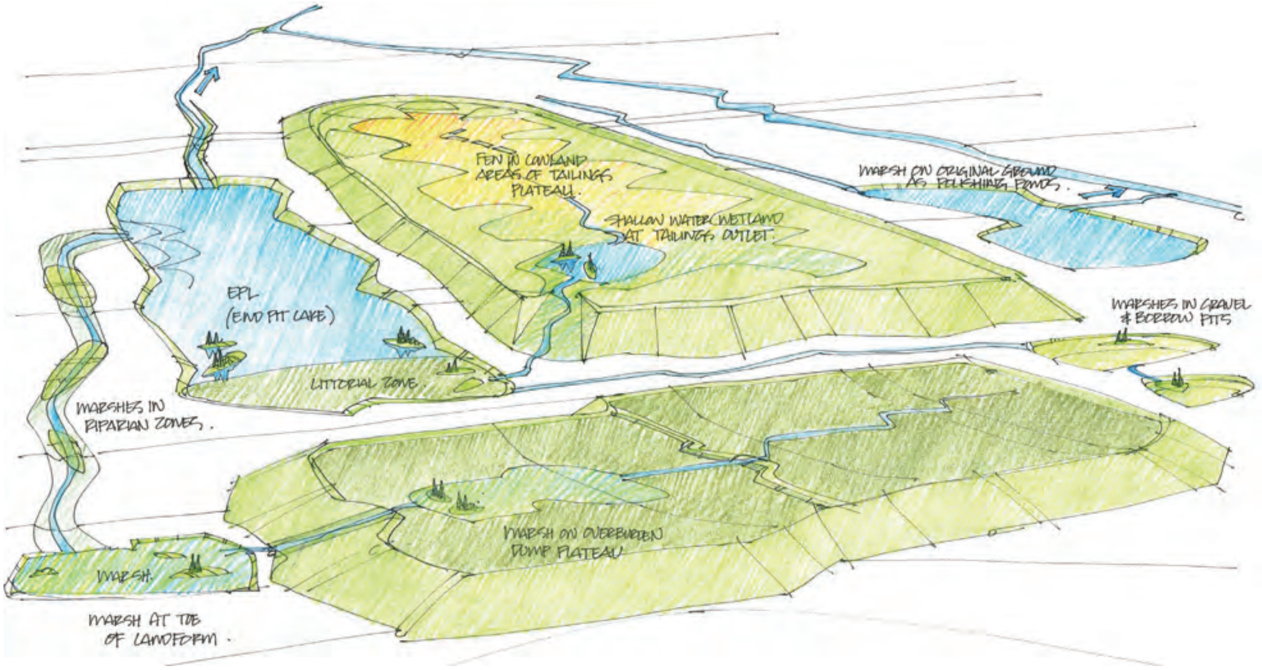

**Figure 5-4. Common wetland settings in lease closure landscapes.**

Whether an area will be a shallow-water wetland, marsh, or fen will be specified at this point (see also Section 5.1.2). Unlike wetland construction in non-mining environments, settlement considerations often govern the choice of wetland type. Beavers will modify many of these wetlands (Section 5.2.10), creating marsh environments and flooding additional areas.

Table 3-6 provides dimensions (areas, widths and water depths) of selected natural marshes in the oil sands region. Table 3-4 provides water-quality features for the same natural marshes. These are useful starting points for wetland design at the closure level.

#### 5.2.7.1 Initial water balance rules of thumb

Rough rules of thumb are available to guide the initial design of wetlands. These are based on experience and simple heuristics:

> The average annual yield (surface runoff, interflow, and groundwater) of a natural or reclaimed watershed in the oil sands region is about 100 mm/year (but can easily range from near zero in a dry year to more than 200 mm/year in a wet year and depends on many factors including substrate and reclamation material).[3]
>
> Marshes and shallow-water wetlands are estimated to lose a net of about 100 mm/year to evaporation (as estimate by difference between average annual precipitation and potential evaporation, see Section 2.1.2). Fens likely lose less water to evaporation (Lafleur and Roulet, 1992).
>
> Local low areas will generally be zones of groundwater discharge, even for tailings sand areas (see Section 2.3).
>
> Wetlands usually evapoconcentrate water over the summer. They will flush each spring if the snowmelt discharge is about equal to the volume of water in the wetland at the end of the hydroperiod (see Section 2.2).
>
> A residence time of one year is enough to reduce much of the acute toxicity of organics in process-affected water.

Applying these rules results in some general guidance:

> Areas expected to have groundwater discharge and modest differential settlement are candidates for fens (e.g., Pollard et al., 2012). Current understanding is that the fens can be sustainable with watershed areas of 2 to 4 times the fen area. Sandy substrates that permit significant quantities of groundwater seepage into the fen are advantageous.
>
> Areas that have larger catchment areas and low levels of differential settlement (< 0.5m) can sustain marshes. As a rule, the watershed-to-marsh area ratio[4] should be about 3:1 to 5:1 for water balance and 5:1 to 20:1 for flushing.
>
> Areas that will have modest settlements (1 to 2 metres) will be shallow-water wetlands. If wetland slopes are shallow enough, these will be ringed with marsh zones.

---

[3] Designs should generally *not* be based on average annual conditions (e.g., MEND, 2012) but rules of thumb are needed for the initial design. Modelling, experience from instrumented watersheds and monitoring will allow refinement of rules. Many rules and their application remain contentious at present.

[4] The watershed area includes the wetland area (the watershed defined as all the area reporting to the outlet of the wetland).

> Large areas that settle more than about 2 m will create reclamation lakes and are not discussed in this guide. These lakes have more in common with end pit lakes and will require lake design and littoral zone considerations (see CEMA, 2012a).

Table 3-6 indicates that most marshes are between about 4 and 7 ha, each with about 20% open water with a maximum depth of about 1 m with 0.2 m of water level fluctuation. Designers wanting to follow natural analogues may choose to create marshes with these dimensions. Watersheds of about 40 to 70 ha are recommended (based on the 10:1 watershed-to-wetland ratio). This size of watershed is common in oil sands landform designs. Site conditions will influence the ratio, including water quantity and quality, productivity of vegetation, and diversity of wildlife. Modelling (for water quality, quality, and peak flow) is usually required for design of specific wetlands. Future field results may indicate that it may be possible to design a higher percentage of the land to host wetlands based on examination of natural analogs in the region. Our understanding of the water balance is evolving rapidly based on ongoing research and monitoring of reclaimed watersheds (see Chapter 2). Caution in employing these rules of thumb beyond initial design is indicated.

#### 5.2.7.2 Flood flow alteration

Wetlands can act as storage for peak flows from surface runoff, surface water flow, and precipitation, and in so doing, can decrease flood-related damage to surrounding structures (see Section 2.2). The storage capacity of a wetland depends primarily on the type of wetland, the location and size of its outlets, the size of the watershed and amount of associated surface flow that feeds into it. Half of flood peak reductions result from the first 5% of wetland area within a watershed (Novitski, 1979). Once a watershed-to-wetland ratio of less than 10:1 is reached, the incremental gain in flood peak attenuation becomes less significant (Ammon et al., 1981).

Large wetlands with shallow slopes (e.g., large fens on tailings plateaus) and small outlet cross-sections can attenuate floods from large precipitation events. Most wetlands, however, will not attenuate large flows enough to account for their impacts on downstream erosion protection unless the design has a narrow robust outlet design (to throttle flows) and a broad floodplain (that floods to provide additional storage).

#### 5.2.7.3 Productivity and aquatic diversity

To optimize colonization of organisms, progressive construction of wetlands within a watershed from the most upslope to the most down slope, where possible, will encourage downslope transport of propagules and will improve the transport of natural food materials. A watershed-to-wetland ratio of greater than 20:1, with connectivity between wetlands in the watershed, will accelerate the development of diverse landscapes (Marble, 1992).

### 5.2.8 Designing landform by landform

This initial design should have sufficient details of the basic watershed features to be combined with several dozen other watersheds, and modelled at the lease or regional level (McGreevy et al., 2013). A series of steps can take the initial closure-level design to the next level of detail:

Establish additional design goals at the watershed scale (Table 6-2). The list of failure modes discussed in Section 5.4 may be useful for wetland components of the watershed, but there will be much broader watershed goals for all the functions and land uses.

Define the watershed outlet invert elevation to the nearest 0.1 m and the centerline location to within the nearest 10 m. This outlet elevation governs the rest of the watershed topography.

Prepare a base map with the topography, substrates, proposed drainage and wetland locations, with the watershed divide clearly marked.

In some cases, a preliminary surface water model and groundwater model may be performed to guide the designer's work.

Adjust the topography to meet the following criteria:

- The watershed area is well defined, with no ambiguities about which way water will flow within the watershed, even if there are large settlements, major climatic events, or blockages due to beaver dams. Watershed berms can be designed to create specific watershed divides to define the watershed area. Note that groundwater divides may not correspond with surface watershed divides (see Section 2.2)
- There is positive drainage to the wetland locations – surface water will flow towards the wetlands. Opportunistic wetlands may affect water balance.
- Groundwater should be directed to the wetland, if feasible and if water quality is acceptable (see Sections 2.5 and 6.4).

Adjust the substrates as needed or permitted:

- Estimate the amount of settlement and the locations within the watershed based on advice of the geotechnical staff. Create a settlement map (see Section 5.3.2.1).
- The substrate material (overburden fill, various types of tailings) will have been indicated in the closure plan. Sometimes a wholesale change is needed to meet the closure goals, but more commonly, the substrates will need to be accepted as given, or properties and geometry adjusted to create the required conditions, particularly those related to groundwater.
  - Soft tailings properties may be adjusted to produce less or slower settlement though proactive tailings management.
  - The geometry of tailings sand or coke caps over soft tailings may need to be adjusted.
  - Changes to the materials near a dyke will need to be considered to ensure the dyke can eventually be delicensed.

Further topographic adjustments are made at the meso scale to control the water table and diversity for the landscape.

Soil cover prescriptions, developed as part of the overall closure plan, are applied to the watershed (CEMA, 2006; MacKenzie, 2011).

Preliminary water balance and water quality predictions may be made at this point to refine the design. These will usually include average runoff conditions and results from steady-state seepage groundwater models conducted at the lease scale.

The watershed is divided into target ecosites and the planting prescriptions, developed as part of the overall closer plan (Alberta Environment, 2010).

The wetland location, type, and size are adjusted as part of this overall watershed design.

This second-order design is thus set, and the team moves on to the next watershed to complete designs at a similar level.

### 5.2.9 Design modifications

Surface water and groundwater modelling at the lease scale is performed when all watershed elements have received a similar level of design. Results from the surface-water model (quality and quantity) and groundwater (with an emphasis on mapping recharge and discharge areas, and understanding fluxes and water quality) are used to adjust the final level of closure plan design as follows:

Results of landscape and regional land use, wildlife habitat, and other features are also catalogued, and each watershed can be revisited to better meet these goals.

Adjustments are made to the watershed and wetland design based on the assessment above.

From the water balance and construction timelines, an outline of the schedule and plans for filling and operating the wetland is developed.

The result is an accurate topographic design, with the landform substrates, reclamation areas, revegetation plans, material volumes, and project schedules clearly indicated.

### 5.2.10 Beavers

Despite the best planning efforts, beavers (*Castor canadensis*) will invade the reclaimed landscape — felling trees, building lodges and canals and, most important to closure design, damming creeks, outlets of wetlands, and outlets of end pit lakes (McKenna et al., 2000; Eaton et al., 2013). Oil sands mining removes thousands of beaver dams and we can expect thousands to return to the lease-closure landscape. Beaver control is not a long-term option at present, given the requirement for self-sustaining landscapes and the fact that beavers are an important part of boreal forest ecology and important to First Nation and Métis communities. In a few situations, dams can be discouraged, but in most cases beavers must be anticipated and accommodated.

The following impacts are considered:

Beavers will dam nearly any shallow stream or wetland with flowing water. If there is enough water to support a marsh, there is enough to support a beaver colony. The minimum watershed catchment area to support a beaver dam has yet to be determined.

Beavers can build dams at least 1.6 km long. Beaver dams 1 to 2 m high are common, and many in the region reach 3 m (Figure 5-5). Such dams can be constructed within a few days.

Beavers create marshes and shallow-water wetlands in reclaimed streams (Figures 5-5 and 5-6).

Beavers will alter the hydrology of constructed wetlands drastically, increasing water depths by 1 to 2 m, enlarging the wetland, and changing marshes and fens into shallow-water wetlands.

Beaver dams wash out frequently and can cause downstream damage due to outburst flooding.

Beaver dams have caused tailings dams to fail (e.g., Baker et al., 1996).

Beavers cause stream avulsion and can trigger landslides (see Figure 5-7).

Canals with water more than 3 m deep are unlikely to be dammed (beavers will chose to den in the banks instead).

Risks from beaver activity cannot be fully mitigated.

During wetland design for closure plans, specific consideration for beaver dams includes:

Design mitigations:

- Where stream avulsion, geotechnical instability, overtopping of wetland or lake containment is intolerable, depths of sufficient magnitude (at least 4 m) are required.
- Beaver bafflers (riprap French drains) at lakes and outlets can reduce the probability of beaver dams at that immediate location.

Predicting wetland disposition in closure plans.

- Wetlands will be enlarged and water depths increased by damming.
- Marshes and shallow-water wetlands can be expected in constructed watercourses.

**Figure 5-5. Beaver dam near Fort McMurray Airport Photo courtesy Gord McKenna.**

**Figure 5-6. Downstream face of 3 m high beaver dam on Little Fisheries Creek near Fort McMurray (photo by Gord McKenna, 1998).**

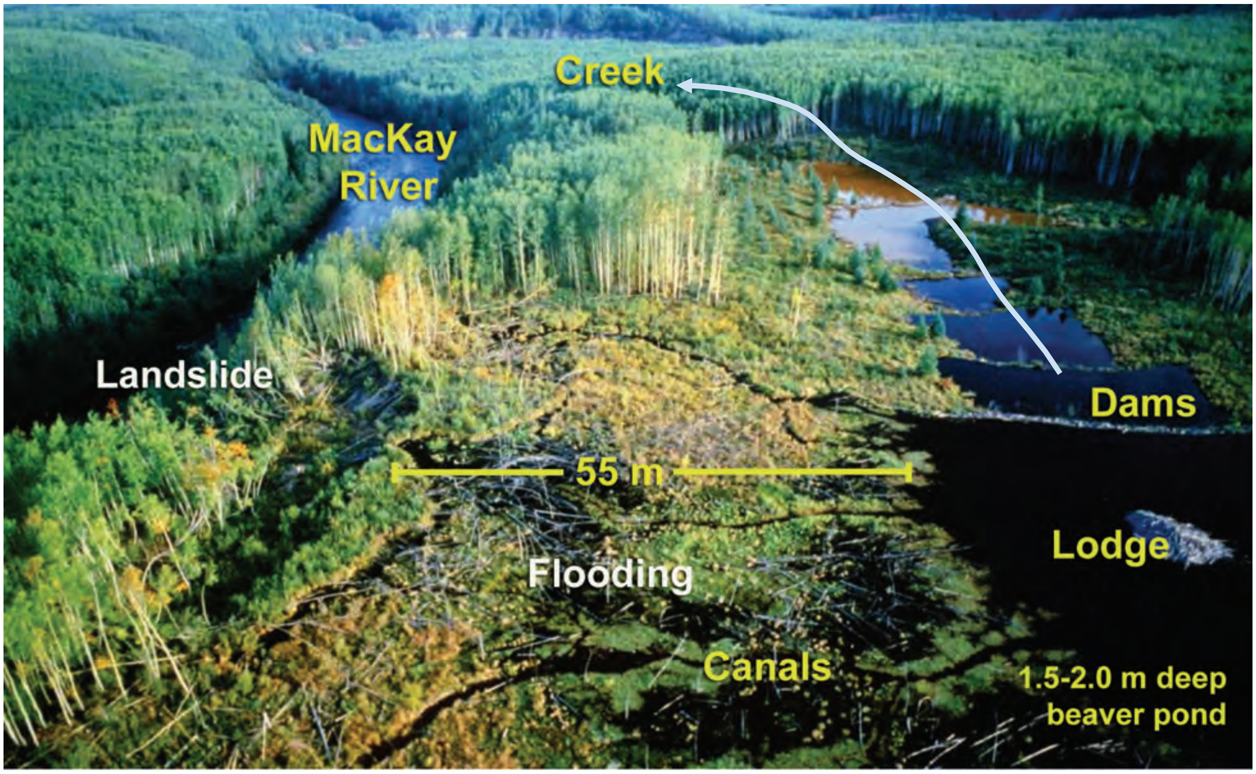

**Figure 5-7. A beaver pond that triggered a landslide along MacKay River (photo by Gord McKenna, 1998).**

### 5.2.11 Operation, monitoring and maintenance plan

A closure plan should include an outline of an operational, monitoring, and maintenance plan for its wetlands, at a very high level (Fair et al., 2014). Chapter 8 provides guidance on the design of the plan for landform scales.

### 5.2.12 Design documentation

Closure plans do not typically document design details. However, failure to adequately communicate wetland information to mine and tailings planners and operations will make it difficult and expensive to retrofit mining landforms for wetlands. This situation makes preparation of internal design documents for each landform and watershed necessary.

Constraint mapping is performed at the beginning of closure planning to identify all key geotechnical, topographic and drainage constraints (An et al., 2013). These constraints inform all levels of mine, tailings, and closure planning and form the basis of the design of volumetrically accurate macro- and meso-topography. A constraint is a requirement that must be fulfilled for the design to succeed. Constraints often include restrictions on types and locations of tailings placement. Outlets often have constraint spot elevations related to their constructability. A nominal design elevation indicates spot elevations around the mine site. They typically include dyke crest and end pit lake elevations.

## 5.3 Closure planning roles for specialists

There is a tension between fitting in wetlands where the mine and tailings plan dictate versus designing the mine and tailings plan to accommodate or promote wetlands.[5] This struggle can be resolved by close teamwork before and over the life of the mine. The following descriptions are aimed at individual specialists, but all of the design activities involve teams that can set collective goals, seek out opportunities, make tradeoffs, and learn from each other.

### 5.3.1 Mine, tailings, and reclamation planners

Each closure plan needs a lead designer and lead coordinator — roles often filled by mine planners. They assemble the team, manage the project and communicate with the mine and tailings planning teams, company management, regulators, and stakeholders (Swanson et al., 2011).

The initial mine planning process is not strongly influenced by wetland design (although it is influenced by end pit lake and surface water drainage). The tailings plan (and tailings technology parameters) is influenced by the need to control settlement of soft tailings and water quality. Once the mining landforms and surface water drainage system are set, planners and the team identify wetland locations. Planners should take advantage of any opportunity to adjust

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[5] During initial mining and tailings activities, rapidly changing situations may prevent full consideration of future wetlands in the early stages of mining development, especially where new tailings technologies are being developed and commercialized. Exceptional planning and execution may be necessary to meet regulatory and corporate commitments.

the substrate and topography for wetland reclamation. The team manages water quantity and quality as it completes the initial wetland design.

At this point, planners will need to know the reclamation material prescriptions so that plans for stripping, stockpiling, and reclamation placement can be made. If necessary, the balance is adjusted at the end of the planning process to accommodate changes in the relative proportion of upland, wetlands, and lakes.

A map set is one of the team's main deliverables. A set typically contains:

Closure surface topography and lease closure drainage plan
Substrate map
Reclamation material placement map (prescription and date)
Revegetation/ecosite map
Constraint map

Other deliverables include:

Tailings consolidation model and settlement map
Lease scale groundwater model/report
Surface water quantity and quality model/report
Reclamation material handling plan, volume, and schedule
Surface water drainage system design report

The design process is non-linear. Each team member needs to feed the process, first with educated guesses using rules of thumb and expert judgment, then by adjusting the designs based on the results of analysis and modelling. The closure surface topography, drainage, and substrate surface are then considered. Modelling can begin in earnest once this surface is created.

Most of the key decisions are made before detailed modelling begins. Usually, only modest changes can be made after the closure surface is created, unless a fatal flaw with the design becomes evident. Most changes will need to wait until the next closure plan. Subsequent closure plans build on previous plans and the modelling and experience gained. Some wetlands will be designed a dozen times at this scale of planning.

### 5.3.2 Geotechnical engineers

Geotechnical engineers are concerned with slope stability, settlement, trafficability, liner design, and dam safety and de-licensing. They often incorporate the work of other disciplines.

#### 5.3.2.1 Settlement

Wetlands on natural ground (and in natural regions outside the oil sands) do not typically have to contend with settlement. Large settlements are unique to mining and oil sands in particular and not covered in standard texts. This makes a settlement map a key design tool. Also useful is a table of loading rates of consolidation water from soft tailings as part of the water budget and water quality prediction. Settlement is monitored during construction and operation.

Soft saturated tailings, deposited as slurries and capped with sand or coke, will typically settle over years or decades, releasing process-affected water (precisely 1 m of water is released for each 1 m of settlement for saturated fills). As a result, constructed wetlands will deepen and enlarge. The shorelines of wetlands should accommodate this settlement either by being steep (limiting lateral growth of the wetland) or flat (allowing more areas to transform from upland to wetland). Consolidation modelling using laboratory and empirically derived parameters can predict the rate and total amount of settlement for each location (e.g., Pollock et al., 2000; Jakubick et al., 2003)

The science is inexact. Settlements will occur over decades or centuries. Soft tailings settlements of 0.5 to 2 m will be common, but can reach 10 m or more. As settlement occurs, the ecosystem will change. Upland areas will flood, becoming fens and marshes, shallow-water wetlands, or even lakes.

Overburden structures and dykes also settle after reclamation (Figure 5-8). Empirical measures are used to estimate the total settlement, which often amounts to 1 to 5% of the initial height of the dump or dyke — toward the higher end for high plastic clays (such as Clearwater Formation clay fills) and for non-engineered (low-density) fills and less for granular and compacted tailings sand dykes. Opportunistic wetlands will form where this type of settlement occurs differentially. This settlement can also crack containment berms and, in the base of wetlands, settlement cracks lead to leakage. Figure 5-9 shows design methods to control wetlands on these structures.

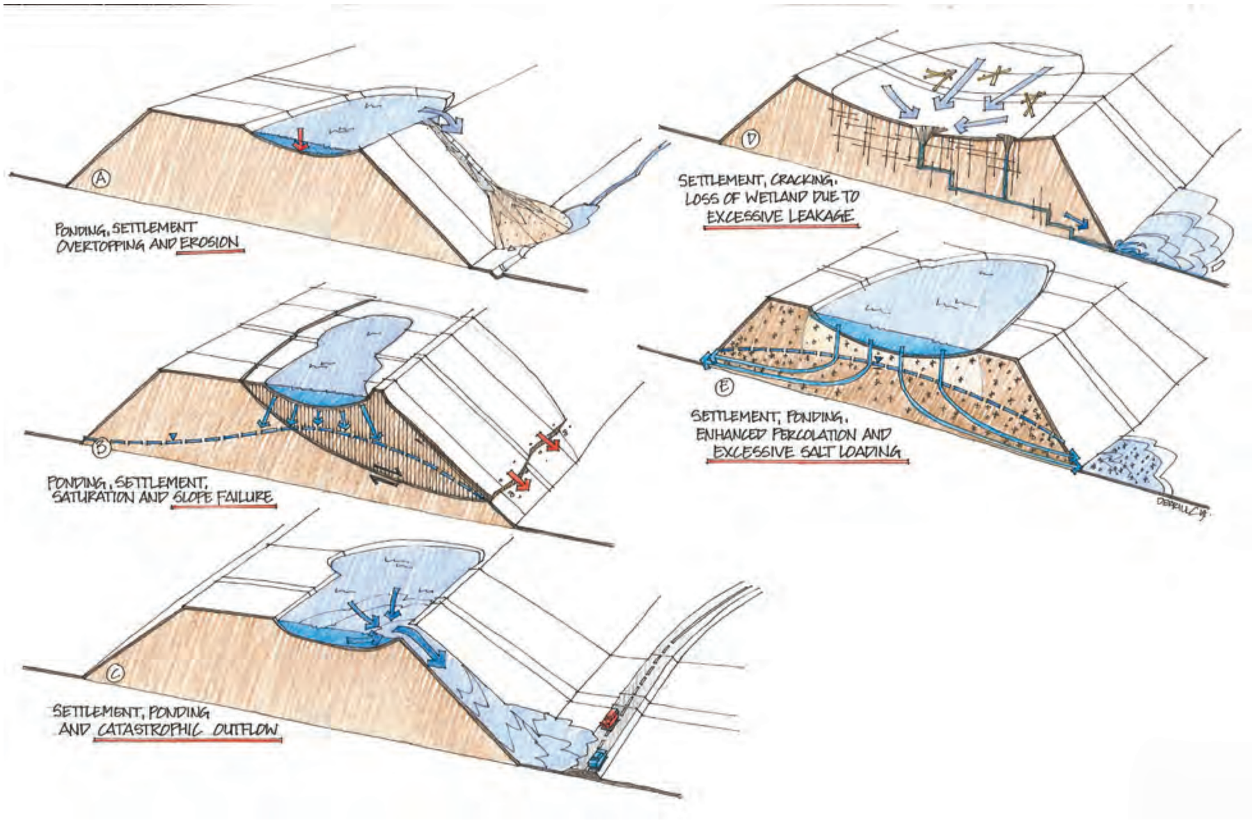

Figure 5-8. Wetlands and settlement of overburden landforms: the problem.

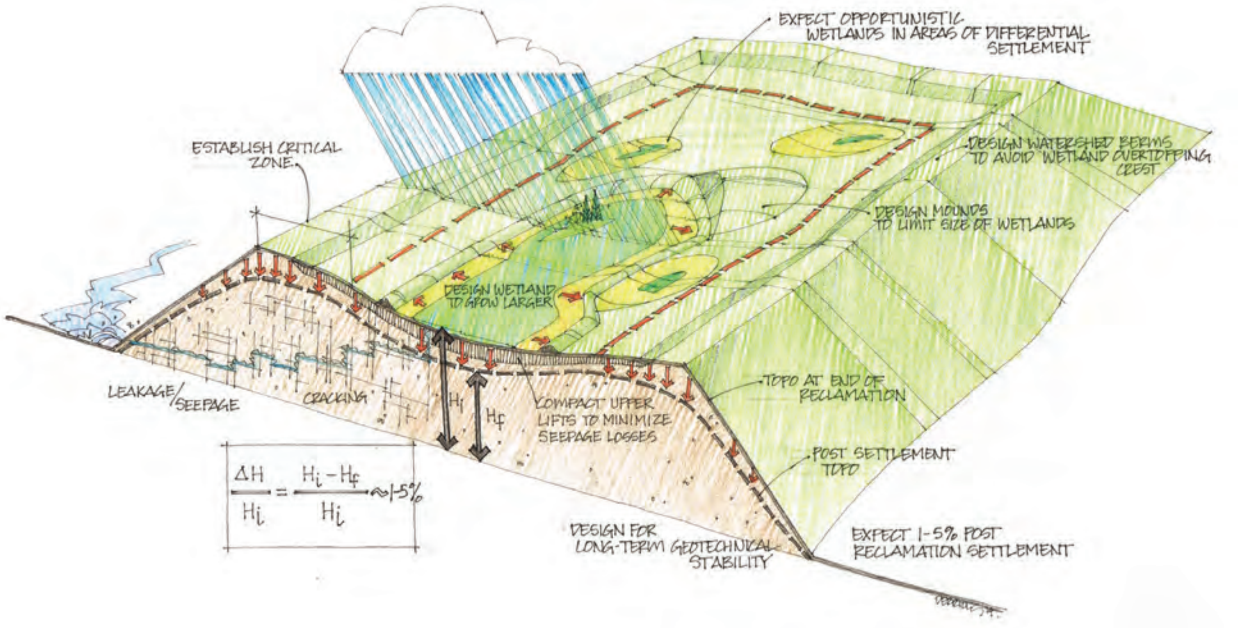

Figure 5-9. Wetlands and settlement of overburden landforms: the solution.

Preparation of an expected-settlement map is a useful planning tool. Using GIS tools (for dumps) and consolidation analysis (for soft tailings), a contour map showing ultimate predicted settlement is created. This map is a major design input. It can also highlight areas with excessive settlement that may require a landform design change.

#### 5.3.2.2 Trafficability

Soft tailings, by definition, have poor trafficability (Jakubick and McKenna, 2001), and many are not accessible by foot. Saturated tailings also have poor trafficability, necessitating the use of specialized equipment or frozen-ground techniques. Much of the early stages of wetland design will be devoted to ensuring that construction and reclamation equipment can place construction and reclamation materials where they are needed. Often, large frost depths in winter can allow modest equipment to access the site, although frost typically inhibits careful excavation. Excavation below the water table for most tailings materials is not practical and severely limits options for wetland construction (McKenna, 2002). In some cases, dredging may be required. Most overburden areas have reasonable trafficability except during spring melt and heavy rains. In many cases, haul roads, light vehicle roads, quad paths, or footpaths and boardwalks will be required.

#### 5.3.2.3 Liners

Wetlands may need liners to reduce seepage through the base, particularly if the wetland is perched above the regional water table (e.g., The Nature Conservancy, 2010; Pollard et al., 2012). Considerations for using liners that dominate their design considerations include:

- constructing a liner with low enough leakage rates to maintain a positive water balance;
- designing liners to avoid leaks in areas where disruptive differential settlement may take place;
- long-term liner integrity is usually in doubt, but in the short term it may have a role in retaining water until the regional groundwater table rises or allows the wetland to naturally seal over time;
- many liner technologies are susceptible to leakage due to root penetration or freeze-thaw effects — important design considerations that typically require a >3 m thickness layer of material over the liner (see Strong and La Roi, 1983; Lazorko, 2008; Russell et al., 2010); and
- they are expensive and require trained crews to construct.

#### 5.3.2.4 Ponding water near dykes/crests

Slope instability due to ponding water in the landscape must be considered. This can be due to increased porewater pressures from enhanced percolation under wetlands, or to flooding of the toes of structures. Ponded water may cause slumping, erosive piping of sand or dispersive clays (McKenna, 2002) by ponded water or seepage, and, if containment fails, the potential for outburst floods (Figure 5-10).

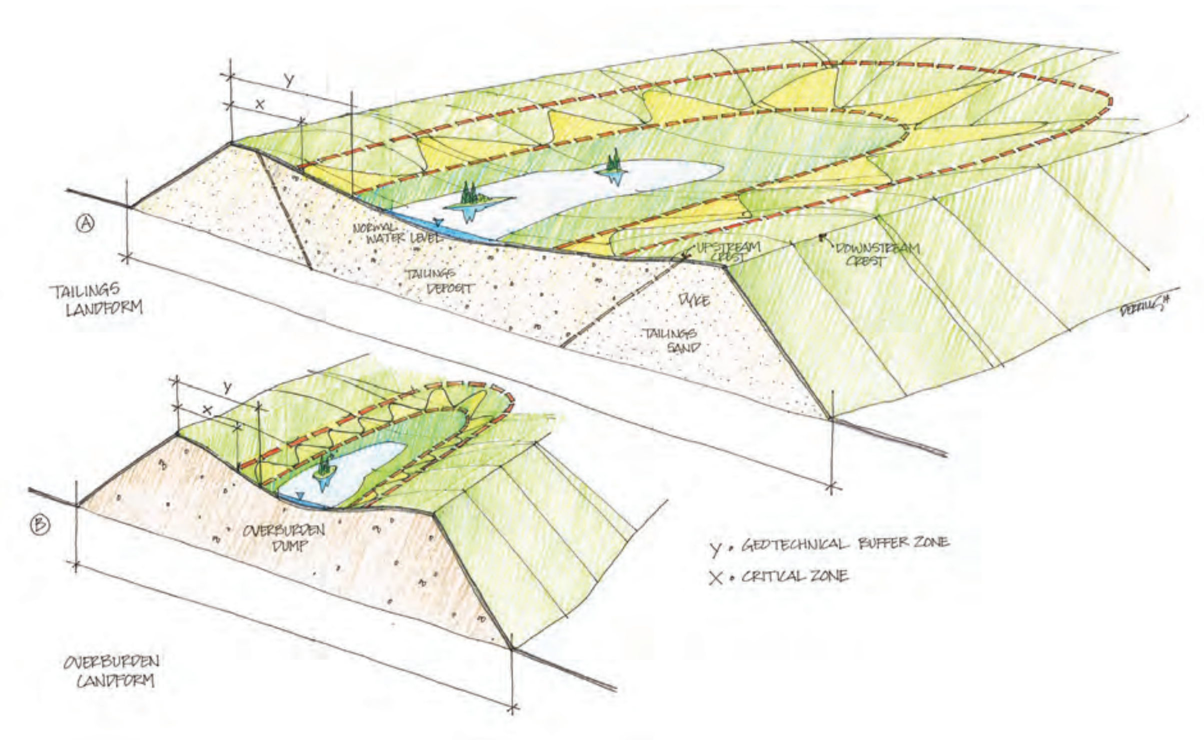

**Figure 5-10. Critical distance calculations for ponded water on landforms.**

The Oil Sands Tailings Dam Committee (2014) has published guidelines for the de-licensing of oil sands tailings dams. De-licensing is presently a requirement of reclamation certification, and as long as a dam is licensed, there are ongoing requirements for monitoring and maintenance. The de-licensing requirements are onerous. Risks of catastrophic breach must be reduced to the lowest degree possible, and dams must pass a formal risk assessment. Large volumes of ponded water can create risks that may preclude dam de-licensing unless the designs are sufficiently conservative.

To provide some guidance:

- Wetlands and watersheds should be designed to avoid catastrophic outflows, even under extreme events.
- Ponded water must not affect the stability of the dam or cause erosion of the dam.
- Ponded water must not appreciably worsen the impact of any future geotechnical instability.
- In general, two zones should be designed along dyke crests for closure designs, the critical zone and a geotechnical buffer zone. The critical zone is typically several hundred metres wide and is designed to eliminate ponding water. The geotechnical buffer zone is designed to avoid permanently flooded conditions, but may be inundated during extreme events. Suitable freeboard for the dyke crest is required in all cases. Wetlands are excluded from these areas by design, regardless of the substrate conditions or propensity for wetland development, such as on soft tailings or where there is dyke settlement. Offsets for overburden landforms as similar but typically much smaller.
- A critical zone is the outlet near a dyke. It has a robust design and is designed to avoid ponding water.

### 5.3.3 Hydrologists

Wetland design is influenced by the outcome of designs for surface water and groundwater, but it also influences these designs on a landform-by-landform basis. The main goal is to safely convey precipitation from each landform (via overland flow, interflow, and groundwater seepage) and each landscape to the surrounding environment. Chapter 2 provides an overview of processes common to the boreal forest, and Section 2.2 in particular addresses the water budget. Most of the waters falling on the closure landscape are directed to an end pit lake for dilution and bioremediation (CEMA, 2012a) and much of the topographic design is focused on achieving gravity drainage to the EPL. The landscape must also provide a suitable quality and quantity of water to the EPL, while satisfying the needs of other on-site units, including upland forest and wetlands.

The type and placement of materials will influence runoff and percolation to the subsurface (Section 2.5). Groundwater specialists develop landscape-scale models to determine the flow paths of water in the subsurface and, where that water will likely be expressed, the quantity and quality of the water. They also identify where contaminants are likely to be transported on- and off-site.

Surface water hydrologists play perhaps the strongest role in the development of the watershed and wetland design as they are responsible for accounting for all elements of the water balance, and estimating water quality, topography, and erosion/deposition. A brief outline of their contributions to the closure planning process is provided below. Groundwater and surface water modelling, while typically completed somewhat independently, are directly linked, and are discussed in more detail in Section 6.4.

#### 5.3.3.1 Hydrogeology modelling

Once the initial topography is designed, hydrogeologists develop three-dimensional regional and lease-scale models that are populated with the existing natural geology and the various landform substrates and estimates of their properties.

Following construction, the model is calibrated or benchmarked to data collected within the model boundaries, such as piezometric head data or pumping rates. Next, sensitivity analyses determine how sensitive the model is to variations in model parameters. Finally, once the model is suitable for design purposes, water quantities and transport pathways can be estimated. This model can be used as an input into the water budget (Section 2.2) and for water quality predictions (Section 2.5) for the wetlands and their watersheds. It is a large undertaking, often consuming a third of the closure planning budget.

The model results do not dictate design (“the model is not the design”). The design team interprets the model results and, in some cases, changes the design so that the watershed and wetland can be reasonably assured of meeting the stated goals, even under extreme conditions. A conservative approach is usually indicated. For example, a model may indicate that there is just enough water to sustain a wetland but the designer may design to create an excess of water as a factor of safety. If a model indicates a geotechnically critical zone won’t flood, the designers may still require construction of robust topography to prevent ponding of water.

#### 5.3.3.2 Estimating net percolation

Net percolation, the amount of recharge from precipitation and snowmelt events that reaches the groundwater table and results in groundwater discharge downgradient, is complex, and includes a variety of different climatic and geological factors. The amount varies annually with climate cycles, with the maturity of vegetation, and with the complex interaction of vegetation, soil covers, substrates, and the water table.

For closure planning, estimates of average annual net percolation are used, one for each hydrologic response unit (HRU). At the landform design level, complex calibrated soil/water/atmosphere models are run to design the reclamation covers in some cases (MEND, 2012).

Various estimates of annual average net percolation are available in the region. Various EIA documents provide a wealth of information. The following may be used as an initial guide:

Reclaimed fine-grained overburden dumps 10-20 mm/yr
Reclaimed coarse-grained overburden dumps: 40-60 mm/yr
Reclaimed sand or coke-capped soft tailings, external tailings: 40-120 mm/yr.

#### 5.3.3.3 Mapping groundwater recharge and discharge zones

A seepage map (discharge zone mapping) based on groundwater modelling that indicates the groundwater recharge and discharge zones along with typical expected fluxes is useful. The map should indicate the areas of discharge (wetness), the estimated discharge (flux rate in mm/yr) and water quality (often as electrical conductivity) for each seepage area. Groundwater models at the closure scale may be insufficient to provide a detailed estimate of the size of the zone and the flux rates, so hydrogeologists may need to use their own judgment to map the likely zones, fluxes and level of uncertainty. Familiarity with seepage patterns in constructed dykes and dumps with similar materials will be especially useful in this regard. Seepage discharge rates from sandy landforms will be orders of magnitude greater than those from clayey landforms. Further complicating matters, it may take decades or centuries for steady-state seepage to form in clayey landforms that are largely unsaturated during placement. Conversely, flow rates from zones of consolidating tailings material will decrease over time.

Groundwater discharge zones are often suitable regions for wetlands. Assuming geotechnical stability can be maintained (Section 5.3.2), the water levels, quality, and quantity will dictate the vegetation that can be supported. The wetland class should be determined by the local hydrogeology, rather than relying on complicated designs and maintenance strategies to establish a desired class.

Detailed contaminant transport models are not typically run to estimate water quality to wetlands for closure plan designs. Salinity of discharging waters may be estimated using Figure 6-5. An estimate of how salt fluxes change with time may be required. It may be desirable to include more highly permeable zones to aid the drainage of a landform to the wetland or to speed or impede the early flushing of salts.

#### 5.3.3.4 Climate

The surface water hydrologist analyzes and assembles the climatic data used in project design files. There are two levels of analysis: use of the average annual yields and evapotranspiration rates, and use of time-series modelling with a daily time step based on historic weather data collected at the Fort McMurray Airport Environment Canada Climate Station.

Average annual climatic conditions should be used as an initial starting point for designs only, but cannot be relied upon for designs, even at a closure planning level. Modelling must account for extremes in climatic conditions, as is discussed in detail in Section 2.1.

#### 5.3.3.5 Surface water quantity and balance

The surface water hydrologist uses a calibrated surface water model based on hydrologic response units and a 70-year climate database to estimate the surface water runoff reporting to and from the wetland. The water balance model for the wetland also includes the groundwater seepage gains or losses and evapotranspiration from the wetland itself (Section 2.2). The predicted water elevation (or water depth) and the areal extent of the wetland should be predicted with time. A sufficiently conservative design will ensure that the wetland has an excess of water but may limit the extent of wetlands on the landscape. In many cases the design is constrained by requirements for water quality or hydraulic retention period.

Much of closure design involves altering the topography to accommodate surface water. All topographic changes are constrained by the volumes of mine materials in the mine plan and the constructability of the proposed design topography, which needs to be approved by knowledgeable members of the team. Lack of coordination with the mine and tailings planners is a common root cause of fatal flaws in closure plan designs (An et al., 2013).

#### 5.3.3.6 Extreme events

The surface water hydrologist will calculate peak flows to the wetland during extreme events to assess the potential for shoreline and bank erosion and overtopping of outlets. Extreme events may be defined as 1 in 200-year storms and, in some cases where consequences of failure are catastrophic, the probable maximum precipitation (PMP) and the probable maximum flood (PMF) event (e.g., Verschuren and Wojtiw, 1980; Alberta Transportation, 2004). A continuous record of climate data is needed to assess wetland response to wet and dry periods. In some cases, extreme wet or extreme dry periods may also be modelled.

#### 5.3.3.7 Water quality

Future design stages and planning for vegetation and wildlife require an estimate of water quality. At the landscape level, a simple spreadsheet can identify concentrations of the ions and dissolved organics reporting to and exiting the wetland. The chemical contributions from the HRUs and the groundwater discharge are considered, using with a simple weighted-average mixing model. Salinity (total dissolved solids or using electrical conductivity) and naphthenic acid concentrations are usually the main considerations in design.

Estimates of seepage water quality and target water qualities can be made using Bayley et al. (2014), Table 3-1, Table 3-4 and Figure 6-5 in the absence of site specific data. Table 6-3 shows an example of a simple mixing model calculation.

The average annual water chemistry needs to be treated with caution. There is often a steady annual influx of constituents and salts from groundwater discharge (seepage and consolidation water), combined with flushing of waters during a few days of snowmelt.[6] Few field data exist for calibration and predictions made using these models. Additional guidance regarding water quality is provided in Section 6.5.

#### 5.3.3.8 Erosion

Design of reclaimed watercourses in the oil sands often uses guidelines provided by Golder Associates (2004) that employ a combination of engineering design calculations and natural analogues unique to the region. Assessment of the potential for erosion of wetland soils or reclamation materials and the impacts of erosion on the design of the wetland geometry may be required. An estimate of the sediment loading and total suspended sediment to the wetland will also be considered. Sediment accumulation at inlets must be anticipated. Models that calculate sediment-loading rates to the wetland are notoriously inaccurate (McKenna, 2002) but some consideration of depositional volumes at inlets is needed.

Erosion of wetland soils in large watersheds (such as tailings plateaus) remains an outstanding concern. Generally speaking, runoff from adjacent landforms should not be channeled across fen-like wetlands where the chance of erosion during extreme events is high. The impact of waves on shorelines may also need to be evaluated in some cases for wetlands with fetches of more than about 200 m (see Ozeren and Wren, 2009; Bureau of Reclamation, 1987; US Army Corp of Engineers, 1984). Mitigation options are discussed in Section 6.4.3.

#### 5.3.3.9 Lease-scale topography

Three-dimensional closure topography develops by integrating individual landform designs and the geomorphic elements of the surface drainage system into a single digital elevation model for the leases and adjacent land. Planning closure topography should include suitable watersheds for wetland development, and consider where to place wetlands relative to each other. Networks of wetlands will improve ecosystem quality and function (Chapter 3 and Figure 5-11).

#### 5.3.3.10 Watershed topography

An hydrologist develops the topography for the watershed that feeds the wetland by creating a digital terrain model. This is a major effort as the main watershed will often include several wetlands. Chapter 3 provides details of natural systems that can be incorporated into the design.

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[6] Note that the runoff water may have elevated levels of salts (and in some cases naphthenic acids) from reclamation materials and near surface substrates, especially in the first few years after reclamation material placement (e.g., Bayley et al., 2014). Where salts accumulate in the reclamation soils due to evapotranspiration, salinity of runoff water may increase during peak flows, contrary to normal experience.

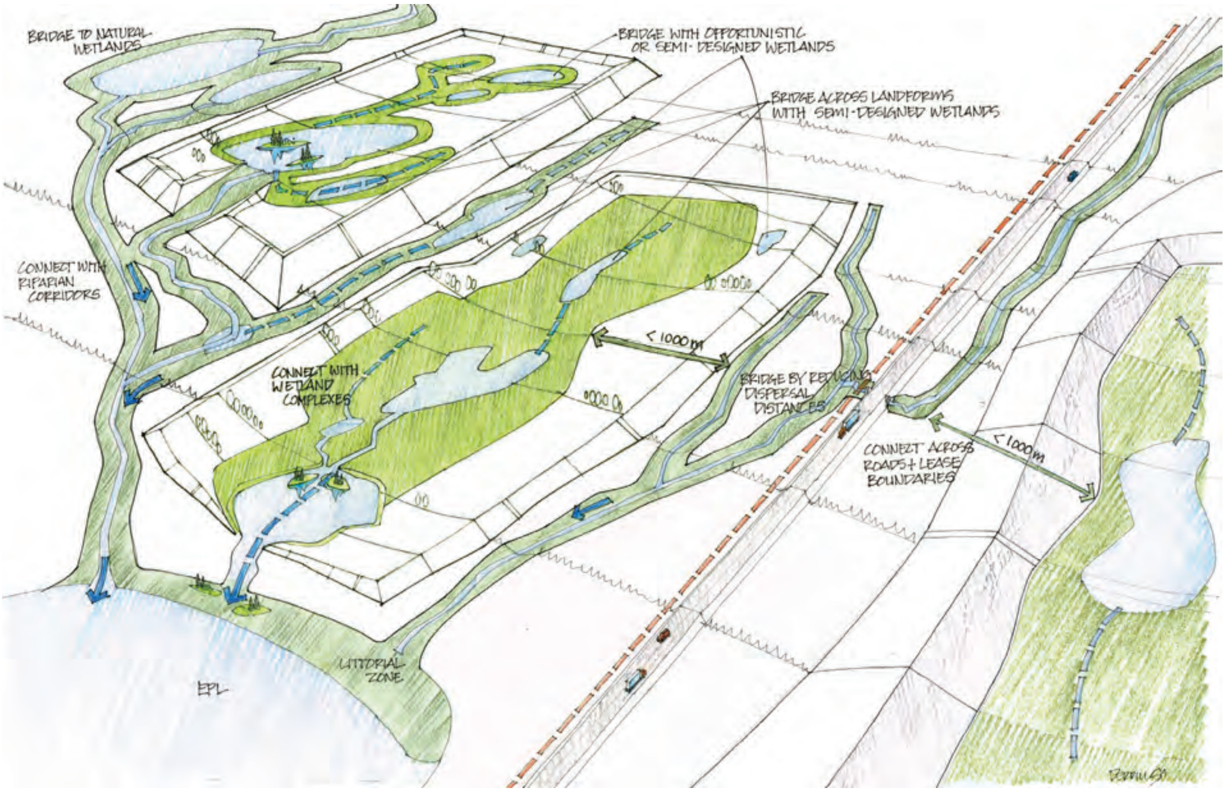

**Figure 5-11. Designing wetland connectivity for wildlife in the closure landscape.**

### 5.3.3.11 Wetland topography

The topography immediately adjacent to the wetland attracts special attention even during closure planning. The shoreline, islands and other features should be specified. These details can be refined later, but any designs that affect how much material is moved and where it is placed should be included.

### 5.3.3.12 Inlet and outlet design

Inlets and outlets are major design elements (Section 6.5). At the closure planning level, any special considerations during construction should be indicated at this stage. In particular, outlet width and elevation need to be specified to ensure adequate real estate to pass large flows and enough freeboard to avoid overtopping during extreme events. For small watersheds, the outlet will be only a few metres wide and designed to accommodate 3-metre-high beaver dams with some reserve freeboard. For large watersheds, the outlet width may be tens or even hundreds of metres wide, with greater allowances in freeboard for extreme events. Riprap[7] quantities and other special considerations should be indicated. Where outlets cannot be allowed to settle, compaction designs for outlets will need to be modified before landform construction starts.

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[7] There is a limited supply of riprap (loose cobbles or boulders used to armour shorelines and watercourses) in the oil sands region and it is extremely expensive to import from outside the region. Its use also can have detrimental impacts on habitat. For these reasons, closure plans and landform designs in the oil sands usually attempt to minimize riprap use.

### 5.3.4 Soil scientists

Soil scientists focus on salvage, stockpiling, and design and placement of reclamation material. Traditionally this approach applies criteria from EPEA Approval and the Land Capability Classification System (CEMA, 2006), such as prescriptive soil thickness, layering and soil quality criteria. Historically, these prescriptions have involved upland ecosystems. There is little guidance regarding placement for wetland reclamation (e.g., CEMA, 2012c) and stark differences in approach, especially for fens (e.g., Pollard et al., 2012; Daly et al., 2012).

Reclamation materials can be designed as covers that balance goals for vegetation growth and yield and downstream water quality and quantity needs for wetlands and end pit lakes. Changing the designs of approved upland prescriptions will require close cooperation with regulators.

Vegetated covers (MEND, 2012), like those in the oil sands, are designed to:

- Partially separate mine wastes from the biosphere;
- Provide a suitable growth media to meet land use targets;
- Control erosion;
- Partition the water balance (evapotranspiration, runoff, interflow, net percolation);
- Control diffusion of salts from substrates into the root zone;
- Adapt to changes in vegetation and moisture conditions; and
- Provide suitable substrates for benthic invertebrates (in the case of wetlands).

Designers will select cover designs that best suit the landform, land use targets, underlying materials, and the hydrological regime. For instance, establishing a peat layer during construction will encourage the establishment of appropriate vegetation in fens. Marshes are not peat-forming, but applying a peat-mineral mix can encourage plant growth in the early years of establishment.

Field data can identify appropriate organic horizon soil reclamation areas, particularly for peat-mineral mix salvage. Salvage depths depend on the texture (or particle size class) of the underlying mineral material, and will be defined on a site-by-site basis. Subsoil has one or more of the following characteristics:

- The remaining portion of B horizon soil following salvage of the upland surface soil;
- C horizon of an upland soil; and
- A mineral material, from either an upland or other location, which is located below an organic layer that is rated Good, Fair, or Poor.

Until formal guidance regarding wetland soil prescriptions is available, the following should be considered:

- Formally declare the reclamation prescription for each type of wetland in a closure plan.
- If the wetland soil prescription differs from the upland, a tie-in between wetland and upland soils is needed.
- Decide at what permanent water depth (if any) a “deep water” prescription may be employed. This prescription may in some cases mean no reclamation material.

> Give consideration to all aspects of reclamation, including specifically surface water and erosion, groundwater, growth medium, revegetation, and wildlife (including benthic invertebrates) and methods and timing of placement in the reclamation prescription for wetlands.

### 5.3.5 Vegetation and aquatics

Upland vegetation is an important driver of the hydrological regime, but in a self-sustaining environment it is difficult to exert long-term influence on it except through initial landform design. If upland vegetation has high water demands, this will affect how much water is available for lowland communities. Revegetation plans at the landscape level must consider the hydrological needs of the entire watershed rather than those of target vegetation species. The predicted hydrology determines the general wetland type. Vegetation species can then be broadly identified, but specific plans, such as treed versus shrubby alkaline fens, cannot be adequately addressed at the closure planning scale.

Generally, a few target species should be anticipated (see Chapters 3 and 7). For instance, in the boreal forest, fens are dominated by brown mosses (alkaline fens) or *Sphagnum* mosses (acid fens), with less dense assemblages of vascular plants such as sedges and shrubs. Mosses are largely absent from marshes (except for a few submergent forms). Treed fens also support black spruce (*Picea mariana*) and tamarack (*Larix laricina*), whereas marshes are not treed.

Generally, a constructed marsh or shallow-water wetland will host sedges and grasses, herbs, forbs, and other graminoids. Natural swamps with a shallower hydrology are dominated by woody plants (trees and shrubs) such as conifers, tamarack, and other deciduous species. Current knowledge is not sufficient to construct these two classes of wetlands, but planned research could improve our understanding for future guides.

Because process-affected water will likely be expressed from wetlands over decades, salt-tolerant species may be required (see Chapters 3 and 7 and Appendix E). Research into the means of effectively propagating these species is ongoing as part of the Syncrude and Suncor fen research programs.

At this level of design, consideration of the source of plant material is important, as are the means by which species will be propagated. Propagation methods will have to be determined on a species-by-species basis, but identifying the possible locations and methods of obtaining plant material early can assist in later stages and particularly during construction.

An approach to revegetation planning is shown in Figure 5-12. It begins at the digital elevation model, and uses solar radiation data, topography, moisture regimes, and substrate options. Different plans for vegetation can be developed and ecosites broadly defined.

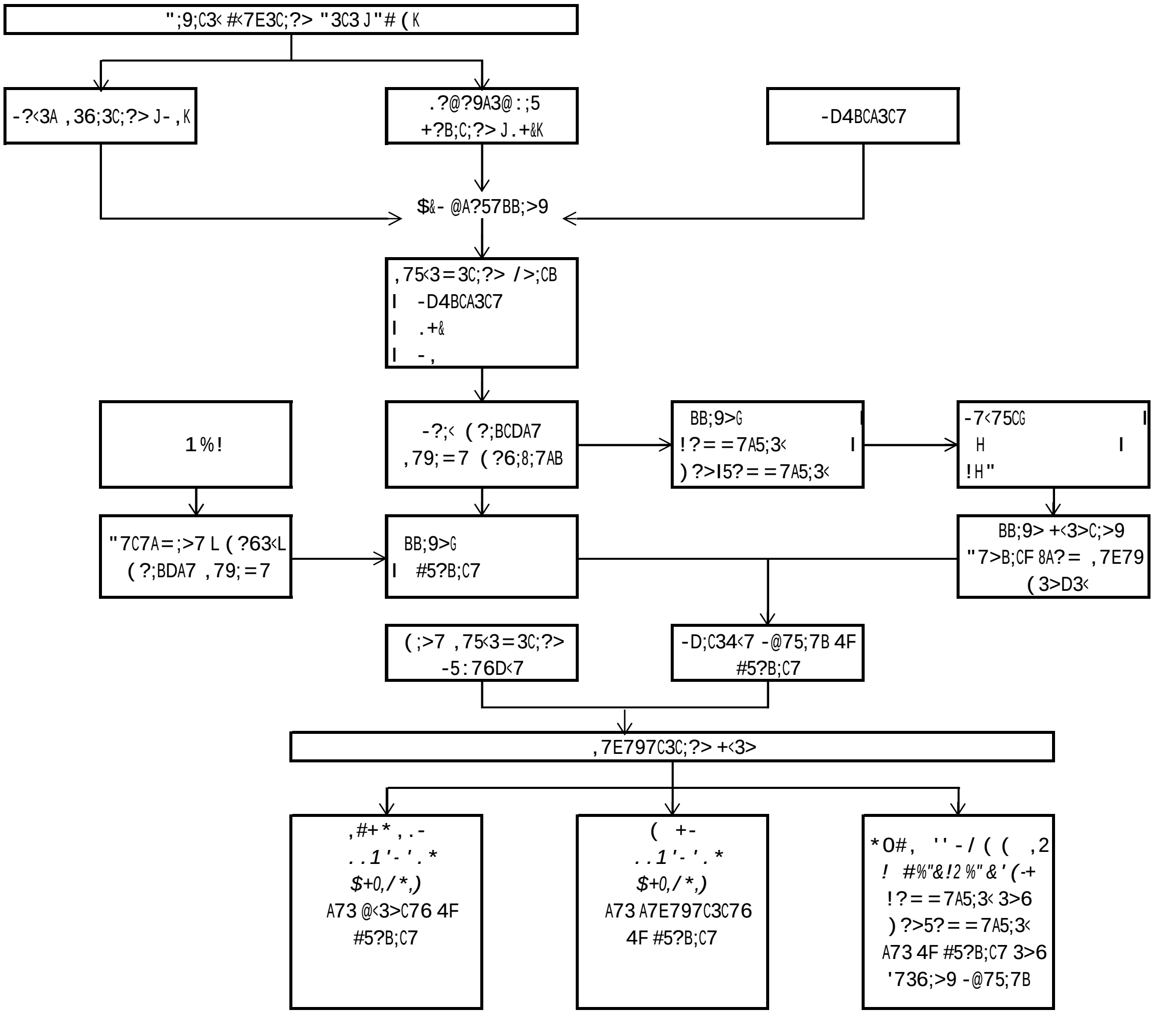

Figure 5-12. Design steps for ecosite selection.

### 5.3.6 Wildlife

Little technical guidance is available for designing wildlife habitat at the lease/landscape scale beyond “build it and they will come.” Wildlife specialists may decide to adjust designs to encourage wildlife movement based on their own research and experience. There is more guidance in Section 6.5.7 and Section 3.5, Chapter 6 and Appendix D for the landform/wetland scale of design.

Watercourses will connect most wetlands, encouraging the movement of wildlife species, including their initial ingress into newly reclaimed wetlands. Lacking specific guidance for connectivity and dispersal, habitat designers may use a rough rule of thumb that no location in the reclaimed landscape be more than about 1 km from an aquatic ecosystem (riparian, wetland, or end pit lake). GIS equipment makes assessment of a design straightforward. Some research into wildlife habitat design is underway through OSRIN.

### 5.3.7 Traditional knowledge

The role of the traditional knowledge in closure planning continues to evolve. In the present state of practice in oil sands, it is usually incorporated into a broader stakeholder consultation program at the corporate level. There is clearly a role for more hands-on involvement.

## 5.4 Assessing the design

The expected performance of the wetland and its watershed should be compared with the goals set out, as outlined in Section 5.2.4. Performance can be estimated by various models or experience. The user of the closure plan needs reasonable assurance that the design, construction, reclamation, and operation of the wetland will meet the goals.

Success of the wetland will depend on the designer's ability to plan a system that can produce the necessary hydroperiod under different climatic conditions. The geological setting is somewhat within the planner's control, while historical climate records can only provide guidance on prevailing conditions. Modelling conducted early in the design process will allow for a general understanding of how a system can be expected to behave and highlight key issues that will require more detailed investigation. It is at this stage in the process that the designer can manipulate individual hydrological units to understand how each piece fits into the larger context of hydrological response areas. The modelling program is not strictly a prediction tool for calculating expected volumes of runoff or groundwater recharge. Rather, the goal is to understand the system at the landscape level and to achieve a more sustainable design. The degree to which designs can accommodate all these conditions remains unproven.

There is uncertainty with respect to the performance of any constructed wetlands in oil sands operations given the scale of mining and reclamation activities and ever-changing plans. Three types of engineering risk assessment[8] are recommended, usually in the following order:

A fatal flaw analysis (FFA) helps to determine which critical issues could jeopardize the success of the proposed wetland (e.g., HNTB, 2010).

A failure modes analysis (FMA) is a high-level tool used to categorize failure mode (Federal Energy Regulatory Commission, 2005). For each failure mode, the assessment team assigns a category as follows:

- Category I - Highlighted potential failure mode
- Category II - Potential failure mode considered but not highlighted
- Category III - More information or analyses are needed in order to classify
- Category IV - Potential failure mode ruled out.

A failure modes and effects analysis (FMEA) is a common tool used in the industry and can be applied at the landform design level (MEND, 2012).

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[8] These engineering risk assessments are different from, but may be precursors to, ecological risk assessments ("the process for evaluating how likely it is that the environment may be impacted as a result of exposure to one or more environmental stressors such as chemicals, land change, disease, invasive species and climate change" (USEPA, 2013)).

Table 5-5 is a list of wetland failure modes useful for all the above analyses and is a subset of a longer list of 142 landscape failure modes (McKenna, 2002). While many “failure modes” can be interpreted as natural processes, the list is useful for formal consideration in design. This list can be augmented with the goals as set out in Section 5.2.4. When used with an FFA and FMA in the closure planning stages, it can help identify issues and concerns and show how they are or will be addressed in a transparent manner. Collectively they form the backbone of an adaptive management program (Chapter 8).

**Table 5-5. Partial list of potential failure modes for reclaimed oil sands wetlands.**

| Physical / Biological / Chemical | | Failure to perform |
|---|---|---|
| Acid rock drainage (ARD) | Ice push | Act as aquifer |
| Animal-induced erosion | Icing | Aesthetics |
| Avulsion and flooding | Landslide | Contain/isolate solids |
| Bank erosion | Leachates | Wildlife corridor |
| Bioaccumulation/food chain | Non-native invasion | End land use |
| Blight/disease | Not self-sustaining | Meet corporate objectives |
| Breach/flooding | Nutrient accumulation | Meet design or code |
| Breaching | Old equipment | Regulate water discharge |
| Browsing | Outlet blockage (beaver dam, ice jam, log job) | Support vegetation |
| Burial by sand | Overtopping | Trafficable |
| Catastrophic outflow | Piping/tunnel erosion | Trap sediments |
| Climate change | Quicksand | Water: Attenuate |
| Deep-seated landslides | Radioactivity | Water: Store |
| Deteriorating road | Road/trail deterioration | Water: Transmit |
| Drought | Salt accumulation/pan | Water: Cleaning/treatment |
| Dust | Salt fluctuations in water | |
| Excessive net percolation | Sediment deposition | |
| Excessive settlement | Shoreline erosion | |
| Excessive water fluctuations | Sinkholes | |
| Fences | Slides/flowslides | |
| Fog | Soft shoreline on lakes | |
| Gas | Spontaneous combustion | |
| Gas evolution | Stream avulsion | |
| Grazing | Stream flooding | |
| Groundwater contaminating plants/animals | Unwanted succession | |
| Groundwater contamination | Water table: Too high, too low, too much fluctuation | |
| Gullying | Wildfire (forest, grass, peat, topsoil) | |
| Health and safety | Wind erosion, deposition | |
| Ice mounds | | |

NOTE: This table should be supplemented with failure modes developed by the team and closure goals set out in design. Most will be compound failure modes, what may necessitate development of simple event trees for assessment.

## 5.5 Reclamation schedule, volumetrics and costs

Closure planning is a long-term, iterative process that starts during planning, carries on through operations and well beyond when the ore is depleted and landforms have been constructed. Schedules include all steps, from the initial closure plan through monitoring and adaptive management once the landscape has been designed and constructed. CEMA (2012a) provides examples of typical lease development schedules that tend to occur over nearly a century.

Thus reclamation wetland planning, design, construction, reclamation, and certification is a multi-decadal affair. Most wetlands will be designed 5 to 10 times at the closure planning level before their landform is designed and constructed. The landform typically takes 5 to 50 years to construct by the mine or tailings operations staff. Wetland construction and reclamation usually takes several years and a period of 3 to 10 years is likely required for monitoring and operations over a few more years, eventually leading to reclamation certification.

Scheduling items to consider during wetland design include:

Can the wetland be reclaimed before the watershed?

Timing of outlet construction and full operation.

Timing for how long the wetland needs to be constructed, reclaimed, operated, and certified.

Section 6.8.1 and Chapter 7 in particular provide additional information about construction schedules.

Volumes are the currency of mine planners — calculating required volumes and indicating the borrow sources is a key element of design. In particular, the reclamation balance (the available, salvaged, stockpiled, and placed volumes of all the various types of reclamation material) on an annual basis is central to the closure plan. Wetland reclamation requirements are an important input into this process.

Costs are generally not calculated for closure planning in the oil sands but are included in the internal long-range mine plans and the 10-year business plans. Wetland reclamation is an important element of the overall closure plan reclamation cost estimate. Closure plans may be used to help determine the amount of reclamation security (see Alberta Government, 2014).

## 5.6 Keeping the plan current

The mine and closure plans need to be kept current. Designs are generally updated every five years. This revision also provides an opportunity to incorporate the latest science, engineering, and operational experience.

Prior to building each landform, a full landform design will be done, including design of the watersheds and wetlands (Chapter 6). Where the landform is under active construction, the landform design for the wetlands and their watersheds will be updated. This updated design is simplified and imported into the next iteration of the closure plan. Once constructed, the as-built conditions of the wetland and its watershed are shown in the closure plan maps. Some wetlands will be as much as 50 years old when the final closure plan is submitted.

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# Chapter 6

# Wetland Design at the Landform Scale

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Wetland design, construction, and operation in the oil sands is a maturing field. The key elements of successful reclamation of wetlands include keeping the water shallow enough to support desired vegetation communities, ensuring there is enough water of acceptable quality, and creating designs that are easy to construct to minimize overall costs.

Wetland design at the landform scale builds upon the closure plan design and is integral to the landform design (for individual dumps, dykes, pits). The initial design is completed before the mine fleet (or tailings operation) constructs the landforms and is updated as more information becomes available. Flagging key elevations and substrates is important to guide the operation and avoid costly retrofits.

Three types of wetlands are proposed: designed wetlands that receive formal analysis and design and issued for construction (IFC) drawings, semi-designed wetlands (small wetlands largely field fit by regrading during reclamation), and opportunistic wetlands which form naturally on reclaimed land. For designed wetlands, a multidisciplinary team is formed (similar to that preparing closure plans as described in Chapter 5). Objectives and goals are declared that are focused on obtaining reclamation certification and the design aimed to reach these goals. An engineering risk assessment is completed as schedules are created and volumes identified. Five design components are recognized: design of the watershed, design of the overall wetland, design of the wetland elements, revegetation design, and creation of an OMM manual.

Specialists in the team take the lead on specific design tasks:

- Mine planners coordinate the team and guide much of the bulk material handling.
- Geotechnical engineers design the landform to be stable and may restrict the location of ponded water, design the landform to have suitable trafficability for reclamation material placement and the ultimate land use, and estimate the amount and timing of settlement in wetland and adjacent areas.

Surface water hydrologists design the watershed and the hydrology feeding the wetland. They will often run distributed watershed models to estimate water quantity and quality and predict water levels over time in the wetland. They adjust the design topography to make wetland reclamation straightforward with a minimum of retrofit. They will also estimate erosion and sedimentation and adjust designs accordingly. The single most important design choice is the wetland outlet elevation as this governs the shape of the rest of the wetland and its watershed.

Groundwater hydrologists calculate the base flow conditions, or the water quality and quantity leaving the wetland through the substrates. They may create models in greater detail than the closure plan model, using that model as boundary conditions for the landform and wetlands.

Soil scientists, aquatic biologists, and revegetation specialists design the soils and revegetation plans for the watershed and wetlands. They may run terrain unit models to predict soil moisture and future ecosystem development.

Wildlife biologists design the wetland to support wildlife and design enhancement measures. Wildlife habitat design is in its infancy and will benefit from structured design and monitoring.

Various routine site investigations will be required for designed wetlands to understand the landform construction history, the substrates, the groundwater regime, settlement rates, and borrow investigations. Seed collection and propagation will run in parallel.

Guidance for creating semi-designed wetlands and for estimating the location, size, and frequency of opportunistic wetlands is provided. Minor changes to design and construction practices can encourage or discourage formation of wetlands in key locations in the reclaimed landscape. Beavers will modify these designs with dam and canal construction — something that needs to be anticipated and accommodated in design.

Documentation of design and construction is an important element of designing for certification as the application for reclamation certification will need to make the case that the reclaimed wetlands can be reasonably assured of meeting the agreed upon design basis. In many cases, design, construction (Chapter 7) and monitoring (Chapter 8) will go on in parallel within the wetland and its watershed.

## Table of Contents

## 6.1 Introduction

Building on the successful reclamation of over a dozen designed (and many more opportunistic) wetlands, the oil sands is moving into a continuous improvement phase with a focus on both narrow and broad adaptive management as well as “Design for Certification” (Section 5.1).

We already have the tools and experience to construct shallow-water wetlands, marshes, and fens, although for fens there is more uncertainty about the details of the ecosystem that will evolve. Gosselin et al (2010) provide a discussion of oil sands reclamation reliability. Significant advances have been made in recent decades (compare with early works by Boerger et al., 1990, Carrier et al., 1987, and Nix and Martin, 1992) and oil sands reclaimed wetlands remain intensively studied with an eye to improving design and performance.

This chapter provides designers with a framework, references, and data to streamline the design process. It also describes how to build semi-designed wetlands and provides insights into opportunistic wetlands (Section 6.7). Chapter 2 provides key information on substrate and reclamation properties and geochemistry for design (Section 2.5) with additional information summarized in Trites et al. (2012). Mine operators will also rely on their own experience and databases of material properties.

Wetlands are but one component of a healthy reclaimed landscape, whose designs are competing for water and real estate with uplands, end pit lakes, and the hundreds of kilometres of channels (and associated riparian zones) that will connect them. Practical concerns mean a significant portion of the landscape can only be reclaimed to wetlands.

The main design issues addressed in this chapter are:

- Keeping most of a wetland shallow enough to provide the desired vegetation community structure
- Ensuring there is enough water of acceptable quality to support a wetland
- Creating designs that are easy to construct and maintain (if needed) while keeping design and construction costs to a minimum.

As a literary convenience, the chapter provides guidance in the form of “practice” in the oil sands region, though design practices vary widely. All of these design approaches in the chapter have been employed, but not extensively, and not all are required for every wetland. The guidance provides both an overview for all people involved in design, construction, monitoring, and regulation as well as specific details for specialists. In keeping with the team approach, there is an emphasis on cross-training of specialists so as to be better able to interact with other specialists and generalists on the team.

### 6.1.1 The design team and management approach

The multidisciplinary design team is outlined in Chapters 1 and 5. At this stage, more operations staff will be involved and the team will need to decide whether to engage First Nations, other stakeholders, and regulators in the process (or whether their input during closure planning is sufficient).

Depending on management practices, a wetland may be part of routine mine reclamation or it may be treated separately with a project manager, a project team, and specific project controls. There are risks and benefits to each and wetlands will be constructed using both approaches. The key is to take advantage of the controls that come with heavy civil engineering (especially survey control and construction of the finer elements), and with the sensibilities and economies of scale inherent in traditional mining and mine reclamation (such as bulk material-handling and established cover soil and revegetation practices).

The timing of wetland/landform design promoted in this chapter (a reasonably detailed landform design before the landform construction is started) is seldom realized by the existing oil sands mining operations. In addition, mining and reclamation plans usually change rapidly over the first decade of operations, during which time up to about a half dozen new landforms may be under construction. Given these conditions, mines may choose to reduce some of the design efforts until a steady-state operation is reached, recognizing that there may be some lost opportunities and some additional costs later.

### 6.1.2 Wetland functions and contribution to end land use

Wetlands provide services to the reclaimed landscape and its users — lengthy descriptions of wetland roles and functions can be found in most wetland textbooks (e.g., Mitsch and Gosselink 2007). In the oil sands region, wetlands are an integral part of the boreal forest ecology. It is useful to touch upon their functions, their role in end land use, and their role in reclaimed landscapes.

Wetlands provide numerous functions in the reclaimed landscape. They provide hydrologic functions (such as groundwater recharge, storm runoff generation, flood attenuation, water polishing/treatment, storage of water for upland ecosystems). Wetlands also support various land uses (such as wildlife habitat for a variety of species, low-impact recreation, trapping, hunting, and other traditional uses). They also provide other services (such as patch-, landform-, and landscape-scale diversity, and carbon storage).

As described in Section 5.2.7 and Figure 5-3, several types of locations in the closure landscape essentially “require” wetlands for reclamation owing to the nature of the constructed landforms (for example, seepage discharge areas and areas that will undergo slow settlement). Conversely, some areas of the landscape are specifically designed to avoid the formation of wetlands to minimize the risk of geotechnical instability or salinization (see Figure 5-8). The amount and types of wetlands that should be planned and built for reclaimed landscapes is the subject of healthy debate. Tradeoffs with other land uses, such as commercial forestry, are inevitable, as are implications for site-wide water balance and released water quality (CEMA, 2012; Oil Sands Water Release Technical Working Group, 1996).

The design team takes these competing objectives into account during closure planning and landform design. There is a minimum wetland component to the closure landscape dictated by areas of seepage and settlement, and a maximum area dictated by water balance, geotechnical issues, and cost considerations. Optimizing these competing objectives is largely a closure planning exercise that influences landform design.

### 6.1.3 Reclaimed wetland types

Table 6-1 sets out three wetland types according to the level of design and operation effort. Most of the efforts listed in this chapter relate to designed wetlands. Semi-designed and opportunistic wetlands are featured in Section 6.7.1 and 6.7.2 respectively.

**Table 6-1. Design efforts for various classes of reclaimed wetlands**

| Class | Description of wetland | Typical level of effort in design | Typical level of effort in operation, maintenance, and monitoring (OMM) |
|---|---|---|---|
| **Designed wetland** | A wetland that received a formal multidisciplinary engineering design | Medium<br>Modest site investigation, detailed design and report, IFC drawings, modest as-built documentation. | Medium<br>Operated (in most cases) and monitored |
| **Semi-designed wetland** | A wetland that receives minimal design, largely or entirely in the field. Minor topographic and reclamation features added during landform design and construction | Low<br>Minor adjustments to substrate topography made in overall landform design. Minor documentation. | Low<br>Annual inspection, and intervention if needed |
| **Opportunistic wetland** | Forms without design or intervention | None | Very low<br>Annual inspection, and intervention if needed |

Chapter 4 provides examples of reclaimed wetlands in the oil sands region.

### 6.1.4 Target wetland sub-types

At the landform design phase, the three main types of wetlands (shallow-water wetlands, marshes, and fens) are divided into 1, 2 or 3 sub-types (see Section 3.3 and 5.2.1 and Table 5.3). Additional reclamation research effort is necessary before swamps and bogs can be included in a future version of this guide.

For designed wetlands, building on the closure plan and a more detailed understanding of the future hydrology (quality and quantity), the design team will select a sub-type (shallow-water wetland, persistent marsh, intermittent marsh, acidic fen, saline fen, alkaline fen). Limitations to this approach include uncertainty regarding the future hydrology and substrate properties, the tendency for sub-types to change over time as the watershed matures, and the presence of different type or subtype in a wetland complex.

#### 6.1.4.1 Shallow-water wetlands

Shallow-water wetlands have water depths from 1 to 2 m (Table 5-2) and have predominately mineral soils. Although some peat may be present, little tends to accumulate. They are usually associated with marshes as part of a wetland complex, occurring along a continuous gradient as a transition zone between marshes and lakes. Vegetation in the shallow-water zone is restricted to submerged and floating forms. Phytoplankton may dominate the plant community in some instances.

Shallow-water wetlands will be common where large settlements are expected. More details on natural shallow-water wetlands are presented in Sections 3.3.4.2 and 3.5.3, with design guidance in Section 6.5.

#### 6.1.4.2 Persistent and intermittent marshes

Marshes are dominated by herbaceous water plants (reeds, rushes and sedges). They are periodically inundated by standing or slowly moving water, and have a neutral to basic pH. Average water depth is -0.1 to 1 m, but can briefly and infrequently reach 1.5 m. Substrates may be any mixture of mineral material, peat and a mud of partially decayed peat known as gytjja. Water may enter marshes from direct precipitation, runoff, seepage or groundwater flow. Where present, standing water tends to be eutrophic and supports submerged and floating vascular plants. Marshes in the boreal forest grow and shrink dramatically with the decadal wet-dry cycles, during which levels of standing water vary significantly from one year to the next. They can tolerate a wide range of hydrologic and nutrient regimes. Natural analogues in the region exist for several variants, including alkaline (high in calcium and bicarbonate) and saline (high in sodium and sulphate) marshes.

Further details on natural marshes are presented in Sections 3.3 and 3.4.2, with design guidance in Section 6.2.5.

#### 6.1.4.3 Saline and alkaline fens

Specifically, fens are predominantly peat-forming. They are the dominant natural wetland in the region. Hydrology is governed by groundwater, but may include surface water contributions. Water may be stagnant, flowing, or flood water. In fens, the water table is relatively stable — flooding in the spring freshets and often static at about 20 cm below the top of the peat in mid to late summer. Groundwater and near-surface flow are important for the maintenance of saturated conditions. In the boreal forest, one of the key distinctions between open fens and marshes is that fens are dominated by brown (alkaline fens) or *Sphagnum* mosses, with less dense assemblages of vascular plants like sedges and shrubs. Mosses are largely absent from marshes (except for a few submergent forms). Treed fens also support black spruce (*Picea mariana*) and tamarack (*Larix laricina*). Fens vary widely in physiognomy.

Saline and alkaline fens are the most likely design targets for oil sands reclamation. Site conditions and particularly water chemistry will dictate which type of fen is likely to result. Further details are presented in Sections 3.3.3.2 and design guidance in Section 6.5.4. Figure 6-5 provides a primer on salinity.

## 6.2 Design process overview

The wetland will usually comprise only a small portion of the landform (often less than 10%[1]) and is but one ecosystem on the landform and satisfies only some of the goals of overall landform design. As there is little published guidance on overall landform design, this chapter focuses on watershed design to support the wetland.

The landform design, including the wetland design, is first done as part the overall permit-level design of the dump, dyke, or other tailings deposit, before mining of this area (or fill placement for out of pit landforms) begins. Landform design after dump or dyke construction has begun often leads to major retrofits, with double handling of bulk materials, and sub-optimal solutions. The landform designs can change considerable with time.

If the proposed wetland is not already in the lease closure plan, and does not have the benefit of a preliminary design or regulatory approval, the wetland is designed at the closure planning level first to meet the goals previously set out (see Section 5.2.4). The closure plan is then updated.

While closure planning matures as a mining activity, landform design remains an emerging field. Dozens of landforms have been constructed in the Athabasca oil sands region without a formal landform design. Present designs focus on mining, geotechnical and dam safety issues, with reclamation only a small component of the design. Efforts in landform design are growing rapidly both in the oil sands and internationally.

### 6.2.1 Design steps

The landform design process begins where the closure plan design ends. A constructed oil sands landform ranges from 50 to 3,000 hectares in size and will usually include several watersheds with many kilometres of ephemeral and permanent reclaimed streams plus several reclaimed wetlands — all of which is delineated in the closure plan. A simplified view of the landform design process[2] is as follows:

> The team itemizes more detailed design objectives and adjusts the conceptual designs from the closure plan. A design basis memorandum (DBM) is created.
>
> A geotechnical and hydrogeological site investigation to characterize substrate conditions is performed and the borrow material (typically overburden and interburden and tailings) is characterized.
>
> Mine and tailings planners update the volume placement plans and schedules based on the latest site-wide mine and tailings plan.
>
> Geotechnical engineers perform detailed designs, including modelling of slope stability and settlement, and design the overall topography and internal structure.

---

[1] As mentioned elsewhere in the guide, there is an opportunity with more experience and better design tools to increase the amount of wetlands planned and constructed in the reclaimed landscapes, recognizing there are design tradeoffs as noted in Section 6.1.2.

[2] These are the generic design steps for a mining landform (typically dumps or tailings facilities). These facilities will typically have one or more designed wetlands.

Groundwater specialists work with geotechnical engineers to predict the location of the phreatic surface (water table), pore-water pressures, seepage rates and water quality and adjust the design (topography and substrates).

Surface water hydrologists model flows and water quality; designs are further modified.

Soil scientists design the reclamation material cover and placement plans.

Vegetation specialists create an ecosite design and revegetation plan, working closely with engineering teams and biologists.

Wildlife specialists provide direction on habitat enhancements.

Mine planners update plans and schedules until design goals and constraints are met.

Engineering risk assessment programs evaluate the predicted performance and allow further refinement of the design.

The team generates a detailed report of the results of calculations and models, the designs, design drawings, specification, and schedule. This permit-level report may be submitted to provincial regulators.

While closure planning mostly uses rules of thumb and lease-scale modelling, designing at the landform scale involves detailed calculations, and sometimes modelling as part of an integrated design process. It is up to the designers to choose the level of analysis for any given wetland.

Practices at different operators vary and in many cases not all these steps are carried out. That said, a more formal process than is often employed is required for most wetlands if the declared design objectives are to be met. This guide sets out that process.

### 6.2.2 Nomenclature

Figure 6-1 provides some wetland design nomenclature for wetland and watershed elements.

### 6.2.3 Revisions

The first landform and wetland design[3] is prepared prior to construction. During construction, the design is adjusted to adapt to new discoveries, regulations, and changes to mine and tailings plans. When the landform is largely constructed, a site investigation to inform wetland design will be completed. The investigation will include a LiDAR survey for topography and detailed visual inspection and mapping of substrates and may involve drilling, installing instruments, and field and laboratory testing. The initial design will likely require a significant update at this point. In some cases, the design basis may need revision (owing to new site or approval conditions). Issued for construction (IFC) drawings will be created just prior to construction (Chapter 7).

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[3] Designed wetlands often receive a higher level of effort than the design of the rest of the landform/ watershed. Ideally these two activities would receive the same level of attention.

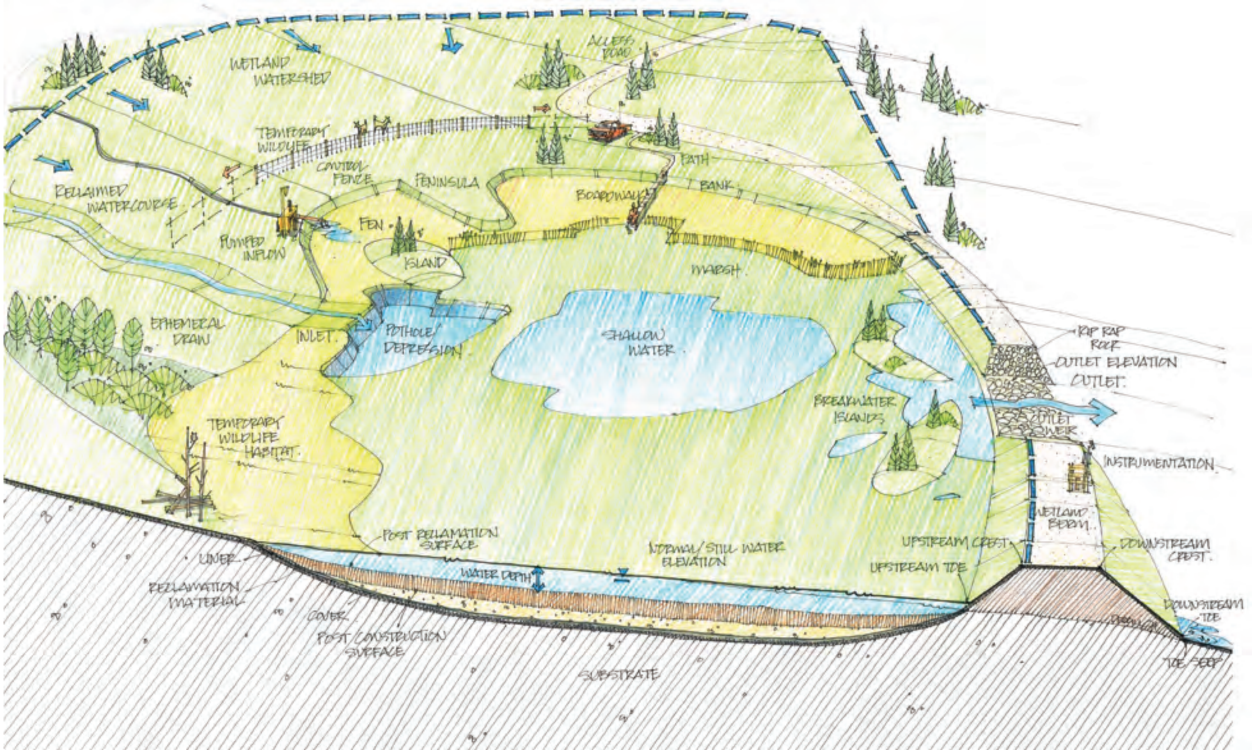

Figure 6-1. Wetland design nomenclature.

## 6.2.4 Five design components

It is useful to divide landform design into five components: (1) design of the watershed; (2) design of the overall wetland; (3) design of the wetland elements; (4) revegetation design; and (5) preparation of the operation, maintenance, and monitoring. In practice, these design activities run concurrently and iteratively.

## 6.2.5 Approval conditions

One of the first steps in design is to extract those EPEA conditions specific to wetlands and set them out as design objectives. Until recently, few such conditions were included in EPEA approvals. However, a recent approval (Alberta Environment, 2011) requires submission and implementation of a wetland reclamation plan, which could be considered a subset of the closure plan. Requirements for this plan form a partial basis for wetland design as paraphrased below.

Identification of the location, wetland type, target ecosites.

A wetland soil salvage and placement plan (borrow, see Section 7.7.2).

Incorporation of vegetation and vegetation communities of traditional value characteristic of the boreal forest and that provide habitat for wildlife, including birds.

Vegetation establishment techniques, including source of target species.

Re-establishment of the capability for long-term biodiversity (Closure Plan, Chapter 5).

Establishment of the continuity of vegetation patterns, and connectivity of wildlife species, with adjacent natural and reclaimed lands (Closure Plan, Chapter 5; Stantec, 2010).

- Target wetland types, wetland area, hydrology budget (including atmospheric fluxes, surface water and groundwater fluxes), watershed area, major reclamation landforms in the watershed, surficial substrates, and soils (this chapter).
- Monitoring plans (Section 8.4).
- Performance measures to assess wetland reclamation success, including measures of wetland sustainability (including water quality and quantity), ecological function, traditional use, and biodiversity (Table 6-2).

### 6.2.6 Setting the design basis

The design objectives for the wetland at the landform scale build on goals declared at the closure planning level (Table 6-2) and in the wetland reclamation plan. Objectives are more specific and measurable than goals. Professionals take responsibility for the designs, indicating that the design is reasonably expected to achieve the goals. This collection of conditions, needs, and requirements is typically set out in a design basis memorandum (DBM) — a common engineering project management tool used widely in the oil sands.

The DBM will include:

- Project description
- Existing conditions
- Project goals
- Design basis objectives
- Evaluation of any alternatives or options available to the design team and selection of the best suite of options for design
- Project execution plan and schedule

The DBM includes declaration of normal operating conditions, extreme events (such as major storms) and a prediction of the intended performance. A comment on the expected performance in case of a “beyond design-basis event” (e.g., a precipitation event larger than anticipated in the design) is included (see Section 6.8.2).

Design objectives should be achievable and measurable and most are met during the design phase, with some to be met in the construction and reclamation phase. Others are performance-based. Needs and requirements are typically framed as design objectives. Table 6-2 provides a hypothetical example of a suite of design objectives to provide the design team with typical examples, formats, and the breadth of design objectives.

As indicated in Section 5.1 and Figure 1-9, the operators’ main goal for mine reclamation is to eventually receive a reclamation certificate for the land, either in a progressive fashion for individual blocks of land, or for the site as a whole. This is the overarching objective.

**Table 6-2. Examples of landform design wetland objectives.**[4]

| Category | Example design objective (for a hypothetical marsh) | Design | Construction | Performance |
|---|---|---|---|---|
| Land use/target wetland type | Create approximately 0.5 ha (normal water level) to 1 ha (beaver flooded) area for wildlife habitat and landscape diversity | | | |
| Planning/ management/ operation | Earthworks designed to be completed in one twelve month period with initial revegetation the following year | | | |
| | Provide Class 3 (good when dry) access from west haul road to wetland outlet for monitoring and maintenance | | | |
| | Provide Class 5 (footpath) access around the wetland perimeter for inspections | | | |
| | Provide a small pier near outlet for water quality sampling and boat access for monitoring | | | |
| | Use landform grading to make any berms have natural appearance (Schor and Grey, 1995) | | | |
| | Substrates and sequencing to allow safe and efficient access to all wetland areas for 40t trucks and D6 dozers | | | |
| Geotechnical | Wetland banks designed to be stable during a 1 in 100-year design flood event | | | |
| | Wetland designed to accommodate 1 m of settlement of underlying fill | | | |
| | Wetland designed can contain beaver ponds created by 3 m high beaver dam at outlet with 0.5 m residual freeboard; beavers likely to change type of wetland to a shallow-water wetland | | | |
| | Ability to lower outlet invert elevation by up to 1.0 m in the event of excessive settlement of base of wetland | | | |
| | Wetland substrate has sufficient bearing capacity to avoid miring a moose | | | |
| Surface water, groundwater, and topography | Outlet designed to provide a minimum of 5,000 m$^3$/year of water to end pit lake based on simulation using 1944-2013 climate data | | | |
| | Wetland designed to flush every year (at least one water volume) based on simulation using 1944-2013 climate data | | | |
| | Average still water depth <0.5 m in the absence of beaver dam at outlet. (It is assumed beaver will be controlled until the beginning of the certification qualification period. There is risk that the wetland leakage rate will allow the wetland to dry up in some years and this condition is deemed acceptable and need not be repaired). | | | |
| | Wetland designed to have minimal erosion during 1 in 100-year design flood event | | | |
| | Wetland designed to accommodate up to 1,000 m$^3$ of sediment deposition at inlet | | | |

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[4] This table generated numerous comments from reviewers, some suggesting more details, some less, some more corporate approaches, some more multi-party approaches. The main message is that for designed wetlands, objectives should be clearly stated and the designs should steward to them, as is the case for most other engineering designs, but uncommon in mine reclamation.

| Category | Example design objective (for a hypothetical marsh) | Design | Construction | Performance |
|---|---|---|---|---|
| | Rip rap outlet designed to control water level and designed to withstand 1 in 100-year design flood event | | | |
| | Provide a combination of steep (>25% slope) and shallow (<5% slope) transition zones from upland to wetland | | | |
| | Create a wetland perimeter with a shoreline development index of approximately 1.2 to 1.3 | | | |
| | Wetland can be flooded between May 15 and 30 following revegetation to maintain viability of wetland plants. | | | |
| | Two nested standpipes installed though wetland near outlet to measure seepage gradients | | | |
| | Staff gauge with pressure transducer and EC meter installed near outlet to measure water level and quality | | | |
| | Outlet water conductivity < 2,000 µS/cm by end of Year 2 | | | |
| | Water quality within the wetland meets the CCME guidelines for protection of aquatic health (or passes ecological risk assessment if required) | | | |
| Soils | Reclamation materials meet the requirements for upland forest in terms of thickness and quality: 1 m thickness of suitable overburden overlain by 0.5 m coversoil | | | |
| Vegetation | Native wetland vegetation is established for a marsh ecosystem. By end of declining maintenance phase<br>75% cover by native herbaceous species in emergent areas<br>3 woody species with 5% cover<br>Less than 10% coverage by non-native invasive species<br>3 species suitable for traditional use | | | |
| | Plant and establish a riparian zone around perimeter of wetland | | | |
| | Establish continuity of vegetation with adjacent lands | | | |
| Wildlife | Create a two-peninsula island for bird nesting habitat, install five nest boxes for ducks, install four snags as raptor perches and three rock piles for small mammal habitat | | | |
| | Locate wetlands less than 500 to 1,000 m apart for landscape level wildlife connectivity | | | |
| Infrastructure | Create peat stockpile within 100 m to reclaim access road when no longer required | | | |

### 6.2.7 Securing access

The design team secures access to the wetland and watershed prior to major design work. While this seems obvious and perhaps an unnecessary bureaucratic step, failure to do so often ends in costly rework if others have designs and uses for the land in question. Mines typically develop their own process for transferring custodianship of lands between operating groups. Even with control of the land, mine and tailings plans will change and designs may need to be adjusted or abandoned. Where there is nearby mining or tailings activity, it may be necessary to physically block access to the project. It may be necessary to wait a year or two for tailings operations to leave to avoid unintended tailings deposition in the wetland area (Pollard et al., 2012).

## 6.3 Initial watershed design

### 6.3.1 Introduction

The closure plan provides the conceptual design of the watershed (see Section 5.2) and is integrated into the lease-scale closure design (An et al., 2013). The general locations of the wetland and expected hydrology have been predicted. Focus now shifts to more refined elements, such as shorelines and revegetation plans. Hydrological models that include even finer details can be run without the data and computational challenges associated with large, lease-scale modelling. Optimizations to designs are also made at this stage. For example, the design team may recognize that the extent of the surface watershed and that of the groundwater reporting to a wetland differ considerably (Devito et al., 2012). This complication should be factored into the watershed design.

The design team names the various elements of a reconstructed watershed — e.g., Fen No. 7, the South Berm, the Outlet, Island A, Island B, etc. Choosing these names carefully and using the exact names in design, construction, reporting, and monitoring makes documentation and communication simpler and avoids confusion.

This section on watershed design is aimed at designed wetlands. Considerations for semi-designed and opportunistic wetlands are in Section 6.7.

### 6.3.2 Bulk landform design

The initial landform design is typically prepared by mine and tailings planners and geotechnical engineers with key input from other team members. The focus is on footprint and volume. The closure plan design provides the starting point and a list of design issues, but at this point, the detailed design is usually started from scratch. The constraint map (Section 5.2.12) is a key tool at this stage and is revised throughout the design process.

The poor foundation conditions in many areas of the mineable oil sands require relatively flat slopes compared with most mining landforms elsewhere. The observational method (Peck, 1969; Morgenstern et al., 1988) is used for most dump and dyke designs and construction and the landform design often changes considerably during the decades of construction, often to foundation movements (or lack thereof).

For dumps, the main focus is on storing as much overburden and interburden in as small a footprint and as close to the mine as possible. Stability analyses will determine the steepest practical slopes. Various configurations are modelled geotechnically using mine-planning software. The resulting topography usually has fairly straight toes and benched slopes, capped with a flat constant height or constant-elevation plateau.

For external tailings facilities, ring dykes are common and may be constructed of a combination of overburden, interburden, and tailings sand and may have internal drains to control pore-water pressures or the location of the water table. During construction of the dyke, tailings are typically hydraulically placed (beached) from the inside dyke crest to form long beaches and water filled tailings ponds. Beach and pond areas within the dyke are often not trafficable because of soft tailings, and the plan will call for a nominal 5 m sand cap beached at a constant angle from the perimeter dykes. (The actual sand cap will be much more variable in thickness.) The dykes will generally be terraced up to a final dyke crest elevation. The beaches will be designed with a constant slope angle (often 0.5%) towards an internal sump located adjacent to the final outlet.

In-pit tailings involve first mining overburden and oil sand ore, then backfilling with tailings. Pits are typically 50 to 80 m deep. There are usually internal dykes to allow tailings deposition as mining expands the pit. The central areas are typically soft tailings, again capped with a nominal 5 m sand cap with 0.5% slopes towards an internal sump located near the final outlet. Often low dykes are built around some or all of the perimeter of the pit to increase storage volumes. BGC (2010) and OSTC (2012) provide overviews of oil sands tailings technologies. The geotechnical stability of dykes and dumps is paramount and dominates technical considerations for all iterations of landform design.

A placement and filling schedule is put in place. A first estimate of settlement patterns for dumps and soft tailings is mapped. This first landform-scale design, usually as a three-dimensional topographic surface, is then shared with the rest of the design team.

### 6.3.3 Surface water drainage and topography

The major drainage locations are set by the closure plan. The topographic surface is adjusted first to ensure good drainage from the top of the landform (plateau) down the slopes to the original ground. Most of the remaining design is governed by surface water hydrology and its impact on the topography. Critical geotechnical buffer zones are added near crests (see Section 5.3.2.4), which are the first restrictions on any ponded water. These zones tend to be much smaller and less restrictive for dumps than for dykes.

The surface water drainage system is usually the primary integrating factor for watershed design. The single most important consideration is the wetland/watershed outlet location and elevation (McKenna and Cullen, 2008) for the simple reason that the rest of the watershed needs to flow to this point (Section 5.2.5). For landform design, the outlet elevation needs to be selected to the nearest 0.1 m and the plan location of the outlet invert to the nearest 10 m.

The main wetlands shown in the closure plan are roughed into the design at this point, typically simply drawn onto the map. Next, areas of expected settlement for soft tailings are examined and wetlands added if not already anticipated. Surface water drainage for slopes is roughed in and watershed berms are added near the outside crest of the plateau. The drainage channel at the toe of the slope (toe creek) location is typically already determined in the closure plan.

For dump design, the next step is to divide the plateau into small (typically 10 to 50 ha) dish-shaped sub-watersheds, with ephemeral drainage to the toe of the landform.

A sand cap is designed to provide trafficability on the soft tailings plateau. The cap will also create large upland areas to minimize the risk of water ponding in the geotechnical critical zones as well as buffer zones (Section 5.3.2.4), enhance the recharge for downstream fens, and create upland ecosystems (and commercial forest). Upland “hummocks” roughed in during the closure plan are refined now. The lowlands will be fens in the groundwater seepage discharge zones that have ephemeral flows, marshes in areas with shallow settlement, and shallow-water wetlands (and in some cases reclamation lakes[5]) where settlement is expected to be greater. These wetlands are sketched onto the map.

Next, areas suitable for semi-designed wetlands are identified (Figure 6-14). Debate among surface water hydrologists and geotechnical engineers regarding inclusion of such features on dump plateaus or slopes is likely (Figure 5-9). Areas that may expect opportunistic wetlands are highlighted (Figure 6-15).

See Section 5.2.7 for guidance on sizing wetlands. Table 3-6 provides sizes of marshes in the region and Figure 6-16 provides examples of fen sizes, which can be much larger.

### 6.3.4 Groundwater

The geotechnical and surface water specialists have received input from groundwater specialists, but it is at this point that the groundwater is considered more formally, often with some simple steady-state modelling of local conditions that builds on the landscape closure plan groundwater model. Areas of high water tables and zones of expected groundwater discharge are mapped in plan view and an estimate of steady state baseflow discharge rates is made along with a seepage water quality prediction. Wetland extents are adjusted.

### 6.3.5 Soils, vegetation, and wildlife

An initial map of the reclamation soil cover (based on the EPEA approval conditions) is set out and ecosystems for revegetation tentatively mapped in. Adjustments for wildlife habitat may be made. Wetlands and vegetation should be designed first to support a functioning ecosystem that provides habitat, connectivity, and other needs for a range of organisms. Species-specific enhancements may be added, but individual species can only survive if the entire system is in place. See Chapter 3 and Appendix D for guidance on reclaiming wetlands for wildlife.

### 6.3.6 Iteration

After a few more checks using rules of thumb and simplified modelling, further adjustments to the base case design can be made. The design team should be reasonably confident that the new design is on track to meet the objectives set out in the DBM. There is now a new base case design that has a surface, the drainage courses and wetlands laid out, with the soil and vegetation cover selected to the degree that detailed modelling of the watershed in support of detailed wetland design can begin in earnest.

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[5] For this guide, reclamation lakes are defined as constructed waterbodies in the oil sands that have significant areas that are more than 2 m deep but do not otherwise meet the criteria as an end pit lake as outlined by CEMA (2012).

## 6.4 Detailed watershed modelling

Modelling in support of design is the next step. Rules of thumb are set aside in favor of detailed predictions and designs now available to the team.

### 6.4.1 Geotechnical

The stability of landform slopes (dumps and dykes) is a precondition to good landscape performance (e.g., McKenna, 2002). Ponded water, high pore-water pressures, and seepage are usually root causes of geotechnical instability (landslides, in particular), giving geotechnical engineers a necessary role in design.

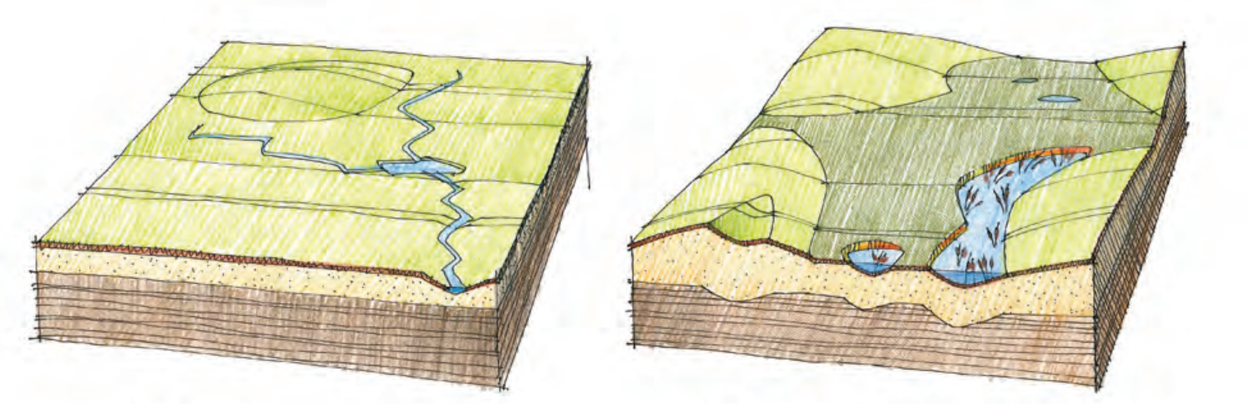
There is a large body of experience for dyke and dump slope designs, and the practice is mature. Slope designs may be changed during construction to take advantage of good performance or to accommodate slope movements. Construction of low embankments on soft tailings (and some “junk fills” in overburden dumps) is more challenging and a combination of analysis, experience, and field trials is often employed. Geogrid slope reinforcement is sometimes used to provide temporary stability on these soft materials. Models will explicitly evaluate the impact of ponding water near slopes.

Seepage-gradient calculations will be used to design against tunnel erosion (piping).

Settlement of soft tailings is typically predicted using one-dimensional finite strain consolidation modelling (e.g., Pollock, 1988; Pollock et al., 2000), based on a combination of laboratory consolidation data and local experience (Jakubick and McKenna, 2001). Different tailings types and thicknesses will settle different amounts and at different rates.

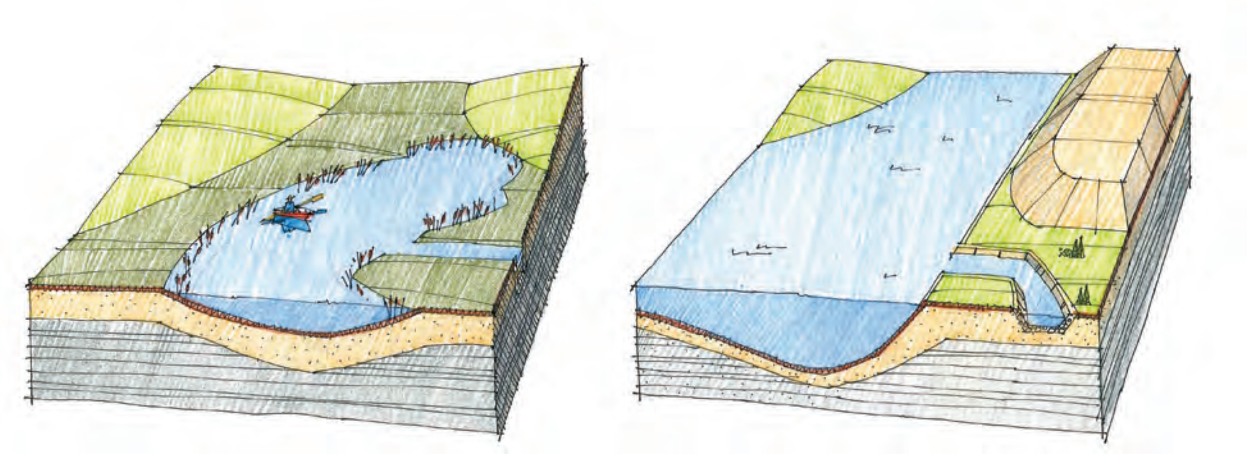
Measurement of settlements and pore-water pressures in the area of interest are used to calibrate the model to actual site conditions. Maps of predicted ultimate settlement are produced for design and dictate the ultimate wetland extents. Settlement within the watershed expresses tailings pore-water, which affects the baseflow and quality of water entering the wetland.

Soft tailings settlements have a profound impact on wetland design, affecting the size and shape of the lowlands and their water chemistry (See Figure 6-2). Settlement of several metres or more over decades is common.



<0.5m settlement
Fen

0.5 - 1m settlement
Marsh



1 - 2m settlement
Shallow-water wetland

>2m settlement
Reclamation lake

**Figure 6-2. Soft tailings settlement and expanding wetlands.**

Settlement of dump fills is predicted empirically from local and international experience (Section 5.3.2.1). Little on the subject has been published with respect to oil sands. Post-reclamation settlement of dump fills is a combination of elastic settlement, consolidation, creep, and first-time wetting collapse. The degree of settlement is a function of the plasticity of the dump materials and their placed density (higher plastic, loose fills settle more than lower plastic compacted fills). Settlement can occur soon after placement or may take decades or longer to manifest. Predicted ultimate post-reclamation settlement is usually expressed as a percentage of initial dump/dyke total fill thickness.

> For dense sandy fills, settlement is generally less than 1%.
>
> For dense clayey (high plastic) fills, settlement is typically less than a few percent, but for loose high plastic fills can reach 4 to 8%.

Typical settlements for 40 m high dumps of Clearwater Formation, glacial fill, and lean oil sands are commonly estimated at about 2 m (5%).

Dumps contain a variety of materials of differing moisture contents, density, and strengths. Though methods to reduce the extents and amount of dump settlement are available, it would be difficult to design all dumps as highly engineered structures that limit settlement.

Differential settlement has a profound effect on the dump/dyke hydrology:

> Dump settlement often causes or exposes sub-vertical cracks in the fills that affect hydrology. Sinkholes are observed infrequently. Such features may prevent wetlands from filling with water. Building liners on settling fill is expensive and long-term reliability is questionable. Some increased compaction and use of geogrid in near-surface materials may allow wetlands to form. Should the wetland drain, the area will revert to upland forest.
>
> Such settlements will produce opportunistic wetlands. Watersheds are designed with watershed berms (also called snaky berms, bunds, or horseshoe berms) to stop this ponded water from flowing over a dump crest and causing erosion.
>
> Formation of wetlands in a settled area may change the water balance for the watershed dramatically, may enhance net percolation and ultimately enhance rates of salt release from the landforms, potentially affecting downstream aquatic ecosystems.
>
> There are opportunities to create semi-designed wetlands on dump plateaus that will both promote and take advantage of settlement (Section 6.7.1)

Liners and underdrains may be required to control water fluxes in wetlands. Consideration must be given to the longevity of any liners or drains. The effects of frost, root penetration, settlement, and other factors are considered in design (e.g., Pollard et al., 2012). Usually use of liners is avoided. Closure planning can be used to create conditions where liners and/or underdrains are unnecessary. Liner and under-drain designs are usually prepared by geotechnical engineers. In some cases, temporary reliance on liners can be used to help speed early wetland reclamation success (e.g., Russell et al., 2010).

Beaver dams and other activities have caused large landslides, dam breaches, and washout of downstream structures, in some cases causing human deaths (see Section 5.2.10). The potential for beavers to dam outlets is a constant risk factor in design (Eaton et al., 2013).

Dam delicensing for reclamation certification is a new activity (Oil Sands Tailings Dam Committee, 2014). Wetlands are designed to avoid triggering landslides (mainly by having large enough offsets from slope crests) and causing outburst flooding (by avoiding ponding too much water). If wetlands are too large or too deep, they may be considered reservoirs held by dams, precluding reclamation certification. Constructed water bodies more than 2.5 m deep with volumes of more than 30,000 cubic metres are presently classified as reservoirs with dams under the Dam and Canal Safety Guidelines (Alberta Environmental Protection, 1999), limiting the construction of such marshes in many instances. In addition, designs must avoid causing the wetlands to overtop if a catastrophic release of water or mobile materials could result.

Geotechnical critical and buffer zones are identified near the crests of dams (Küpper, 2013) and dumps. Designs are adjusted such that there is a low probability of water ponding in these zones. Areas within these buffer zones are not suitable for wetlands. Dam-breach analyses can assess potential downstream impacts of sudden release of a wetland, especially those of a failed beaver pond at the wetland outlet. Generally, the critical zone and buffer zone will be designed to minimize this hazard, avoiding the need for such analyses.

Bearing-capacity calculations (after Terzaghi and Peck, 1948) can estimate trafficability for reclamation equipment, end land uses, and wildlife. Jakubick and McKenna (2001) provide guidance on soft tailings trafficability. The issues are generally resolved through good design of the capping layer or capping with more than 2 m of water to avoid miring wildlife (e.g., Chamberlin, 1971 and 1975; Associated Press, 2010).

## 6.4.2 Surface and groundwater hydrology

### 6.4.2.1 Overview

Landform-scale surface water hydrology and groundwater hydrogeology (Chapter 2) use the “boundary conditions” from landscape-scale modelling produced for the closure plan. Modelling at the landform scale is used to design the watershed and the wetland. While each team will have a preferred method, the following approach is typically used for designed wetlands:

The dataset for the Environment Canada Fort McMurray Airport climate station offers a continuous daily record since 1944. Some hydrologists modify the data for elevation and latitude for their watershed. Data from a number of research climate stations in instrumented watersheds may also be used.

Upland net percolation (groundwater recharge) is modelled using coupled soil-atmosphere models. Models are calibrated for various substrate, soil and vegetation conditions based on data from instrumented watersheds (e.g., Barbour et al., 2004; Syncrude Canada, 2004; Hilderman, 2011).

Surface water flows are modelled using calibrated streamflow simulations. Models are calibrated against large natural catchments and small, instrumented watersheds. Water quality modelling may use the same simulation programs or simple spreadsheets.

Groundwater is modelled using calibrated transient three-dimensional models. Fluxes to and from wetlands are estimated. Contaminant transport models may be employed in special situations (but many contaminants can be assumed to be conservative).

The three models (net percolation, surface water and groundwater) are run independently and the results from all the models are used iteratively to update the other models as needed.

For design of certain wetland elements, special detailed models with small time steps may be employed.

Climate change scenarios are usually only considered at the closure planning scale. For individual wetlands and watersheds, observed decadal variations in climate (Devito et al., 2012) are presently expected to be greater than expected climate change impacts.

The existing approach, using data from instrumented watersheds, is typically sufficient for reliable watershed and wetland design. Inherent geological uncertainty in substrates, soils, and the performance of vegetation typically overwhelms the uncertainty of climate change and the weak coupling of the water models, and designs should be robust enough to overcome this uncertainty (McKenna, 2002). Research to couple the net percolation, surface water, and groundwater models, and to refine the models and datasets, is ongoing.

Semi-designed wetlands and opportunistic wetlands are not typically modelled (see Section 6.7). Designs are based on expert judgment and simple rules of thumb, many derived from watershed modelling and other designs.

Modelling is computationally demanding, and additional activities at the landform-level of design are used to address specific questions about landform. For instance, in cases where local- and intermediate-scale groundwater flow patterns are expected, a landscape-level model may not fully capture the groundwater discharge and recharge from a wetland. Contaminant transport is also better captured at a more local scale, where additional details can be included regarding source zones and flow paths. Regional models may require many assumptions or coarser model resolution, possibly oversimplifying transport considerations.

At this level of design, different options for topography of the watershed can be tested, and different hydrological conditions explored. Based on the available area, flow directions can be modified to some degree, and models can provide guidance on appropriate locations for major wetland elements, such as inlets, outlets, and water levels.

A detailed water balance (Section 2.2.1) for the watershed itself is developed at this stage to understand the hydrogeological regime and the gains and losses of water by the wetland itself during the early years of establishment. This is important for identifying dry periods and introducing mitigation options, such as fresh water supplies and liners (Pollard et al., 2012).

#### 6.4.2.2 Net percolation

The behaviour of the soil-atmosphere interface is complex (Ayres and O’Kane, 2013). Most of the region’s precipitation infiltrates and later evapotranspirates. Up to 20% of annual precipitation falling on reclaimed land reports as net percolation, which may discharge upstream of, or into, the wetland. The fraction reporting as net percolation varies with time as the soil cover and vegetation matures (Barbour et al., 2007; Lamoureux et al., 2012) and even more dramatically from year to year (Tallon et al., 2009).

There is value in decoupling the soil-atmosphere aspects of cover from the water table (Shurniak et al., 2008) by designing the water table to be well below the soil cover in upland areas (Pollard et al., 2012). It is also useful to take advantage of the effects of thick unconfined aquifers (such as tailings and caps) to smooth the annual responses and provide a steady supply of baseflow to wetlands (Price et al., 2010), especially for reclaimed fens.

#### 6.4.2.3 Surface water modelling

Continuous streamflow models can estimate surface water flows. This type of model is generally deterministic and continuously accounts for physical processes, such as precipitation, runoff, infiltration, evapotranspiration, interflow, deep percolation, baseflow, and streamflow (Viessman and Lewis, 1996). Various tools to simulate streamflow are available, established, and vetted. Popular codes for continuous streamflow simulation include the Stanford Watershed Model (SWM), Hydrological Simulation Program – Fortran (HSPF), Système Hydrologique Européen (SHE), and Topography-Based Hydrological Model (TOPMODEL). While formulations differ, each can represent the land phase of the hydrologic cycle and produce a hydrograph at the watershed outlet (Viessman and Lewis, 2002).

Streamflow models have been used successfully in wetland design (Konyha et al., 1995; Thompson et al., 2004). Separate physical components in the watershed can be included or excluded, providing an early high-level assessment of water flows within the system. Their utility stems in large part from the fact that they depend on the solution of a simple water balance. That is, all inflows, outflows, and changes in storage of water in the model domain must be accounted for before proceeding to the next time step. Despite being developed decades ago, models such as HSPF and SWM are conceptually sophisticated, represent hydrological processes with correct interrelationships following empirical rules, and allow for evaporation to be modelled quasi-spatially (Ward and Robinson, 2000). HSPF and SWM are widely used in the oil sands region (e.g., Golder, 2003).

Conceptual models are data-intensive and published data for reclaimed watersheds in the region are scarce. However, conceptual streamflow models are still instructive at the design stage as they can alert the planner to issues that will require detailed attention as the wetland is being constructed (Ward and Robinson, 2000).

Interflow is an important aspect of cover design for oil sands watersheds, especially dumps (Meier and Barbour, 2002). But it plays only a small role in wetland water balance. Water balance data from reclaimed instrumented watersheds is particularly useful for these models.

> Dobchuk et al. (2013) and Barbour et al. (2007) describe the Syncrude 30 Dump instrumented watershed, a reclaimed overburden dump with two marsh wetlands and one shallow-water wetland.
>
> Price (2005) describes the Syncrude SWSS Instrumented Watershed, which at the time had several wetlands on a reclaimed tailings sand dyke.
>
> Russell et al. (2010) describe the Suncor Wapisiw Lookout (Pond 1) watershed and Wapisiw Marsh on a reclaimed tailings sand plateau.
>
> Daly (2011) and Daly et al. (2012) describe the Suncor Nikanotee Fen instrumented watershed with a reclaimed fen over tailings sand.
>
> Pollard et al. (2012) describe the Syncrude Sandhill Fen instrumented watershed that contains a reclaimed fen and two perched fens on tailings sand-capped soft tailings.
>
> Fenske (2012) describes the Syncrude petroleum coke watershed project on a reclaimed coke beach.

Barbour et al. (2007) provide a synthesis of information to 2007 for a reclaimed overburden dump. It is anticipated that more data will become available as more theses on these watersheds are published and the data synthesized. Elshorgagy and Barbour (2007) and Elshorbagy et al. (2005) provide an overview of a probabilistic modelling approach. Most of the instrumented watersheds are being monitored intensely and additional data and papers can be anticipated.

#### 6.4.2.4 Groundwater modelling

The distinction between groundwater and surface water is artificial, as much of the water moving through the landscape transitions back and forth depending upon landscape position (e.g., Devito et al., 2012). Surface water and groundwater are described separately as they are usually modelled separately.

Most wetlands will be designed in groundwater discharge areas, as indicated during closure planning modelling (see Section 5.2.3). There are numerous commercial models available. Hydraulic conductivities and storage values for many fill units are presented in Section 2.5.

Groundwater modelling is used at the landform scale to understand:

- Changes to pore-water pressures for geotechnical slope stability;
- Location of the water table with time (initial draindown or wet up, seasonal, decadal);
- Location of “wet” areas (initial draindown or wet up, seasonal, decadal);
- Rates and locations of seepage discharge;
- Water quality/flushing; and
- The water balance/input to surface water modelling.

Three common situations involving groundwater modelling provide several insights.

- Large tailings sand dykes with internal drains help understand groundwater conditions on the beaches and slopes, but modelling is complicated by uncertainty in long-term internal dyke drain performance and complex permeability patterns in the lower beach areas (Price, 2005).
- Sand-capped soft tailings deposits help understand the performance of the hummocks over time, though modelling is complicated by consolidation of capped soft tailings (expression of consolidation water, and high localized pore-water pressures, changing permeability) (Pollock et al., 2000; Pollard et al., 2012; Price et al., 2005).
- The complex hydrogeology of reclaimed waste dumps comprised of Clearwater Formation clay shale and McMurray Formation lean oil sands makes predicting seepage water quantity and quality into and out of wetlands difficult. Chapman (2008) provides a case history of these complexities, including the impact of large unsaturated zones, swelling of clays upon first-time wetting, and the large and changing network of construction and settlement-induced fracture patterns in these dumps.

Wetland designs need to accommodate the inherent uncertainties in this type of modelling. Recent research is available on modelling of flushing of oil sands tailings sand and attenuation of naphthenic acids (e.g., Gervais and Barker, 2004).

#### 6.4.2.5 Modelling of wetland water-level fluctuations

Water level in peatlands is a function of the amount of water stored in the underlying soil. Water storage is in turn a balance between precipitation, evapotranspiration, and groundwater discharge and recharge (Gong et al., 2012). Typically, modelling efforts directed at understanding water table fluctuations have focused on the balance of precipitation and evapotranspiration. Given that highly non-linear processes at the soil-atmosphere interface need to be simulated, modelling efforts focus on water table dynamics under climatic forcing using soil-vegetation-atmosphere transportation (SVAT) models (Gong et al., 2012). The SWAP model (Spieksma et al., 1997) uses formulations of Richard’s equation for subsurface changes in conductance, along with the Shuttleworth-Wallace model for simulating atmospheric transfer. Models such as HYDRUS-1D and VADOSE/W can be used to model non-linear changes in peat transmissivity and mass and energy exchanges with the atmosphere (Schwärzel et al., 2006). The Hollow-Hummock (HOHUM) model has been used to demonstrate the influence of topography on water table fluctuation by simulating hummock and hollow structures in wetland areas (Nungesser, 2003).

One-dimensional models emphasize the exchanges of mass and energy at the interface between the soil and atmosphere. However, the lateral movement of water within the wetland also strongly affects water table levels (Gong et al., 2012) and may be of greater importance to hydroperiods in the oil sands region (Devito and Mendoza, 2008; Devito et al., 2012). In the case of large-scale models, gridded streamflow models used for surface flow have been used to simulate redistribution of water, albeit with simplified formulations of SVAT-based feedbacks (Gong et al., 2012). The balance required between rigorous simulation of SVAT processes at small scales, and large-scale simulations of lateral water movement emphasizes the need for a strong conceptual framework and a clear understanding of a model's strengths and weaknesses.

### 6.4.2.6 Modelling water quality

Figures 6-3 and 6-4 provide conceptual models for wetland water quality. Figure 6-5 shows a summary of research regarding typical oil sands reclamation salinity and potential impacts.

Water quality modelling for wetlands typically involves a spreadsheet-mixing model but more complex methods are available. Seasonal variation in wetland water quality may be important to design.

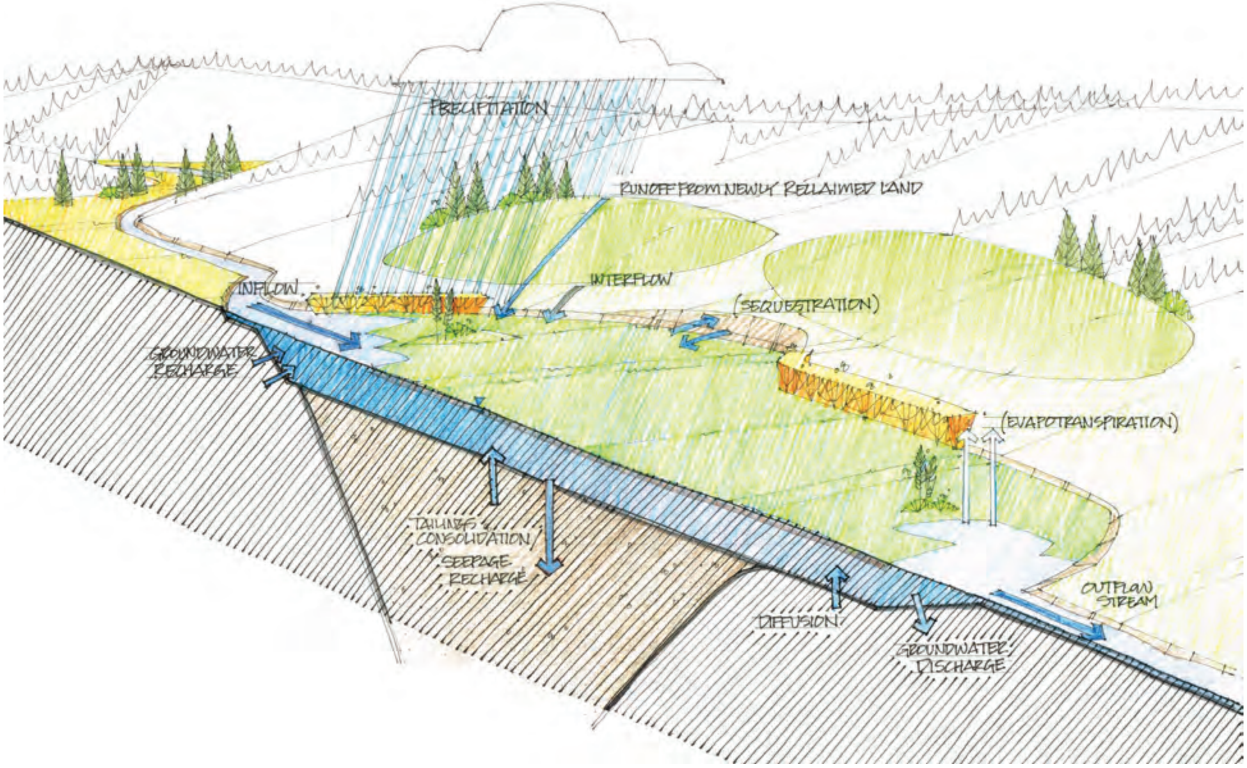


**Figure 6-3. Salt inputs and outputs to reclaimed wetlands.**

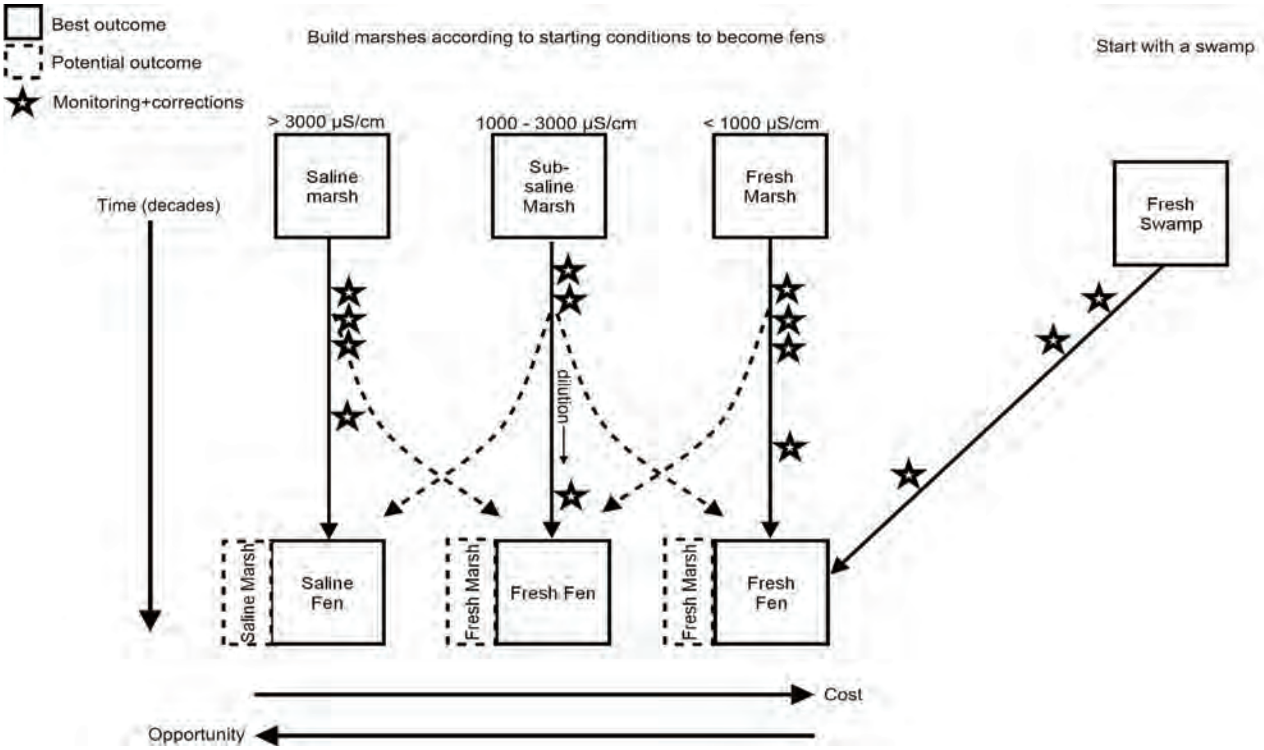


**Figure 6-4. Wetland evolution with decreasing salt inputs.**

Table 6-3 provides an example of a simple annual water balance. Modelling would run on a narrower time step and may allow different inflow concentrations with time (seasonally and over decades) if data are available. Figure 6-3 provides an overview of salinity.

The Oil Sands Reclamation Wetland Model (OSRWM) was established as a predictive water quality model for reclaimed wetlands in the oil sands landscape (CEMA, 2006). The OSRWM identified how different physical, chemical and climatological factors influenced levels of salinity in oil sands reclamation wetlands. According to the OSRWM (CEMA, 2006):

Initial concentrations of salts were most sensitive to:

- Changes in overburden area
- Sand cap placement timing
- Tailings type
- Water quality of the initial filling source.

Over the long term, salinity levels were most sensitive to:

- Changes in overburden, sand and gravel areas
- Timing of tailings placement.

Peak concentrations of salinity were sensitive to:

- Wetlands surface area and depth
- Ice thickness
- Ice cover period.

Climatological factors such as net evaporation rate and long-term changes in precipitation will have little effect on salinity. However, concentrations of conservative water quality constituents are predicted to rise in response to drought (CEMA, 2006). Improving wetland input water quality through modelling and design might include the following strategies:

- Enhance surface water runoff (unit fluxes and large surface water watershed)
- Incorporate runoff from natural areas (fresher)
- Minimize tailings seepage into wetland
- Control tailings water quality
- Minimize overburden seepage into wetland
- Reduce deep percolation in watersheds (to reduce groundwater discharge rates) through landform and cover design (evaporative covers, minimize wetland area, minimize interflow)
- Perch or underdrain the wetland (to minimize seepage discharge into wetland)
- Wait: input water quality will often improve with time.

Recently, OSRIN funded work on a new watershed hydrology model that may be useful to designers (see Watson and Putz, 2013).

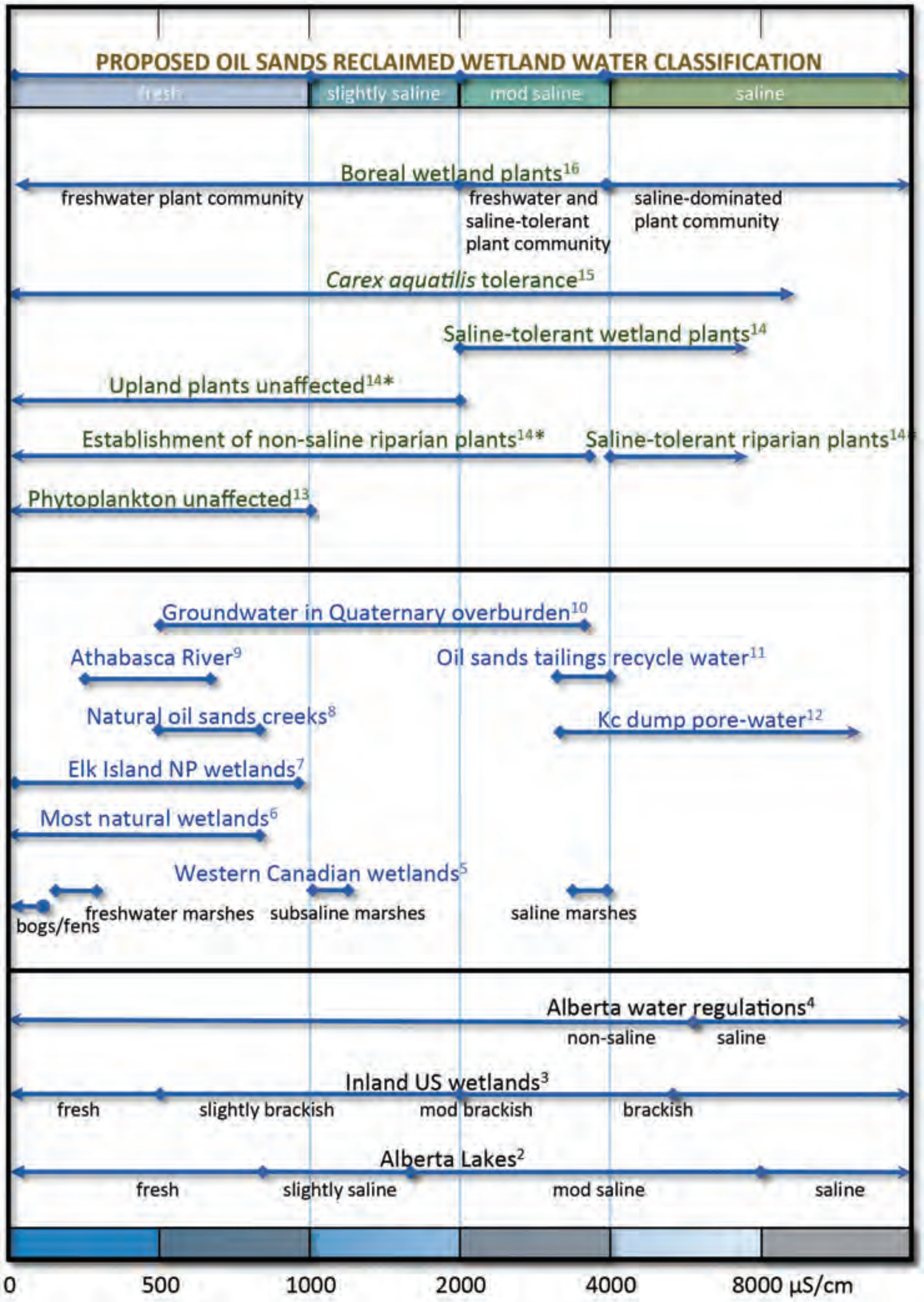


**Figure 6-5. Water or pore-water electrical conductivity (EC, modified log scale).**[1] Note that the "Proposed oil sands reclaimed wetland water salinity classification" is a roll-up of plant tolerances at the top of the figure and is largely based on Vitt et al. (2013).

1. Mitchell and Prepas (1990). A typical conversion is Total dissolved solids = TDS (mg/L) = 0.62 EC (µS/cm) but varies with the types of ions. 0.62 is fit from Alberta Lake data and fits within a common range of 0.55 to 0.80 employed internationally.
2. Mitchell and Prepas (1990) for Alberta Lakes: Total dissolved solids (TD): fresh 0-500 mg/L, slightly saline 500-1000 mg/L, moderately saline 1000-5000mg/L, saline >5000 mg/L
3. Cowardin et al (1979)
4. Alberta Water (Ministerial) Regulation 1998(2013). Saline waters TDS >4000 mg/L.
5. See Tables 3-x and 3-y this guide (based on work by Bayley et al)
6. Golder (2003)
7. Nicholson (1995)
8. From various EIA submissions for creeks and rivers in oil sand region.
9. From various EIA submissions for creeks and rivers in oil sand region.
10. From various EIA submissions for creeks and rivers in oil sand region.
11. Allen (2008a,b). TDS commonly 2000-2500 mg/L. Varies with time and by operation.
12. Chapman (2008)
13. Purdy (2005)
14. Hayes (2005)
15. See Chapter 4 this guide
16. See Chapter 4 this guide
17. Gibson et al.

**Table 6-3. Illustrative simplified water and salt balance for a hypothetical 2.9-ha marsh in a 31-ha reclaimed overburden watershed.**

| | Average water flux to wetland $m^3$/yr (mm) | Salt concentration mg/L | Salt load tonne/yr | Comment |
|---|---|---|---|---|
| Inlet flux (inflow) | 17,000 (589) | 1,200 | 20.4 | Ephemeral inlet stream from reclaimed watershed |
| Reclaimed overland flow flux | 6,600 (229) | 1,000 | 6.6 | Overland runoff direct to wetland |
| Tailings substrate discharge flux | 0<br>(0) | 2,500 | 0.0 | No tailings in watershed |
| Overburden discharge substrate | 800<br>(28) | 9,000 | 7.2 | Net percolation in watershed leading to groundwater discharge in wetland |
| Interflow discharge flux | 20<br>(1) | 5,000 | 0.1 | Interflow from cover/substrate interface above wetland |
| Direct precipitation | 12,994<br>(450) | | 0.0 | Annual precipitation on wetland surface |
| Direct evapotranspiration | -15,881<br>(550) | | 0.0 | Annual evapotranspiration from wetland surface |
| Net flux to wetland | 21,533<br>(746) | | 34.3 | Summation |
| Average salt concentration in wetland | | 1,593 | | Perfect mixing, average through year (over simplification) |
| Losses to groundwater recharge | -1,400<br>(-48) | 1,593 | -2.2 | Loss to bank seepage recharge in one area |
| Outlet flux (outflow) | 20,133<br>(697) | 1,593 | 32.1 | Outflows to EPL |

### 6.4.3 Erosion and deposition

Wetlands are generally designed as deposition areas, with flow velocities low enough to avoid eroding wetland reclamation material and substrates. Some wetlands, however, will have large watersheds, and channelization through the wetland may be problematic.

Wetland design considers three aspects of erosion:

Sediment carried into the wetland from the upstream watershed

Erosion of wetland reclamation material and substrates

Wind wave erosion of wetland shorelines.

Erosion is a natural process and in some cases is beneficial to landscape performance. In some cases, erosion may lead to:

Undercutting of banks leading to slumping/landslides

Loss of containment, loss of water contents laterally

Suspended sediment leading to poor water quality in the wetland and downstream

Deepening of wetland

Redistribution of cover soils, exposure of mine wastes

Downcutting of outlet and drying out of wetland

Deposition causing shallowing of water, avulsion, or changes to general morphology.

For prediction of sediment loads carried into wetlands, there are dozens of erosion-rate prediction models, but few if any are useful for mine reclamation (McKenna, 2002). Two methods widely used in North America are sheet flow models: the Revised Universal Soil Loss Equation (RUSLE) (USDA Agricultural Research Service, 1997); and the Water Erosion Prediction Project erosion model (WEPP) (Flanagan and Nearing, 1995). Research models that deal with gully erosion include Sidorchuk, (1999), Woodward (1999), and Kirkby and Bull (2000). Trimble and Crosson (2000) prefer erosion models over design or regulatory tools. Most erosion in reclaimed oil sands areas occurs via gully erosion, where highly erodible substrates (such as tailings sand and Clearwater Formation fills) can produce large amounts of sediment. Delaying placement of wetland reclamation material until the adjacent uplands are covered with their initial vegetation may be warranted in some cases, or some maintenance should be expected. McKenna (2002) presents a method to determine offsets for wetlands and critical riparian areas to avoid fan deposition from upland gully erosion.

Deposition of eroded material can be a concern, but has not proven problematic. Inlets are designed to accommodate deposition from upstream. Deposition of windblown sand and silt (“dusting”) may be a design or operational issue for nearby exposed tailings beaches.

Two design approaches for erosion of wetland material are common. The first is to use a surface-water model to calculate peak design velocities in the wetland. The wetland and substrate can be designed to minimize erosion up to a certain design event in the short term (during establishment) and in the long term (with mature vegetation). Temporary erosion protection methods may be indicated. A second method uses the Golder (2004) nomographs for design of vegetated watercourses. Most wetland vegetation will help minimize erosion, but such wetlands and watersheds are vulnerable in the several years to full establishment.

For wetlands with fetches longer than 200 m, long-term shoreline erosion by wind waves may be an issue. Ozeren and Wren (2009) estimate wave heights and periods for small reservoirs. Shallow vegetated shorelines are generally resistant to erosion, and critical areas (in geotechnical buffer zones, for instance) may require riprap berms that can be buried under reclamation material. In most cases, only minor shoreline erosion is anticipated.

The wetland outlet may require specific hydraulic modelling to design the shape and the erosion protection measures.

### 6.4.4 Gas generation

Wetlands create carbon dioxide, methane, and hydrogen sulphide, all of which will be trapped under the ice or in nearby sheds or tents (Fedorak et al., 2002; Guo et al., 2004; Guo 2009; Holowenko, 2000; Stephenson, 2012). Gas generation is not usually considered in reclamation design, but closed spaces (tents, trailers, bunkers, traps) should be avoided unless they are well ventilated and alarmed. There is also the potential for oxygen-deficient atmospheres. Several fatalities have been reported (e.g., Sullivan Mine Incident Technical Panel, 2010). Safe work plans or health and safety plans should address confined spaces and low-oxygen concerns. Awareness of the potential risks is key.

### 6.4.5 Terrain unit modelling for ecosites

Each square metre of watershed will receive a reclamation prescription and a target ecosite. Judgment should be based on the substrate design and topography along with the results of the surface water and groundwater modelling. An alternative approach is to use GIS tools to automate the analysis, using substrate, slope, aspect, and predicted moisture conditions to assign prescriptions and target ecosites. Such modelling is in the research stage.

### 6.4.6 Wildlife habitat modelling

Design (and construction) for wildlife in reclaimed landscapes is still in its infancy in the oil sands. GIS habitat suitability index models or empirical species-habitat models may be employed to assess designs for habitat for various species, including beavers, and designs adjusted accordingly.

## 6.5 Wetland basin and element design

This section includes several design activities:

Borrow-source identification and characterization is required early in the process, as these will govern much of the design to follow.

Basin design (size, shape, and topography) for shallow-water wetlands, marshes, and fens.

Design of various elements (berms, islands, inlets, outlets). Table 6-4 provides an overview of these elements and each is discussed below in greater detail.

### 6.5.1 Site characterization

Site characterization is integral to design and is typically conducted in two stages — the first stage informs initial landform design and the second verifies assumptions and finalizes the design.

#### 6.5.1.1 Site characterization for initial wetland design

For initial wetland design, the landform/wetland design team specifies the material that will be in the area under and adjacent to the wetland. These materials will form the wetland and watershed substrate. They will be mine wastes (overburden and tailings).

For typical construction of overburden dumps, the waste materials are placed in 5 to 10 m thick lifts. Wetland and watershed substrate and their properties (material types and degree of compaction), especially the final lifts, should be specified. Large mining equipment constructs the final roughed-in topography, although the shaping of the wetland basin by smaller equipment can be considered (see Figures 1-2 through 1-5).

On tailings areas, the composition of any soft tailings should be specified, along with the placement method and thickness of a sand cap. Most materials will be placed hydraulically from the perimeter of the landform, so controls on materials and topography is challenging. Mechanical placement of tailings is usually limited due to its high cost. At minimum, the outlet elevation and concept of the watershed and wetland need to be communicated to tailings operations, so that as much as reasonably practical can be achieved during deposition. Hauling or dredging tailings is costly.

The wetland design will likely need updating during landform construction to date as-built conditions.

#### 6.5.1.2 Site characterization for final wetland design

Nearing the end of construction of the rough landform, a site investigation is conducted for the wetland and watershed design. For designed wetlands this investigation starts with:

collection and analysis of landform construction records
a topographic survey (usually by LiDAR)
surface mapping of substrates and ponded water/seeps

Results are documented in a report with maps and other field data. In some cases, this simple investigation may be sufficient for design. In others, a more involved investigation may include any or all of the following for designed wetlands:

Determining the watershed boundaries (can be complex and ambiguous; sometimes watershed berms are needed to delineate watershed and to keep unwanted run-on from entering the watershed)

Identifying any infrastructure (ditches, sumps, roads, powerlines, pipelines, buildings, laydown, equipment, stockpiles, debris) to be avoided, moved, or accommodated

Test pitting for stratigraphy and material characterization

Drilling to determine geotechnical properties (sampling, strength testing, installation of instruments); standard penetration testing (SPT) or cone penetration testing (CPT) may be employed for stratigraphy and strengths

Geotechnical and geoenvironmental laboratory testing of substrates and water quality

Advanced geotechnical testing of samples for strength, hydraulic conductivity, or consolidation properties

Surface percolation testing, using the augerhole method or a Guelph permeameter (Reynolds and Elrick, 1987)

Installing standpipe piezometers for determining pore-water pressures, water quality at depth, and slug testing for hydraulic conductivity; for fine-grained materials, diaphragm piezometers may be employed

Installing and monitoring of survey monuments to determine settlement rates

Testing trafficability with small and large mobile mining equipment

Testing borrow material (see next section)

Most sites have a collection of data on various mine materials that can be used for design, saving advanced laboratory testing; index testing is often enough to characterize materials to allow the database and site experience to be employed

Good record-keeping and monitoring can minimize the need for expensive and time-consuming site investigations. Drilling is typically the greatest expense, especially where access is an issue. Much can be learned from reviewing existing archived information and through surface mapping with shallow test pits and supported by limited laboratory testing.

It is difficult to maintain instruments installed during the site investigation through the construction and reclamation period. Most are destroyed during the earthworks construction and they complicate the work. A protection or decommissioning plan for all instruments should be developed prior to construction, as some may need to be re-installed.

### 6.5.2 Borrow source identification and characterization

Reclamation specialists think in terms of “reclamation material balance,” while geotechnical engineers building dams formally verify the “suitability and availability of an adequate supply of borrow materials” (New York State, 1989). Wetland designs often need to be adjusted to reflect the availability of suitable materials, which may include suitable overburden with certain geotechnical parameters, various types of peat and peat mineral mixes, tailings sand, glaciofluvial sand, gravel, coke, coarse woody debris, and other materials (see Section 2.3.1). Firming up the location, volume, geotechnical and properties, and haul routes for all materials is a tedious and unrecognized element of design but it is critical to the success of the project.

### 6.5.3 Wetland shoreline shape

The shoreline plan view shape is designed for initial conditions (what goes on the drawings for construction) with an eye to the final conditions (once settlement of the wetland area is complete). For wetlands with little settlement and steep banks, the footprints are approximately the same. For wetlands with large settlements and shallow slopes (those built on tailings sand beaches over soft tailings) the final extents can be many times larger than immediately following construction.

The topography for wetland design is based largely on the (unsettled) end of the construction substrate surface, with a constant thickness of reclamation material added afterwards. In the case of shoreline configuration, the reclamation material can have a profound effect on a wetland with shallow slopes and a fixed outlet elevation. Where shoreline slopes are steep, such considerations are usually incidental.

Shoreline development index (SDI) (Hutchinson, 1957) is a ratio of the wetland perimeter to the perimeter of a circle of the same area.

Increased shoreline complexity and diversity can be beneficial for wildlife habitat (Chapter 4; Austin and Buhl, 2009). For comparison:

> A circle has an SDI of 1, a square 1.13, a 5:1 rectangle or ellipse 1.5, natural lakes 2 to 5, reservoirs 3 to 9 (Thornton et al., 1996; Gottfried, 1985).
>
> SDIs of most natural marshes in the region are between 1 and 2, more circular ones around 1.1, and many beaver ponds around 1.5 to 1.8.
>
> Natural fens in the region are about 1.8, but are highly variable and range from about 1.1 to 3.
>
> Oil sands constructed wetlands to date are about 1.3 to 1.8.

Kent and Wong (1982) indicate the shoreline shape for lakes is fractal and hence the perimeter distance is a function of how closely it is measured. But for the purposes of reclamation shape design, a rough measurement on a drawing or aerial photograph is of sufficient accuracy for design. Figures 6-6 and 6-7 (developed for this guide) provide examples of wetland outlines and their SDIs.

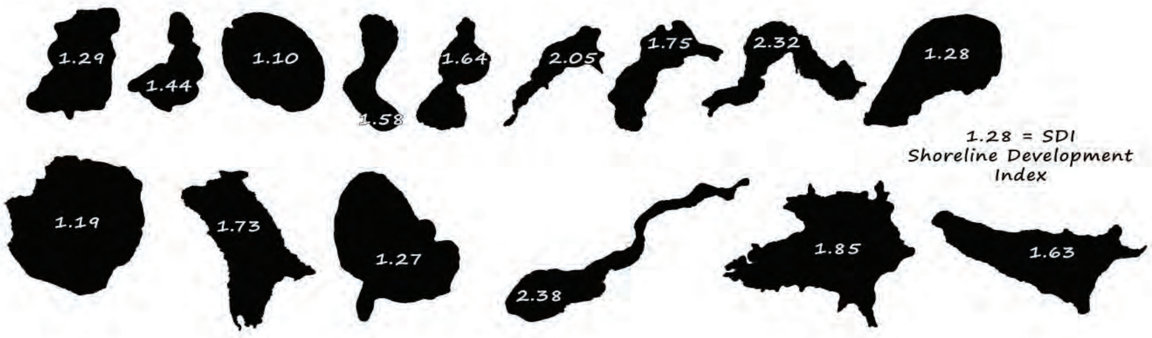


**Figure 6-6. SDIs of natural shallow-water wetlands and marshes in the region.**

**Figure 6-7. SDIs of natural fens in the region.**

The effective shape can also be adjusted with peninsulas and islands to create more shoreline. If the SDI is high, flows may be restricted to some areas, and effective water resident times may be increased or decreased depending upon the configuration.

### 6.5.4 Design guidance for wetland basin and elements

Table 6-4 is largely based on experience with oil sands, constructed wetlands elsewhere, natural areas in the region, and the extensive literature. It has been adapted from AENV (2008) and will continue to evolve as more experience is gained. Examples of plan views and cross-sections that illustrate many of these design concepts are provided in Figures 6-8, 6-9 and 6-10 for shallow-water wetlands, marshes, and fens respectively.

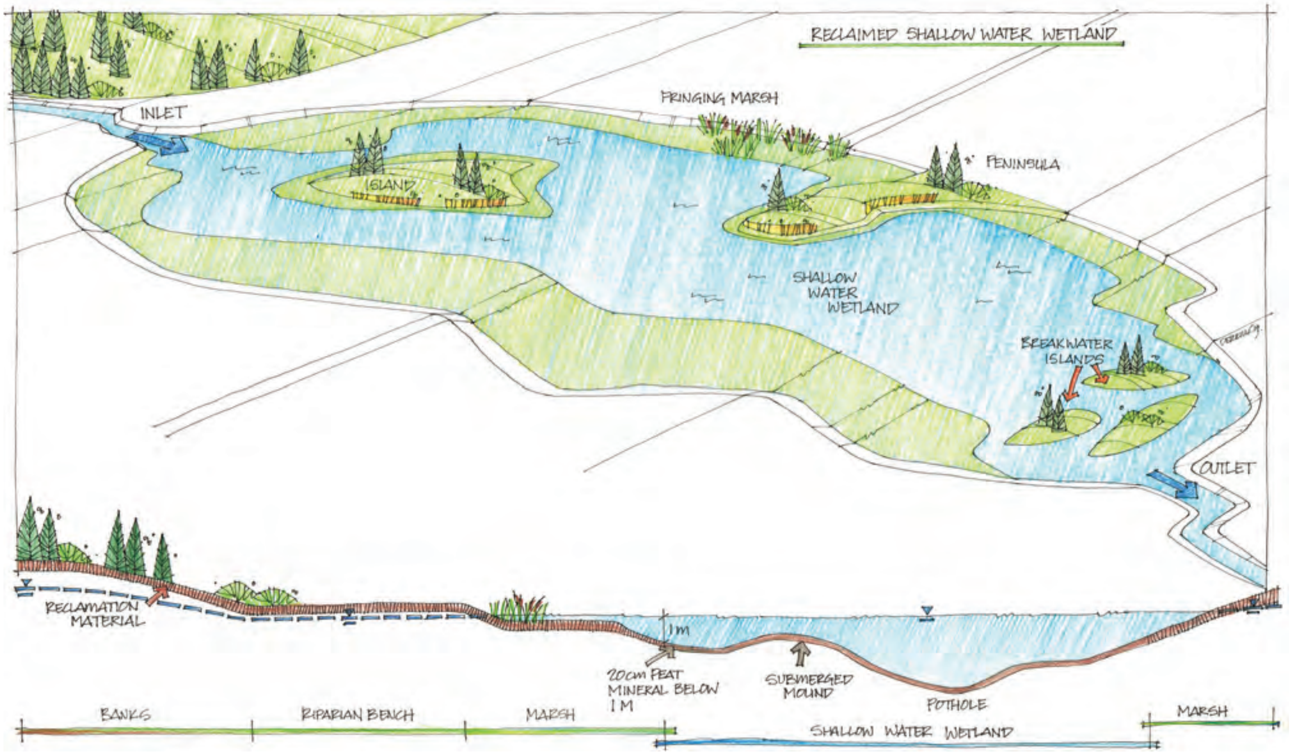


**Figure 6-8. Design elements for a reclaimed shallow-water wetland.**

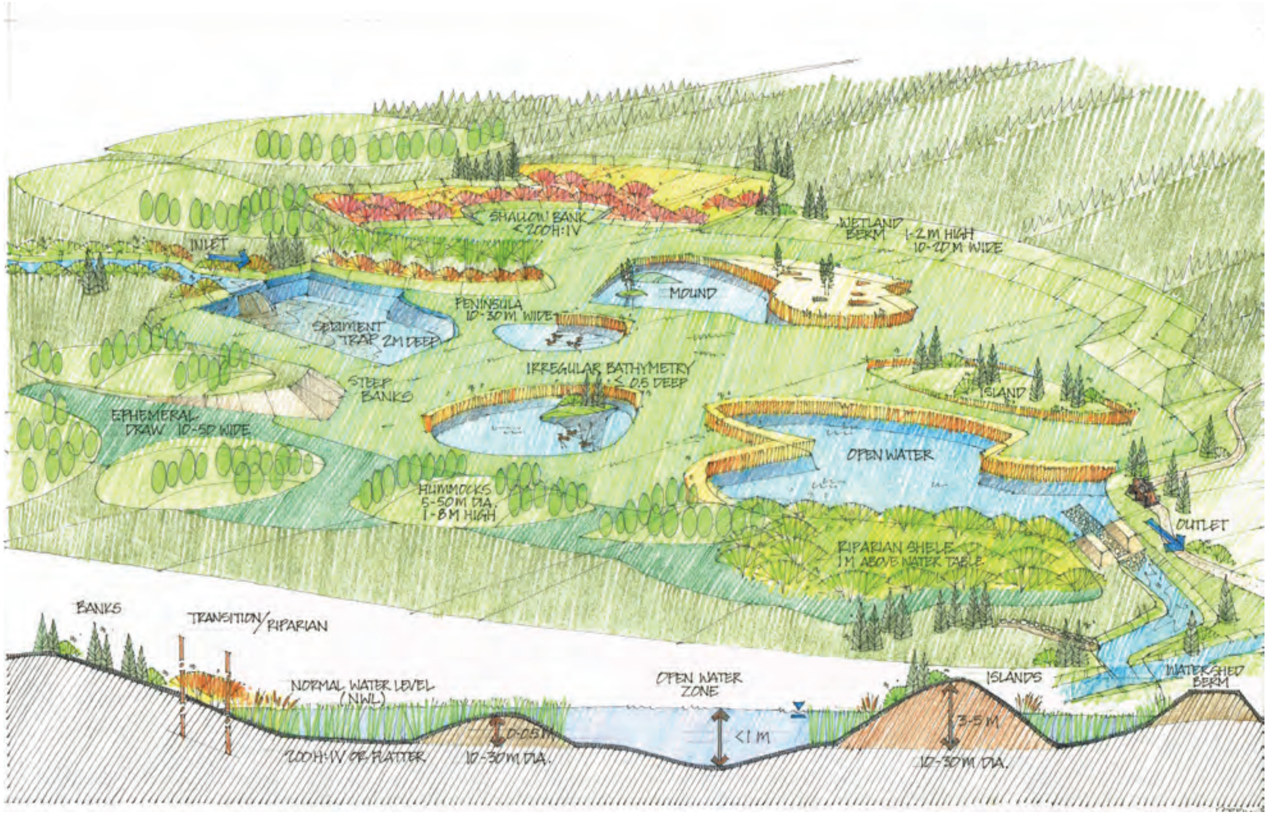


Figure 6-9. Design elements for a reclaimed marsh.

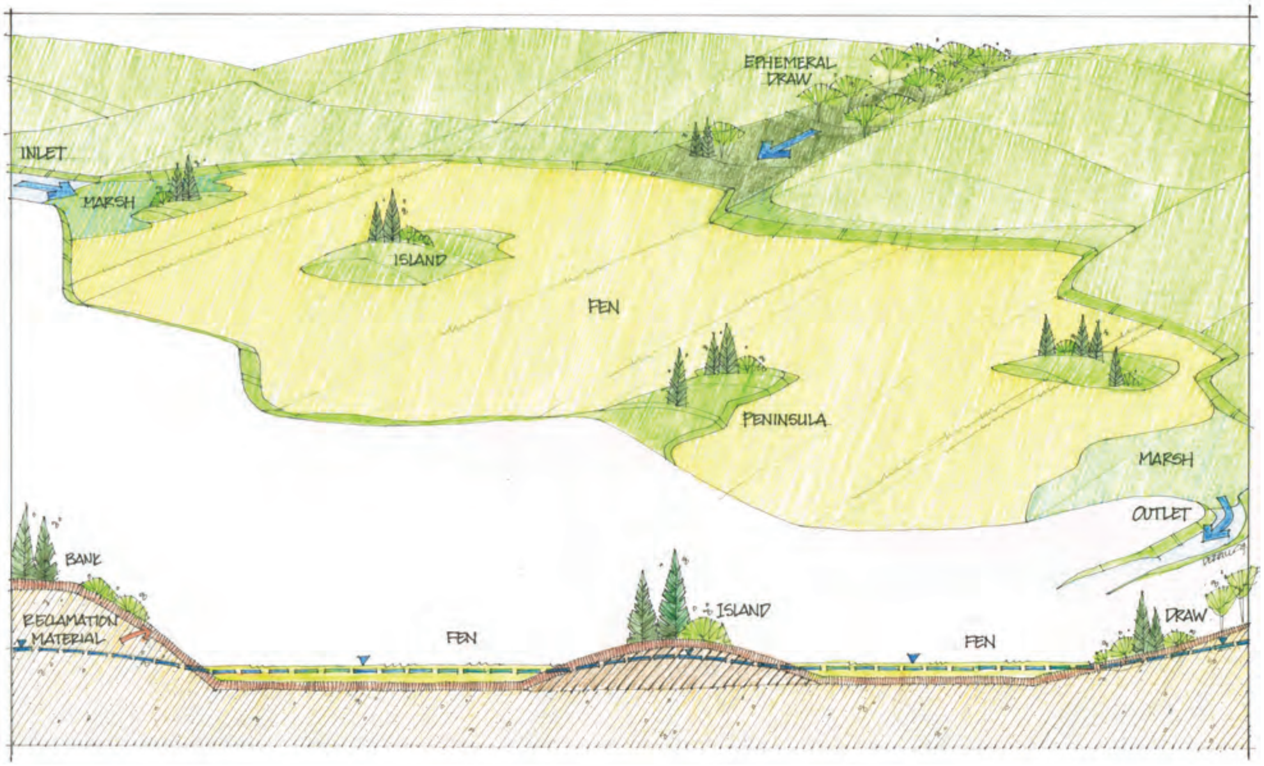


Figure 6-10. Design elements for a reclaimed fen.

**Table 6-4. Design guidance for reclaimed shallow-water wetlands, marshes and fens.**

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| **Landscape diversity and connectivity** | | The degree of surface water and groundwater connectivity between wetlands affects wetland development and habitat functions and values (see CEMA, 2012; Chapter 2).<br>Leases and landforms include diversity in the types and placement of wetlands. A reclaimed landscape is designed to include ephemeral and permanent wetlands juxtaposed with forest stands and patches of emergent and shrubby vegetation.<br>Isolation of wetlands reduces immigration of reproductive propagules (plants, zooplankton, phytoplankton, microbes). Connectivity enhances colonization of reclaimed wetlands. | Connectivity supports landscape and landform diversity, which are important to achieve the objective (an ecologically functional wetland within an equally functional landscape). Supports wildlife establishment since different plant and animal communities occur in different wetland classes. |
| | | Wetlands should be placed in proximity as they provide ecological stepping stones that increase connectivity, thereby increasing stability and long-term persistence. Small wetlands, even if they are ephemeral, can provide important connectivity during the spring breeding migration of amphibians. These may or may not be connected by streams, depending on the wetland type.<br>- peatlands develop when the degree of groundwater connectivity is high (Doss, 1995; Halsey et al., 1998)<br>- connecting wetlands by using watercourses with riparian zones will increase habitat value and wildlife diversity<br>- migratory waterfowl use wetlands with a variety of hydroperiods, including ephemeral wetlands as spring pair habitat, and more permanent wetlands for nesting and brooding<br>- distance between wetlands should be <1 km to support the dispersal of species with poor dispersal abilities (amphibians; Chapter 3).<br>- creating wetlands in hydrologically diverse landscape locations will promote diversity (Shedlock et al., 1993)<br>- terrestrial habitat connectivity between wetlands is important for semi-aquatic species or species with aquatic larval stages but terrestrial adult stages (see Chapter 3) | Supports the Aboriginal view that wetland connectivity and wetland flow through the landscape are critical functions (Section 1.5.3). |
| **Basin Morphology** | **Wetland size** | **General**<br>Design for a variety of wetland sizes to provide a variety of functions and habitats for different species (AENV, 2000). | Supports the Aboriginal view that wetland design should be considered at a broader landscape level (Section 1.5.3).<br>Chapter 3 provides size ranges for fens and marshes based on natural wetlands. |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | **Water balance** | **General**<br>Wetlands are often designed to flush every year to avoid excessive evapoconcentration of salts.<br>Small daily inflows (recharge) or outflows (leakage) through the wetland basin can have large impacts on annual water balance and wetland performance. | See Chapter 2 for more about hydrology<br>Fen evapo-transpiration rates are under investigation at Suncor Nikanotee Fen and Syncrude Sandhill Fen.<br>Supports the Aboriginal view that water flow is critical for water quality (Section 1.5.3). |
| | **Shape and forms** | **General**<br>The shoreline should be irregular to provide habitat diversity and to minimize bank erosion resulting from wave action.<br>The basin profile should be variable and include islands, where possible, to provide habitat diversity and enhance the wildlife value of the wetland. Pothole depressions 1 to 5 m diameter, 0.5 to 2 m deep can be employed.<br>**Marshes and shallow-water wetland**<br>Long fetches can develop waves that resuspend sediments. Fetches more than 200 m are checked for wave erosion. Shoreline development index (SDI) = 1.2 to 2 is common in natural marshes in region.<br>**Fens**<br>SDI of 2 to 3. | See Chapter 3 for more info.<br>Examples of natural shapes provided in Figures 6-6 and 6-7.<br>Chapter 3 provides shape ranges for marshes based on natural wetlands.<br>Islands provide important refuge areas for waterbirds and local irregularities in the contour of the wetland bottom will increase habitat heterogeneity.<br>Areas with deeper water will provide overwintering habitat for semi-aquatic mammals and small-bodied fish. |
| | **Water depth** | **General**<br>The normal water level is typically at or slightly below the outlet invert elevation. Estimate high and low water levels through the year and through climate cycles. The width of the outlet will control water levels during high flows.<br>Fluctuation in water levels is normal and can enhance wetland productivity, but extreme variations can adversely impact both plants and animals (Kadlec and Knight, 1996; Hammer, 1989).<br>Beavers will profoundly change water depths when they dam the wetland – considered in design. Dams of 1 to 2 m high will be common and can be up to 3 m high. | Where settlement is a concern, may choose to have large areas with a nominal 0.1 m initial water depth.<br>Section 3.4.2.2 provides depth and amplitude ranges for marshes based on natural wetlands.<br>Section 7.9.3 provides depth and amplitude ranges for fens. Info about water fluctuation and effects, see Ch. 3. |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | | **Shallow-water wetland**<br>< 2 m water depth with 25% of surface area as vegetated (typically < 0.5 m). Design may be influenced by need for water retention time (for biodegradation).<br>Depths of > 3 m provide overwintering pools for fish (Golder, 1998).<br>Make deep areas contiguous to prevent entrapment of fish or fur-bearers during water level fluctuations (Wiacek et al., 2002; Axys, 2003)<br>Permanent/semi-permanent marsh<br>0.2 - 1 m water depth (sometimes 1.5 at deepest spot), nearly always flooded (Section 3.4.2).<br>Seasonal water fluctuations are essential for marshes. The difference between the maximum and minimum water levels is about 0.2 m.<br>**Intermittent marsh**<br>< 0.2 m maximum water depth, flooded only seasonally.<br>**Fens**<br>Maintain water levels at or just beneath peat surface with fluctuations no greater than 0.3 m. | |
| | **Shorelines (subaerial)** | **General**<br>In general, relatively flat floor slopes support wetland productivity and ecosystem development (< 5% for marshes; Section 3.4.2).<br>In some cases, steep slopes (3H:1V to 5H:1V) may be used to specifically promote bank storage if sandy substrates employed (Devito et al., 2012).<br>Slopes flatter than 6H:1V allows access to forage by wildlife (e.g., moose). Slopes flatter than < 15H:1V aids flood attenuation.<br>Very low angle narrow (5 to 50 m wide) ephemeral draws between steeper slopes act as “fingers” for the wetland (Devito et al., 2012).<br>Riparian zone approximately 1 m in height above normal water level can provide excellent riparian vegetation conditions (e.g., Wissmar and Swanson, 1990).<br>Create low wetland berms 3 to 10 m wide to allow ease of placement, access, reduce risk of piping and damage by burrowing muskrat or beavers (Ducks Unlimited, 2005). | See Chapter 3 for more information. Wiacek et al., 2002; Axys, 2003 also provide useful data and references |
| | **Bottom gradient (Submerged slopes)** | **General**<br>In general, relatively flat floor slopes support wetland productivity and ecosystem development. (See below for slope recommendations.) | 5% slopes allow a 10 m wide transition zone from 0 to 0.5 m water depth. |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | | Use irregularities in basin elevation to provide topographic/bathymetric diversity. Roughening with substrate and/or reclamation material.<br>**Fens**<br>Design for downslope gradients of 0 to 1%. Lower gradients are at less risk of erosion and channeling. | |
| | **Percent open water** | **Shallow-water wetlands and marshes**<br>By definition, <75% open water for marshes. However, the percent of open-water area for natural permanent/semi-permanent marshes in boreal Alberta is about 25% (Section 3.4.2).<br>By definition, shallow-water wetlands have more open water than vegetated zone.<br>**Fens**<br>Minimize open water in early years to promote fen ecosystem development.<br>Flarks and strings: Natural patterned fens have 1 m tall strings perpendicular to groundwater flow. Kost et al. (2010) provide additional information. | |
| | **Inlets and outlets** | **General**<br>Create sacrificial deposition area at inlets.<br>Outlets require robust design and construction.<br>A mechanical weir or mechanical pumps can be used in the short-term to control water levels. Riprap or vegetated weir can usually be permanently raised or lowered with effort. Design temporary mechanical/stoplog weirs to be water-tight and avoid piping, frost, ice, and other failure mechanisms.<br>Restrict outlet width to attenuate floods; widen outlet width to minimize water fluctuations.<br>Use low angle (<10% sideslopes) for outlet if part of access route for equipment or light vehicles.<br>French drains, through the outlet and at least 10 to 30 m upstream, may reduce risk of beaver damming the outlet (they act like a beaver baffler (Eaton et al., 2013)). Mechanical beaver bafflers can be used for temporary control of damming.<br>An emergency overflow outlet is typically built into the wetland perimeter in the event that the main outlet weir is overwhelmed (Pollard et al., 2012; Ducks Unlimited, 2005). This outflow may be armoured and designed to protect any mechanical weir emplacements, or it may be designed to downcut rapidly in a safe location for later repair. | Additional outlet design guidance provided in Section 6.5.5.<br>Outlets can take several years of maintenance to bring to proper operation.<br>Ill designed or ill constructed outlets can be the Achilles heel of wetland performance. |
| | **Mounds, islands and peninsulas** | **General**<br>Design mounds, islands, and peninsulas to have irregular shapes with submerged slopes using guidance under shorelines. | These features add topographic and bathymetric diversity, habitat, visual appeal, and can act as |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | | Mounds are periodically/seasonally submerged in marshes and add bathymetric diversity. Mounds are 10 to 30 m across and 0.2 to 2 m high (20 to 1500 $m^3$) and may be permanently flooded.<br>Islands are often 10 to 30 m across (minimum 3 m for habitat) and 3 to 5 m high (300 to 3000 $m^3$).<br>May be re-graded from substrate, new substrate may be imported, or they may be made from reclamation material.<br>Peninsulas are similar to islands, but have connection to shoreline for ease of passage for predators (also helps control nesting bird populations).<br>Prescriptions for islands may be the same or different than for wetland areas or upland areas. | breakwaters and direct or calm flow. |
| **Reclamation material** | **Substrate type**<br>**Substrate depth** | **General**<br>The soil used must be appropriate for the wetland type. A peat–mineral mix with 15 to 20% organic matter is beneficial for root penetration and turbidity control.<br>A clay-rich subsoil may reduce rate of downcutting in extreme flood events.<br>Transplanting of organic soil from natural marsh enhances the development of a vegetation community populated with native species.<br>The transition zones between the various wetland areas and the upland areas need to be specified in design and usually require consideration of how the materials will be placed.<br>**Shallow-water wetlands and marshes**<br>Use depth to which roots grow as a guide for the depth of soil to be placed (Section 7.9.4.2).<br>**Fens**<br>There is debate whether sand or clay substrates are better for fens, and whether none, some (0.2 to 0.5 m, or a large thickness (1 to 2 m) of peat is beneficial as an initial reclamation material thickness. | Low soil organic content can limit the number of species that can colonize in reclaimed wetlands (Section 7.9.4.2)<br>Reclamation material cover needs to be designed to meet DBM rather than prescribed. |
| | **Engineered liner** | **General**<br>Liners may be employed to reduce water leakage losses from a wetland, especially where perched above the water table. They are often considered temporary measures and require high levels of design and close controls on installation (e.g., Pollard et al., 2012; Russell et al., 2010).<br>Liners in areas of upward seepage gradient may fail by ballooning.<br>Roots will puncture liners, reducing liner efficacy. Rooting depths in the region are largely restricted to the upper 1.3 m (Lazorko, 2008) but a few roots | Liners are costly and most have a finite life, which limits their use. |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | | can reach 3.3 m or more (Canadell et al., 1996).<br>Freeze-thaw effects reduce the effectiveness of some types of liners. Frost depths of 1 to 2 m are common and can reach 3 m or more. Settlement can impact integrity of most liners.<br>Liner construction during winter needs special considerations. Geosynthetic clay liners can be placed year-round (Pollard et al., 2012; Russell et al., 2010) but potential impact of sodium on clay performance must be considered. | |
| **Hydraulic design** | **Retention time** | **Shallow-water wetlands and marshes**<br>Average hydraulic retention time is calculated by the ratio of the water volume in a wetland to inflow volume. Where critical, designs take into account freshet fluxes, potential for short-circuiting, and impacts of low water temperatures.<br>Several months of retention time is enough to degrade labile naphthenic acids (reducing toxicity) (Armstrong, 2008; Bishay, 1998; CEMA, 2012; Colavecchia et al., 2004; Crowe, 1999; Crowe et al., 2002; Del Rio et al., 2006; Golder, 2006; Scott, 2007). Often a 12-month period is employed for calculation/design. | |
| | **Hydroperiod** | **General**<br>Flows and water levels are typically dominated by spring melt (freshet).<br>Spring drawdown and re-flooding by 0.15-0.45 m enhances waterfowl habitat (Taft et al., 2002; Kaminski et al., 2006).<br>Germination of emergent plants requires species-specific water level fluctuations. Therefore, water level control may be necessary early in the reclamation process to allow establishment of emergent vegetation. | Methods for designing hydroperiod for reclaimed wetlands have yet to be tested. There are limited opportunities. |
| **Approved end land uses** | **Spiritual and cultural activities** | Certain wetland areas are of spiritual and cultural importance to aboriginal communities (see Chapter 1 for examples). Consult aboriginal communities to determine the design factors that are important for cultural and heritage purposes (AENV, 2000). | Ease or difficulty of access can be designed. Various designs for duck blinds can also be employed (as at Suncor Crane Lake). |
| | **Recreation** | Hiking, wildlife viewing, hunting, fishing, and tourism are indicated uses (e.g., Ramsar, 2009). | |
| | **Wildlife** | Wetlands should be first designed to support a community, rather than specific species. Where specific species are desired, or where regulations stipulate that habitat for specific species must be created (e.g., for a species-at-risk), identify what additional management steps are necessary (e.g. provision of overwintering habitat) after designing the wetland to support a functional community first. Realize that providing habitat for some species at a wetland will require a landscape-scale approach, | |

| Topic | Design element | Design guidance | Comment |
|---|---|---|---|
| | | rather than just the reclamation of a single wetland.<br>Coarse woody debris should be added to reclaimed wetlands (see Robinson and Beschta, 1990). CWD provides habitat for aquatic invertebrates, which are very important prey items for wildlife species and important for wetland function. The design needs to consider the propensity for CWD to float. | |

There is a significant research opportunity to treat the design guidance in Table 6-4 as hypotheses and test it on a commercial-scale.

## 6.5.5 Additional design guidance

### 6.5.5.1 Salinity and ecological performance

Fresher water with lower concentrations of naphthenic acids is preferable. Creating watersheds that provide good water quality (through source control, dilution, flushing, minimizing deep percolation, and seepage controls) will be challenging. There is a growing consensus (Section 2.5.4) that useful and productive wetlands will form in the types of reclamation waters expected, though for wetlands with salinity above 1,000 to 2,000 µS/cm, the resulting ecology may differ from most freshwater wetlands in the region. Toxicity may be an issue for fish and benthic invertebrates (e.g., Barton and Wallace, 1970; Bedford and Godwin, 2003; Foote, 2012). Research is ongoing to better understand any toxicity thresholds for wetland design.

Trites et al. (2012) provide the latest summary and an extensive reference list and fact sheets on naphthenic acids and their toxicity. There are interactive effects with salts (Nero et al., 2006).

### 6.5.5.2 Wetland berms

It is often necessary to define a wetland with low containment berms (See Figure 6-12). Part of the shoreline, berms help contain the water and provide topographic diversity. These berms need to be designed by a geotechnical engineer and are typically constructed using reclamation materials or overburden. They are designed to avoid being classified as dams (Section 6.4.1).

Wetland berms should have:

- Low in height (1 to 2 m). Larger berms will require higher levels of design;
- 3H:1V or flatter slopes; typically slopes are much flatter;
- A crest width of 3 m or wider to facilitate reclamation equipment, sometimes to provide access for light vehicles or other equipment;
- <5% seepage gradient at maximum water height to minimize risk of piping;
- Varying width and height and sinuosity for topographic diversity and natural appearance (McKenna et al., 2011b);
- Geotechnical stability (even low-height berms on soft ground (soft tailings, junk fills) may need special design);
- Sufficient freeboard (often the berms are designed mainly to provide the desired freeboard); and
- Resistance from erosion.

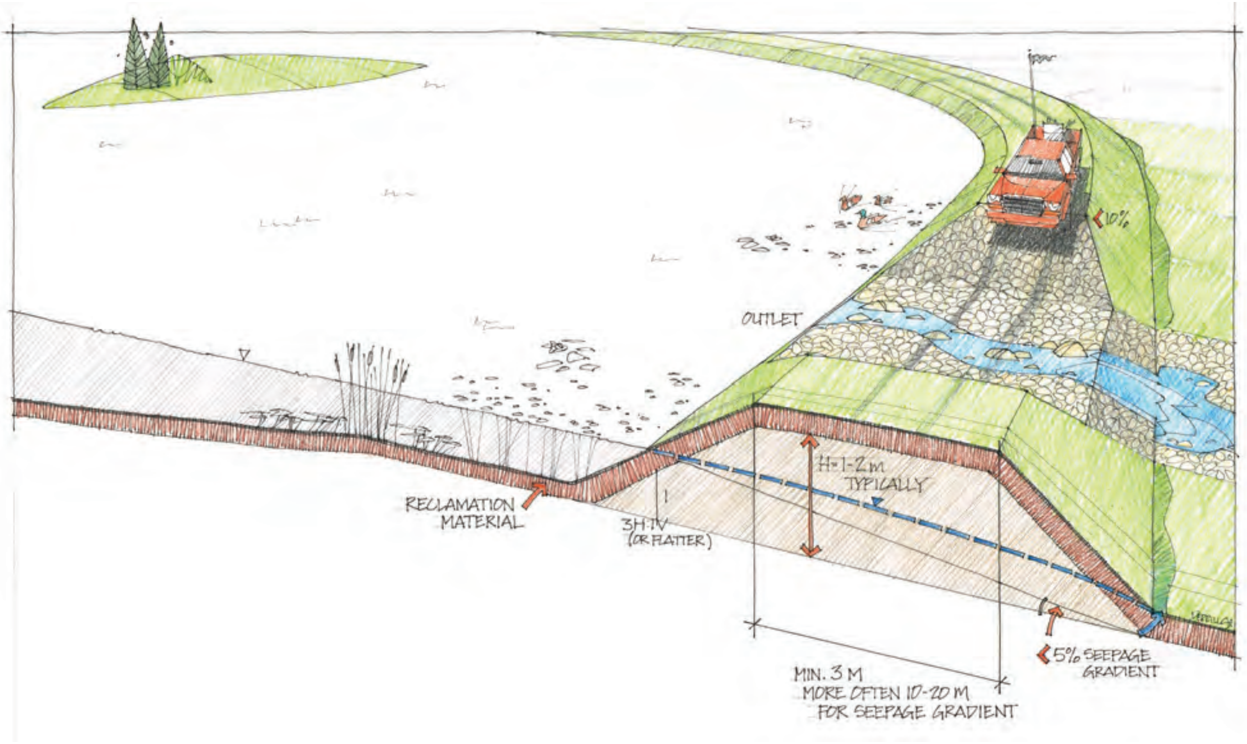


**Figure 6-11. Wetland berms.**

### 6.5.5.3 Inlets and outlets

Inlets and outlets influence water volumes and retention times in the wetland and are critical to wetland design and performance. Inlet configuration is an important element, and care must be taken to ensure a diffuse inlet to limit channelization of flow and erosion of the wetland materials. Outlets typically are either a stop-log or bent-pipe configuration to control water levels at the downstream end of the wetland during the active management period.

Most large wetland reclamation projects are constructed with water-level control structures to allow for drawdown, particularly when dykes impound water (Galatowitsch et al., 1998). The ability to manipulate water levels in the first few years of operation may be required to establish plant communities firmly. Throughout the life of the project, control structures can be used to periodically manipulate water levels just enough to re-establish productivity, often by encouraging new plant growth. Galatowitsch et al. (1998) recommend that even wetlands designed to remain flooded in most years allow periodic drawdowns for the repair of any infrastructure structures or dyke systems.

For inlet and outlet design, high-water and low-water conditions must be based on climatic conditions and accommodate extreme weather. The designer identifies what types of controls may be needed to maintain required water levels, particularly during wetland establishment. For instance, if additional water retention is required, then a constricted outlet can increase the detention time in the wetland and provide opportunities for percolation. Figure 3-9 provides guidance of water level fluctuations in natural wetlands. Figure 6-12 provides some guidance on design water levels and outlet configuration.

Construction of permanent inlets and outlets allows for more frequent flushing and decreased retention times. In areas where salt buildup is a concern, defined inlets and outlets can improve water quality by increasing the amount of fresh water introduced over time and providing water with a means of escape before concentrations of salts or other contaminants become growth-limiting or otherwise destructive. Where water treatment is desired, designing a constricted outlet can provide flow attenuation to increase contact time and improve treatment outcomes. Additionally, connections to surrounding surface water bodies improve biological diversity by promoting the transport of colonizing organisms.

Maintaining soil covers, particularly during the first few years of vegetation establishment, will improve overall wetland success rates. Retaining berms prevent soil transport out of constructed wetlands in conjunction with weirs that provide an outlet for water and allow for water level control (Pollard et al., 2012).

Outlet weirs have proven problematic in the oil sands. They tend to be high maintenance, with leakage around and through the weir (due to piping and poorly fitted stop logs), silting up, and freezing up among the known issues. Many research weirs are heated with propane in spring at great expense. Removing them tends to cause damage that takes many years to heal. The design team will need to decide whether to use these kinds of weirs or build a permanent overflow spillway with riprap (or dense vegetation) and use pumps to lower water levels as needed. The outlet can be reconstructed if needed at a later date for a new permanent invert elevation. Operations have less flexibility with this type of design. But in many cases, it is easier to manage, more reliable, and less invasive.

#### 6.5.5.4 Inlet design

Influent water will often arrive from non-point source locations, such as run-off, precipitation, and groundwater seepage. Inlets are designed to allow diffuse flows into the wetland to ensure that channelization does not occur, and water flows throughout the wetland.

Constructed inlets will be required where water is directed or diverted from other locations for treatment or storage, or to manage flood flows during extreme storms. Where inlets are constructed, suitable freeboard is required to contain the effects of extreme events. Climate models (Section 5.3.3.4) can estimate maximum flow events, and determine channel designs. Inlets will also be designed in conjunction with outlets, as described below, to achieve target wetland functions.

#### 6.5.5.5 Outlet design

Outlet elevations should be specified to the nearest 0.1 m to meet the target hydrology (Figure 6-12). Typical water level fluctuations will be governed by the width of the outlet. Design objectives and target land uses (Section 6.1) indicate which criteria are most important to the outlet design.

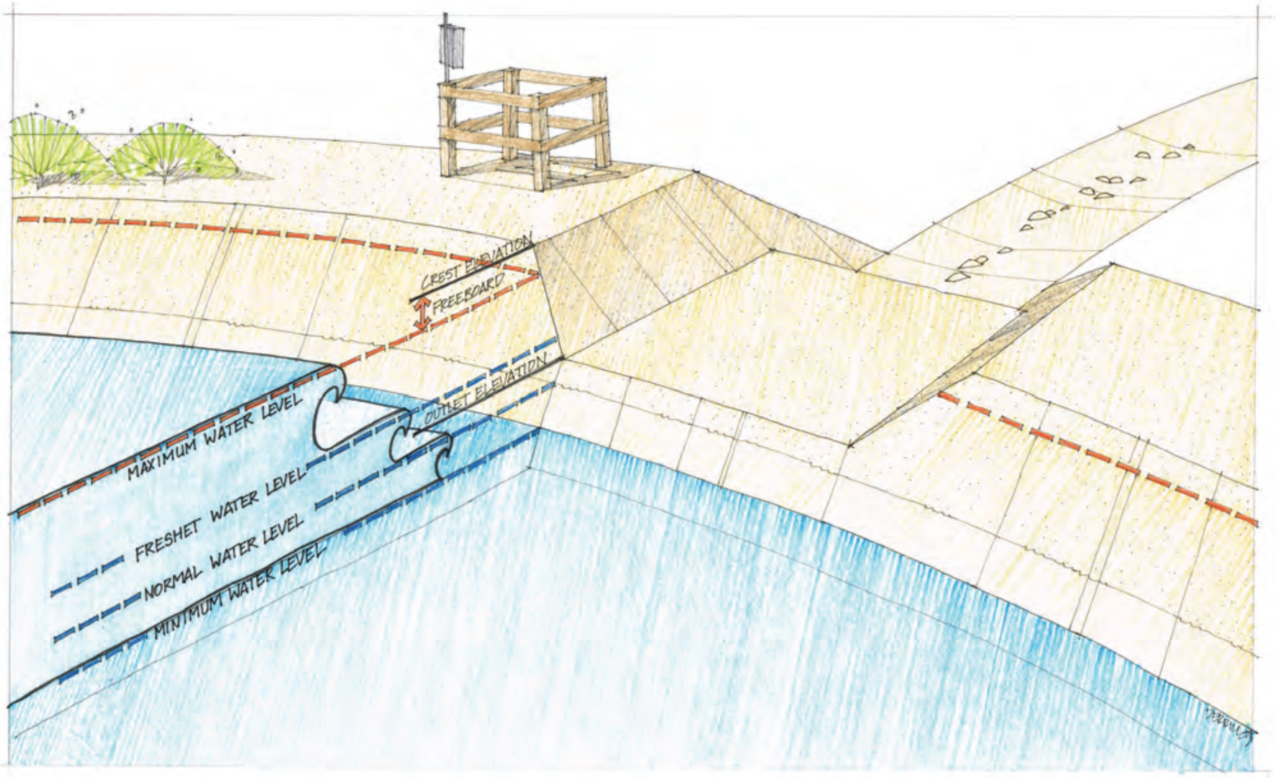


**Figure 6-12. Outlet design elevations.**

Channelized flow can be a significant concern, particularly for erosion of placed reclamation materials during early years of development. Minimizing channelized flow can be accomplished by introducing berms, avoiding constructed inlets where technically feasible, and implementing measures to discourage direct flow paths between inlets and outlets.

### 6.5.5.6 Beavers

Beavers (*Castor canadensis*) are dominant drivers affecting landform hydrology within the boreal forest (Eaton et al., 2013). They do not even require mature woody species to build large dams. It is difficult to overstate their impact on wetlands. Virtually all wetlands will be subject to outlet blockage by beavers with dams of 1 to 3 m high, flooding and enlarging the constructed wetlands for years or decades. The dams will occasionally wash out, causing rapid draining of the beaver ponds and destruction downstream. Section 5.2.10 provides guidance on accommodating beavers.

### 6.5.5.7 Instrumentation

Instrumentation provides data to inform design and understand performance during construction and operation. Instrumentation details should be included in the design package.

#### 6.5.5.8 Groundwater mapping

The design team prepares a groundwater map that is used in guiding reclamation cover, revegetation, and wildlife habitat design. Groundwater mapping is conducted to verify the initial ecosite and reclamation material prescription design. During mapping, observations for the following areas should be recorded:

Upland areas (may be useful to distinguish upland forest from riparian forest)

Saturated areas

Active seepage discharge areas (and their salinity)

Standing water areas (shallow and deep)

As construction and reclamation progresses, the groundwater map is updated and reclamation prescriptions or revegetation designs are optimized, recognizing that reclamation vegetation details (e.g., seeds, seedlings, and propagules) may have to be specified before as-built information is available (see Figure 7-1).

#### 6.5.5.9 Design of reclamation cover and liner

The prescriptions provided in this report may be adopted as a base-case planning basis. However, there is an opportunity to engineer the reclamation materials as true covers in upland areas (e.g., MEND, 2012) and as liners in wetland areas (e.g., Rowe, 2011). Such designs formally examine tradeoffs among water quality, water quantity, erosion protection, revegetation success, construction practicality and cost.

### 6.5.6 Revegetation

Wetland revegetation is still a new activity in the oil sands, and there are numerous limitations with respect to access, seasonality, and availability of key species. A tentative revegetation plan for the project area, including upland and riparian areas, is based on the groundwater map and the expected performance at the end of reclamation. Part of the art of revegetation is identifying, sourcing, and ordering seeds, seedlings, and propagules so that they can be available when it is time to revegetate the wetland and surrounding uplands. Some areas may be constructed or perform differently than intended and not all the seeds, seedlings, and propagules will be available on demand.

The planting plan covers the entire project area (upland, riparian, and wetlands), which is divided into planting polygons based on the revegetation design. The plan delineates all planting polygons for each type of revegetation. For each revegetation type, it describes:

the planting prescription (each species, its planting density, planting method, timing restrictions (winter, spring, summer, fall));

seed source, propagation method, location (nursery or seedbank);

details of necessary hydrology; and

a schedule for seed collection, propagation, storage, planting

It also includes contingencies in case field conditions or available species differ from the plan (if desired) and incorporates a weed and wildlife control plan that will become part of the OMM plan (Section 8.1.5). More revegetation guidance is provided in Chapter 7 and Appendix E.

### 6.5.7 Wildlife habitat

Guidance on the placement of wildlife habitat features, including how many and how to place them, can be drawn from natural systems. Eaton and Fisher (2011) describe how this information can be empirically derived in the site-planning stage to provide operators with solid, well-founded guidelines for reclamation. They provide the example of how manipulating conifer stem density will affect the likelihood that snowshoe hares will occupy a site. The same analysis can and should be undertaken for all species of interest and their required habitat features. Success will probably be found through thoughtful design of patches/ecosites rather than strictly species by species.

The presence of fish, muskrats (*Ondatra zibethicus*) and beavers (*Castor canadensis*) profoundly alter wetland dynamics. Predatory species of fish affect benthic invertebrate, plankton and macrophyte assemblages (Gould, 2000; Hornung and Foote, 2006). Boreal wetlands inhabited by brook stickleback (*Culaea inconstans*), for instance, show reduced biomass of grazing and predatory invertebrates. Muskrats can produce channels through marshes and affect the proportion of shallow water through grazing, while beavers influence the size, depth and organic makeup of wetlands. They also dig canals and cause flooding and avulsion (Eaton et al., 2013).

Most of the wildlife habitat design requirements are embodied in the hydrology, soils, and revegetation parameters. Additional wildlife habitat enhancement measures may be required and are noted on a drawing and in the design report (Chapter 7 and Appendix D).

### 6.5.8 Construction considerations for wetland designs

Construction and implementation must be considered and incorporated into detailed designs to minimize costs and reduce re-handling of material during construction. Plans for material placement and grading, routes for site access, and required infrastructure all need to be identified.

The timing and scheduling of design implementation is particularly sensitive. Wetland construction is seasonally dependent, and any delays in schedule can delay wetland establishment by an entire year. It is essential to identify the critical paths for wetland construction, such as sources of vegetation, seasonal availability of water, and the ability of heavy equipment to access the site and complete construction during each season. Figure 6-13 provides some typical design dimensions for various earthworks elements to allow easy access for mining equipment.

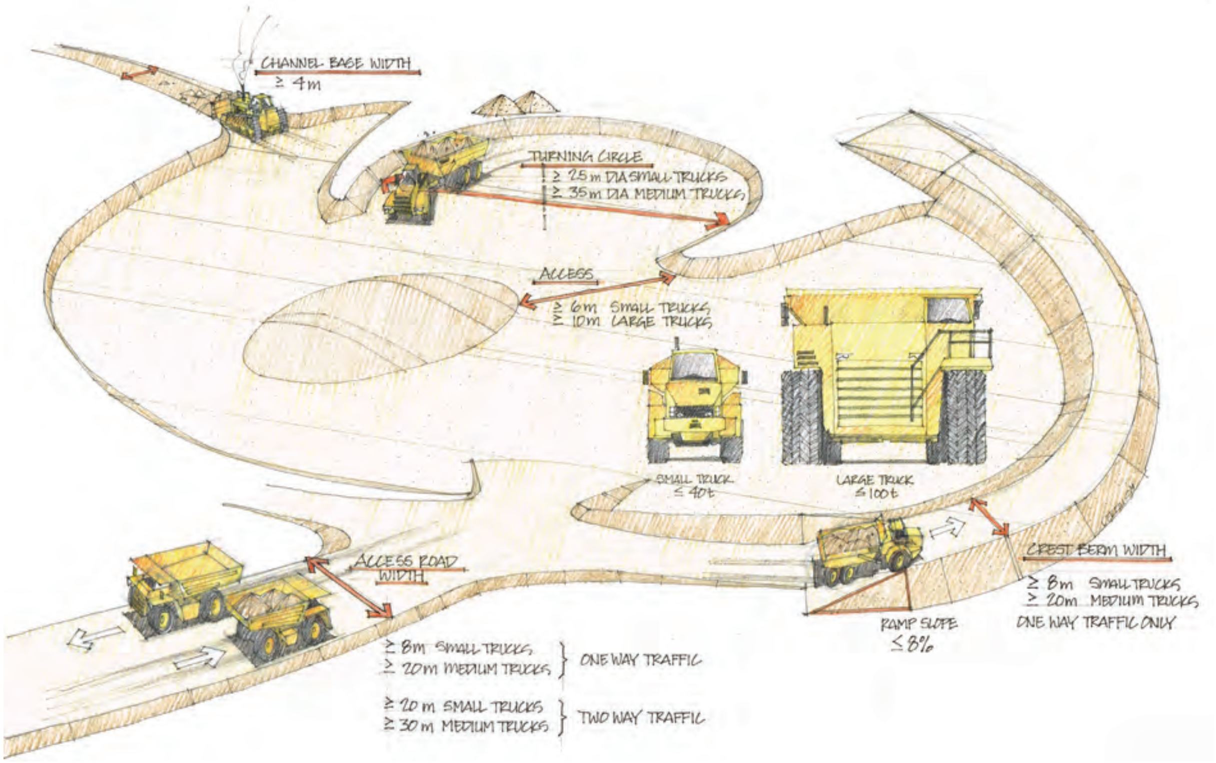


**Figure 6-13. Typical design dimensions to allow construction access by mining equipment. (Dimensions based on Caterpillar Handbook, 2013).**

## 6.6 Developing an operating, monitoring, and maintenance plan (OMM)

An operating, monitoring, and maintenance (OMM) period for the first few years while the designed wetland becomes established (Table 8-1) may involve monitoring, vegetation management, diverting or pumping in water, controlling beavers and other wildlife, and maintenance to help ensure that the wetland and its watershed begin on a good trajectory (Section 8.1.4).

Wetlands tend to fill during the first freshet. If additional water is required, a freshwater pipeline to the wetland can be designed and constructed. They are expensive and have long lead times (see Section 7.2) but provide full control on water inputs. Where practical, diesel mine dewatering pumps and hoses can be used to pump water in and out of the wetland. Erosion protection may be required where inflows are added, via pipeline or pump, to the wetland. This may be as simple as a several-metre-deep sump or an armoured discharge apron. Such features are easy to include during design or even as a contingency, but expensive to retrofit.

The general assumption in this guide is that close monitoring of designed wetland is required in the first few years and adjustments may be required to adjust their early trajectory. An alternative approach is minimal monitoring and making only those corrections that are strictly necessary. Operators have the opportunity to declare their approach during development of an OMM plan.

There is an opportunity for development of a generic OMM plan that would cover most wetlands, either as a corporate or multi-party endeavor (See Chapter 8). Some wetlands will require specific and detailed OMM plans to guide them through the first years. Others, such as semi-designed and opportunistic wetlands may only require an annual inspection (see Section 8.4.5).

## 6.7 Semi-designed and opportunistic wetlands

### 6.7.1 Semi-designed wetlands

Semi-designed wetlands involve minor topographic and reclamation features added during landform design and/or construction. The amount of design and field effort is minimal. Figure 6-14 illustrates opportunities for semi-designed wetlands. They generally involve creating shallow wetland berms or depressions to allow wetter conditions to evolve. Not all will form or stay as wetlands.

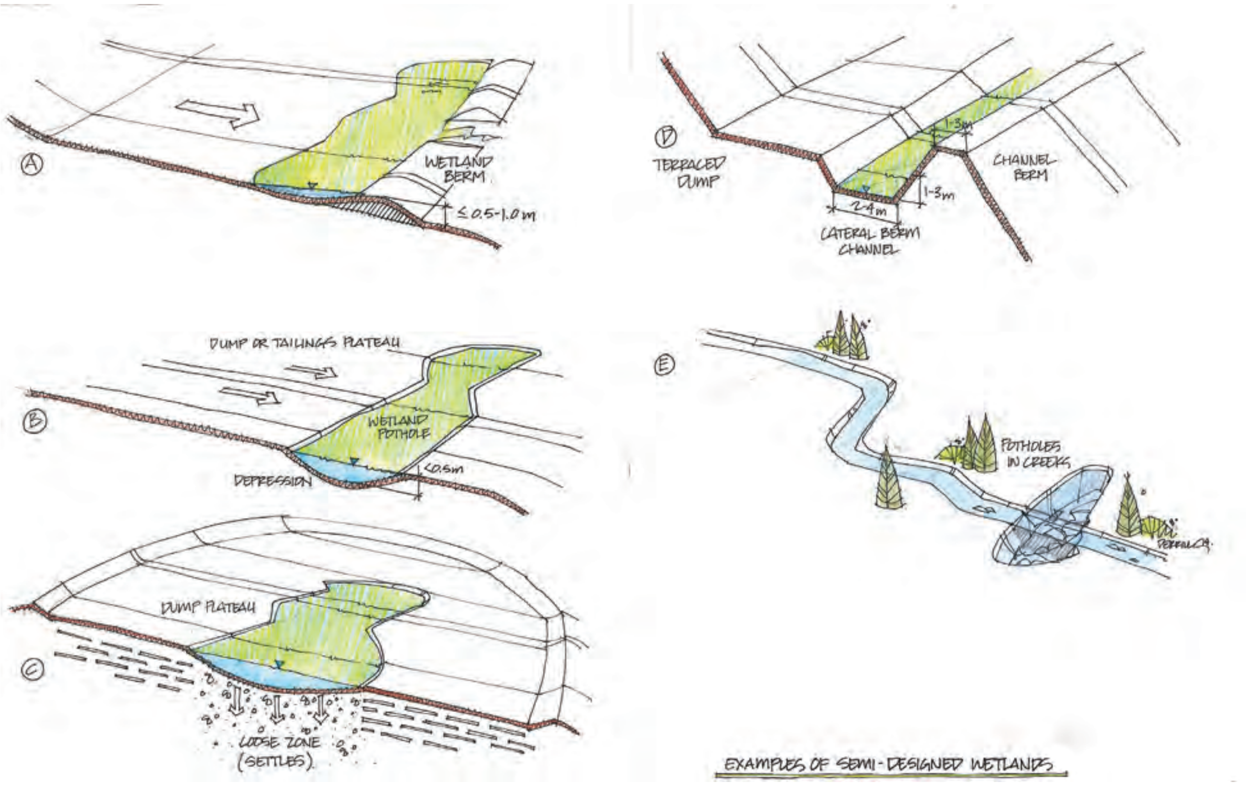


**Figure 6-14. Semi-designed wetlands.**

Semi-designed wetlands:

Are generally small (a few to tens of metres across)

Are usually located in ephemeral draws or central swales of tailings and dump plateaus

Occupy a small portion of the contributing watershed (5 to 15%)

Receive upland reclamation prescriptions and vegetation

Do not generally involve engineering calculations

Are assessed to avoid creating geotechnical hazards, problems with access (particularly for reclamation material placement), or concerns with respect to downstream water quantity or quality

May stay terrestrial, or may become wetlands, or may revert to terrestrial (as is also the case with other types of reclaimed and natural wetlands)

Are likely to be modified by beavers (unless the watersheds are extremely small)

May be included in estimations of wetland cover for lease-wide designs (Figure 5-3)

May be indicated as candidates on wetland design drawings, marked on IFC drawings, and/or field fit during regrading or reclamation

Are officially mapped and cataloged, receive a staff gauge and a pressure transducer, and an annual inspection (Section 8.4.5). Monitoring and reporting is minimized. In rare cases, some maintenance may be involved.

For semi-designed wetlands, wetland berms may be built from regraded substrate or overburden (reclamation material). Similarly, potholes may be created with subexcavated substrate during regrading (often by using dozers to create small basins), in low areas left by substrate/dump placement, or by locally thinning reclamation materials.

There is an opportunity, prior to regrading and after dump or tailings placement, to use satellite imagery to map wet areas that have formed and enhance them with berms or shallow excavations where practical. In some cases, opportunistic wetlands (see next section) will start to form in newly reclaimed areas. Some may need to be removed and others left, but in a few cases there may be a desire to enhance them with semi-designed elements, especially berms. Devito et al. (2012) provide additional information.

There may be desire to construct semi-designed wetlands to minimize hazards to workers, or otherwise to equip the sites with signs and life rings.

### 6.7.2 Opportunistic wetlands

Opportunistic wetlands form in response to hydrological conditions in the landscape regardless of human design intentions. They may form in reclaimed areas that have:

Active seepage discharge

Low areas left behind by construction or reclamation

Low areas formed by settlement of fills

Beaver dams

Many areas with these conditions will be anticipated in closure planning designed or semi-designed (and so will not be opportunistic anymore).

Opportunistic wetlands will have upland soil prescriptions and initial vegetation. Wetland plants will generally invade quickly, but there may be a desire to supplement this vegetation. Additionally, as noted in Section 6.7.1, there may be instances where other modifications to opportunistic wetlands are desired, turning these into semi-designed wetlands.

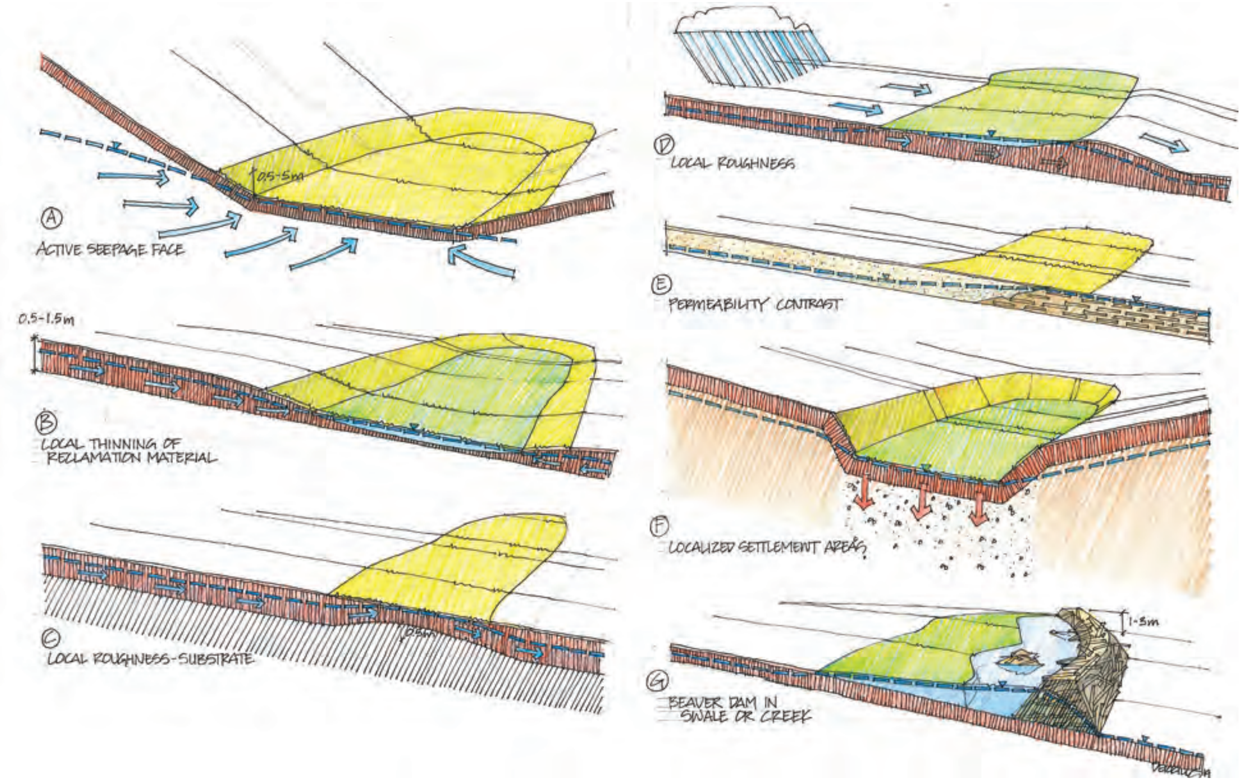


**Figure 6-15. Opportunistic wetlands.**

Examples of opportunistic wetlands are presented in Chapter 4. Additional opportunistic wetlands have been observed in oil sands reclamation but have yet to be catalogued. As indicated in Section 8.4.4, these wetlands, as they are discovered, will receive an identification number, a staff gauge, and an annual inspection. Annual examination of aerial photos and LiDAR combined with field inspections of reclaimed areas will be used to identify new opportunistic wetlands as they form.

Most opportunistic wetlands are expected to be small and localized (10s of metres across or less) and may become marshes or fens. Shallow-water wetlands are usually not allowed to form opportunistically as they may be a threat geotechnically. Opportunistic wetlands may form in the far future, or young ones may dry up and become re-terrestrialized (especially as upland ecosystems mature over the first 5 to 10 years). Opportunistic wetlands may outnumber the rest of the reclaimed wetlands combined, but they are likely to form only a small percentage of the reclaimed area at the lease or landform scale.

In some cases, opportunistic wetlands may form in areas that present risks to the reclaimed landscape (geotechnical hazards, problems with access, or unwanted impacts on downstream water quantity or quality). These opportunistic wetlands may need to be altered or removed from the landscape (AENV, 2008). Geotechnical constraints for landforms must be well documented and communicated to compare opportunistic wetlands with constraints and those deemed unacceptable will need to be removed.

A certain number of opportunistic wetlands can be expected to form in the reclaimed landscape. The future presence of these and existing wetlands can be included in closure planning reporting and water balances (see Figure 6-16). In fact, some of the best wetlands in reclaimed areas are opportunistic. AENV (2000) provides guidance on potential *enhancements* to opportunistic wetlands:

Berm one or more sides to increase depth and/or total area and retention time

Connect to existing wetlands, watercourses, streams or lakes using vegetated watercourses

Add overburden and/or muskeg around the shoreline to increase shoreline length and create irregular configurations (to maximize edge and habitat diversity)

Add overburden within wetlands to create islands as wildlife refuges

If saline, revegetate with saline tolerant plants or with material (sediment, seeds) from a suitable donor wetland (rather than waiting for natural colonization). Mitsch et al. (2012) provide a comparison of each approach.

In many cases, vehicular access to opportunistic wetlands will be minimal and enhancement may require disturbing other reclaimed land.

Figure 6-16 provides some guidance in estimating the number and size of opportunistic wetlands that may form on the landscape based on review of recent satellite imagery of reclaimed land in the region and knowledge of settlement patterns in typical mining landforms.

### 6.7.3 Perched fens

Perched fens are common in the boreal forest (Devito et al., 2012) and research-oriented perched fens have been constructed at Suncor and Syncrude (Pollard et al., 2012). Perched fens have little upland watershed, are dominated by direct precipitation (rain and snow) and so have extremely low salinity. They will be perched above the water table, through textural discontinuities such as unsaturated soil effects or thin clay layers. They will flood seasonally and during large rainfall events (See Chapter 2).

Conditions necessary to construct perched fens in a reclaimed setting (see Figure 6-16) continue to be researched. A lower permeability basal layer or capillary break is likely a prerequisite. The future performance of these reclaimed perched fens remains unclear but there is optimism. Should they fail, they will become additional upland forest areas. It is hoped that these fens will prove easy to design and construct and could be used widely for oil sands reclamation.

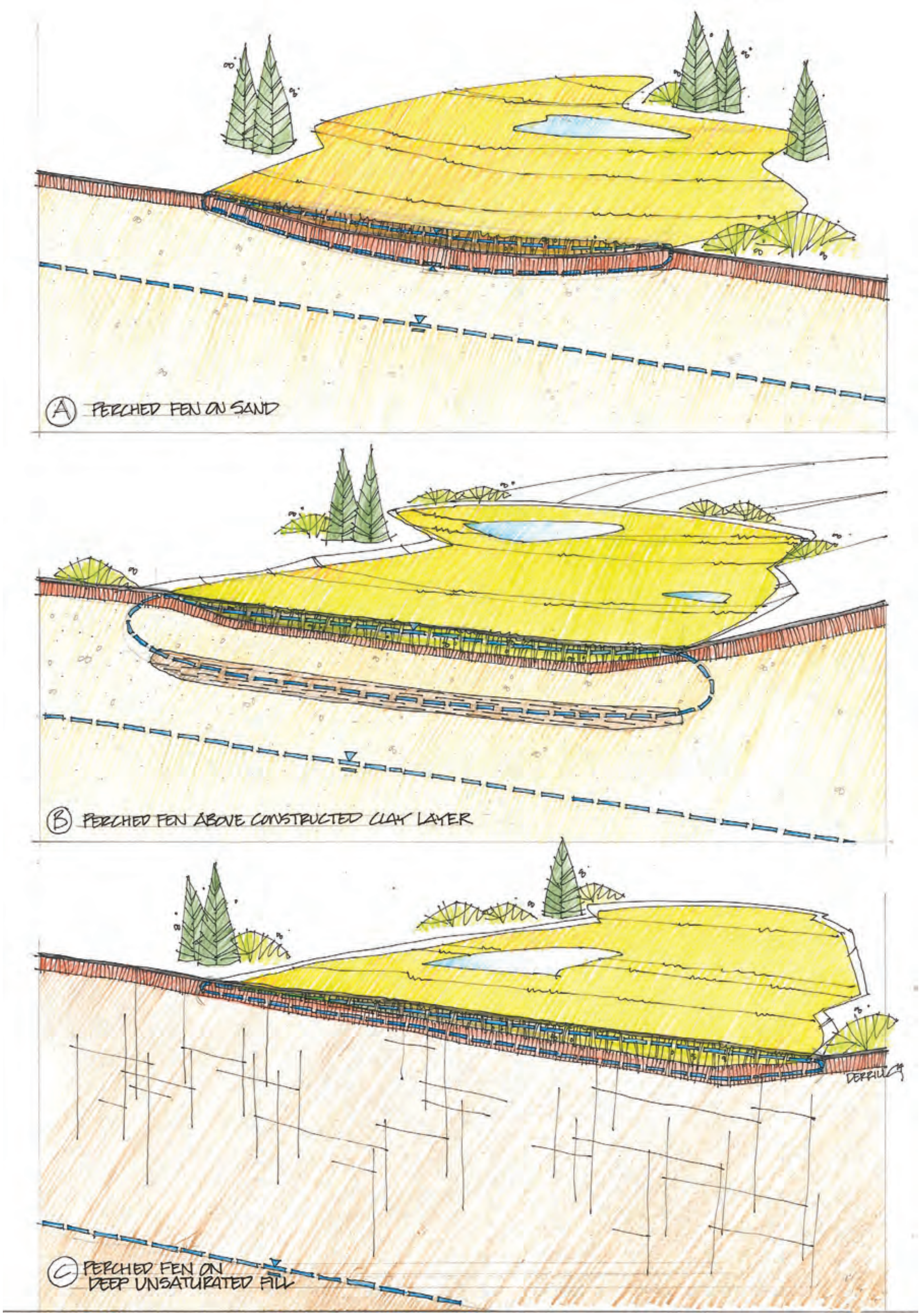


Figure 6-16. Reclaimed perched fens.

## 6.8 Other design requirements

### 6.8.1 Schedule development

The wetland design includes a schedule for earthworks, reclamation, revegetation, operations, and monitoring (see Section 7.1, Pollard et al., 2012). Of particular importance is the sequencing of the earthworks, reclamation and revegetation. Seasonal limitations (e.g., no fill placement during winter conditions) and the long lead times for revegetating some species can be a factor in design. Figure 1-7 provides a typical annual cycle useful in preparing a schedule.

### 6.8.2 Risk assessment

Designs are tested with various risk assessments that include (sequentially): Fatal Flaw Analysis (FFA), Failure Modes Analysis (FMA), Failure Modes and Effects Analysis (FMEA), Constructability Review, and in some cases Ecological Risk Assessment. Information on these methods is presented as part of adaptive management (Section 1.4.3 and Section 8.1.1). CEMA's EPL Guidance Document (CEMA, 2012) has additional information on risk assessments.

The expected performance of the design (as well as that of landform construction, wetland construction, reclamation, revegetation, and monitoring) is compared with the DBM design goals. Where risks are identified, designs can be altered and/or contingencies put in place. The team assessing the risks will often be broadened to include operations staff, perhaps regulators and stakeholders in some cases. Often the FFA and FMA can be first conducted when the initial wetland design is nearing completion (Section 6.3.6).

Where there is risk that the wetland or outlet water quality objectives may not be met, an ecological risk assessment may be required. The site investigation and monitoring program is modified to provide toxicity data, and in particular source water quality and water quality trends over time. Table 8-8 provides a list of contingencies in the event of poor wetland performance.

Risk associated with new technologies can be reduced by testing that element or aspect early in the design process (e.g., Pollard et al., 2012, McKenna et al., 2011a).

### 6.8.3 Documentation

Each wetland is cataloged as it is designed. A repository of field observations, design, construction records, and monitoring data is created and maintained. Most of the design documentation for a designed wetland design is enclosed within an engineering report, developed by the wetland team, and sealed by professional members of the design team. In addition to details of the design, the report typically includes the results of the site investigation, laboratory testing, modelling and prediction, schedules, cost estimate, the monitoring and maintenance plan, the reclamation plan, and a risk assessment. The design report is a key reference for future monitoring, assessing design changes during construction, and operating and maintaining the wetland. Furthermore, the design report is a critical resource for the preparation of an application for reclamation certification. Construction (IFC) drawings are generally prepared based on the design report.

The design team provides technical monitoring of the construction and reclamation (Section 7.3), and uses the field notes, inspections and surveys to prepare an as-built report. The report is prepared as construction and reclamation continues, checking construction and performance against design goals and objectives from the DBM. As major design changes are suggested, the goals and objectives are revisited to guide decision-making. Sometimes revisions to the goals and objectives are needed.

The as-built report focuses on the period from the start of construction through to reclamation and signoff (Year 0). It contains the following:

- Description of the landform and wetland design
- The title of the design report and list of IFC drawings and any revised IFC drawings
- The sequence of activities, when each was started and finished
- The weather during this time (and its effect on field activities)
- Elements that were constructed to design and those with significant deviations from design
- Observed landscape performance
- Results of any special materials testing (lab and field testing, including quality control testing)
- A reference to the reclamation material placement monitoring (usually its own activity)
- A reference to the revegetation monitoring (also usually its own activity)
- Survey information, usually in the form of a series of as-built drawings
- Records of any water additions or withdrawals (and their chemistry if pertinent)
- Instrumentation readings during this phase.

Whether or not the as-built wetland generally meets the goals and objectives in the DBM, design notes for semi-designed wetland are kept in the repository or in the landform design report. Opportunistic wetland information is maintained as part of the ongoing monitoring and adaptive management program. Chapter 7 provides additional guidance.

# Chapter 7

# Wetland Construction

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Wetland construction and reclamation may be part of routine mine reclamation or as a standalone project and may range from highly designed wetlands with a set of issues-for-construction (IFC) drawings to semi-designed wetlands that are simply field-fit by reclamation practitioners. The landform is first constructed by the mine or tailings operations group, and the wetland roughed in. Extensive soft tailings stabilization and capping may be required. A final site investigation of the as-built landform, including a proof roll to identify soft areas, is often required.

Designed wetlands involves considerable construction planning and scheduling — many construction and reclamation activities are limited to either summer or winter activities. Usually the watershed is reclaimed before or at the same time as the wetland. These activities are routine for miners.

Site preparation involves establishing the project boundaries and securing access. Water management is usually a critical first step in construction. Access for large equipment may need to be established.

Earthworks (shaping the land) and reclamation material placement are typically the largest costs. Guidance on various constructed elements (berms, fills, liners, islands, penninsulas, potholes, inlets, outlets, and irrigation) is provided. Much of this work is done in summer.

Reclamation material is usually placed during the winter. Various placement strategies and soil prescriptions are being researched (and debated) at field scale in the oil sands, and guidance is provided.

Revegetation is usually a major element of wetland reclamation and various methods, strategies, and advice regarding use of various plant species are provided for fens, marshes, and shallow water wetlands. The choice of species (and their assemblages) is highly dependent on the expected hydrology conditions (flows and levels), salinity, nutrient levels, and landscape position. Various vegetation establishment techniques are available and more are being actively developed.

Finally, after revegetation, wildlife enhancements are added, infrastructure is added or removed, as-built records are prepared, and the wetland is allowed to fill (or is filled) with water as it moves into the operation, monitoring, and maintenance (OMM) phase (see Chapter 8). Designed wetlands typically take one to three years to construct and revegetate. Semi-designed wetlands will typically be done within one year.

While there is considerable experience in the oil sands, there remain many earthworks, reclamation material, and revegetation strategies that could be improved through careful monitoring and reporting of commercial-scale designed and semi-designed wetland reclamation.

## Table of Contents

## 7.1 Introduction

This chapter provides guidance for the construction of reclaimed wetlands in the Athabasca Oil Sands Region (AOSR). It briefly discusses landform and watershed construction, then describes construction activities, including revegetation techniques.

Much of the information presented here was derived from experience building marshes in the AOSR over the past 15 years (Chapter 4), construction of Syncrude's Sandhill Fen and Suncor's Wapisiw Lookout Marsh and Nikanotee Fen, wetland construction by Ducks Unlimited Canada, and guidance from textbooks. Oil sands wetland construction shares many activities and management practices with upland reclamation, which is now a mature field with routine activities and management practices. While this guide focuses on wetlands, it is recognized that wetland reclamation is but one part of the larger task of oil sands mine reclamation, which includes mining and tailings, landform construction, and reclamation of uplands, wetlands, streams and riparian areas, and end pit lakes. In the context of this chapter, the wetland team (or the construction team) is the group of management, technical and operational staff who are constructing the wetland. Often this will be simply the reclamation team; in other cases, it may require a special project team that possesses additional expertise.

### 7.1.1 Construction overview

Table 7-1 describes the general sequence of wetland construction and serves as an outline for the rest of the chapter. Note that many of these activities run in parallel and that not all activities and components will be required for every wetland.

**Table 7-1. Sequence of oil sands wetland construction and reclamation.**

| Construction phase | Topic | Activities |
|---|---|---|
| Landform construction<br>Section 7.2 | | Mining/ore production<br>Site preparation and infrastructure construction<br>Dyke construction<br>Dump construction<br>Tailings deposition/dredging<br>Pond stabilization, pumping, draining<br>Regrading dump, or dyke benches |
| Watershed construction and reclamation<br>Section 7.3 | | Landform grading (Schor and Gray, 1995; 2007)<br>Watercourse construction (Golder, 2004)<br>Reclamation material placement (CEMA, 2006)<br>Upland revegetation (CEMA, 2010) |
| Preparation and planning<br>Section 7.4 | Scheduling | Define construction team roles and responsibilities<br>Identify borrow sources and quantities<br>Identify haul routes and access requirements<br>Create cost controls and budgets<br>Set construction plan and schedule<br>List contingency measures<br>Perform risk assessment and create safe work plan |
| | Final site investigation | Conduct final geotechnical site investigation to support final design<br>Determine borrow sources, properties and cut/fill quantities, disposal areas<br>Revegetation planning, seed collection and greenhouse propagation |

| Construction phase | Topic | Activities |
|---|---|---|
| | Final design/IFC drawings | Finalize design and project area<br>Issue construction drawings (IFCs) |
| | Contracts and procurement | Conduct tendering, bidding and contracting<br>Procure construction supplies and materials |
| | Equipment selection | General equipment types and usage |
| Site preparation<br>Section 7.5 | Establishing access | Secure access<br>Build haul roads to borrow sources<br>Build access roads to and within wetland<br>Prepare stockpile areas and laydowns<br>Construct laydown areas, construction trailers, washrooms |
| | Water management | Establish run-on control<br>Remove water from project site<br>Establish and maintain ongoing water management |
| | Wildlife management | Identify need for wildlife management<br>Methods to protect wetland from wildlife |
| Earthworks and infrastructure construction<br>Section 7.6 | Substrate excavation and grading | Grade substrate to design topography<br>Remove unsuitable materials<br>Prepare base (cut/fill)<br>Rough in basin (using mine equipment) |
| | Wetlands berms and fills | Construct watershed berms<br>Fill material placement to achieve design elevations and construct wetland elements |
| | Liners | General liner information and types used for wetland reclamation |
| | Islands, peninsulas, and potholes | Construction |
| | Inlets and outlets | Construction |
| | Irrigation | Filling wetlands early if needed |
| Reclamation material placement<br>Section 7.7 | Reclamation materials | Specifying typical materials |
| | Borrow site and stockpiles | Investigation/volumes |
| | Reclamation material placement | Coversoiling |
| Reclamation infrastructure<br>Section 7.8 | | Methods to access wetland and watershed<br>Infrastructure types and requirements |
| Revegetation<br>Section 7.9 | | Revegetation plan and procurement of seeds<br>Strategy for revegetation |
| Final construction<br>Section 7.10 | Complete construction and reclamation | Wildlife enhancement features<br>Test infrastructure for operation<br>Remove unnecessary access roads and infrastructure<br>Final survey |
| | Wetland commissioning | Initial wetland filling with water<br>Begin wetland operation<br>OMM Manual |
| | Signoff and handover | Identify and address deficiencies<br>Signoff and handover to OMM team by project team<br>As-built drawings and report |

### 7.1.2 Construction teams

Staff and contractors should use established procedures for construction and monitoring, with a full-time field monitor for each activity. They record field activities, prepare daily reports, and report to the project manager and designer. A surveyor supports the project as needed. It is most effective if wetland reclamation work is performed as part of the normal reclamation operations to take advantage of existing mining systems and efficiencies, and ensure good tie-in between the wetland and its watershed.

Preparation of an as-built report (Section 7.10.3) is associated more with wetland reclamation than for upland mine reclamation but it is similar to that done for dam or foundation construction. The team starts the report even as wetland construction begins. After the project is complete, a reclamation material audit and a revegetation audit are conducted to standards in the soils manual (CEMA, 2006) and the vegetation manual (CEMA, 2010) as adapted for wetlands.

## 7.2 Landform construction

The landform is constructed over years or decades and the design is adjusted over time. The closure plan constraint map (Section 5.2.12) highlights, among other things, key elevations and substrates in the proposed wetland areas to allow the operations staff to create topography that can be easily converted into a reclaimed wetland.

Near the end of this phase, mining or tailings equipment may be used to adjust the as-built landform prior to wetland construction. For example, the mine fleet may be used to rough in channels or the wetland basin (see Figures 1-2 through 1-4), or the tailings operations may be able to deposit tailings to create the desired topography. There may be a need to dredge some out-of-specification tailings and finish capping or stabilizing tailings.

How much of the earthworks is completed by mine or tailings operations and how much is left to the reclamation/wetland project team varies with each operation and site. Earthworks at the mining stage have low unit costs, but finesse is usually limited with the use of such large equipment and time of year. At some point, there is an agreement that the mining or tailings work is complete and the wetland project team takes over responsibility for the area and the remaining earthworks and revegetation.

## 7.3 Watershed construction and reclamation

Watershed and wetland reclamation share similar steps: planning, re-grading, reclamation material placement, revegetation, monitoring and maintenance. The wetland is typically a small portion of the watershed. The watershed and wetland reclamation may be done in parallel as part of the same project or separately. This guide discusses them separately for ease of explanation, but efficiencies arise if they are built together by one team, which can coordinate design and schedules of both. It is useful to reclaim the watershed before the wetland (to limit erosion and deposition into the wetland), although access to the wetland through the watershed must be maintained for construction and reclamation. Special provisions may be necessary if the wetland is constructed before the upland is reclaimed.

## 7.4 Preparation and planning

Construction planning begins with delineating the project area, which will be similar to that of the wetland design but adjusted for opportunities and restrictions of mining, tailings, and reclamation operations. The design project area is formally assigned to the project team, which is then responsible for all activities involved in reclaiming every square metre in the project area.

The planning team sets out an execution plan using the inputs described below. For some projects (e.g., semi-designed wetlands) this may take a few hours. For research or designed wetlands, it may take months. The plan will contain a schedule, roles and responsibilities, borrow sources and quantities, haul routes and other access, sequencing of activities, identification of contracting needs, budget, and a list of contingency measures. Mine reclamation staff create execution plans routinely. Wetland reclamation is highly constrained seasonally and the vegetation strategies may require a lead time of one to three years.

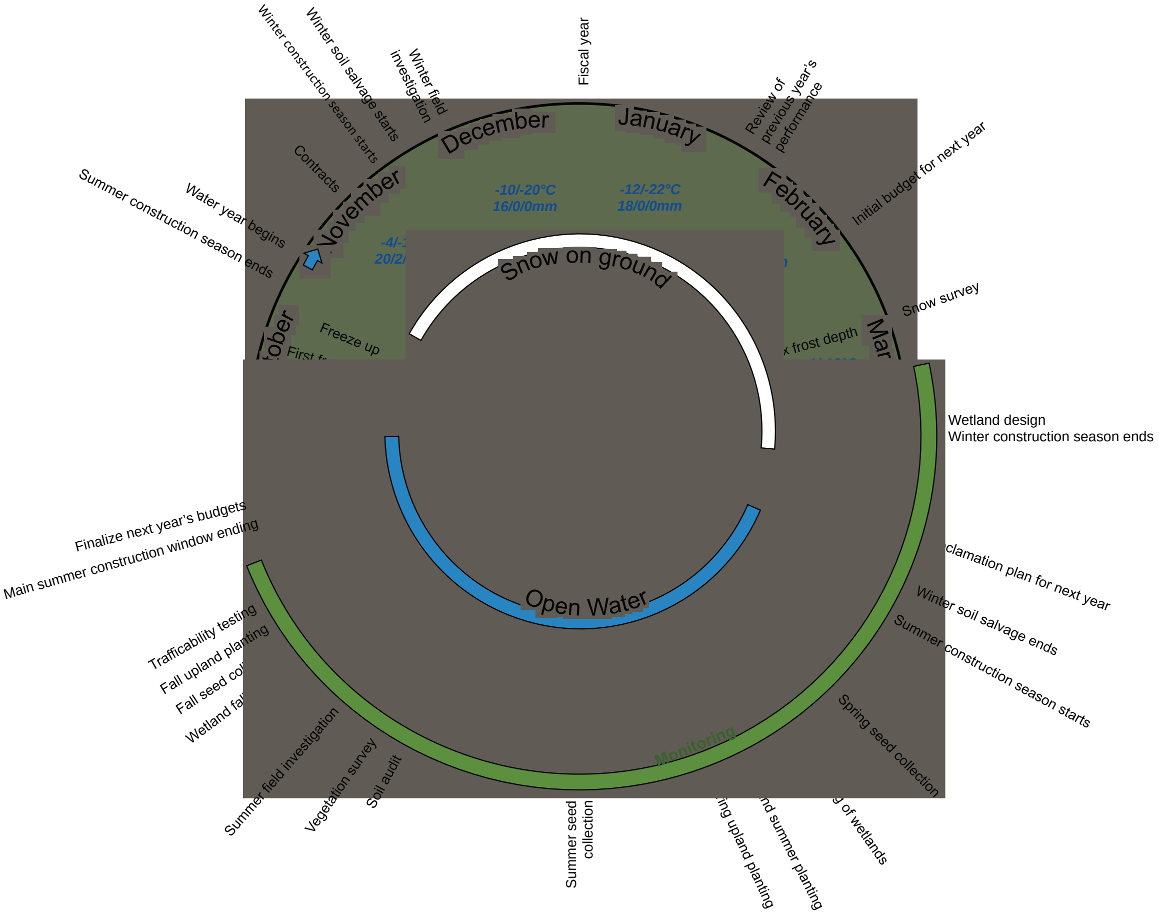

**Figure 7-1. Annual cycle for oil sands wetland construction.**
Key: *+10/-4°C; 21/75/25mm* Average monthly: daily high/daily low; precipitation/potential evaporation /actual evaporation (Canadian climate norms, Fort McMurray airport, 1981-2010). Total annual average potential evaporation (PE) 617 mm, Total annual average actual evaporation (AE) 292 mm. PE & AE estimates courtesy of Sean Carey, McMaster University and are approximate, based on the Penman method employed for the period 2002-2013, and tempered with judgment.

### 7.4.1 Scheduling

Scheduling will influence the design and there is a rhythm to the annual cycle of activities as shown in Figure 7-1. Note that the dates are generalized and do not reflect the full range of potential conditions or activities of various operators.

Construction earthworks referred to in the figure relate to regrading and compaction. Frozen ground or frozen fill cannot be regraded or compacted, greatly restricting the construction window, as show in Figure 7-1. Most liners cannot be built in winter. However, in a few situations, especially using the large mine fleet haul trucks, non-frozen overburden and interburden fill can be quickly dumped, spread, and compacted before it freezes (e.g., Cameron and Fong, 2001; Cameron et al., 2001). For non-structural fills, unfrozen tailings sand may be placed in subzero conditions (Russell, 2010; Pollard et al., 2012).

In some cases (in mounds or other non-structural fills, for example), it may be allowable to place fills loose and uncompacted. In areas of soft ground, access may be limited to winter. That said, most wetland construction activities (e.g., regrading, placing wetland berms, constructing inlets and outlets, regrading reclamation material, channel construction) will normally be restricted to the summer construction season.

It is easy to lose one or more years in wetland construction by failing to meet a seasonal deadline. Good construction teams take advantage of an early construction season, and are ready to start May 1. Designs must be complete several months earlier. In some cases, there may be seasonal construction activity restrictions related to wildlife (e.g., migratory birds, nesting birds, caribou). Avoid planning earthworks beyond the end of September, after which snow and frost can be an issue.

Frequent thundershowers can create poor driving conditions and cause water to flood a construction area. These conditions can cause delays if fill materials require drying before placement. Good construction techniques (e.g., Section 7.5.2) will help reduce lost time. Frozen fill can often be used to build topographic mounds in the rare cases in which settlement is not an issue. Reclamation material is generally placed frozen, partly for efficiency and access to borrow, partly to avoid overcompaction during placement (Moran et al., 1990).

Scheduling of wetland reclamation on large tailings plateaus deserves special attention. The watershed areas can be large (500 to 1,500 ha) and the wetlands may be hundreds of hectares in size. The land may become available for reclamation all at once, or in stages as tailings deposition is completed. Construction and reclamation in the latter case may take up to five years. Opportunities to set up construction infrastructure (offices, lunchroom, laydowns, repair facilities) on the site, as was done at Suncor Wapisiw Lookout, should not be overlooked (Russell et al., 2010).

### 7.4.2 Final site investigation

In some cases, the site investigation task list may be as simple as mapping substrates and surrounding areas. For larger or more complex projects, it might involve drilling, test-pitting, settlement monitoring and some laboratory testing lasting several months. The site investigation (Figure 7-2) covers the following aspects:

At the wetland

- Construction history of the area
- As-built topography
- Ongoing nearby operations, existing reclamation
- Existing infrastructure
- Substrates and substrate physical/chemical properties
- Any debris or other facilities requiring demolition or removal
- Instrumentation readings
- Access
- Surface water flows, wet areas, areas of poor trafficability
- Groundwater conditions (in some cases)
- Tie ins for wetland inlet, outlets, and reclamation material

At the borrow sites

- Quantity and physical/chemical properties of borrow materials
- Access
- Haul routes

Findings from the site investigation are typically supplied as a stand-alone report, and are sometimes included as an appendix to the final design report.

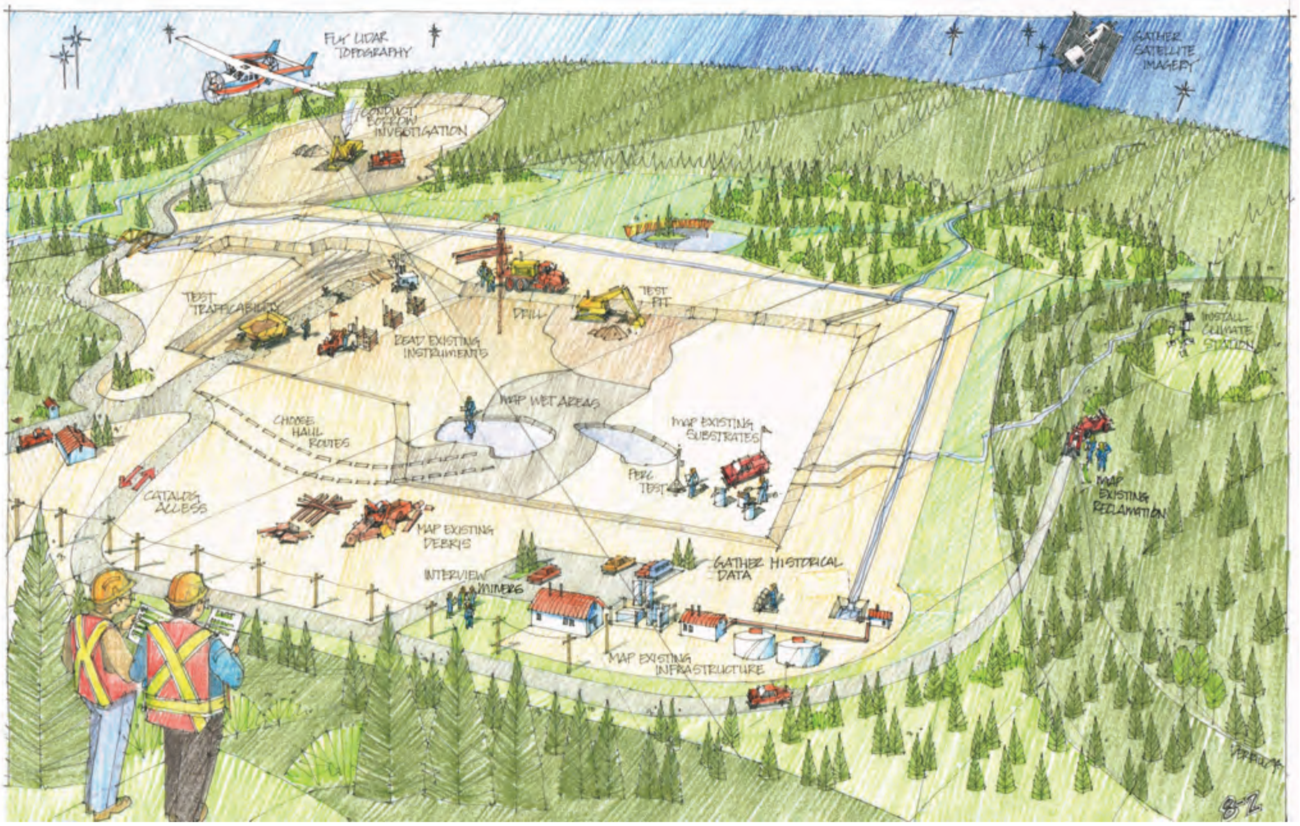

Figure 7-2. Wetland final site investigation.

### 7.4.3 Final design and IFC drawings

The wetland design is finalized based on the results of the site investigation, hydrology of the site, borrow availability, and equipment constraints. A design report is created and issues-for-construction (IFC) drawings are usually generated. The IFC drawings are the basis for construction and reclamation of the wetland and are included in contractor bid packages. IFC drawings typically include:

Specific drawings for:

- General arrangement
- Site preparation
- Regrading
- Fill placement and excavations
- Liner installation (if required)
- Inlet and related infrastructure
- Outlet and related infrastructure including emergency spillway
- Erosion control structures
- Infrastructure (roads, pads, pipelines, powerlines)
- Topographic features (islands, mounds, and peninsulas)
- Reclamation material placement
- Revegetation
- Wildlife habitat enhancements
- Instrumentation

Material quantities and specifications

Construction specifications and tolerances

Survey coordinates for construction control

For research and designed wetlands, the IFC drawings are usually sealed by a professional engineer and other qualified professionals. The number of drawings in the IFC package will range from a few to more than 20, depending on wetland complexity. For semi-designed wetlands, a simple drawing or sketch may suffice, or the material placement areas may be included in the weekly or monthly reclamation material placement plans.

### 7.4.4 Contracts and procurement

Many wetlands will be constructed with reclamation operations equipment, but others will require contractors with experience with smaller equipment. The wetland team will support the contracting process with design packages, bid packages, and bid evaluation. The successful contractors become part of the team.

Pipes, weirs, data loggers, instrumentation, and materials (e.g., gravel or sand and reclamation materials from the mine), may be required. Some of these supplies and materials are readily available, but others may require special orders, so planning for procuring supplies and materials is needed early in the construction process. Details on required supplies and materials are provided in the IFC drawing package.

### 7.4.5 Equipment selection

Based on decades of oil sands mining and reclamation experience, the following equipment is typically used for wetland construction:

> Tracked bulldozers (dozers) for rough and fine grading and contouring, resloping, spreading fill and reclamation materials, ripping dense or frozen materials, pushing material to shovels, and making small cuts for ditches and swales. Typically, push distances for dozers are limited to less than 50 to 200 m.
>
> Excavators ("backhoes") for removing materials, loading trucks, trenching or ditching, fine-grading or sloping small areas, placing fill, handling and lifting materials, and, when equipped, for jackhammering frost or rock.
>
> Trucks, haul trucks and articulated trucks for transporting materials. Trucks vary in size and are selected according to application, site access, and trafficability.
>
> Graders fine-grade, maintain roads, clear snow, and prepare sites for construction.

Other equipment includes bobcats for small-scale grading and tramming, cranes for lifting supplies and infrastructure, scrapers for cutting and filling over distances of 500 to 1,500 metres, tamping-foot rollers for compacting clay materials, drum rollers for compacting granular materials, small backhoes for small excavations or ditches, and loaders for tramming materials distances of 100 to 500 m.

Soft ground can preclude use of large equipment. The following strategies are useful:

> Sub-excavation in loose saturated tailings sand is nearly impossible. Designs are mostly built entirely with additional fill and without sub-excavation.
>
> There has been some success using 12 to 20T gravel trucks and D3 dozers working on sandy fills with geogrid over soft tailings. A test fill may be used for soft tailings capping designs (Jakubick and McKenna, 2001).
>
> Coke has been used as a lightweight fill (with geogrid) on very soft tailings (Wells et al., 2010; Abusaid et al., 2011). It has also been employed as a drain at the Suncor Nikanotee Fen (Pollard et al., 2012).
>
> Summer trafficability testing (when there is no frost) can determine which equipment is safe for which part of the project area and then perform construction activities during winter conditions while a thick frost cap is present.
>
> Padding over soft overburden fill with 1 m of dry fill usually provides good trafficability for articulated trucks (up to 40T).
>
> 40T articulated trucks are preferred for soft ground conditions (where there is truck trafficability; see Figure 7-3.). If conditions permit, 100T trucks can be employed.
>
> Excavators loading haul trucks are best for excavation of large overburden fill areas.
>
> Caterpillar D6 wide-pad dozers are used for channel construction, regrading and spreading reclamation material. Cat D8/D9 and large scrapers are useful in unsaturated overburden dump fills.
>
> Geogrid reinforced berms can be employed for building wetland berms on soft overburden fill where settlement is an issue (Pollard et al., 2012).

**Figure 7-3. Small equipment working at Suncor Wapisiw Lookout (formally known as Pond 1). Photo courtesy of Suncor Energy.**

### 7.4.6 Safety issues

Safe work plans and field-level risk assessments (FLRAs) are generally required for any mine activity.

Avoid structures (tents, buildings) in reclamation areas where there may be issues with gas from landforms, pipes, or pumping. Gases such as carbon dioxide ($CO_2$), methane ($CH_4$), or hydrogen sulphide ($H_2S$) can accumulate. Where structures are needed, a full assessment of confined entry conditions is required.

Poor trafficability of soft ground puts personnel and equipment at risk. Procedures need to be developed for access and testing prior to construction. Special care is required when working in areas that may have flooded and iced over.

Design for good footing for monitoring access with gravel paths, roughened piers, and boardwalks, easy access, and good signage.

Artificial liners are slippery, especially with snow or frost.

Procedures for working in areas of blowing sand or coke dust should be developed.

Safety on boats, docks, boardwalks, shorelines and open water is paramount.

Workers need to be trained to deal with bears, rodents, ungulates and other wildlife.

## 7.5 Site preparation

Site preparation is conducted prior to construction to provide site access, start the water management process, and, in some cases, sign and gate the main access. It is often necessary to remove unwanted materials (such as debris, unwanted stockpiled materials, old infrastructure) or relocate stockpiles from the project area.

### 7.5.1 Establishing access and site clearing

All areas must be accessible by reclamation equipment. Haul trucks from the mine or reclamation salvage areas should have access to the construction or stockpile areas to deliver reclamation materials. Local haul roads or equipment operation procedures need to be developed, especially if soft ground is a concern. Hauling conditions are better while the ground is frozen, reducing the need for constructed roads. Stockpile and laydown areas are prepared at this stage, along with construction trailers and washroom.

### 7.5.2 Water management

Areas designated for wetland construction are usually the lowest in the watershed. They tend to be wet, soft, and frequently inundated. Trafficability can be an issue and conditions may be unsuitable for fill placement. Many substrates turn to mud when wet, requiring sub-excavation and removal. Sacrificial fill may be used to limit removal of high-quality fill. Early in the planning, run-on controls (temporary diversion ditches and berms) can keep water from flowing into the project area. Ditching, sumping and pumping can remove precipitation and run-on water within the project area (Figure 7-4). Maintaining a reliable water management system reduces construction costs and delays.

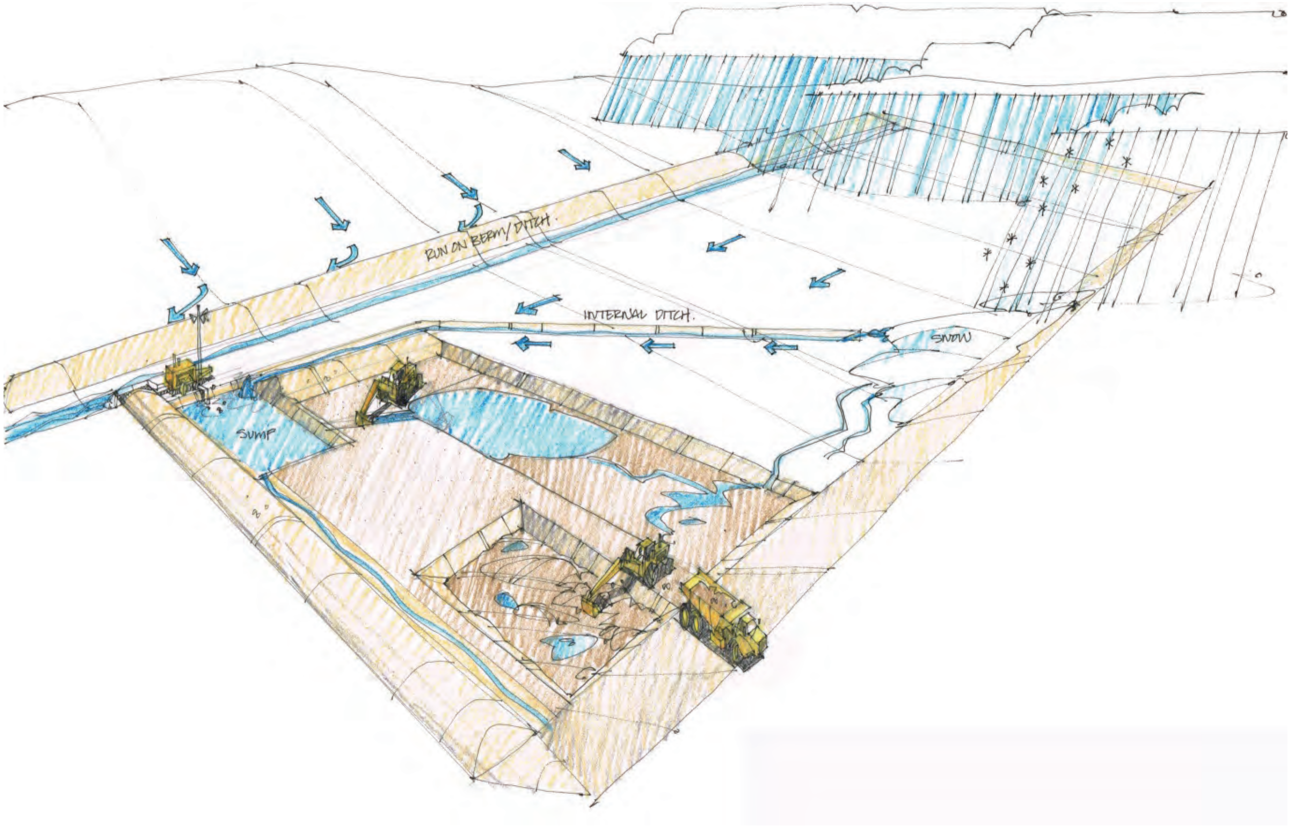

**Figure 7-4. Water management during construction.**

### 7.5.3 Wildlife management

Wildlife management may be required to protect seedlings and emerging vegetation, or prevent damming of inlets and outlets (van der Valk, 2009). Deer, elk, and other mammals can cause problems, but most problematic are birds and rodents. Birds and waterfowl can graze seedlings, and uproot plants. Muskrats (*Ondatra zibethicus*) and beavers (*Castor canadensis*) can damage wetland vegetation by herbivory, mound-building, and borrowing, and can alter wetland hydrology by damming or clogging channels, swales, inlets, and outlets.

Unlike many mines and many wetland projects, the oil sands presently have few problems with wildlife impacts on revegetation. Historically, meadow vole (*Microtus pennsylvanicus*) consumption of tree seedlings has been managed by avoiding agronomic grasses (Radvanyi, 1980; O'Brian, 1994). Birds may eat newly sown seeds if broadcast. Migratory geese will eat young wetland seedings. Some beaver control is practised; damming in reclaimed areas is generally seen as positive (e.g., Section 3.5), but is not as desirable for wetlands sensitive to changes in water levels, at least during the first few years of commissioning.

Methods to protect wetlands from wildlife include:

> A wide variety of fencing can be used to keep larger terrestrial animals from entering the watershed or wetland area, or to keep smaller amphibians from the wetland or certain areas within the wetland (Ramseier et al., 2009). When fencing wildlife out of a site, they can also be trapped in by accident. In those situations, create exit points in the fencing to allow wildlife to leave a site if trapped. For example, one-way fences have been developed to allow ungulates to pass through fences (Reed et al., 1974). Fences are widely used outside the oil sands.
>
> Trapping and relocation, though often challenging to manage successfully, remove rodents (Ross and Murkin, 2009).

Depending on scale and costs, it may not be practical to implement protection measures unless wildlife is observed at the site. Also, many protection measures will be temporary and should be removed once vegetation is established. Site access and equipment trafficability needs to be considered to minimize disturbance during removal of the protection system. After the wetland is established, wildlife should be encouraged.

## 7.6 Earthworks and infrastructure construction

This section describes some of the construction techniques employed to create the overall basin, various wetland elements, and to install associated infrastructure.

### 7.6.1 Substrate excavation and grading

The substrate is graded to its design topography using dozers pushing, loaders tramming, scrapers hauling, and excavators and haul trucks moving materials. Sometimes additional fill will be trucked into the project area, but generally the material being hauled to and from site is minimized for economic and material availability reasons. Often there is excess cut material, which can be used to build watershed berms, peninsulas, islands, mounds, or hummocks, under the design team's direction.

Grading and contouring accuracy is typically indicated on the design drawings and depends on components and design; some specifications may be within tens of millimeters while others will aim simply for positive drainage. Grading and contouring to the outlet needs to be closely monitored to ensure intended flow.

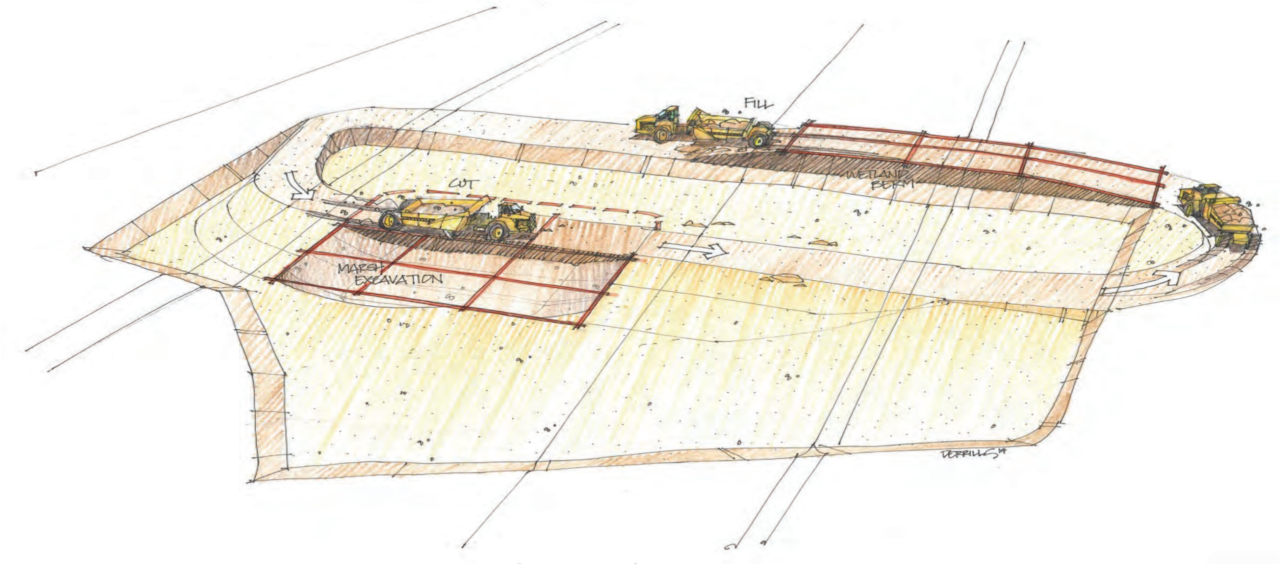

**Figure 7-5. Balancing cut and fill.**

## 7.6.2 Wetland berms and fills

Wetland berms may be built in lifts or through end dumping (Figure 7-5) depending on specifications in the IFC drawings. Berms on soft ground may require geogrid for temporary internal reinforcement and slope stability. Sometimes this is done as a field fit during construction; other times it requires formal geotechnical design. As the outlet governs much of the wetland operation and performance, berm construction near the outlet requires particular attention. For semi-designed wetlands (and retrofits to opportunistic wetlands) Section 6.5.5.2 provides some typical geometries.

Fills include the layers above the rough landform, typically tailings deposits or overburden dumps, but below the reclamation material. Fill materials are typically placed to achieve the desired elevations and function of wetland elements. They are typically hauled and dumped by trucks, spread by dozers, and compacted by trucks, dozers, or more rarely by compactors (a vibratory smooth drum for coarse material and tamping-foot compactors for fine-grained materials).

There are typically three levels of specification for fill placement: unengineered fill, low-specification fill, and high-specification fill. Fill placement may be restricted to non-freezing conditions to avoid frozen materials and to achieve compaction of the material to the specified density. Cameron et al. (2000) provide techniques for winter fill placement and compaction using mining equipment, but these methods are usually limited to construction of large dams.

The design will provide the specification for fill placement and any fill placement restrictions. Test fill programs may be conducted to assess the suitability of using a specified, or suggested, material for the intended application. Design specifications must be met.

### 7.6.3 Liners

Liners can reduce undesirable leakage from a wetland. They are generally avoided in design due to expense, limited longevity and logistics, but can be useful in certain circumstances. Wetland reclamation liners:

are expensive and time-consuming to install. Liner procurement and installation are likely on the critical path for completion of wetland construction.

need to be designed by a professional engineer, be installed by a qualified installer, and monitored closely during construction.

have a finite functional life; performance beyond several decades is unproven.

exhibit performance related to the quality of construction and require QA/QC monitoring. Adequate cover and equipment operating procedures will avoid damaging the liner during construction and control degradation once installed.

may not be suitable in areas where large settlements are expected.

Liners used in oil sands earthworks include:

Compacted clay liners (CCLs): constructed by placing and compacting clayey fill, and some can contain additives, such as bentonite or polymers. CCLs are used as landfill liners and reclamation material cover systems, have the ability to absorb or attenuate some contaminants, and are generally more resilient. But they are limited by availability of suitable clay fill, require construction in dry weather, are thicker than geomembrane liners, are susceptible to desiccation and freeze-thaw affects, and may be difficult to construct to specification on soft ground or saturated tailings beaches.

HDPE, LLDPE and LDPE liners: include a wide variety of plastic liner types that are produced in sheets or rolls and seamed on site. Most designers and contractors are familiar with their design and construction. These liners are resistant to degradation by contaminants or chemicals, but usually need to be installed during summer and can have issues with material sliding on the liner if installed on slopes. Longevity and performance with settlement are also significant issues for plastic liners.

Geosynthetic clay liners (GCLs): produced in rolls that are seamed onsite. GCLs are quick to install, seamed using bentonite instead of welding, can be installed in winter and are fairly insensitive to frost effects. But they require modest subgrade preparation and can have low shear strength if unreinforced. GCLs have been used at Suncor’s Wapisiw Lookout (Russell et al., 2010) and Suncor’s Nikanotee Fen (Pollard et al., 2012).

Bituminous liners (BGMs): produced in sheets or rolls that are placed and seamed onsite. BGMs provide long-term durability, require less subgrade preparation, can be installed in wet weather, are less sensitive to puncturing than other liners and can be repaired by installing and sealing another sheet on the damaged area. But cold-weather installation is challenging and not generally recommended.

Manufactured liner materials come in large rolls requiring equipment for handling and special attention to storage before use. Manufacturers often provide considerable design and construction support for liners.

### 7.6.4 Islands, peninsulas and potholes

Islands, peninsulas, and potholes are potential barriers to earthwork equipment and may be constructed later in the project. Islands and peninsulas can be used for access via paths and as anchors for boardwalks, though at the cost of wildlife disturbance. For semi-designed and opportunistic wetlands, it may be desirable to create loose zones to promote the formation of potholes. This can be accomplished by:

- Dumping materials in thick lifts (>2 m) and avoiding trafficking;
- Placing frozen fill;
- Including snow and ice in fill;
- Encapsulating slop, ice, or snow below a compacted cover; and/or
- Placing loose organic material or coarse woody debris.

These areas will settle, creating or adding diversity to a wetland. The geotechnical implications need to be assessed and be approved by an engineer. Loose fill may be difficult to traffic.

### 7.6.5 Inlets and outlets

The inlet area can be used as a sump for pumping water entering the wetland during construction, and then converted to a sediment trap for final reclamation. The outlet needs to be connected to a downstream watershed, typically by ditches or channels. Temporary erosion protection may be required to protect the outlet outfall from erosion if downstream areas await reclamation. Many oil sands wetlands receive infrequent input flows, and the outlets are active only a few days per year.

While topography should be used to control the water levels, control structures may be required at the outlet, whether there is a levee or not. Examples of control structures (Mitsch and Gosselink, 2007) include:

- Drop pipes: do not allow for the manipulation of water levels, which may be an issue.
- Flashboard risers: effective but easy to damage.
- Full-round risers: a combination of the other two, they are more secure, have the ability to control for beavers, but are more expensive.
- Outflow risers: can use removable stoplogs so that manual changes to water levels can be made, but these require maintenance (e.g., removal or debris, repair after beavers remove them).
- Clean tailings operation spillboxes: common tools in the oil sands.

If a vegetated outlet is employed, water can be pumped around the outlet for a year or two until the vegetation becomes established. Temporary erosion protection is an alternative.

A weir may be installed to measure the outflow at the outlet. A simple V-notch weir (a metal plate with a V-notch cut into it) can be installed to measure the flows passing over it. Most oil sands weirs have difficulty with leakage (through and around), sedimentation and icing.

For most wetlands, it may be best to build an outlet armoured with vegetation or riprap. To lower the water level, a portable pump can be employed or, for a permanent solution, the outlet can be reconstructed at a lower elevation.

### 7.6.6 Irrigation

Oil sands wetlands are designed to be self-sustaining, but in some cases, temporary watering (for initial filling, initial wet up, vegetation management, drought conditions, dilution of saline water) may be advantageous. Volumes are easily calculated and alternatives easy to consider. Ideally, first filling can wait until after the first snowmelt, avoiding the need, costs, and logistics for irrigation.

A pumping system requires a freshwater source, intake, pump, power, controls, pipeline, flow meter, discharge, and erosion protection at the discharge. The system may be a simple portable diesel-powered pump with a long hose, or a highly engineered permanent pumping station and pipeline. Such a system would ideally discharge into the inlet area to help simulate the longer-term conditions. Earthworks at the inlet should accommodate inflows.

Use of water trucks is sometimes considered, but for wetlands greater than a fraction of a hectare, the number of trucks required and cost of this approach is usually prohibitive. A station for water trucks to discharge water may be required; sometimes a tank is sufficient and sometimes more sophisticated infrastructure is required.

Sprinklers for irrigation of newly planted fens are invasive, costly to maintain, and prone to erosion. A buried leaky pipeline (irrigation gallery) may be an alternative.

Sumps inside or outside the watershed that naturally fill with runoff water may prove a practical irrigation option. In some cases, a shallow-water wetland or sump immediately downstream of the wetland may be a useful source of irrigation water that can be recycled back into the wetland. For example, spring runoff from a newly constructed fen can be pumped back later in the summer if drought conditions prevail. Water quality of runoff water needs to be tested and assessed prior to pumping into the wetland.

Water can easily be added to marshes, but reclaimed fens may be prone to erosion by concentrated inflows.

## 7.7 Reclamation material placement

Depending on the intended uses of the wetland, the reclamation material may be peat, hydric reclamation material salvaged from other wetlands in the area, or upland-sourced mineral topsoil, or some combination thereof. Reclamation material may be acquired from borrow sources or stockpiles.

### 7.7.1 Reclamation materials

Four types of reclamation materials are used for wetland construction in the oil sands:

Suitable subsoil: often glacial till, glaciolacustrine clays, or glaciofluvial sands that meet certain textural and chemical criteria (CEMA, 2006).

Peat-mineral mix: consists of a mixture of mineral soil and peat that has usually been stored in a stockpile or sometimes direct hauled. It may be used in reclamation as the top layer placed over the other layers in the wetland area. This material is usually placed in the winter (access to borrow site, ease of placement).

Litter-fibric-humic (LFH): a material that is salvaged directly from the top of the forest floor. LFH may serve as the top layer on upland sites for the watershed but is not used in wetland areas and can inhibit the initial germination and establishment of grass species in riparian and wetland zones.

Coarse woody debris (CWD): material containing logs and broken-up logs, smaller pieces of debris such as roots, twigs, and branches that have been harvested from forests, usually as a result of tree-clearing activity. This material may be placed on top of the LFH to add diversity and microsites to the landscape. CWD suffers from the same drawbacks as LFH.

### 7.7.2 Borrow sites and stockpiles

Borrow sites are identified in the design phase and confirmed in the site investigation phase. In-situ peat borrow is typically accessible only when frozen; stockpiled peat is also typically accessed during winter. Direct-hauled peat (with its propagules) is preferred to stockpiled peat, as stockpiling reduces seed and propagule viability to near zero within a year (MacKenzie, 2011).

### 7.7.3 Reclamation material placement

Reclamation material is dumped and spread, often in a two-lift operation (subsoil capped with peat-mineral mix). Winter construction helps reduce the potential for over-compaction, which undermines reclamation performance. To avoid compaction, do not traffic placed material. The accuracy of placement depths with this equipment means lifts of less than 0.2 m are difficult to place. Reclamation material thicknesses are often placed to within about +/– 0.1 m on average; the natural variability in thickness and material types helps create diversity.

The placement of coarse woody debris is typically field-fit with ongoing trials to optimize placement and density. Topographic features in and around the wetlands (wetland berms, islands, mounds, peninsulas, coarse woody debris areas) and infrastructure (roads, paths, boardwalks, pipelines, laydown areas, power lines) should allow trucks to efficiently enter the reclamation area, dump, and exit with two-way traffic. Experienced operations staff vet designs to ensure adequate clearance for traffic.

The results of research into transpositioning two-square-metre frozen intact blocks of wetland soils/vegetation ("live peat transplant") from fen donor sites to new reclamation sites are available (CONRAD ERRG, 2009). Costs are high and logistical challenges are inevitable. This technique remains at the research stage.

Trafficability is often an issue for wetland material placement. Only equipment certified as safe in a final site investigation trafficability test (Section 7.4.2) may be employed. Trafficability is usually best in the winter. Care needs to be taken not to take equipment into areas with insufficient frost or iced-over ponded water.

## 7.8 Reclamation infrastructure

Reclamation infrastructure is typically minimized as it is costly and most or all must be eventually removed for reclamation certification. But some infrastructure is required for access and maintenance of the wetland and for long-term end land use (Chapter 8, Figure 8-1). Types of access include:

> Large roads provide two-way equipment and light-vehicle access year-round. Large roads are typically engineered and maintained as required.
>
> Light vehicle roads provide one-way access for light vehicles to the watershed, typically to a trailer or laydown area, for three seasons of the year.
>
> Quad trails provide one-way access to remote areas of the watershed or wetland and allow personnel to transport samples and instrumentation. Typically quad trails are surfaced and require minimal maintenance.
>
> Walking trails provide access to certain areas of the watershed to allow personnel to sample reclamation material, read instruments, or inspect areas. Typically narrow paths, they can be surfaced if needed. Snowshoes may also be used in winter.
>
> Boardwalks provide foot or quad access to areas that are soft or saturated. Boardwalks can range from wooden planks laid on the peat, to floating boardwalks on marshes, to elevated boardwalks anchored into the underlying material. Boardwalks may require handrails.
>
> Piers provide foot access to ponds or marshes. Piers will need to be anchored into underlying material and will usually require handrails and safety equipment.

Access requirements (type and frequency) are developed during design and accounted for in budgeting and construction planning. Access, particularly for boardwalks, can be challenging and costly to install. Their use is generally minimized.

Infrastructure required for operation, monitoring, and maintenance may include trailers and facilities to provide work areas and washrooms, equipment storage, and access to instrumentation readings and reports. In most cases, only research wetlands or large designed wetlands will need remote trailers or other facilities. Parking and site access need to be considered for trailers. Facilities may be serviced by a portable generator or power lines.

Other infrastructure may be required throughout the watershed or wetland including instrumentation, instrument protection, and signage. Quads typically used to protect instruments in the oil sands are placed around instrumentation, assembled from wooden 2x4s and 4x4s, painted and have a buggy whip attached for visibility (McKenna, 2006). Signage may be required for identification of instruments. Making the sites easy to access and navigate provides a safe work environment, reduces training, and makes monitoring more efficient.

## 7.9 Revegetation

The constructed wetland ecosystem will only function if the appropriate plant and animal species are introduced or are designed to colonize the wetland naturally. Strategies for each type of wetland pose distinct challenges. The techniques and species described here comprise only a portion of a wide spectrum applicable to reclamation of wetlands in the oil sands. This is in part due to the fact that international experience to date has largely been concerned with restoration of partially disturbed wetlands rather than reclamation of surface-mining landscapes.

### 7.9.1 Equipment and material needs

The wetland reclamation operations project team is charged with:

Procuring the seeds, propagules, and seedlings according to Figure 7-1.

Seeding and planting the vegetation after the reclamation material is placed.

Organizing follow-up seeding and planting and management as part of OMM.

Seeds can be broadcast from the ground or helicopter, from the water, or commercially drilled. Wetland seed will germinate best when good soil to seed contact is made. It is best to carry out seeding in those locations where no standing water is present in the wetland. Transplanted emergent plants have 0.2 to 0.3 m stems and either whole plants, tubers, or rhizomes increase chances of successful establishment. If transplanting cores from donor sites, cores with a diameter of about 0.1 m are required (Mitsch and Jorgensen, 2004). If plants are planted, mulch could be packed firmly around them to allow for good water contact with roots (Kadlec and Wallace, 2009; Rochefort and Lode, 2006). Mulch is not necessarily required when establishing whole plants in marsh systems.

Shade or water may be required to keep the planting stock viable (Kadlec and Wallace, 2009). It is important not to stockpile live plant material for more than a day. Even in winter conditions, stockpiled plant material will quickly compost due to increased temperatures within the pile. Some wetlands are insulated with shredded bark or mulch, but shredded bark or mulch can reduce available nitrogen and phosphorous in the soil. This reduction in nutrients may affect germination of some wetland seed. After revegetation, if the wetland operator is not able to control the water level to give the plant species what they need, temporary watering or dewatering may be necessary. Fertilization with phosphorus helps plants and mosses establish in peat wetlands (Rochefort and Lode, 2006), but is not usually required for establishing marsh wetlands. If fertilization is required, time-release fertilizer incorporated into the substrate is preferred. Broadcast fertilizer can increase weed cover and can be expensive (Kent, 2000).

Overloading a system with phosphorous will quickly degrade water quality, especially in downstream systems.

During establishment, when young plants are most vulnerable, it may be necessary to manage salinity, wind and wave action, and grazing. Salinity issues could be ameliorated by flushing the wetland prior to planting, restricting some water sources, and/or increasing the layer of peat or organic soil in the planting zone. Flushing certain systems may actually create higher salinity levels at the surface as soils dry out. The drying effects of wind can be minimized by planting in shallow depressions, mulching with (weed-free) straw, or establishing nurse plants first. Wave action and grazing (by muskrats and Canada geese in particular) can be addressed using temporary fences to discourage herbivores and woody nurse plants or bank armouring for waves. In certain situations muskrats may need to be trapped in the first few years until the plants can survive on their own.

Densities of between 2,000 and 5,000 plants per hectare have been used for successful and quick colonization and to successfully compete with weeds or *Typha* (Mitsch and Jorgensen, 2004). By comparison, tree-planting in upland watershed areas may involve 2,000 stems per hectare.

### 7.9.2 Scheduling

The timing of seeding/planting and filling of the wetland is intricate. A schedule will coordinate the availability of the species and techniques to be used and the appropriate season for revegetation. Sequencing and timing of revegetation and initial filling of the wetland can vary from project to project, and may include sequencing of different areas of the project (upland, wetland, riparian zone), or sequencing of different types of vegetation or propagules (e.g., seeding, planting trees). Depending on the revegetation method used, sequences can span years in order to establish all vegetation on the site.

Weed control during revegetation is extremely important for both wetlands and their adjacent uplands and practices will vary between operators and locations. Reclamation teams may require the professional skills of a weed specialist for overseeing this responsibility. Water management can be used to control invasion of some wetland and terrestrial species. Pesticide control may also be required in the first few years for commissioning the adjacent upland areas. The timing and approaches used to control invasives depends on the species present, the development stage of the plant, and acceptable methods for control. Figure 6-9 provides a hypothetical example of revegetation design for a small marsh.

Three zones will require different species and planting techniques:

> The lowland zone, which in a fen will be wet but will not have open water, supports emergent plants in the open water. For example, when revegetating a marsh, the lowland area directly surrounding the open water zone is planted with persistent emergent vegetation.
>
> The riparian (transition) zone between the lowland and the upland requires vegetation that is more resilient than the lowland or upland vegetation, as it must be able to withstand variations in water levels and wet soil conditions.

> The upland is planted with species that require much less water than the species in the two lower zones (CEMA, 2010).

Oil sands experience has shown that it is difficult to anticipate the boundaries for these zones, especially in tailings areas, mainly because even small changes to the water balance by the vegetation can cause the zones to shift tens of metres or more. Techniques will gradually improve as more experience is gained and documented.

## 7.9.3 Peat-forming wetlands

Boreal landscapes contain a mosaic of upland and wetland plant communities that together function as a set of interconnected ecosystems. Introduced flora and fauna must interact to allow ecosystem function to take place. In oil sands reclamation, four factors that potentially limit successful revegetation are recognized and actions taken to assure success. These four limiting factors provide a theoretical framework for reclamation in the boreal forest and set operational protocols necessary for successful reclamation planning.

### 7.9.3.1 Limiting factors

1. Site history and resource availability: Disturbed sites have basic resource levels, determined by position on the landscape, hydrology, chemistry and the physical limits of the substrate. Sites vary in size, are positioned along unique portions of resource gradients, and are affected by regional climate. A detailed understanding of the environmental drivers is the first step in developing operational protocols and engineering each site for species arrivals.

2. Plant species availability: The availability of arriving species is controlled by the ability of diaspores to disperse and the available regional species pool. Size of the disturbance, number of potential contributing species, and resource limitations of the recipient site are important thresholds. Seed, spore, and bud banks (including underground rhizomes and tillers) can limit the arriving species pool. Species arriving from natural existing donor sites may not be enough; instead, a founding novel species assemblage may need to be introduced (Brudvig and Mabry, 2008). An understanding of how species respond to environmental gradients is helpful (Gignac et al., 1991; 2004). Both site preparation and species selection will affect reclamation efforts and lead to a series of potential responses.

3. Plant species performance: Arriving species must establish, grow, and reproduce. Establishment and growth are important early-stage indicators of species success, while reproduction is important later on. Early regeneration dynamics such as seedling mortality and narrow environmental requirements may form a bottleneck for successful establishment. The initial establishment of foundation species leads to early community development. Species success is manifested in the development of community structure, wherein species are sorted into vegetational layers. The system must be carefully monitored for individual species responses and structural complexity and development.

4. Interspecific Interactions: Biotic interactions such as competition, herbivory, and invasions of aggressive species determine the eventual outcome of species succession. They determine the success of individual species, but not the functional integrity of the

community. If the correct foundation species are present, additional species arrivals will increase diversity. These species interactions provide for the evolution of ecosystem function, and successful reclamation requires the assessment of both community richness and ecosystem functions.

These four limiting factors must be recognized in any reclamation project. They translate to 1) site development utilizing natural analogues, 2) species selected from comparative natural situations, 3) species performance based on clear natural benchmarks, and 4) development of community stabilization, species richness, and ecosystem function, based again on natural analogues.

#### 7.9.3.2 Key thresholds for oil sands reclamation

Initializing conditions in the oil sands area:

Saline water chemistry: Process waters are characterized by high salt content, mostly $Na^+$ (200-500 mg/L) and $Cl^-$ (500-550 mg/L). Electrical conductivities of these waters are correspondingly high as well (3000-4000 S/cm). Some deep groundwater in the oil sands region is also high in $Na^+$ (Bott, 2007). See Figure 6-5.

Fine, inorganic sands: Tailings sand and consolidated tailings consists of fine sands that compose the substrates of some sites. These sands have residues of bitumen, organic acids, and process-waters in their pores.

Unorganized water flow: Disturbance from mining activities disrupts natural drainage patterns, and water flow patterns may be lacking or have erosional streams.

Absence of organic soil layer: Tailings deposits, mineral fill, and unconsolidated overburden may have little if any historical organic matter.

Absence of vegetation and local source areas for plant diaspores: Wetland plant species may not be locally present in sites with no natural remaining soils, and reclamation sites may be located far from indigenous plant diaspore sources.

High atmospheric deposition of nitrogen: Reclamation sites near to active mining operations may be subjected to high amounts of atmospheric deposition that is high in nitrogen (see Percy, 2012).

#### 7.9.3.3 **Fens** (minerotrophic, accumulate organic matter)

***Thresholds*:** Seasonally wet saturated soils develop on the landscape in two ways. First, shallow pools of water saturate the underlying soil material, producing aquatic habitat. Second, local water tables at or near the soil surface provide wet saturated terrestrial soils. Both of these situations provide habitats for wetland plant species. Historically, fens develop through infilling of bodies of water through the process of terrestrialization or through primary peat formation, wherein organic matter accumulates on saturated mineral soil surfaces. Additionally, organic matter can accumulate on mineral soils that were previously dry and vegetated through the process of swamping (paludification) if local water tables rise from allogenic regional climate changes. All three of these situations can lead to occupation by wetland plants and the accumulation of an organic layer.

***Minerogenous water supply***: The supply of water to wetland site types must include waters subjected to the influences of the surrounding landscape. This minerogenous water supply must be annually constant and contain a suite of elemental nutrients and minerals. High sediment loading is not desirable.

***Stable water table***: Water table fluctuation, both annually (generally less than 30 cm of drawdown over the growing season) (Vitt et al., 1995b) and longer term limits the number of species of plants that can establish. Likewise short residence times of the water leads to nutrient flushing and stream flow. Critical to the establishment of all wetland habitats is slow-moving to nearly stagnant waters that enable overland sheet flow to take place on very gradual slopes.

***Catotelm development***: The development of a deep organic layer occurs when nondecomposed plant material reaches the anaerobic layer (the catotelm). Key to peat accumulation is the development of a two-layered peat column, a lower anaerobic layer wherein decomposition takes place at a constant and very slow rate (Clymo, 1984) and an upper acrotelm that is aerobic and wherein most of the decomposition occurs. A number of factors, including the time spent in the acrotelm, determines the decompositional state of the material when it reaches the catotelm. Due to high, relatively constant water tables, fen acrotelms are shallow, allowing high-quality plant material to be deposited in the catotelm to produce peat.

***Mesotrophy***: High erosional rates, fluctuating water tables with relatively high flow rates, and high atmospheric deposition all provide waters with high amounts of nutrients (N, P, and K). These eutrophic conditions lead to high plant production, but also to high rates of decomposition and thus high organic matter turnover rates and little if any organic matter accumulation. Overall increases in residency time of the water decreases oxygen content, lowers water temperatures, and decreases turnover rates.

***Reclamation strategies*:**

1. Provide a constant water source delivered to the site as sheet flow. Although marsh ecosite types such as emergent marshes may be successfully initialized by shallow pond development, peat-forming ecosite types generally have initiated from paludification and primary peat formation rather than terrestrialization. There is little evidence that shallow ponds and marshes have succeeded to fens in the mid-boreal region of western Canada (Bloise, 2007), although bogs and fens have succeeded from marshes and the infilling of shallow ponds are evident in the southern boreal zone (Kuhry et al., 1993).

2. Maintain a water level near the soil surface that does not have strong fluctuations in level. Although non-peat forming wetlands establish under fluctuating water regimes, many foundational fen plants require a relatively stable seasonal water level. Water levels maintained above the soil surface result in the invasion of *Typha* and provide an evaporative surface and should be avoided.

3. Manage the transition to mesotrophy. Bare peat surfaces contain relatively high amounts of inorganic nitrogen (DIN) (Wind-Mulder et al., 1996) as do mineral soils. Mineral soils have N available as DIN, whereas organic soils have little available DIN but large amounts of dissolved organic carbon (DOC). We know little about the microbial flora and its

functioning in wetland soils, especially on reclaimed or restored sites (Andersen, 2013). Despite this lack of data, the following strategy and recipe should be considered: The strategy is to tie up the original high amounts of DIN in persistent plant material with a subsequent slow release of N. The recipe: 1) As soon as possible after site development on a mineral soil base, establish a vegetation layer. The introduction of nursery stock would provide plant cover more quickly as compared to seed dispersal. 2) Fertilizer is not required. 3) Maintain a constant water supply and reduce water table fluctuation, thus maintaining anaerobic conditions close to the soil surface. 4) Maintain water levels near the soil surface in order to reduce microbial activity. 5) Introduce plant species with high polyphenol contents (e.g., *Sphagnum*, true mosses) that provide resistance to decomposition, these acting to further sequester N in un-decomposed organic material. Moss species would provide such species introduced as either vegetative fragments or as population plugs (Daly et al., 2012).

4. The development of a functioning two-part peat column is at present untried. Two possibilities exist. Provide the conditions (as in number 3) with the necessary attributes for the catotelm to develop naturally or lay down a layer of unconsolidated peat, rewet the peat, and allow the anaerobic conditions to develop.

### 7.9.3.4 **Saline fens** (minerotrophic, with high Na+, accumulate organic matter)

***Thresholds***: Saline fens occur at sites where sodium-rich ground water is or has been in the past discharged onto the landscape. These sites often contain layers of mineral deposits alternating with layers of organic material and over long periods of time may accumulate deep deposits of peat. Bryophytes are not present and the peaty material is composed of sedge roots and stems. Salinity is highly variable and plant species able to tolerate these salinity amounts are few. Electrical conductivity is high, ranging from 500 to over 2000 S/cm (S. Bayley, pers. comm.).

***Reclamation strategies*:**

As saline fens are groundwater-fed, often with water discharging at the base of moderate slopes, engineering for such landscape sites is important. Site development should maintain a constant saline water source.

Establish a set of foundation plant species selected from among salt-tolerant species (Table 7-2). From among these species, several germinate freely, including *Triglochin maritima, T. palustris, Carex aquatilis*, and *Beckmannia syzigachne.* On the other hand, *C. atherodes* and *C. utriculata* have few seeds and are difficult to germinate. *Calamagrostis stricta* also is a species with tolerances to high salinity.

### 7.9.3.5 **Alkaline fens** (minerotrophic, with $HCO_{3-}$ and $Ca^{++}$ as dominant pore water ions, accumulate organic matter)

***Thresholds*:** Natural sites with surface and/or groundwater sources high in $Ca(HCO_3)_2$ are often the first peatland communities evident in the historical record. Once established, these peatland plant communities can persist at individual sites for millennia (Yu et al., 2003). Although site chemistries can be somewhat variable, ranging from 10-20 mg/L of $Ca^{++}$ to over 200 or more mg/L $Ca^{++}$, all contain a species-rich set of plant species. Sites have the ground layer dominated by true mosses (often 90-100% cover) and a well-developed field layer of a variety of sedge species. Accumulated peat is either moss- or root-dominated, with well-preserved seeds and plant parts. Peat depths range up to over 6 m and include some of Alberta's deepest peat deposits.

***Reclamation strategies*****:** In addition to the plans for wetland reclamation in general (see above), the following are recommended.

> Salinity must be reduced to less than 400-500 mg/L (Vitt et al., 2013) either through removal from under drains, position on the landscape that provides insulation from Na-rich sediments, or flushing with fresh water.
>
> A second strategy is to establish plant species that have some tolerance to high $Na^{+}$ and also tolerate $Ca^{++}$-rich waters.
>
> Both N and C cycle functions in alkaline fens are largely controlled by the moss layer, wherein both elements are sequestered in nondecomposed plant biomass and the resulting peat accumulation. Thus establishment of the moss layer is a key threshold that must be crossed. Two approaches are possible based on current knowledge, each best implemented under somewhat different initial conditions: peat-based substrate: (Daly et al., 2012; Rochefort and Lode, 2006) and mineral soil-based substrate. There may be sites where exposed mineral soils as well as bare peat substrates are too severe for moss establishment at the out-set of reclamation and nurse plants may be needed to help with initial establishment. Here sedge species are selected from nursery stock and planted in clusters of 10-20 plants in year 1. After 2-3 years, a shallow organic layer of decaying sedge remains should be present and moss fragments can be introduced using techniques outlined in Quinty and Rochefort (2003). Moss species can be selected from those listed in Table 7-3. Additionally, data from the U-cell research area indicate that indigenous moss species quickly colonize mineral soils under a cover of a field layer (Vitt et al., 2013). Water levels should be at or just above the soil layer in the spring and maintained close to soil surface throughout the first year. Nurse species should be selected from among those in Table 7-2.

#### 7.9.3.6 **Acidic fens** (minerotrophic, with $H^{+}$ as the major pore water ion and accumulate organic matter)

***Thresholds*****:** Acidic fens are *Sphagnum*-dominated peatlands that often occupy watershed divides in high positions on the regional landscape. In other situations they are underlain with sandy deposits with no contact with alkaline groundwater. In these situations, they receive waters with few nutrients and minerals and are oligotrophic. Acidic fens most often occur in association with bogs and form large soligenous peatland complexes. The fen components of these complex peatlands have high water tables covered by carpet (e.g. *S. majus*) and lawn (e.g. *S. angustifolium)* species of *Sphagnum*. Historically, acidic fens have either remained relatively constant over time or rapidly developed from previous alkaline fens as they become more isolated from ground layer sources due to peat accumulation. In these cases, acidification by invading mesotrophic *Sphagnum* species (*S. teres, S. subsecundum*, and *S. obtusum*) appears to facilitate rapid succession. Secondary development of complex landforms sometimes takes place (patterning, bog island invasion) (Glaser, 1983; Nicholson and Vitt, 1990).

***Reclamation strategies*:** Currently, it is unlikely that acidic fens would be feasible on oil sands mine sites due to chemical restrictions. However, this section describes the site requirements for acidic fens that may be contemplated. To our knowledge, no research has been carried out in the reclamation of acidic fens, although ditches and block harvesting of peat leave areas within bogs that have many characteristics of acidic fens. The wet, oligotrophic nature of acidic fens has made them difficult to utilize for peat harvesting or agriculture. Site selection would be of critical importance for initiation of acidic fens. Sites with a natural (in situ) *Sphagnum* peat if maintained with water tables at the surface have naturally revegetated with species of *Sphagnum*, especially *S. fallax, S. angustifolium*, and *S. riparium*. This situation can be found naturally in areas subjected to permafrost thaw in bogs (Beilman et al., 2000). Using this natural disturbance as a surrogate the following would be appropriate:

Introduce pure *Sphagnum* peat to the site

Maintain water levels at or just beneath peat surface

Ensure acidic nature of peat

Reduce inputs of all base cations and nutrients

Introduce *Sphagnum* fragments from locally available wet, oligotrophic *Sphagnum* species; *S. riparium* would be appropriate

Introduce species of *Carex (C. limosa, C.magellanica* ssp*. irrigua, C. aquatilis,* and *C. canescens)* using either seeds or nursery stock

Monitor pH and electrical conductivity (pH 4.5-6.0, EC < 50 S/cm)

### 7.9.3.7 **Bogs** (ombrotrophic, accumulate organic matter)

***Thresholds*:** Bogs result from long-term peat accumulation that isolated the growing moss surface above the local water table. Bogs thus are oligotrophic and have a well-developed acrotelm. This acrotelm consists of hummock species of *Sphagnum*, ericaceous shrubs, and in Alberta a tree layer of *Picea mariana*. The lack of minerogenous water inputs reduces base cations in the pore water and the ions that arrive from atmospheric fallout are rapidly sequestered by acidifying *Sphagnum*. The insulative properties of *Sphagnum* and the well-developed aerobic acrotelm reduce the temperatures in the upper peat layers (Vitt et al., 1995), such that bogs retain frost longer then fens. Historically, bogs in western Canada rarely develop directly on mineral soils, but are the end product of a long history of fen development succeeding to bogs, as a wetland climax plant community.

***Reclamation strategies*:** Sites that have an in situ acidic peat base have been successfully restored in eastern Canada using methods clearly laid out in Quinty and Rochefort's (2003) peat restoration manual, and some of these site have been tracked for success (Poulin et al., 2012). Also, some minimally disturbed petroleum sites have been documented to return to *Sphagnum*-

and *Polytrichum*-dominated sites with young *P. mariana* and ericaceous shrubs (House et al., 2013).

Bog reclamation on mineral soils is potentially feasible. In 2008, at an experimental research site at Syncrude, transplants of live bog peat were successfully transferred to research cells and continuously maintained. After five growing seasons, all transfers maintained a living vegetative layer. No differences were evident in the flora from depth of transfer (10, 50, 100 cm) or in time of transfer (winter or summer) (Vitt et al., 2013). From these results it appears that localized islands of bog peat could be successfully transferred to reclaimed tailing sites.

**Bog block transfers**: Recommendation for success include:

Maintain all base cation levels at an absolute minimum
Maintain water level 15-20 cm below peat surface
Isolate transfers from the surrounding inflowing water
Place transfers on a substrate with good water holding capacity
Make sure there is contact between the transferred blocks
Establish the water regime immediately
Do not apply fertilizer or lime

#### 7.9.3.8 Key messages

In principal, peatland sites should provide suitable habitats for foundation plant species of alkaline or saline fens, depending on the substrate/water chemistry. End-point design should give careful consideration to the foundation plant species and their tolerances to water levels, nutrient supplies, and base cation concentrations. Bog mesohabitats may be initiated by block live-peat transfers from bogs subjected to future mine expansion.

***Selection of vegetation*:** Fens may have shrub or tree layers in addition to a moss-dominated ground layer and a sedge-dominated field layer. The addition of shrub and tree layers will be determined by site dryness; however, little information is available for recommending dryness for shrub or tree layer development. All fens have abundant sedge and moss components, but the historical record of fen initiation by primary peat formation or paludification often does not contain abundant moss macrofossils at the mineral/peat interface. It is not clear whether mosses can be established on oil sands mineral soils without the protection of a larger field layer species.

***Selection of foundation species for fens*:** Table 7.2 (field layer) and Table 7.3 (ground layer) provide lists of recommended species. For the field layer, species are divided into either foundation (dominant) species or accessory, non-dominant species and ranks given for seed availability, germination quality, and hardiness, if known. For the ground layer, species are ranked by field knowledge or literature sources for their suitability for reclamation.

**Table 7-2. Vascular plants in the field layer that have potential for alkaline and saline fen establishment.** D = dominant community role, A = accessory community role.

| Species | Seed availability (1-5) | Germination success (1-5) | Establishment potential (1-5) | Salt tolerance | Role |
|---|---|---|---|---|---|
| *Beckmannia syzigachne* Graminoid (American sloughgrass) | 5 | 5 | 5 | x | D |
| *Betula glandulosa* Shrub (Resin birch) | 5 | 5 | 4 | | D |
| *Calamagrostis inexpansa* Graminoid (Bluejoint) | ? | ? | ? | | D |
| *Calamagrostis stricta* Graminoid (Slimstem reedgrass) | ? | ? | ? | x | D |
| *Caltha palustris* Forb (Yellow marsh marigold) | 1 | 1 | 1 | | A |
| *Carex aquatilis* Graminoid (Water sedge) | 5 | 2-4 | 4 | x | D |
| *Carex atherodes* Graminoid (Wheat sedge) | 1 | 1 | 1 | x | D |
| *Carex bebbii* Graminoid (Bebb's sedge) | 5 | 5 | 4-5 | | A |
| *Carex canescens* Graminoid (Polar sedge) | 4 | 2 | 3 | | A |
| *Carex chordorrhiza* Graminoid (Creeping sedge) | 1 | ? | 2 | | A |
| *Carex diandra* Graminoid (Lesser panicled sedge) | 5 | 2 | 3 | | A |
| *Carex gynocrates* Graminoid (Northern bog sedge) | 4 | ? | | | A |
| *Carex hysteriana* Graminoid (Bottlebrush sedge) | 5 (rare) | 4 | 4 | | ? |
| *Carex interior* Graminoid (Inland sedge) | ? | ? | ? | | A |
| *Carex lasiocarpa* Graminoid (Slender sedge) | 1 | ? | ? | x | ? |
| *Carex limosa* Graminoid (Mud sedge) | 4 | 3 | 3 | | A |
| *Carex paupercula* Graminoid (Boreal bog sedge) | 5 | 4 | 4 | | A |
| *Carex rostrata* Graminoid (Beaked sedge) | ? | ? | ? | | A |
| *Carex untriculata* Graminoid (Northwest Territory sedge) | 2 | 3 | 4 | x | D |
| *Juncus alpino-articulatus Graminoid (Northern green rush)* | ? | ? | ? | ? | ? |
| *Juncus balticus* Graminoid (Alaska rush) | 5 | ? | 4 | x | A |
| *Juncus tenuis* Graminoid (Greater poverty rush) | 3 | 3 | 3 | | A |
| *Potentilla palustris* Forb (Purple marshlocks) | 1 | 1 | 1 | | A |
| *Scirpus lacustris* Graminoid (Hardstem bulrush) | 5 | 2 | 2 | | A |
| *Scirpus validus* Graminoid (Soft-stemmed bulrush) | 5 | 5 | 5 | | D |
| *Triglochin maritima* Forb (Seaside arrowgrass) | 4 | 5 | 4 | x | A |
| *Triglochin palustris* Forb (Seaside arrowgrass) | 3 | 4 | 2 | x | A |

**Notes:** Additional species characteristic of salt flats and saline prairie evaporative pools include *Puccinellia nuttaliana, Carex prairea, Plantago maritima, Potentilla anserina, Salicornia europa, Scirpus pungens*, and *Suaeda calceoliformis.* Seed availability and germination success derived from Vitt et al. (2013) and M. House (pers. comm.). Scale: (1) poor to (5) excellent. Establishment potential summarized from current research at Sandhill Fen, Syncrude Canada. Salt tolerance (x) derived from greenhouse experiments (Vitt et al., 2013; unpublished data, and field observations).

**Table 7-3. Bryophyte species occurring in the ground layer that have the potential for alkaline fen establishment in the oil sands region.** D = Dominant, A = Accessory, S = some salinity tolerance, E = eutrophic habitat, O = oligotrophic habitat, P = peat substrate, F = post fire habitats.

| Species | Accessibility (1-5) | Establishment potential (1-5) | Species role |
|---|---|---|---|
| *Aulacomnium palustre (Ribbed bog moss)* | 5 | 2 | A-P |
| *Bryum pseudotriquetrum (Green bryum moss)* | 4 | 5 | A/D-S |
| *Calliergon giganteum (Arctic moss)* | 3 | 4 | A/D |
| *Campylium polygamum (Campylium moss)* | 3 | 5 | A-E |
| *Campylium stellatum (Star campylium moss)* | 5 | 5 | D-S |
| *Drepanocladus aduncus (Drepanocladus moss)* | 4 | 5 | A/D-E |
| *Hamatocaulis vernicosus (Hamatocaulis moss)* | 5 | 4 | D |
| *Marchantia polymorpha (Common liverwort)* | 2 | 2 | A-F |
| *Polytrichum strictum (Polystrictum moss)* | (4 | 5 | A/D-P |
| *Scorpidium revolvens (Limprichtia moss)* | 2 | 3 | A |
| *Tomenthypnum nitens (Tomenthypnum moss)* | 5 | 3 | A (dry) |
| *Warnstorfia fluitans (Warnstorfia moss)* | 2 | 1 | A-O |

**Notes**: Accessibility and establishment potential (scale 1 (poor) to 5 (excellent)). Values derived from field experience (Dale Vitt) and L. Rochefort (pers. comm.).

Currently no information is available on community assembly in fens, and it is not known how fen species interact in the early stages of establishment. Trials are testing two scenarios: 1) establishment of 1-2 foundation species will create an environment wherein additional species will colonize and form a structurally intact, functioning plant community; or 2) structure and some component of the plant community should be established by nursery stock (i.e., 3 sedges, one shrub, 2 forbs, etc.), creating complex structure early on in community assembly. It would be appropriate for either or both of these designs to be attempted.

#### 7.9.3.9 Selection of substrate

In theory, fens could be established on mineral substrates as well as on a variety of peat depths. In terms of plant response and survival, there are no differences in responses of plants introduced to mineral soils with 10, 50, or 100 cm depths of peat (Vitt et al., 2013). It is unknown whether the addition of a peat layer will enhance the development of the catotelm and currently there is no information on nitrogen cycle function, carbon cycle, or sulfur cycle in any of these artificially induced substrates. Although no recommendation can be made, it appears that introduction of a peat layer to a site is not necessary. In addition, it is unclear whether peat will act as a buffer for sodium content in underlying consolidated tailings.

#### 7.9.3.10 Salinity

Greenhouse trials for a number of key fen species (Vitt et al., 2013; Koropchak and Vitt, 2012) suggest that threshold values for sodium may be in the 300-600 mg/L range. In field trials of cutover peatlands inundated by seawater in the lowlands of New Brunswick (salinity ranging from 100 to 175 mmol/L of $Na^+$), Montemayor et al. (2008) found that *Spartina pectinata* had a greater survival success following transplantation on bare peat surface than *Juncus balticus*. They concluded that the difference stemmed from the fact that *S. pectinata* is a halophyte tolerant to salinity whereas *J. balticus* is a glycophyte tolerant (Montemayor et al. 2010). Furthermore, mosses such as *.0VRJ MPBRALQ0FNRBQ0RJ" / >JMVIFRJ PQBII>QRJ" ;ME>DKRJ T>0KPQL0YF >KA Tomenthypnum nitens* can tolerate saline levels typically found in post-mined landscapes (up to 500 mg/L of NaCl and 400 mg/L of $Na_2SO_4$) for up to 100 days of exposure (Pouliot et al., 2013). All these species are characteristic of alkaline fens; however, time of exposure to even low concentrations of salinity over longer periods (greater than 100 days) may decrease performance of some species. Thus, there appears to be a suite of species that can tolerate pore waters with high concentrations of sodium and calcium as well as associated $Cl^-$ and $HCO_3^-$ anions.

### 7.9.3.11 Nutrient supply

Fens and bogs are ecosystems that normally function under low nutrient regimes. There is no indication that either mineral soil or peat substrates have low concentrations of limiting nutrients, although the available data are insufficient to draw a conclusion. Research at Peace River (Vitt et al., 2011), where a mineral oil pad was treated with 10:10:10 fertilizer annually for four years and compared with an unfertilized pad, yielded no differences in introduced plant responses. However, the fertilized pad contained a significantly greater abundance of weedy species, suggesting that an increased potential for invasion by weeds is due to unused resources (Davis et al., 2000). Thus there is little evidence that fertilizer treatment is beneficial in early fen establishment.

### 7.9.3.12 Water levels

Fens naturally function with a water table close to or somewhat lower than the substrate surface. Mature fens with hummock development have microtopographic drier areas where shrubs and trees are present. Water levels above the substrate surface favor marsh plants and invasion by *Typha.* Water levels too far beneath the substrate surface encourage upland weedy species. Fluctuating water levels provide conditions favoring high rates of decomposition and also favor plant species with tissues that are easily decomposed. Thus water levels should be stabilized 2-8 cm beneath the substrate surface with annual fluctuation no greater than 30 cm.

### 7.9.3.13 Peatland size

Peatland size should emulate the common natural size of less than 1 $km^2$. Fens are typically elliptical to round in shape, and linear (stream-like) designs should be avoided.

### 7.9.4 Marshes and shallow-water wetlands

Restoration experiences and research findings help direct the choices for restoration designs going forward. This includes knowledge of how hydrology, soil choice and placement, and plant selection and propagation affect the development of marsh and shallow-water wetlands.

#### 7.9.4.1 Hydrological considerations for vegetation establishment

The surface of all natural wetlands is waterlogged for at least part of the year (Money et al., 2009). The water source, its quantity and quality, and the mechanism by which it is delivered to the wetland combine to determine the type of wetland that develops in a given location (Gore, 1983; Moore, 1984; Moore and Bellamy, 1974; Wheeler, 1995). Wet conditions can result from impeded drainage, high rates of water supply or both (Money et al., 2009). Water supply can consist of groundwater, surface runoff or direct input from precipitation. Whatever the inputs may be for the newly reclaimed wetland, the hydrology of the newly created wetland will change as both the system, its vegetation and the vegetation within its watershed matures.

Wet meadow wetlands will experience droughts every year or two (Figure 7-6). Marshes dominated by emergent vegetation will experience drought conditions possibly once every 5 or 10 years (Figure 7-7), while shallow-water wetlands will likely experience droughts once every 10 or 20 years. Evapotranspiration is not constrained by water availability in shallow-water and emergent wetlands. In wet meadow marshes, evapotranspiration and direct inputs will surpass all other inputs, but only slightly. In these systems, the water table will frequently be below the soil surface, and plant physiology will be the predominant control on evapotranspiration (McCartney and Acreman, 2009).

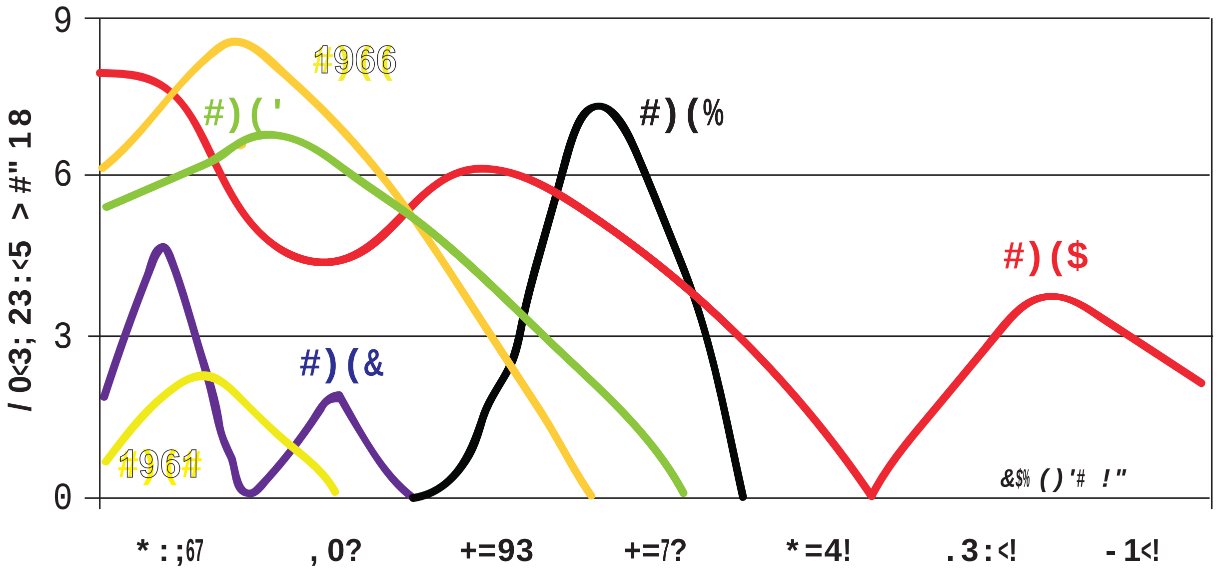

**Figure 7-6. Water Level variability over a 6-year period in a wet meadow marsh (adapted from Kantrud et al., 1989).** Note that the wetland goes dry in almost all years.

In a wetland design, the evaporation may be considerably less from wetlands where the water table sits below the surface than from wetlands with open water (Acreman et al., 2003). Wetland plants can play a major role in the loss of water from a wetland through transpiration. However, the amount of information, and the ability to draw consistent conclusions from it, is limited. The range of evapotranspiration from different species is not well understood and, at present, the use of ratios of vegetation to open-water evaporation is based on fragmentary evidence, with considerable variation among plant species and local conditions (McCartney and Acreman, 2009).

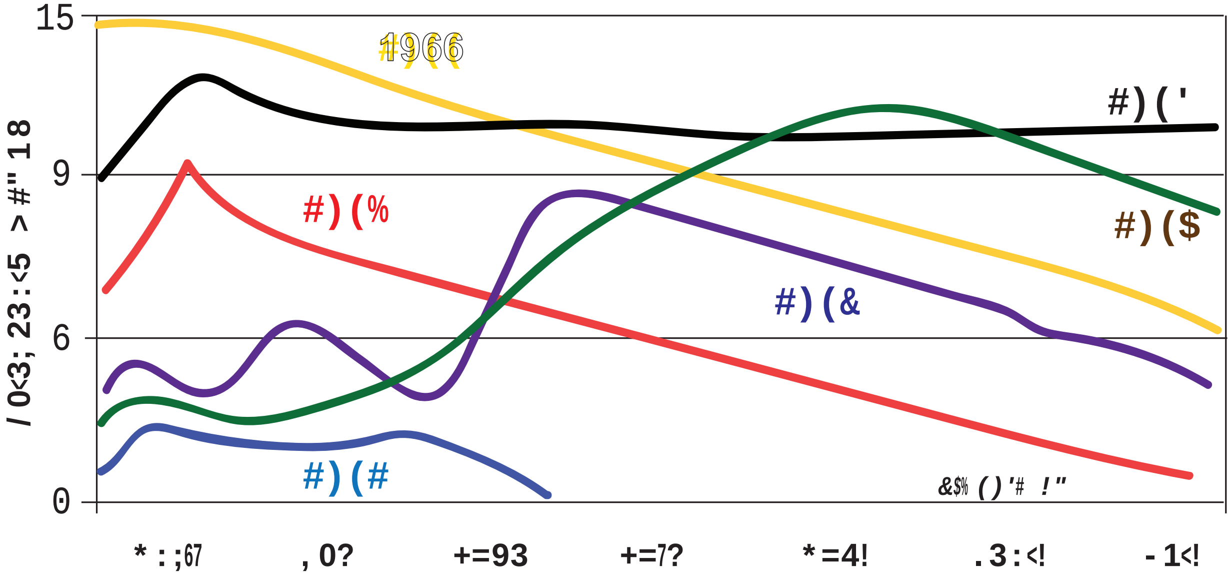

**Figure 7-7. Water Level variability over a 6-year period in a deep emergent marsh (adapted from Kantrud et al., 1989).** Note that the wetland goes dry in 1 out of 6 years of flooding.

Groundwater is an important freshwater reserve, both because of the large amounts of water stored and because it can be utilized when seasonal surface water supplies are depleted. Although aquifer recharge is an ecosystem function often attributed to wetlands, most are located either in topographic depressions where groundwater discharges, or where impermeable soils restrict the downward percolation of water. Recharge rates in wetlands are often much slower than those in adjacent uplands where soils are more permeable. Topographic position, hydrology, soil characteristics, season and climate all affect the amount of groundwater recharge that occurs.

Therefore, the correct hydrology should be engineering from the start. Monitoring in the first few years following construction will be critical for assessing success (see Chapter 8). To a certain extent, each newly created system will optimize its own design by selecting for the assemblage of plants, microbes and animals best adapted and suited for the final existing conditions (Mitsch and Gosselink, 2007). However, planners should be aware that even slight deviations from the intended hydrological regimes could result in a markedly different vegetative community than what was originally designed.

### 7.9.4.2 Substrate

Substrates are poorly understood in marshes and shallow open-water wetlands in general, not just in the Boreal Plains. Much of the focus on soils has historically been on upland soils due to our interests in forestry and agriculture and only recently has more effort been made to describing and mapping soils in wetlands.

Flooding initiates a chain of reactions that lead to reduced soil conditions. These reactions encompass various physical, chemical and biological processes that have significant implications for the positioning and survival of wetland plants (Gambrell and Patrick, 1978; Ponnamperuma, 1984; Gambrell et al., 1991; Blom and Voesenek, 1996; Pezeshki, 2001). The restriction of soil-atmospheric gas exchange depletes soil oxygen. Once flooding has occurred, the limited supply of oxygen is rapidly depleted by roots, microorganisms, and soil reductants (Ponnamperuma, 1972). This oxygen depletion results in a series of soil chemical changes that include accumulation of methane and $CO_2$, $N_2$, and $H_2$ (Ponnamperuma, 1984). The processes that follow include denitrification, a reduction of iron, manganese and sulfate, resulting in changes in soil pH and redox potential (Eh) (Gambrell et al., 1991). In a typical series of reductions $NO_3^-$ is reduced to $NO^{2}$ , $Mn^{+4}$ to $Mn^{+2}$, $Fe^{+3}$ to $Fe^{+2}$, $SO_4^{\ 2}$ to $H_2S$, $S_2$ or HS (depending upon pH) (Gambrell and Patrick, 1978; Ponnamperuma, 1984).

Chemical and physical changes occur when wetland soils become saturated or flooded. Soil waterlogging and submergence creates a series of abiotic stresses that influence species composition, positioning and productivity (Jackson and Colmer, 2005). Dominant among these is the starvation of oxygen and carbon dioxide that is imposed by extremely slow rates of diffusion in flooded habitats compared to that of upland habitats. In addition to individual species requirements for seed germination, it is the hydrological patterns in marshes and shallow-water wetlands that determine the vegetation in both natural and reclaimed sites (Voesenek et al., 2004). Many wetland species can be highly productive in flood-prone areas (Jackson and Colmer, 2005). However, the vast majority of vascular plant species are impeded by soil flooding, and particularly by complete submergence.

Species that thrive in flooded conditions achieve this through a combination of life-history traits (Blom, 1999), avoidance of oxygen-deficiency through effective internal aeration (Jackson and Armstrong, 1999; Pezeshki, 2001), anoxia tolerance (Gibbs and Greenway, 2003), and certain key physiological adaptations and acclimations such as physical “escape” from a submerged environment (Voesenek et al., 2003). Certain species also have the capacity to prevent, or repair, oxidative damage during re-aeration (Blokhina et al., 2003). One of the most common physical features that wetland plants possess is aerenchyma, which allow a plant to transport much-needed oxygen to the roots for maintaining aerobic respiration and to oxidize reducing compounds in the rhizosphere (Pezeshki, 2001). These large internal gas spaces also reduce the internal volume of respiring tissues and oxygen consumption, enhancing the potential for oxygen to reach the distant underground portions of the plant (Armstrong et al., 1994, 1996a, b, c). In many wetland plants the structure and number of aerenchyma dictate its ability to withstand flooding (Justin and Armstrong, 1987; Jung et al., 2008). For example, the number of aerenchyma in the stems of hardstem bulrush (*Schoenoplectus acutus*), and their physical structure within the stem, is much different than those found in softstem bulrush (*Schoenoplectus tabernaemontani*). This difference is what allows hardstem bulrush to withstand much deeper flooding conditions, and for much longer periods of time, than softstem bulrush.

In most design plans for the reclamation of marsh and shallow-water wetlands, an adequate placement of soil containing representative components of sand, silt, clay and organic matter will support seed germination and rhizomatous growth from plant root stock. One main challenge for engineers will be creating the foundation on which the soil is to be placed. The quality of the soil (i.e., presence of contaminants and weedy species) is paramount. If the growth medium contains contaminants, those constituents may be released into the system upon flooding, putting the development of plants, algae and bacterial communities at risk.

Depending on the origins of the silt and clay, soil salinity may develop as a system remains flooded. Many wetland plant species can be sensitive to even small amounts of soil salts, particularly species in the outer margins of wetland where wet meadow plants develop. The ratio of constituents to be used is a determining factor. Clay particles and organic matter are important for the retention of water and nutrients, and in the case of organic matter, for soil structure. Poor soil structure and high bulk densities can impede the development of plant roots and their ability to take up the nutrients required for aboveground growth.

Trites and Bayley (2009) found that plant species richness increased in marshes that exhibited positive correlations between peat depth and soil organic matter. Low soil organic content can limit the number of species that can colonize in reclaimed wetlands (Galatowitsch and van der Valk, 1996). The depth to which roots grow can serve as a guide for the depth of soil to be placed in a newly reclaimed wetland site. The effects of sedimentation on seed germination must also be taken into account.

#### 7.9.4.3 Salinity

In wetlands containing an excess of salts, the dangers to plants are two-fold: osmotic and direct toxicity (Mitsch and Gosselink, 2007). When the osmotic potential surrounding a plant's cells is too high, water is drawn out of the cell and the cytoplasm dehydrates. If concentrations are too great or sustained long enough, adult plants will die. Trites and Bayley (2009) examine the vegetative communities and chemistries of a number of natural wetlands in the western Boreal Plains and compared them to what they referred to as industrial, or reclaimed, marshes constructed in oil sands mining landscapes. They suggested that one challenge to wetland reclamation in post-mining landscapes could be excessive salts. Sediments and aquifers exposed during the mining process can leach salts.

Depending on the reconstruction process and the infill used, wetlands constructed after oil sands mining could have elevated $Na^+$, $Cl^-$, and $SO_4^{2-}$. Leung et al. (2003) indicate that salinities could range from 3,000 to 5,000 mg/L, which corresponds to an electrical conductivity (EC) range of approximately 4,700–7,800 mS/cm. Trites and Bayley (2009) found that ECs ranged from 0.4 to 27.7 mS/cm, with a mean of 5.23 mS/cm for natural wetlands and 1.38 mS/cm for reclaimed wetlands. Their mean values for both natural and industrial marshes were not that different from the normal ranges for EC in wetlands of this type in more southern locations (Ross, 2009).

However, many studies indicate a reduction in species richness and aboveground biomass when salinities begin to range between 1,000 and 5,000 mg/L (Brock et al., 2005). See Figure 6-5.

The effects of salinity on the vegetative communities in marshes may be most profound when the wetland enters a drought and mudflats become exposed. Even wetlands positioned side by side can have vastly different plant responses when mudflats or substrates are exposed. In reality, much of the variation within and between marsh and shallow-water wetlands is due to an ever-changing mosaic of surface waters interacting with the atmosphere, geological and surface material, and groundwater (Arndt and Richardson, 1989). For this reason, no two wetlands will respond in exactly the same way to drawdowns and problems with salinity at the soil surface. Part of this relates to the hydraulic conductivity of the soil in the pond and the fact that much of the water in marsh systems moves laterally towards its outer wet edges, rather than downwards below the wetland.

Solute differences observed in the soils surrounding the outer wet margins of marshes and shallow-water wetlands are the result of two distinct ionic dominance patterns in water chemistries depending on the flooding permanence of the wetland (i.e., how often the wetland goes dry). The main cations/anions present in the surface waters of seasonal or wet meadow marshes are calcium ($Ca^{2+}$), potassium ($K^{+}$), and bicarbonate ($HCO_3^{-}$), compared to magnesium ($Mg^{2+}$), sodium ($Na^{+}$), and sulfate ($SO_4^{-}$) and chloride ($Cl^{-}$) in more permanent emergent marshes and shallow-water wetlands (Driver and Peden, 1977; LaBaugh et al., 1987; Swanson et al., 1988; Arndt and Richardson, 1989; Ross, 2009; Trites and Bayley, 2009). Hardie and Eugster (1970) were among the first to propose the mineral dissolution/precipitation reaction, or evaporative pathway, that results in the chemical differences based on water permanence (Ross, 2009). This process of evaporitic concentration results in water dominated by Mg-Na-$SO_4$-Cl in marshes that are the most permanent in a landscape. It also means that these wetlands will exhibit the highest values of soil salinity on their outer margins when they go dry.

For emergent and shallow-water wetlands in oil sands landscapes, establishing and maintaining vegetation in these outer saline zones will be challenging. Selecting species that are resilient in saline soils will be important. Recognizing that these areas will be particularly susceptible to invasive species such as foxtail barley (*Hordeum jubatum*), and that invasives could be challenging to control from the outset, is also very important.

#### 7.9.4.4 Establishment in reclaimed marshes and shallow-water wetlands

Plantings in newly reclaimed or restored wetlands are often required to achieve vegetation communities that contribute to a functioning ecosystem and resemble natural reference communities (Cooper and MacDonald, 2000; Cobbaert, et al., 2004; Galatowitsch, 2006). While it is possible that the vegetation composition of reclaimed basins may emulate natural marshes as a result of normal dispersal of seed and other propagules (Galatowitsch and van der Valk, 1998; Trites and Bayley, 2009), evidence in the oil sands region suggests otherwise (Cooper and Foote 2003). Trites and Bayley (2009) found noticeable differences in the vegetative communities in reclaimed wetlands versus natural wetlands in the oil sands. While differences are not uncommon (Brown, 1999; Cooper and MacDonald, 2000; van der Valk, 2009), submersed vegetative communities, salt-tolerant communities, and certain species of *Carex spp., Juncus spp.*, *Schoenoplectus spp.*, *Scolochloa festucacea*, and *Eleocharis spp.* were missing in reclaimed wetlands. This may relate to the length of time since the site was established (Galatowitsch and van der Valk, 1998). Part of the disconnect may also relate to the geographic proximity of one site to another (Trites and Bayley, 2009). The oil sands landscape covers only a portion of the region and is not contiguous (Møller and Rørdam, 1985). Therefore, the connectivity that exists for natural wetlands in the area has not yet been established in reclaimed landscapes. Dispersal mechanisms operating in reclaimed landscapes may not yet mimic natural dispersal patterns in undisturbed areas.

Any assumptions about a wetland's innate ability to naturally revegetate itself over time must be reconsidered (Chapter 3). Even 20 years after restoration, many of the restored marshes in the northern Great Plains region of the United States still do not possess the same vegetative communities as natural wetlands of the same type (Aronson and Galatowitsch, 2008). The other risk faced when using this approach is the potential for the rapid establishment of invasive species. This is evident in the wet meadow zones of marshes and shallow-water wetlands, where sporadic wet-dry cycles and the nature of seed germination of these species make it difficult to out-compete invasives. While we possess better knowledge on how to re-establish submersed aquatic species and emergent species in newly reclaimed sites, wet meadow and upper slope species still remain more of a challenge.

#### 7.9.4.5 Vegetation establishment techniques

Establishing species in newly constructed marshes and shallow-water wetlands can be accomplished in four basic ways: 1) transplanting seedlings, rootstocks, or whole plants; 2) mechanical or hand seeding; 3) using donor soil with its seed and roots across an entire site; and 4) inoculating a reclaimed wetland site with donor soil in predetermined locations (Galatowitsch and van der Valk, 1998). In most situations, species are selected and a variety of propagation and establishment strategies are employed according to the species of interest (Table 7-4). In certain locations the combination of donor soils, direct seeding and transplantation is likely the best approach for revegetating areas of 0.4 ha or more. Table 7-4 outlines revegetation strategies in marshes and shallow-water wetlands based on site limitations and planting dates.

#### 7.9.4.6 Revegetation strategies using donor soil

Under the right hydrological and construction conditions, soil transplantation can significantly increase both the number of plant species in a new wetland site and the amount of plant cover (Brown and Bedford, 1997; Cooper and Foote, 2003). A donor seed bank exists in surface soil taken from an existing wetland. It is then spread onto the substrate of a reclaimed wetland. The soil contains seeds and other plant propagules as well as a host of microorganisms (bacteria) and invertebrates (van der Valk, 2009). Because the intention is not to destroy a natural wetland site to recreate a wetland in a new location, creativity in locating potential donor soil sites is required.

**Table 7-4. Propagation and establishment strategies for various common marsh species in the boreal region. An asterisk indicates a preferred or best propagation/establishment method.**

| | Potential marsh or shallow-water wetland Spp. | | Propagation/establishment information | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Common Name** | **Scientific Name** | **Recommended Planting Depth** | **Seeding Depth** | **Whole Plants** | **Roots/ Rhizomes** | **Seed** | **Cuttings** | **Winter Buds** | **Tubers** |
| **Floating-leaved Aquatics** | Duckweed | *Lemna spp.* | > 0 cm | | ! * | | | | ! | |
| | Small yellow pond-lily | *Nuphar lutea* | 30-100 cm | 0-3 cm | ! * | ! * | ! | | | |
| | Pygmy water-lily | *Nymphaea tetragona* | < 2 m | 0-3 cm | ! * | ! * | ! | | | ! |
| | Pondweed | *Potamogeton spp.* | < 2 m | | ! * | ! * | ! | ! * | ! | ! |
| | Water smartweed | *Polygonum amphibium* | 0-50 cm | 48-0 cm | ! * | ! * | ! * | ! * | | |
| | Broad-fruit bur-reed | *Sparganium eurycarpum* | 1-2.5 m | 2-3 cm | | ! * | ! * | | | |
| | Water shield | *Brasenia schreberi* | 0.5-3 m | | | | | | | |
| **Submerged Aquatics** | Pondweed | *Potamogeton spp.* | < 2 m | | ! * | ! * | ! | ! * | ! | ! |
| | Spiked water milfoil | *Myriophyllum sibiricum* | 26-59 cm | | ! | ! | ! | ! | ! | |
| | Coontail | *Ceratophyllum demersum* | | | ! * | | ! | ! * | | |
| | Mare's tail | *Hippurus spp.* | 18-200 cm | | ! * | ! * | ! | ! * | | ! |
| | Narrow-leaved water plantain | *Alisma gramineum* | | | ! | | ! | | | |
| | Bladderwort | *Utricularia spp.* | 0-100 cm | | | | | | | |
| **Emergents** | Giant bur-reed | *Sparganium eurycarpum* | 15-45 cm | 2-3 cm | ! * | ! * | ! | | | ! |
| | Common cattail | *Typa latifolia* | | | | | | | | |
| | Sweet flag | *Acorus americanus* | 15-50 cm | 0 cm | ! * | ! * | ! | | | |
| | Hardstem bulrush | *Schoenoplectus acutus* | < 1.5 m | 0 cm | ! * | ! * | ! * | | | |
| | Softstem bulrush | *Schoenoplectus tabernaemontani* | < 120 cm | 0-1 cm | ! * | ! * | ! * | | | |
| | Rush | *Juncus spp.* | < 20 cm | 0 cm | ! * | ! * | ! | | | |
| | Arum-leaved arrowhead | *Sagittaria cuneata* | 0-30 cm | 0 cm | ! * | ! * | ! | | | ! * |
| | Water arum | *Calla palustris* | 0-20 cm | 3 cm | ! * | ! * | ! * | ! * | | |
| | Buckbean | *Menyanthes trifoliata* | 0-30 cm | | | ! * | ! | | | |
| | Marsh-five-finger | *Comarum palustre* | -53-3 cm | | | | ! | ! * | | |
| | Scheuchzeria | *Scheuchzeria palustris* | | | | | | | | |
| | Spike rush | *Eloecharis spp.* | -3-60 cm | 0 cm | ! * | ! * | ! | | | !! |

| | **Potential marsh or shallow-water wetland Spp.** | | | **Propagation/establishment information** | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Northern water plantain | *Alisma triviale* | 0-15 cm | 0 cm | !* | !* | !* | | !! |
| | Sedge | *Carex spp.* | -50-50 cm | 0-5 cm | !* | !* | ! | | !! |
| | Yellow marsh-marigold | *Caltha palustris* | | 0 cm | ! | ! | ! | | !! |
| | Hemlock water parsnip | *Sium suave* | -50-15 cm | | | ! | ! | | !! |
| | Water horsetail | *Equisetum fluviatile* | -50-70 cm | | !* | !* | | ! | !! |
| | Reed Grass | *Calamagrostis canadensis* | -50-15 cm | < 1 cm | !* | !* | ! | | !! |
| | Slough Grass | *Beckmania syzigachne* | < 15 cm | < 1 cm | | | !* | | !! |
| | Wool-grass | *Scirpus atrocinctus* | < 30 cm | 3 cm | !* | !* | ! | | !! |
| | Small-fruited bulrush | *Scirpus microcarpus* | | 3 cm | !* | !* | ! | | !! |
| **Wet Meadow** | Reed Grass | *Calamagrostis canadensis* | -50-15 cm | < 1 cm | !* | !* | ! | | !! |
| | Sedge | *Carex spp.* | -50-50 cm | 0-5 cm | !* | !* | ! | | !! |
| | Slough Grass | *Beckmania syzigachne* | < 15 cm | < 1 cm | | | !* | | !! |
| | Tufted Hairgrass | *Deschampsia cespitosa* | < 0 cm | < 0 cm | | | !* | | !! |
| | Manna Grass | *Glyceria grandis* | | < 1 cm | ! | | !* | | !! |

Considerations for using donor soil as a revegetation strategy for a new location include:

1. The use of wetland donor soils from locations where the removal of soil will not degrade or place a natural wetland at risk.
2. Is donor soil close enough to the site to avoid or minimize stockpiling of material?
3. Is adding donor soil to the entire site feasible or does it make more sense to strategically place specific wetland communities into the hydrological zones to which they are best adapted?
4. Does the donor soil contain species that will survive in the planned hydrological regime?
5. Does the donor soil provide a diverse seedbank and propagule base or is it relatively monotypic?
6. Is the soil from the donor site clean of invasive or aggressive plant species?
7. The use of donor soil requires some ability to manipulate and manage water levels in the first few years of site development. Does this project have that ability?
8. Will the water chemistries from the donor soil site be similar to the water chemistry of the new wetland site?
9. Does the timing of construction and water entry into the project match the times of years required for placing donor soils?
10. Consider establishing outdoor nursery sites for revegetating large wetland reclamation projects. Many disturbed sites have areas where natural flooding and pooling occurs. Look to establish wetland plant material in these locations 3 to 5 years before the donor material is required.

While the seeds in donor soils can be moved at any time of the year, live plant or root propagules cannot. Roots and adult plants are most at risk when they are translocating nutrients between above- and below-ground parts. Therefore, matching the timing of soil movement to those times when the plants are at the least risk of trauma is vital. Stockpiling donor soils for too long (i.e., days to weeks) can also pose a risk to propagules. Even during the winter months stockpiled material can begin to compost and roots and rhizomes can quickly decompose. Efficiencies during donor soil transport from one location to another are important.

#### 7.9.4.7 Revegetation strategies using live propagules/plantings

For wetland sites where live propagules or live plants are used as the main approach to revegetation, each species must be transplanted into an environment and water depth to which they are adapted. While this approach is labour-intensive, it does work well in reclaimed sites where water availability in the spring may be unreliable or in locations where water levels are unpredictable until the site is operational. Only a small window exists each summer for transplanting live propagules. In most northern locations the transplanting window is just one to two months each summer. Live plant material must be transplanted when the majority of its nutrients are in the stem and leaves, rather than the roots.

#### 7.9.4.8 Out-planting

The benefit of using nursery grown stock is that a consistent quality of individual plant species can be ensured. The drawback is that it is labour-intensive and impractical as the sole approach for vegetating larger sites. Nursery stock can be produced from vegetative propagules (for example, root, rhizome and/or stem cuttings) or seed and multiplied prior to placement. When harvesting vegetative material, again the integrity of donor sites must be maintained. Producing plants in a nursery setting can maximize the use of a limited seed supply. When growing seedlings (as with direct seeding) knowledge of viability, dormancy, pre-treatments and germination of candidate species must be understood and applied.

#### 7.9.4.9 Revegetation strategies using seed

A combination of donor soil and seeding is likely the best approach for revegetating large areas. Seeding can be less costly than moving donor soil, although the results are not always as predictable when used as the only approach. The regeneration of newly reclaimed wetland sites by seed bears a higher risk of plant mortality than vegetative propagation by rhizomes (Harper, 1977; Schütz, 2000). Germination can be considered as the transition from the relatively safe state of the embryo protected by the seed coat to the vulnerable state of the emerging seedling. It is often considered the most critical event in a plant’s life cycle (Schütz, 2000). Germination at the right time and in the right place largely determines the probability of a seedling surviving to maturity (Thompson, 1973). Therefore, it is not surprising that dormancy characteristics and germination responses are under strong selective pressure (Meyer et al., 1990; Rees, 1996).

Careful planning and considerations for seed harvest, site placement and germination are all key components for ensuring the successful re-introduction of wetland plants on a newly constructed wetland that uses seed. Appendix E presents a thorough discussion on seed harvest, germination strategies and environmental considerations affecting seed germination.

#### 7.9.4.10 Timing of Water on New Projects

The timing of water for plant recruitment and survival is crucial, especially in the early years. Most construction occurs while landscapes are dry and it is only after the project is complete that the wetland becomes flooded. Wetland plants require flooded conditions to survive, but too much water can kill a young wetland plant. Sites where revegetation occurs using donor soils or root propagules will require standing water early in the spring (i.e., April/May). These sites also require variable water levels in the first few years to get the plants growing. Too much standing water on top of donor soils or root propagules will also quickly inhibit or destroy emergent plant growth. Too little standing water will lead to composting of plant roots and poor recruitment from the seed bank in the donor soil. Sites that use wetland seed as one strategy for plant recruitment will require a short period of soil wetting in the spring to encourage germination; seed will not germinate under water. Projects that use live propagules will require flooded conditions by late June for transplanting to occur during the summer.

#### 7.9.4.11 Controlling invasive species

Almost all natural marsh and shallow open-water wetlands possess a wet meadow zone (Stewart and Kantrud, 1971). These are important for a wetland’s overall species richness. The species in these zones reflect the very specific environmental and hydrologic requirements of wetland plants (van der Valk and Welling, 1988; van der Valk and Pederson, 1989; van der Valk et al., 1999; van der Valk, 2000). They are also most susceptible to competition from invasives (Ross, 2009). These zones play an important role in preventing invasives from moving into the deeper emergent vegetative zones. More invasive and weed species will establish in the inner vegetative zones when the outer margins of wetlands are degraded or overcome by invasive plant growth (Ross, 2009).

Poor weed control and excessive grazing by Canada geese or muskrats on newly emerging wetland plants can also lead to the establishment of weedy species, especially in the first few years following the reclamation of a new wetland site. Excess sedimentation and high nitrogen content in the surface sediments also encourage invasives to grow, while discouraging native species to germinate. It is therefore important to not only establish resilient wetland plant growth in the outermost zones of a newly reclaimed wetland, but to protect these zones with a resilient upland buffer zone of native upland species. If the outermost vegetation zones of wetlands have the capacity to slow the inward migration of aggressive or noxious species, then these outermost zones should be kept as weed-free as possible (Ross, 2009). Every reclamation wetland plan should have a strategy clearly outlined from the time of site design for managing invasive species through construction, revegetation and commissioning.

### 7.9.5 Summary of revegetation considerations

Understanding wetland plant communities and how they respond to changes in hydrology is paramount in all site designs. These two factors will determine which plant communities will grow and how they will position themselves in a newly reclaimed site. From a reclamation perspective, the following are important to consider:

1. Hydrology is the most important driver affecting the distribution and diversity of vegetative communities in fens, marshes and shallow-water wetlands.
2. Fluctuating water levels (both short- and long-term cycles) must be integrated into the site design from the start of all marsh and shallow-water wetland reclamation projects. They will determine the long-term functioning of the new wetland as well as the communities to select for revegetation.
3. Vegetative communities in fens, marshes and shallow-water wetlands assemble and survive in response to water depths, the chemistry of the site, soil composition and competition from other plants.
4. Site limitations, the availability of water, and construction will help determine the strategies to use. Each new reclamation location will require its own set of strategies based on individual site differences.
5. Consider using a variety of revegetation techniques and adaptive management on a newly reclaimed site.
6. Invasive species will quickly impede the growth and expansion of native wetland species. Each reclamation design should include a plan for minimizing the growth of invasive plants on site, especially in the first few years.
7. All wetlands interact with their surrounding uplands (Chapter 3). Minimize invasive species growth on the surrounding uplands as well.

8. While the presence of wildlife is an end goal of a wetland construction, certain species can quickly destroy young wetland plants. A strategy for minimizing wildlife impacts before they occur should be part of the wetland design.

## 7.10 Final construction

Prior to signoff and handover to the OMM team, construction and reclamation must be substantially complete (Section 8.1.6). To complete the construction and reclamation phase, the following activities are typically undertaken:

- Constructing wildlife enhancement features
- Initial filling of wetland with water
- Testing infrastructure required for wetland operation, such as instrumentation, outlet weir, pumps or freshwater input (if required)
- Removing water management infrastructure required for construction
- Decommissioning unnecessary instrumentation
- Removing temporary construction infrastructure, such as trailers and laydowns, and reclaiming areas as required
- Removing temporary access roads and berms
- Completing final survey of topography and material placement boundaries

### 7.10.1 Wildlife habitat enhancements

Some wildlife habitat will be constructed before reclamation material is placed, some before revegetation, some before initial filling, and some after. Among the species for which accommodations should be made are Canada geese (*Branta canadensis*), which are fond of young wetland plant shoots as a potential food source. Where donor soils or seeding methods are employed for revegetation, careful monitoring of the site for plant damage from grubbing is important. In many locations, additional assistance through the use of temporary enclosures may also be required (i.e., fencing). Muskrat (*Ondatra zibethicus*) can also be particularly harmful to adult plants and they can quickly decimate an entire emergent plant population in a marsh or shallow-water wetland. They use cattail for den construction in the fall, and seek out both hardstem and softstem bulrush as a food source throughout the year. Newly reclaimed sites are at greater risk than established locations. Monitoring for muskrat early in the development of a reclaimed site is important for achieving long-term success.

While a number of wildlife enhancement techniques have been used in other jurisdictions during reclamation or restoration of wetland habitats, it is important to understand that relatively little is known about species-specific enhancements. Much of the current knowledge about species-habitat associations comes from other regions, and should be applied with caution to reclamation in boreal Alberta. As discussed elsewhere in this document, the focus for wildlife should be to establish functioning ecosystems that mimic relevant natural systems; specific enhancements for species at risk can be added as necessary, but developing lists of techniques for each species at risk potentially occurring in the mineable oil sands region is beyond the scope of the present document.

Enhancement techniques should be used within a reclamation framework that encompasses the overall needs of target species (e.g. foraging areas, cover, nesting sites, over-wintering sites), to increase the probability that these wildlife species will establish and maintain populations at a site. Examples of a variety of wildlife habitat enhancement techniques are provided below; note that the majority of these approaches target wildlife *communities*, rather than individual species. In addition, these techniques are typically focused on enhancing the physical habitat, prey base, or ecological functioning of a wetland that are necessary to support healthy wildlife populations. Enhancements for specific species can be added, as needed, to increase the probability that these sites will support target wildlife species. The correct ecological functionality must be established at the site as well in order to achieve success.

Example wildlife habitat enhancement techniques include:

- Inoculate the new wetland with 20-litre buckets of water and sediment to encourage plankton and bacteria community development.
- Construct nest boxes, rock piles or snags in and near the wetland. Nest boxes for swallows and bats can encourage their use of the system and have the added bonus of controlling mosquitoes (Mitsch and Gosselink, 2007).
- Use live and dead vegetation, islands, and floating structures to create habitat.
- The greater the vegetation and structural diversity within a wetland, the more wildlife will be attracted. Ducks will eat algae and other animals will eat seeds, tubers, leaves, stems, roots and rhizomes, invertebrates, fish, amphibians, reptiles, mammals, and birds (Ross and Murkin, 2009).
- Manipulate the timing of food availability to attract wildlife. For example, provide invertebrates during late winter for ducks to eat on their spring migration. Flood the vegetation to encourage invertebrates (Ross and Murkin, 2009).
- Install bales of straw to encourage nesting for some birds (like mallards) and habitat for colonizing invertebrates. Ruddy ducks like aquatic grasses for nesting (Ross and Murkin, 2009). Cover provides for nest sites, protection from predators, and shelter from weather.

### 7.10.2 Paths, boardwalks and signage

To prepare the wetland for operation, monitoring, and handover, access to various elements of the landscape will be required (Figure 6-13). In most cases, simple footpaths with some attention to tripping hazards around monitoring points will suffice. Pathways can be constructed for walking or using all-terrain vehicles to connect roads, and boardwalks to minimize the trampling of vegetation and wildlife habitats. Snowshoes may be used to access some areas of wetlands, most likely in fens without boardwalks.

Boardwalks can be constructed to access areas and instrumentation in the wetland but can be expensive, with unit costs similar to that of road construction. Only a few wetlands will have the luxury of boardwalks. Considerations include who will use them and for how long, what safety measures will be necessary, and what impact the boardwalk will have on wildlife. Boardwalks may need to be removed for reclamation certification.

### 7.10.3 As-built drawings and construction records report

As-built drawings and a construction records report are completed are part of commissioning. Efforts to streamline this reporting will help ensure it is completed for more wetlands. The focus is on capturing the minimum amount of information needed to monitor, operate, and certify the wetlands. For semi-designed wetlands, there is an opportunity to develop a simple form to capture the relevant information in the field.

Research and designed wetland will have formal as-built reports. For semi-designed wetlands, design notes, observations, and records are kept and filed in a repository for the landform. For opportunistic wetlands, information is recorded and documented as part of the ongoing OMM program (see Chapter 8 for more information on the OMM program). For new wetland sites not performing as predicted, as-built drawings will be one of the first places to look for explanations.

### 7.10.4 Initial filling

Plants can be sensitive to water levels. The success of initial plant establishment is closely linked with proper management of the hydrology in the initial stages of reclamation. If water levels rise or fall too quickly, it can result in the drowning of seeds or young seedlings, or mortality by desiccation (van der Valk, 2009).

During planting, the water level should be low enough to facilitate planting, then raised to ensure the root zone is continuously flooded. If the wetland is not filled in time for the new vegetation to draw from it, the chance of vegetation surviving is low. Many marsh plants need a dry period to germinate, then a wet period for establishment and growth. The water quality and quantity are monitored during initial infilling. If water quality deviates from design, infilling is stopped. The outlet water quality is monitored as well.

### 7.10.5 OMM manual

For research wetlands and designed wetlands, prior to signoff, the OMM manual is updated and finalized to guide operations. Refer to Section 8.1.7 for more information about operational manuals. Sites will likely develop a standard OMM manual that covers all semi-designed and opportunistic wetlands.

### 7.10.6 Signoff and hand over

When construction is substantially complete, signoff and handover of the wetland to the operation, monitoring, and maintenance (OMM) team follows. The signoff will include a comparison of the as-built conditions with the IFC design and correction or acceptance of any deficiencies by the OMM team. The construction team’s work formally ends at signoff and responsibility is handed to the OMM team. Ideally, the design team remains engaged.

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# Chapter 8
# Wetland Operation, Maintenance and Monitoring

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Operation, monitoring and maintenance activities have multiple uses. They keep wetlands on a trajectory toward certification by demonstrating performance against design goals and objectives (focused adaptive management). They entail gathering information to allow preparation of the application for reclamation certification and relinquishment at the end of the monitoring period (certification). They also involve collecting information useful for changes and design of other reclaimed wetlands in the region (broad adaptive management).

All wetlands have distinct characteristics, making it difficult to apply one standard approach to monitoring and managing wetland projects. Successful reclamation requires the careful implementation of several interrelated activities, including planning, design, post-construction monitoring, and adaptive management. An operation, monitoring and maintenance (OMM) manual, along with adaptive management, will provide efficient and practical approach for the many wetlands that will be reconstructed in the oil sands. Monitoring is most effective when:

Performance measures inform reclamation practitioners of the degree of performance for the indicator, measured against an established threshold;

Practitioners investigate the physical, chemical, biological and functional attributes of a wetland site to assess how well the system is performing; and

Monitoring begins as soon as the wetland system starts functioning and continues through to a pre-determined end.

Practitioners should follow certain guiding principles. For one, each wetland must have appropriate and achievable goals for management over both the short and long term. Second, wetlands should be designed and maintained through infrequent interventions within an ecological regime appropriate to the wetland. Third, efforts should be made to establish a broad assortment of aquatic vegetation and aquatic species. Diversity builds robustness into a new wetland site and makes it more resilient against unexpected disturbances. Adequate diversity can only be achieved, however, with a clear vision of what the hydrological conditions will allow.

Throughout the wetland reclamation project, the planning, design goals and objectives will set direction and help steer the right course. Monitoring starts immediately after a site is constructed. It can provide early warnings that a site may not be performing as intended and that maintenance activities require adjustment. Adaptive management strategies will help define and develop measurements for project accomplishments that are biologically meaningful, affordable, and useful for informing management actions. Such strategies are effective for both current and future wetland reclamation projects.

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## 8.1 Introduction

One of the main objectives in constructing new wetlands is minimizing management interventions over the lifespan of the project, ultimately leading to successful and expedient reclamation certification and relinquishment to the Crown. Meeting this objective requires project planners to identify and clearly define measurable goals. The most common causes of the failure of constructed wetlands are unrealistic expectations or undefined objectives (Ross, 2011). In too many cases, an assessment depends on observations made too hastily, over too short a period of time, or across too narrow a landscape perspective. Project planning, design, post-construction operation, maintenance and monitoring are essential and interrelated activities for any organization involved in constructing wetlands.

Project planning and design objectives will set direction, steer the course or provide early warnings that a site is not performing or responding as intended. Monitoring will provide early indications that design parameters or site expectations may need to be adjusted. Adaptive management strategies will help define and develop indicators that are biologically meaningful, affordable, and useful for informing management actions, not only on the project in question but on future projects as well.

### 8.1.1 The OMM process

The final stage of wetland reclamation, prior to certification and relinquishment, is operation, maintenance, and monitoring (OMM). Included in this stage is ensuring all processes are working as they should from the start of operation (i.e., commissioning). The objective of the OMM stage is to efficiently steer wetland performance toward simple and timely reclamation certification (Crossley et al 2012; Fair et al 2014).

Table 8-1 shows the management phases and typical OMM activities. The length of various OMM activities depends on the type and size of wetland being commissioned (e.g., marsh versus a fen). Wetland OMM activities are part of an overall reclaimed watershed, landform, or lease-scale program. Presently, only a few oil sands wetlands benefit from a formal OMM program. These programs keep operators and regulators focused on achieving certification, provide opportunities to perform timely maintenance (narrow adaptive management) and incorporate experience into future wetland design (broad adaptive management).

**Table 8-1. Wetland phases and OMM activities.**

| Phase | Description | Time frames | Designed | Semi-designed | Opportunistic |
|---|---|---|---|---|---|
| **Landform construction** | Monitoring of bulk overburden and tailings placement in accordance with landform design specifications | Year -9<br>to<br>Year 0 | Routine operational construction monitoring<br>Site-wide climate monitoring<br>Annual inspection and reporting<br>Routine operational construction and reclamation monitoring | | |

| Phase | Description | Time frames | Designed | Semi-designed | Opportunistic |
|---|---|---|---|---|---|
| **Wetland construction and reclamation** | Construction monitoring of landform elements and general monitoring of reclamation soil placement and revegetation | Year 0<br>to<br>Year 1 | Monitoring of water quality and flows in vicinity of wetland where practical<br>Annual inspection and reporting | | |
| **Wetland establishment /active management** | Active management of water, vegetation, and wildlife | Year 0<br>to<br>Year 7<br>Depending on wetland type | Automated outlet flow measurements<br>Weekly to monthly site visits<br>Monthly to quarterly instrumentation readings, data collection, and water/ soil sample collection<br>Annual surveys and spring/winterization maintenance<br>Regular wildlife management measures | Annual inspection and reporting | |
| **Declining management** | Reduced and declining management to keep on the path | Year 4 to Year 6 | Automated outlet flow measurements<br>Monthly site visits<br>Quarterly to bi-annual instrumentation readings, data collection;<br>water and soil sample collection<br>Annual surveys and spring/winterization maintenance | | |
| **Certification qualification** | Minimal management inputs to demonstrate self-sustaining nature of wetland | Year 6 to Year 9 | Automated outlet flow measurements<br>Monthly site visits<br>Annual instrumentation readings, data collection, and water/soil sample collection<br>Annual surveys | | |
| **Post certification** | Monitoring and maintenance as required | Year 10+ | As desired by the Crown | | |

**Notes**: The start of Year 0 is defined as the end of bulk mining activities and the start of wetland-specific activities (see Chapter 8). Field activities are largely confined to the open-water season, which runs from April 1 to Oct. 31. Timeframes may be longer or shorter depending upon goals, trajectory, and performance.

This chapter describes activities during the OMM stage from the end of construction to successful issuance of a reclamation certification — three to at least nine years, depending on landform, wetland type, wetland goals, ecological trajectory, and performance. The framework for this approach is adapted from Operation, Maintenance, and Surveillance (OMS) manuals for dams (CDA, 2007) and tailings facilities (MAC, 2011). This well-established industry approach for dams has also been adapted to oil sands mine reclamation by Crossley et al. (2011).

This guidance draws on the experience and success of wetland restoration and reclamation projects by Ducks Unlimited, numerous textbooks on wetlands, and oil sands experience over the past 15 years (see Chapter 4). To be successful, the operation and monitoring of the hundreds of reclaimed wetlands that will be created through oil sands landscape reconstruction must allow operators to reliably maintain and guide their reclaimed wetlands along acceptable ecological trajectories until they are demonstrably self-sustaining. For the OMM program to be sustainable itself, it must be affordable, efficient, practical, and focused on achieving reclamation certification (e.g., AENV, 2011).

Monitoring starts even before landform construction (Table 8-1). But for simplicity, this chapter assumes construction of the wetland and its infrastructure is complete and the wetland is filling with water (as described in Chapter 7). Ideally, monitoring instrumentation and equipment are in place and the upstream watershed reclamation is also complete. For some wetlands, not all of these assumptions will be valid and the operator will need to adapt accordingly.

In particular, this chapter sets out the minimum requirements to guide the wetland trajectory to meet specific goals (focused adaptive management), gather enough data for the reclamation certificate application, and improve design, construction, and operation of future reclaimed wetlands (broad adaptive management). While most of the described activities are common in wetland projects, there are unique advantages and challenges for reclaimed wetlands in the region. Advantages include:

A long-term and ongoing presence on the landscape for at least the next five decades;

A vested interest in ensuring good performance of reclaimed lands by industry, regulators, and stakeholders;

A highly trained local workforce intimately familiar with all reclaimed areas;

Established safety protocols;

Extensive infrastructure;

Collaborative organizations that assist in wetland reclamation;

Actively support and conduct research to improve future wetland development activities in the region; and

An established regulatory environment.

Challenges for monitoring and adaptations are set out in Table 8-2.

**Table 8-2. Challenges to monitoring oil sands reclaimed wetlands compared with reconstructed wetlands outside the region.**

| Challenges | Adaptation |
|---|---|
| The large number of wetlands that will be created over the next five decades | Establish and test minimum monitoring requirements using existing reclaimed wetlands |
| Long-term data management | Encourage operators to develop a common and robust framework for data management in a GIS format |
| A tendency to focus on research monitoring rather than operational monitoring | Clearly identify which wetlands are predominantly for research and which are operational/functional |
| Different types of wetlands will require different levels of monitoring | Design monitoring based on minimal needs and project goals |
| Access to wetlands is limited<br>Some will cover hundreds of hectares<br>Many will have more than 1 m of water depth<br>Cost of constructing, maintaining, and reclaiming access roads and trails in reclaimed land | Minimize the need for ground access<br>Build the minimum access needed to each area<br>Develop remote-sensing techniques and automated instrumentation readings wherever practical |
| Access via boardwalk network typically too expensive | Shorelines designed for access |
| Snow and ice in winter conditions | Design with winter conditions in mind, and restrict monitoring largely to the open-water season |
| Limited opportunity for intervention, especially given a trajectory to wetlands becoming self-sustaining | Design for minimal intervention<br>Identify and plan for specific practical interventions |

### 8.1.2 The professional team

Newly reclaimed systems often require the expertise of a variety of professionals with skill sets in various areas and the ability to interpret what they see on the ground in a meaningful way. Every project team should include expertise in the following areas:

Engineering – to assess hydrological and physical performances and infrastructure integrity

Biology – to assess and interpret vegetative development (both upslope and downslope), water-quality, soil development and wildlife responses

Technical/operational – to oversee water inputs/outputs and to manage power and pumps and site access

Regulatory, certification – for input and guidance on setting goals, monitoring activities, project documentation, and reporting responsibilities

### 8.1.3 Focused and broad adaptive management defined

Adaptive management involves iterative cycles of planning and implementation/modification, followed by evaluation, allowing “a disciplined approach to learning while doing” (Holling, 1978; Walters, 1986). Section 1.4.3 of this document and Appendix D of the CEMA (2012) *EPL Guidance Document* describe this approach for oil sands reclamation in more detail. Building upon that work, it is useful to define two additional aspects:

***Focused adaptive management*** involves integrating monitoring results directly into management decisions and taking action in a timely manner to guide trajectories (Table 8-6). Focused adaptive management is for a specific wetland that is designed, operated and maintained for reclamation certification.

***Broad adaptive management*** involves monitoring and analyzing data and experience from all reclaimed wetlands to guide the reclamation of new wetlands on the operator's site or at other operations in the region. The process allows improvements to design, increased reliability, reduced costs and uncertainty, and better environmental performance (BCFR, 2011). Research wetlands are designed primarily to support broad adaptive management. Monitoring programs for all reclaimed wetlands are also designed in part to support focused adaptive management. Embracing adaptive management allows operators to tap into decades of work and experience. A successful adaptive management program includes the following elements:

1. Clear quantifiable goals and objectives
2. Predictions about the outcomes of pre-planned management actions
3. Monitoring procedures to measure the success of the outcomes defined in the objectives
4. Evaluation/planning processes in place to compare the outcome with the original prediction

Too often, adaptive management is an afterthought or vague promise to do trial-and-error reclamation (Hauser, 2008; Allen and Gunderson, 2011). However, effective adaptive management (CEMA, 2012) is central to the creation of wetlands that meet corporate and regulatory goals to efficiently achieve reclamation certification and relinquishment. The OMM activities in this chapter are mainly aimed at focused adaptive management (the here and now), but with an eye to broad adaptive management (which will also inform future editions of this guide). Unlike many other adaptive management programs that are essentially permanent (e.g., managing forests and fisheries), adaptive management for oil sands wetlands is a finite activity for each wetland. The focused adaptive management ends as each wetland is certified, and the broad adaptive management program presumably ends when the last reclaimed wetland is certified.

Although somewhat of a burden on operators, stakeholders, and regulators, adaptive management is a necessary (Lee, 1999) and cost-effective tool to mitigate uncertainty in a region where numerous wetlands will be reconstructed.

### 8.1.4 Intensive versus extensive monitoring

A successful strategy in oil sands reclamation has been the use of high levels of intensive monitoring on instrumented watersheds built for research and low levels of extensive monitoring of commercial-scale reclamation (e.g., Syncrude, 2004). The strategy is to research and monitor the performance of about a dozen instrumented watersheds over the life of the oil sands development to understand the mechanisms and develop experience, datasets, models, and design tools for commercial reclamation (McKenna et al., 2011).

Extensive monitoring (of multiple landforms and watersheds) involves much lower levels of short-term focused monitoring of the commercial-scale reclamation to confirm similar performance and trajectories of the instrumented watersheds (focused adaptive management). General inventorying and the cataloguing of data could also be considered a type of wetland monitoring requiring a lower level of effort than extensive monitoring.

### 8.1.5 Operation, maintenance, and monitoring defined

Overlap among operation, maintenance, and monitoring is common (CDA, 2007) and likely involves the same staff.

> ***Operation*** is the set of normal, planned field activities involved in managing the water levels, and (perhaps) the quality and quantity of water flowing through or released from the wetland; maintaining access to the wetland; and various wildlife habitat or wildlife control measures. Operation also includes the organizing of and reporting on maintenance, monitoring, data management, and preparation of the application for certification.
>
> ***Maintenance*** is the planned and reactive field activities to maintain or repair infrastructure (fences, access, power and pipelines, weirs, monitoring equipment) and the reclaimed land (earthworks and revegetation).
>
> ***Monitoring*** is the periodic surveillance and data collection that includes visual field inspections, field surveys, manual and automated instrumentation, and remote sensing.

**OMM activities are designed to:**

> Keep the wetland on a trajectory towards certification by demonstrating performance against design goals and objectives (focused adaptive management);
>
> Collect the information to allow preparation of the application for reclamation certification and relinquishment at the end of the monitoring period (certification); and
>
> Collect information useful for changes and design of other reclaimed wetlands in the region (broad adaptive management).

The literature includes many wetlands with similar programs (e.g., USEPA, 2002). Table 8-2 lists some challenges for monitoring reclaimed wetlands in the oil sands compared with other wetland projects elsewhere. The wetland monitoring program is designed with these similarities and differences in mind.

### 8.1.6 The OMM approach

Goals and objectives should be set early in the design process (Chapters 5 and 6). Early versions of the monitoring program are established during closure planning and landform design based on the risk assessment process. The OMM Manual will have been produced as part of the construction program (Chapter 7) and based on guidance from this chapter.

The OMM team has the same experts (technical and operational) as outlined earlier in this guide. Ideally, the same team that designed and constructed the wetland remains active through to reclamation certification and relinquishment. However, it is likely that team membership will change over the decades. First Nation communities and their residents also have a vast store of knowledge about wetlands in the oil sands region, and the life histories of the culturally significant species that inhabit them. Their input and knowledge on OMM teams can provide both valuable insight and consistency in the transfer of knowledge to new team members over the life expectancy of a wetland project. The OMM approach and manual is a method to transfer knowledge from experienced staff to new staff.

One of the features of an OMM approach is clear identification of management responsibilities, expectations, and reporting requirements for performance of the wetland (Crossley et al., 2011) for all phases of construction and reclamation. This helps avoid transition periods for which responsibility may be unclear, and the wetland could become temporarily orphaned (McKenna et al., 2002).

To keep the OMM program sustainable, the program is designed to be as efficient as practical.

- All wetlands in a reclaimed watershed are monitored together.
- Remote sensing is used wherever practical.
- Instrumentation is minimized, but where needed, data-loggers collect and store data, and telemetry is employed where practical.
- Visual inspections are preferred to field surveys where appropriate.
- Sample collection is minimized.
- Clear protocols and workflows are designed to guide all activities.
- The level of training of field and office personnel is high, allowing individuals to work in several disciplines (Kellin et al., 2009).
- There is an efficient site-wide reclamation data management system with formal quality assurance and quality control systems in place.
- Reporting is minimized and automated to the degree practical.

Monitoring activities and management interventions are clearly linked to the project’s general and specific goals and objectives, and are assigned the appropriate resources for monitoring (e.g., personnel, equipment, time, and finances) (van der Valk, 2009).

A site’s performance can be determined by assessing its vegetative development and spatial characteristics (Walters 2000; Wilkins et al., 2003), species diversity (van Aarde et al., 1996; Reay and Norton, 1999; Passell, 2000; McCoy and Mushinsky, 2002), and ecosystem processes (Rhoades et al., 1998), or by using an integrated approach that includes many variables (Neckles et al., 2002; SER, 2004). For reclaimed wetlands, performance measures can include, but are not limited to, hydrological performance, the presence of target plant or animal species, species diversity, species abundance (percent cover, density), species biomass, soil conditions (nutrients, texture, organic matter), carbon fixation rates, flood storage capacity, and water quality or overall watershed functioning (van der Valk, 2009). The level of OMM effort will vary with the type of wetland and its reclamation phase.

Previous editions of this guide implied that reversion of a wetland to terrestrial conditions (partly or entirely) was a failure mode. Building on the HEAD project (Devito et al., 2012), it is now recognized that boreal wetlands often cycle through dry periods, and drying or flooding of reclaimed land is evolutionary rather than evidence of failure (see Chapter 3). The potential for changes are clearly detailed goals (Section 5.2.4) and need to be reflected in the OMM manual.

### 8.1.7 The OMM manual

The OMM manual provides the project description and procedures for the operation, maintenance, and monitoring of the wetland and is employed for new reclamation projects (Crossley et al., 2011). It provides the design intentions and the goals and objectives for the wetland, as well as guidance on performance criteria and metrics.

The OMM manual covers managing or monitoring water quantity and quality of inflows and outflows, assessing vegetation development, weed assessment and management, evaluation of wildlife habitat and wildlife use, actions for wildlife control, assessment of infrastructure integrity and operation and reporting requirements. It lists and describes wetland components and infrastructure that may require maintenance to achieve desired operation or performance. For components that are known to require maintenance for a finite time, the manual outlines the schedule for this maintenance (i.e., winterization and spring melt procedures).

The OMM manual provides guidance on the monitoring requirements and frequency. Only with proper monitoring can issues affecting wetland performance be identified and remediated. Operators will choose to write an OMM manual for the entire site, for all wetlands, or for specific wetlands. Other types of reclaimed landforms or ecosystems that will need to be covered by an OMM manual include end pit lakes, reclamation lakes, upland forests, riparian/creek systems, and landfills. Observation, maintenance, and surveillance (OMS) manuals will already be in place for all licensed dyke structures and tailings facilities but they will focus on dam safety issues rather than reclamation performance specifically.

### 8.1.8 Physical access to wetland

Access is one of the main challenges for OMM activities unless designed and created specifically (see Chapter 7). Table 8-3 lists the types of wetlands to be monitored and discusses access requirements and restrictions.

**Table 8-3. Access to various types of reclaimed wetlands.**

| | | | Access to perimeter and interior | | |
|---|---|---|---|---|---|
| **Wetland type** | **Description of wetland** | **Typical access to outlet** | **Marsh** | **Shallow-water wetland** | **Fen** |
| **Research wetland** | Intensively monitored wetland, often within an instrumented watershed. Designed to promote learning for future adaptive management | Class 2: All-weather light vehicle road access to outlet | Access is specially constructed according to research needs | | |
| **Designed wetland** | Part of routine reclamation but receives full design | Class 3: Three-season light vehicle road access to outlet (good when dry) | Common, may allow foot access | Common, shoreline and boat access only | Typically tens to hundreds of hectares in size, limited access |
| **Semi-designed wetland** | Minor topographic and reclamation features added during landform design and construction | Class 4: Footpath or quad access only. | Common, may allow foot access | Not recommended | Common, may allow foot access |
| **Opportunistic wetland** | Forms without design or intervention | Class 5: Foot access only. Footpath may be constructed. | Common, small, may allow foot access | Not recommended | Common, small, may allow foot access |

**Note**: Chapters 6 and 7 provide details on access design. "Research wetlands" are a specific case of designed wetlands in which the main focus is on learning and demonstration. They represent an end member in the amount of monitoring and reporting carried out.

### 8.1.9 Documentation, reporting, and the action log

Documentation is integral to design, construction and certification. Documentation starts at the beginning, when the objectives are chosen before wetland design begins. It carries through the design process and details the successes and challenges during the construction of the site. Documentation includes locations of where construction varied from the design and why. The type of report required and the amount of information gathered will depend largely on the needs of the stakeholder and the requirements of the project. Ross (2011) provides examples of the various forms of documentation and reporting processes for most wetland projects. Documentation can:

Inform colleagues and other stakeholders on project development and modifications;

Identify recommendations and describe solutions for change when modifications or management actions are required;

Help identify and solve problems;

Present the findings of specific investigations and monitoring results;

Record ongoing progress; and

Identify all management activities and the results from those activities.

GIS databases are used widely for tracking reclamation data and are employed in the oil sands as part of regulatory reporting (Bampfylde et al., 2010). There is an opportunity to use this system for reclaimed wetland data management. Clear identification of every wetland (including a unique wetland number) is indicated in the system.

Another common tool is a reclamation maintenance action log, both to guide maintenance activities and as a historical record of events (Table 8-4).

**Table 8-4. Example of a wetland maintenance action log.**

| Action log # | Date | Wetland number and name | Concern noted | Action required, date required, and priority | Date completed |
|---|---|---|---|---|---|
| 13-001 | June 14, 2013 | #0134 – North Pond | Debris clogging outlet | Clean outlet with small excavator by month end. High. | June 27, 2013 |
| 13-002 | June 14, 2013 | #0136 – Rose Marsh | Sparse wetland vegetation at south end | Replanting in spring 2014. Medium. | Scheduled |
| 13-003 | Sept 15, 2013 | #032 – Pond 17 | Gully at crook in access road | Repair gully, before freeze up. Medium. | Sept. 29, 2013 |

## 8.2 Wetland operation and management

More than for terrestrial reclamation, wetlands require operation during the establishment phase, at least for designed wetlands. (Semi-designed and opportunistic wetlands are assumed, by definition and for the most part, to take care of themselves). Operations include three general activities:

Field – carrying out field activities

Technical – making technical decisions

Management – guiding activities

The main focus of day-to-day operation is controlling water and wildlife at the wetland and providing management and supervision for monitoring and maintenance activities. The OMM identifies one person as responsible for the wetland performance and directs others to help carry out various tasks. Table 8-5 provides an overview of these activities. Table 8-6 provides an example.

**Table 8-5. Wetland operation and management.**

| Category | Element | Typical activity | Comment |
|---|---|---|---|
| **Physical** | Inflows and outflows | Adjust the flow rates of water entering or exiting the wetland | Most wetlands need to simply accept the water from the reclaimed watershed |
| | Water elevation | Adjust outlet elevation to control water level<br>Drain and/or refill if needed | Achievable for pumped outlets and for those with adjustable weirs |
| **Chemical** | Water quality | Adjust pumped inflow to regulate water quality | May be other opportunities to control water quality in future (addition of reagents, water treatment) |
| **Biological** | Vegetation | Weed control<br>Planting infill vegetation | |
| | Wildlife enhancement | Installation or maintenance of wildlife enhancement features | |
| | Wildlife control | Controlling or trapping | Birds, muskrats, beavers |
| | Wildlife reporting | Noting presence or absence of certain species | |
| **Infrastructure** | Pump maintenance | | |
| | Outlet weir | Raising or lowering outlet elevation to control wetland water levels | |
| | Access | Keeping access open, maintaining gates | Snow removal, grading, vegetation control |
| | Instrumentation | Reading and maintaining instrumentation or data | |
| | Summer commissioning, winterization | Draining lines, instrument calibrations, debris/garbage disposal | |
| **Financial/other** | Supervision of monitoring program | Developing monitoring program<br>Managing staff and data | |
| | Supervision of maintenance program | Deciding on interventions and maintenance<br>Carrying out maintenance and documentation | |
| | Supervision of staff and contractors, researchers | Team leadership, safety, education, permits | |
| | Budgets/accounting | Cost control | |
| | Public access/tours/ communication | Interviews/tours, team communication | Especially for research wetlands this is a major activity |
| | Monthly visual inspection | | |

**Table 8-6. Examples of the activities related to early site commissioning of a reclaimed marsh.**

| Element | Winter (Nov. to March) | Spring (April to May) | Summer (June to Aug.) | Fall (Sept. to Oct.) |
|---|---|---|---|---|
| **YEAR 1** | | | | |
| Water levels | Dry until April | Fill to normal water level (NWL) by May 1 | Set at 30 cm below NWL by June 20 | Reset to NWL if conditions allow |
| Vegetation enhancement | Mechanical placement | Distribute wetland seed by June 15 | Assess and enhance with live plantings (July 15-Aug. 15) | Inspect and assess |
| Weed management | | | Summer herbicide/ Mow-bale as required | Fall herbicide |
| Waterbird use | | Breeding bird surveys (April-June) | Brood surveys (June 15-Aug. 15) | Bird surveys (Sept. 1-Oct. 15) |
| Canada goose control | Fence all newly vegetated wetland areas | Inspect | Inspect | |
| **YEAR 2** | | | | |
| Water levels | Water level set at NWL | Assess level to determine performance | Set below NWL if required after vegetation inspection | Reset to NWL if conditions allow |
| Vegetation enhancement | Mechanical placement if required for enhancement | Distribute wetland seed by June 15 if required | Assess and enhance with live plantings (July 15-Aug 15) | Inspect and assess |
| Weed management | Data analysis | | Summer herbicide / Mow-bale as required | Fall herbicide |
| Waterbird use | | Breeding bird surveys (April-June) | Brood surveys (June 15-Aug 15) | Bird surveys (Sept. 1-Oct. 15) |
| Canada goose control | | Inspect | Inspect | Remove fencing if wetland plants are well established |

## 8.3 Wetland maintenance and repairs

Wetland maintenance and repairs are needed to guide the wetland in its early years. The maintenance may be high in the establishment phase but declines over time. Reclaimed wetlands are generally designed and constructed to minimize maintenance.

Table 8-7 provides an overview of examples of maintenance for designed wetlands that might be performed during early life of the wetland and during operation and typical activity after operation. Semi-designed and opportunistic wetlands only receive maintenance if they have significant issues. Table 8-8 provides a longer list of potential problems that may be encountered and maintenance and repair remedies.

**Table 8-7. Wetland maintenance/repairs for designed wetlands.**

| Performance category | Element | Typical activity during operation | Typical activity in preparation for reclamation certification |
|---|---|---|---|
| **Physical** | Inlet | Dredging excessive sediment | |
| | Outlet | Dredging excessive sediment<br>Removal of debris<br>Change to rip rap invert height | Removal and re-reclamation? |
| | Temporary berms | Repairs to temporary berms and their eventual removal and reclamation | Removal and re-reclamation |
| | Gullies/channels | Repairs to areas of excessive erosion | |
| | Culverts | Annual maintenance | Removal? |
| | Main body of wetland | Dredging of excessive sediment | |
| | Perimeter | Repairs to any excessive erosion or salinization | |
| | Powerlines | Annual maintenance | Removal? |
| | Earthworks | Add material where there is excessive settlement | |
| | Ice damage | Repair as needed | |
| | Wetland shoreline reconfiguration | Repair as needed | |
| **Chemical** | Water quality | Drain/fill wetland if needed | |
| **Biological** | Vegetation | Replanting as needed | |
| | Wildlife habitat enhancement features | | Removal? |
| **Infrastructure** | Pumps and pipelines | Annual maintenance | Removal or burial |
| | Structures and buildings | Annual maintenance | Removal |
| | Outlet weir | Annual maintenance | Removal |
| | Access | Major road repairs | Removal? |
| | Instrumentation | | Removal if desired |
| | Fencing | Annual maintenance | Removal |
| | Signage | Annual maintenance | Removal? |
| | Boardwalks / trails | Annual maintenance | Removal? |

**Note:** Present reclamation certification practice is to remove “improvements.” However, it may make sense in some cases to leave them in the landscape. Such items are denoted with a question mark (?).

The level of maintenance and repairs declines with time. There may be a temporary increase in some repairs as the infrastructure is removed (and especially if the outlet is altered) at the end of the declining maintenance phase.

**Figure 8-1. Wetland maintenance in the oil sands.**

**Table 8-8. Potential problems encountered with constructed wetlands and associated adaptive management strategies (adapted from Alberta Environment, 2008).**

| Problem | Indicators | Adaptive management strategies |
|---|---|---|
| Water loss/drying | Exposed soil areas<br>Salts present at soil surface<br>Invasive plant coverage expanding | Assess control structures for performance, settling<br>Assess and reduce outflows (berms, dams, weirs)<br>Conduct as-built survey to evaluate wetland surface elevations<br>Increase upland runoff (convert from forests to grasslands)<br>Convert drier areas from wetland habitat to upland habitat<br>Reduce actual evapotranspiration (windbreaks, shading, shift in vegetation)<br>Install a vegetative plant mix that possesses species which thrive in both drier and wetter conditions<br>Reduce recharge (incorporate fine-grained substrate)<br>Change water management schedules to take advantage of when water is available and when it is not |
| Inadequate flood control | Collapse of existing infrastructure and settlement of outlet structure and weir/flume<br>Water level higher/lower than expected<br>Aquatic vegetation coverage diminishing<br>Upstream or downstream flooding in normal climate years | Adjust operating levels of the wetland<br>Increase wetland size, either by widening or deepening certain sections<br>Add fringes of other wetland types (swamps, marshes)<br>Add additional storage either downstream or upstream; upstream is more cost-effective<br>If a consequence of beaver engineering, then re-assess and remove as required through trapping or removal of preferred vegetation |

| Problem | Indicators | Adaptive management strategies |
|---|---|---|
| High rate of infilling with sediments | Increased turbidity<br>Decrease in vegetative and biological diversity<br>Increase in invasive plant species<br>Blocking of pipes and outfalls | Dredge and reclaim<br>Stabilize upland soils with fast-growing vegetation using appropriate species<br>Add sediment traps upland/upstream<br>Use vegetative buffers throughout watershed<br>Slow flows to help sediments settle out<br>Let it revert to a terrestrial state and reconsider uses |
| Settlement of wetland bottom | Water depths deeper than designed<br>Expansion of open water areas<br>Thinning in coverage of deeper emergent plant species over time | Add to the sediment cap (infill back to original water depth)<br>Allow to stabilize and adapt target functions of wetland/lake<br>Include variable control structures in the initial design to allow adaptation to new situations<br>Manage water levels at lower elevations than planned |
| Shoreline erosion | Establishment of rills and gullies<br>Excess surface sediments around wetland edges<br>Decrease in vegetation around outer wetland margins<br>Increase in invasive plant species | Use soft berms and piping to redirect upland flows during wetland establishment periods<br>Plant upland area at the same time wetland is planted<br>Accelerate vegetation establishment by planting live facines, cuttings<br>Shelter from prevailing winds (breakwaters, upland vegetation belts)<br>Install riprap or coarse aggregate in locations of greatest concern |
| Elevated salinity | Evidence of salt on soil surface<br>Change in species composition from freshwater plant species to saline species<br>Decrease in plant diversity over time<br>Poor plant establishment from the start in all locations<br>Establishment of saline ring around outer wetland edge | Increase flushing/dilution<br>Control/increase surface input sources<br>Increase/change cap on bottom substrates<br>Establish saline-tolerant communities |
| Toxicity | | Increase microbial community<br>Increase HRT (size, depth)<br>Change organic content, nutrients (fertilizers, peat) |
| Lack of vegetation | In early years | Manipulate water levels to encourage new plant growth in early years<br>Maintain water levels at slightly below normal in first few years<br>Plant additional propagules, rhizomes, seed plugs/bank to suit wetland location and situation<br>Assess soil/water quality and adapt as required<br>If a consequence of herbivory (muskrat or Canada geese grazing), then trap and remove muskrats and fence off geese |

| Problem | Indicators | Adaptive management strategies |
|---|---|---|
| | In later years | Conduct summer drawdown<br>Decrease time between drawdowns<br>Fertilize<br>If a consequence of herbivory (muskrats), trap and remove muskrats |
| Low plant diversity | Monotypic stands of vegetation present | Control invasive species<br>Change water quality or adapt vegetation plantings to suit<br>Plant species that have low rates of natural dispersal<br>Manipulate water levels to encourage improved plant growth and wetland coverage |
| Low benthic invertebrate diversity | Water clarity becomes poorer<br>Use by waterbirds decreases over time<br>Sampling efforts at various times of the growing season results in poor captures | Increase broad-leaved macrophyte cover (secondary substrate, other than milfoils)<br>Increase habitat complexity by physically creating more wetland edge<br>Inoculate or stock with poor dispersing species<br>Eliminate or reduce predatory fish populations<br>Manipulate water levels to encourage improved plant growth and wetland coverage |
| Low habitat use | | Eliminate barriers to colonization<br>Transplant vegetation and invertebrates<br>Increase connectivity with other wetlands<br>Increase habitat complexity (islands, depths, vegetation)<br>Introduce artificial nesting/spawning habitat |

As noted in Section 8.1.7, the documentation of maintenance activities is a component of the application for reclamation certification.

## 8.4 Wetland monitoring

Wetland monitoring is carried out in accordance with the OMM manual. This section describes the design of the monitoring program, how it is executed, and how it evolves.

### 8.4.1 Context

The OMM manual is based on the design of the wetland, potential failure modes and the needs of wetland operation, management and maintenance. The manual supports the application for reclamation certification. Monitoring can be linked to operational, regulatory or research related goals and objectives. Operational monitoring is often dictated by the objectives. Regulatory requirements are set down by regulatory bodies or by law. Research monitoring is designed to detect change at a significant level.

Although measuring every physical, biological and chemical variable can provide an excellent assessment of reclamation success, few projects have the financial and human resources to monitor everything. Furthermore, estimates of many attributes often require detailed long-term intensive studies, but most monitoring programs do not allow for those sorts of time frames.

Therefore, it is important to choose performance measures and monitoring methods that answer specific project questions. Standardized monitoring programs from other locations or regions may not apply. Few standardized programs are aligned perfectly to measure how well a site meets its own objectives and goals.

It is useful, as shown in Table 8-9, to design the general monitoring approach for the type of wetland involved and the goals of the project. Reclaimed wetland types are as follows:

**Research wetland** – highly monitored, often on a daily or weekly basis, declining to monthly with time
**Designed wetland** – highly monitored, weekly then monthly
**Semi-designed wetland** – low level of monitoring, typically on an annual basis
**Opportunistic wetland** – low level of monitoring, also typically on an annual basis.

A scanning program is formally initiated to identify new opportunistic wetlands on an annual basis through use of remote sensing, and reports back from geotechnical and upland reclamation monitoring in the field. Once identified, these opportunistic wetlands are catalogued (with a name and number assigned) and added to the formal monitoring program.

Wetland monitoring does not occur in isolation, but is just one of numerous operational and reclamation monitoring programs, such as:

Annual photogrammetry and LiDAR surveys
Geotechnical dam safety inspections and audits
Site-wide and regional climate monitoring
Site-wide and regional groundwater monitoring
Site-wide surface and regional water monitoring
Soil placement audits
Various vegetation surveys, especially related to upland reforestation
Site-wide and regional wildlife sightings
Annual budgeting and project management
Those associated with various short- and long-term reclamation research projects

### 8.4.2 Identifying what to monitor and when to manage

The ultimate goal of a wetland reclaimation project is a self-supporting ecosystem that is resilient to perturbation with minimal assistance (Urbanska et al., 1997). The question then becomes, “How do we know when we have reached that goal?” (Ruiz-Jaen and Aide, 2005). Objectives and goals dictate what, when and how often to monitor. Performance measures inform reclamation practitioners of the degree of performance for the indicator, measured against an established threshold (Poscente and Charette, 2012). They investigate the physical, chemical, biological and functional attributes of a wetland site to assess how well the system is performing. They often begin as soon as the wetland system starts functioning and are continued through to a pre-determined end. Depending on the goals of the project and the measures that are identified as important, this may extend from five to 15 years (Ross, 2011).

The aim should be to track performance measures against the established thresholds or goals (Figure 8.2). Without this process, success cannot be determined or documented and adaptive management interventions cannot be planned. Monitoring activities and management interventions need to be clearly linked to the project's general and specific objectives and goals (i.e., hydrological, biological, chemical or legal), and they need to be assigned the appropriate resources for monitoring (i.e., personnel, equipment, time, and finances) (van der Valk, 2009).

**Figure 8-2. Typical stages in the design, implementation and assessment of wetland creation projects. Adapted from Poscente and Charette (2012) and van der Valk (2009).**

**Considerations for monitoring performance measures:**

1. They are designed to inform reclamation practitioners of the degree of performance for the indicator, measured against an established threshold.
2. They investigate the physical, chemical, biological and functional attributes of a wetland site in order to assess how well the system is performing.
3. They often begin as soon as the wetland system starts functioning and are continued through to a pre-determined end.

### 8.4.3 Criteria for designing monitoring programs

**All monitoring programs are designed to be:**

**Purposive** – the process informs decision-making and results in appropriate levels of intervention.

**Rigorous** – apply “best practicable” science, employing methodologies and techniques appropriate to address the opportunities and challenges being investigated. Incorporate accepted and defensible sampling methodologies that are statistically robust, with a clear understanding of how the physical, chemical and biological components relate to one another.

**Practical** – the process results in information that helps solve problems and is acceptable to, and can be implemented by, all those involved.

**Relevant** – provide sufficient, reliable and usable information for development planning and decision-making with respect to protection and creation.

**Cost-effective and efficient** – the process achieves objectives in a cost-effective and efficient manner, both in the short- and long-terms.

**Adaptive** – the recommended processes take account of the realities, issues and circumstances of the situation that exists (i.e., hydrological and anthropogenic influences).

**Participative** – the process provides appropriate opportunities to inform and involve all interested and affected parties, with their inputs and concerns addressed both in the documentation and in decision-making.

**Multidisciplinary** – the process ensures that the appropriate techniques and experts in the relevant biophysical and socio-economic disciplines are employed at the appropriate times.

**Credible** – the process is carried out with professionalism, rigor, fairness, objectivity, impartiality and balance, and is of a quality to withstand scientific review and verification both pre- and post- wetland development.

**Transparent** – the process has clear, easily understood requirements; identifies the factors to be taken into account; and acknowledges the limitations and difficulties that could occur.

**Systematic** – the process results in full consideration of all relevant information on the constructed wetland and of proposed alternatives.

### 8.4.4 Data recording, data management, and annual reporting

Wetland monitoring programs are designed to be carried out efficiently and practically, recognizing that monitoring generates short-term operational and maintenance activities, as well as long-term trends in support of maintenance. With the number of wetlands already constructed, and so many more to come, monitoring programs should be useful, efficient, and practical while not becoming resource-intensive. As such, checklists, standard procedures, and automation are methods to make monitoring efficient and practical.

### 8.4.5 Annual inspection of all wetlands

All wetlands are inspected annually until reclamation certification is granted. The following activities are completed and included in an annual report:

- LiDAR or similar survey of watershed for topography and settlement (remote sensing)
- Photogrammetry (typically satellite imagery) (remote sensing)
- Delineation of wetland boundary/standing water and water elevation (remote sensing)
- Annual fall water quality sample for anions, cations, pH, conductivity, total dissolved solids (TDS), naphthenic acids at outlet (field water sampling)
- Wetland inspection (inlet, outlet, deposition, erosion) (field visual survey)
- Infrastructure inspection (pipelines, powerlines, pumps, fences, roads and trails, piers, monitoring equipment) (field visual survey)
- Vegetation and wildlife inspection (aquatic vegetation, riparian vegetation, weeds, habitat enhancement) (field visual survey)

The level of effort will depend on the type of wetland, its goals and objectives, size, age and performance. Ideally these activities would be carried out concurrently, but in practice they are likely to be staggered through the open-water season. For semi-designed and opportunistic wetlands, a small team (of two or so) should perform all the fieldwork and surveys for several wetlands per day. A checklist on a field tablet or automation is required for efficiency.

### 8.4.6 Typical wetland monitoring activities and schedule

Table 8-9 offers an example of monitoring activities and a schedule organized by specialty. Actual activities and schedules will be provided in the OMM manual for the wetland, such as:

- Routine construction and reclamation as-built surveys form the baseline for monitoring. They are completed for topography, bathymetry, initial filling, initial soil placement (thickness and quality), and initial vegetation establishment prior to start of monitoring.
- Site-wide climate monitoring is ongoing. Upland and watershed monitoring is a parallel program to wetland monitoring but is less intensive. (Additional rain gauges and climate stations are generally only useful for research wetlands).
- Semi-designed wetlands and opportunistic wetlands are initially revegetated to upland ecosites and largely evolve on their own. Management intervention is not envisioned unless the wetland is developing in an unacceptable manner (especially if it is on an undesired ecological trajectory). There may be an operational desire to include wetland vegetation to hasten the transition to an aquatic ecosystem; however, access to these locations may be restricted due to safety challenges or geotechnical concerns.
- Landscape performance monitoring at the watershed and landform level run in parallel, as does geotechnical monitoring for dam safety and dump stability.
- Dates serve a general guide only. Each wetland may require more or less monitoring.
- Surveys involve specific protocols. Inspections are brief site visits — a snapshot in time. They use a checklist/form and are conducted by a trained reclamation generalist.

**Table 8-9. Example wetland monitoring activities and schedule.**

| Specialty | Measurement | Research wetland | Designed wetland | Semi-designed wetland | Opportunistic wetland |
|---|---|---|---|---|---|
| Geotechnical, surface water, and topography | Settlement, bathymetry, wetland extents | Annual satellite photo | | | |
| | | Annual LiDAR/topographic survey | | | |
| | | Annual bathymetry | | N/A | |
| | Geotechnical stability of berms | Annual visual inspection | | | |
| | Outlet elevation | Annual survey | | N/A | |
| | Soft tailings consolidation | Monthly survey of monuments Year 1, quarterly thereafter | Monthly survey of monuments Year 1, annually thereafter | N/A | |
| | | Continuous consolidation pore-water pressure measurement for soft tailings using pressure transducers and data-loggers | | N/A | |
| | Erosion and deposition | Annual visual inspection | | | |
| | Water level (elevation) | Continuous in Year 1, 2, 3, less with time | | Annual visual staff gauge reading | |
| | Inlet and outlet water flux | Continuous in Year 1, 2, 3, less with time. | | Annual visual inspection | |
| | Inlet and outlet water quality | Continuous EC and weekly sampling Year 1, 2, 3, less with time. | | Annual sample | |
| | Water quality in isolated ponds | Annual pH/conductivity reading with GPS coordinates | | | |
| | Pumped inflow and outflow | Continuous | Daily totals | N/A | |
| Groundwater | Groundwater levels | Monthly or quarterly standpipe levels | | N/A | |
| | Groundwater quality | Annual water quality sample | | Annual water quality sample in years 1, 5, 9 | |
| Soils | Peat thickness | Annual thickness survey | | Peat thickness in several locations in years 1, 5, 9 | |
| | Soil salinity | Broad survey years 1, 5, 9<br>Annual visual inspection | | Annual visual inspection | |
| Vegetation | Vegetation establishment | Twice-monthly inspection | | N/A | |
| | Plant productivity, coverage, composition | Survey in Year 1, 2, 3, 5, 9<br>Annual satellite mapping | | Annual visual inspection<br>Annual satellite mapping | |
| | Invasive plants: wetland and surrounding uplands | Multiple times in years 1 through 4, annually from Year 5 on | | | |
| | Traditional use species | Survey in Year 1, 5, 9 | | Annual visual inspection | |
| Wildlife/ benthic invertebrates | Wildlife habitat | Survey in Year 1, 5, 9 | | Survey in Year 9 | |
| | Wildlife use | As noted in field survey in Year 9 | | | |
| | Benthic invertebrate species/abundance | Survey in Year 1, 2, 3, 5, 9 | Survey in Year 1, 5, 9 | Survey in Year 9 | |

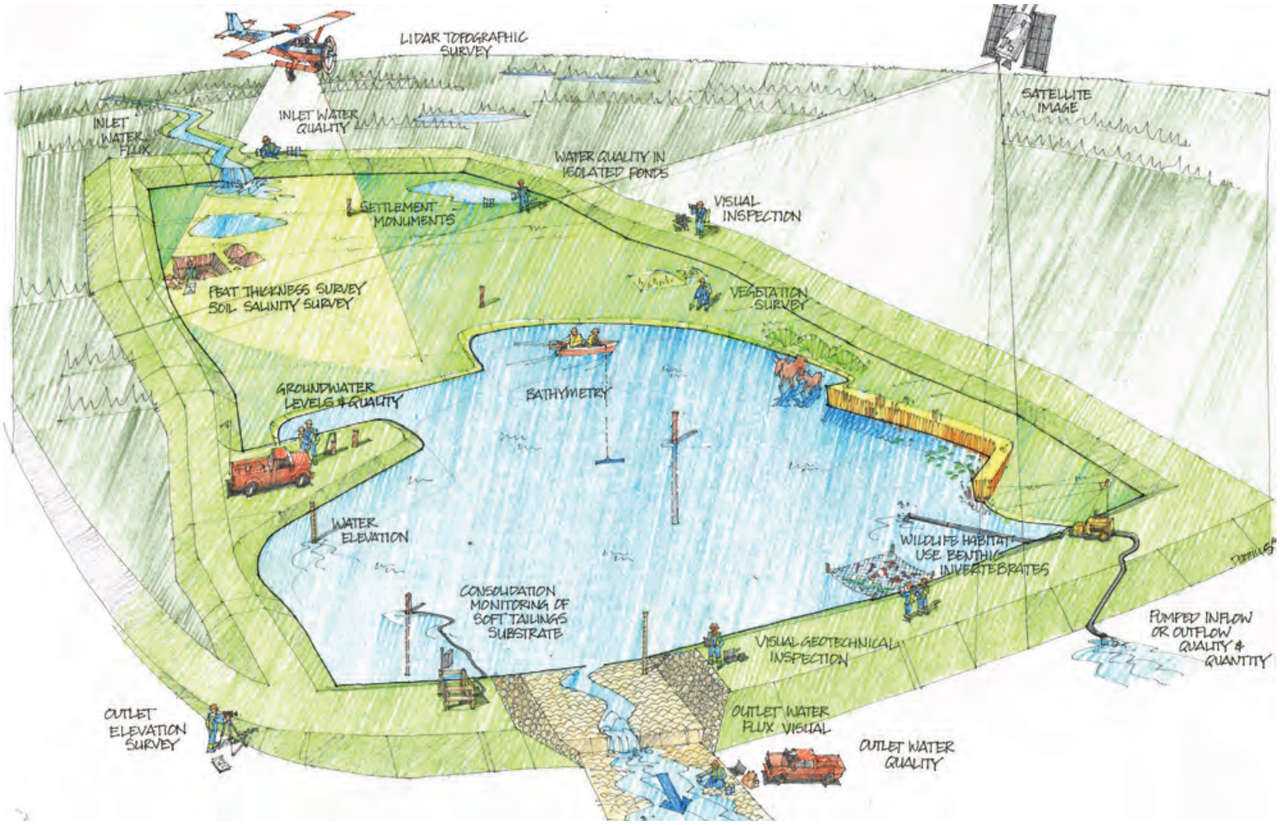

**Figure 8-3. Example of monitoring scheme for a designed wetland.**

### 8.4.7 Sampling design

Sampling designs can vary from simple to complex, depending on the number and type of attributes to be measured and the monitoring programs selected. Specific elements such as the size and shape of the site, the presence of environmental gradients, and data distribution patterns are factors that influence the sampling design. Elements may include the establishment of a baseline and transects, the method of data collection, and the number and type of sample units to be monitored or collected. Independence and interspersion of sample units are also important considerations (Ross, 2011).

### 8.4.8 Statistical considerations

The selected field methods should provide high-quality data that are scientifically defensible (Kentula et al., 1993), particularly for monitoring programs that are research-based. Variation in sampling, collection and processing methods must be kept low, otherwise differences may not be detected. Kentula et al. (1993) highlight five basic quality assurance components: precision, accuracy, completeness, representativeness, and comparability. Coulloudon et al. (1999) provide a checklist of statistical alternatives to consider for collecting field data.

### 8.4.9 Timing

The timing, frequency, and types of samples collected will vary depending on the goals and objectives and the time since construction and reclamation.

Sampling is timed to capture important phenomena (Brooks and Hughes, 1988; White et al., 1991; Leibowitz et al., 1991; Murkin et al., 2000). Wildlife is studied at those times of the year when the target species is most likely to occupy the area or region of interest (Kentula et al., 1993), while vegetation is often assessed when growth is at its peak (i.e., late July/early August for above-ground growth and mid-September to early October for below-ground growth). Hydrological sampling schedules will be determined by the normal patterns of flows and inputs in the area. Many reclaimed wetlands will be flushed during spring freshet and be nearly stagnant in late September.

A wetland will require more intensive and frequent monitoring early in its development. Newly reclaimed systems are most susceptible to quick failures because wetland plant communities cannot withstand even mild disturbances, even those that are short-lived (i.e., one month or more). Flooding regimes that are slightly too shallow or too deep can quickly modify a developing plant community. Likewise, wildlife communities can quickly change when vegetation coverage changes or certain species are eliminated. In the early stages of a wetland's development, individual wetland plants have yet to produce seed heads as most of their energy is put into above-ground plant growth. Therefore, the vegetative seed bank in young wetland soils is often insignificant compared with mature wetland soils.

In mature wetlands, it can take two or three years to observe major shifts in plant and animal communities following flooding. In comparison, it can take one month or less for aquatic vegetation to completely disappear after a disturbance event in a newly developing wetland, depending on the intensity of the disturbance. Therefore, wetland monitoring is usually scheduled more frequently in the first few years of development. If the system is performing as intended after Year 3, monitoring activities can be slowly reduced (a declining management phase) and only the most useful variables monitored (i.e., wildlife, vegetation, annual/seasonal hydrology, infrastructure integrity and function) (Ross, 2011). If the wetland appears to be on a successful trajectory, management inputs are minimized or eliminated and the wetland goes into the certification qualification phase, nominally lasting from Year 6 to Year 9. Near the end of this qualification period (nominally during Year 9), an application for reclamation certification is prepared (see Section 8.6).

Sites will often be monitored beyond the designated period to track the development of appropriate wetland characteristics and to inform future wetland reclamation projects that are similar in nature (broad adaptive management; see Section 8.1.3).

**Considerations for when to monitor:**

1. The timing, frequency, and types of samples collected will vary depending on the goals and objectives and the time since construction and reclamation.
2. Variables of interest are studied at those times of the year when the target of interest is most likely to occupy the area or region.
3. A wetland will require more intensive and frequent monitoring early in its development.

### 8.4.10 Additional monitoring guidance

This section provides additional guidance on monitoring and is organized by performance category.

#### 8.4.10.1 General considerations

**Winter conditions** complicate monitoring. Almost all measurements are made during the open-water season (typically April through October). Little wetland monitoring occurs in winter when the wetland is covered by snow and ice and access is more difficult. All monitoring instrumentation and infrastructure will be designed to survive the effects of winter and spring melt or will be able to be winterized or removed and reinstalled seasonally.

**Automation** of certain components of monitoring is often favoured, sometimes at the expense of more frequent visual observations. The cost of personnel and maintaining access is typically higher in the oil sands than elsewhere. Automated data may be data-logged on site and retrieved and checked periodically and transmitted by cell phone or radio directly to the monitoring office. Items commonly automated include water level indicators, flow meters, and water electrical conductivity sensors. Remote cameras for wildlife monitoring may be employed. Similarly, remote sensing is also a valuable tool and deserving of additional R&D.

**Protocols** for sampling, sample handling and transport, testing, inspections, surveys, and instrumentation are formally adopted and adapted for each monitoring activity. Similarly, procedures for data collection, recording, data entry and database management, and quality assurance/quality control are all employed in a successful monitoring program. Training and supervision is critical. A common regional protocols would foster more efficient training, data sharing, and regulatory review.

**Monitoring locations** are clearly marked in the field to allow comparison of the data over the years. If the posts are clearly signed and logically numbered, training new staff is easier and there are fewer opportunities for error. Small gravel pads or piers can be used to safely sample and observe from the periphery of wetlands. A photo record from these locations (one photo in each of the cardinal directions) is a powerful monitoring and communication tool.

### 8.4.10.2 Physical

**Settlement** is a key component of reclaimed wetland performance as it affects water depth and wetland size, and can affect the water balance. In some cases the outlets will settle appreciably, but in most cases the outlets will settle slowly (if at all) and much less than the wetland, causing the water depth in the wetland to increase.

In soft tailings areas, broad vertical settlements of many metres over many decades may be expected due to consolidation. Settlements are monitored using annual LiDAR surveys for terrestrial areas (typically accurate to about +/– 10 cm vertical), staff gauges (for water depth), bathymetric surveys (from boats for marshes and shallow-water wetlands), and from annual satellite imagery (for measuring changes in wetland extents due to settlement or changes in hydrology).

Settlement monitoring requires a suitable dataset to be able to identify trends and be able to disregard suspect readings.

**Consolidation of soft tailings** (dissipation of excess pore-water pressure of the underlying tailings) can be further monitored through data-logged pore-water pressure transducers combined with settlement monuments (surveyed manually from a stable benchmark for finer estimates of settlement rates). A demanding and complicating factor with pore-water pressure transducers is that the precise tip elevation needs to be monitored as the tailings settle.

> If consolidation is deemed too slow, it may be practical (but expensive and unproven) to install vertical drains to speed the rate of consolidation (although the total/ultimate settlement will be unchanged). CTMC (2012) provides a list of other alternatives.

For overburden fills, settlement of unsaturated fills of 0.5 to 3 m (or in some cases more) can be expected in the form of broad areas, 10- to 30-metre-wide pans, and 1- to 5-metre-diameter depressions and sinkholes. In many cases, settlement is due to first time wetting of fills — wetting causing settlement, ponding of water, enhanced recharge, and further settlement.

> If there is excessive settlement, it may be possible to permanently lower the outlet invert elevation or bring in additional fill or reclamation material to raise the elevation of areas that have settled.

**Settlement of upland areas** of the watershed affects the upland vegetation, causes opportunistic wetlands to form, and changes the watershed hydrology reporting to the wetlands downstream.

> If there is excessive upland settlement (causing undesirable changes in watershed hydrology or water chemistry) it may be possible to bring in additional fill or reclamation material to convert wetlands to uplands.
>
> Unless planned in advanced, bringing in fill to reclaimed areas is typically a last resort. Access is limited, sources of fill are usually located at some distance, and before fill placement, the vegetation (often tall trees) needs to be cleared, and reclamation materials

> removed and stockpiled. The area (and the access) then needs to be re-reclaimed and revegetated. Addition of fill will trigger additional settlement. Operators are typically very hesitant to go down this path unless absolutely necessary.

**Erosion** monitoring is best carried out visually in combination with satellite imagery. Shoreline erosion, erosion of containment berms, and erosion of the wetland substrates may all be of concern. Erosion before establishment of thick vegetative cover (both in the upland and shallow wetland areas) is common.

> If there is excessive erosion, there are numerous solutions, from revegetation, to regrading and re-reclaiming, to placing more reclamation material, to various temporary erosion control materials, to armouring with gravel or cobbles. Understanding the cause of the erosion is critical to designing remedial measures.

**Deposition** is inextricably linked to erosion. Deposition at the wetland inlet can be expected and is ideally accounted for in the wetland design. Visual monitoring, LiDAR, satellite imagery, and bathymetry can be used to monitor deposition.

> If there is excessive deposition, capping it with reclamation material and/or revegetating deposits may be indicated. In extreme cases, removal with an excavator or dredge may be required.

**Physical hydrology** monitoring includes measuring water elevations with time and monitoring inflows and outflows.

Water level monitoring using a staff gauge and/or a data-logged pore-water pressure transducer is common. The elevation of the staff gauge and outlet invert is surveyed annually (the ground may settle or instruments may heave with frost).

> If water levels need to be altered, the outlet control structure (See Section 7.6.5) can be raised or lowered within a certain range. Additionally, water can be pumped out using a fixed or mobile water pump.

Outlet water flows are monitored continuously using outlet weirs with pressure transducers or discontinuously using periodic staff gauge readings. For pumped outlets, flow meters are employed.

> If needed, flow rates can be temporarily accelerated, slowed, or halted by controlling the outlet.

Groundwater monitoring involves monitoring water levels in standpipe piezometers, sampling water from those standpipes, and using pore-water pressure transducers. Pressure transducers left out over winter must be deep enough in the well so they do not freeze (e.g., >1 m). Groundwater seeps may also be sampled. Instrumented watersheds may have dozens or hundreds of instruments. Most wetlands will only have one well nest.

#### 8.4.10.3 Chemical

Surface-water quality testing is most commonly done at the wetland outlet. Continuous-reading electric conductivity meters are common for designed wetlands. Readings are backed up by occasional bottle samples. In rare cases, automated samplers are used, especially for the freshet.

Additional surface-water quality sampling locations may include fixed or random sampling sites. Groundwater is sampled from standpipe piezometers after purging.

Soils, in some cases, are monitored for changes in salinity, especially for reclamation soils placed around the periphery of the wetland, in areas of seepage discharge or wetting and drying.

In the lab, as a minimum, soil and water quality samples are tested for salinity (anions and cations), pH, and electrical conductivity. Additional analyses may include temperature, water depths, turbidity, dissolved oxygen, nutrients, chlorophyll *a*, coliforms, dissolved organic carbon, color, TDS, alkalinity, and both major and minor metals of interest. Toxicity testing may also be carried out.

> If wetland water quality does not meet goals, there are few known remedies. For short-term conditions, the water can be pumped out or displaced with water of better quality. In some cases, the water can be treated in place. For longer-term conditions, vegetation communities more aligned with the water quality can be planted, or changes to the watershed or wetland configuration may be needed. Water quality will tend to improve as the watersheds mature, but acceptable water quality may be decades away and remedial measures may be desired. Ecological risk assessment may be employed if water quality guidelines are not met.

#### 8.4.10.4 Biological

Monitoring of standing emergent vegetation or submersed vegetation is usually performed on an annual basis, preferably in late July or August when above-ground plant growth is at its peak and plants are easily identified, and/or in the fall when below-ground nutrients are at their highest in the roots and rhizomes of the plants. Wetland vegetation is both a tremendous integrator and an indicator of wetland performance. For reclaimed wetlands, it is the single most important indicator of wetland health. Monitoring is carried out both on a schedule and as inspections identify unexpected occurrences. Vegetation is usually monitored more often in the first two years of site development; however, sites may be inspected on a weekly or bi-weekly basis in Years 1 and 2 to ensure both the hydrology of the site and the vegetative communities progress as planned. Waiting to monitor the vegetation in mid-summer may miss important site indicators for poor site performance early on. Table 8-10 provides a list of common vegetation survey techniques.

**Table 8-10. Wetland vegetation survey techniques.**

| Metric | Method | Description | Reference |
|---|---|---|---|
| Wetland type and vegetative cover | Aerial/remote sensing | Aerial and remote sensing techniques can help understand shifts in vegetative communities over time and in helping to classify wetlands of interest. Aerial photography interpretation is often used at site-specific locations to look at communities at a much finer scale. Remote sensing is used when trying to understand wetlands or habitat changes at a landscape scale.<br>The Alberta Wetland Inventory (AWI) designed by Halsey et al. (2003), is a classification system structured specifically for Alberta wetlands, with a focus on peat-based wetland ecosystems. The classification scheme contains sublevels that describe the vegetation and landform type, from the wetland complex (meso-level) to the local wetland element (micro-level). The AWI uses aerial photography as the primary remote sensing imagery input, with visual delineation of polygons around different wetland types. Visual cues for aerial photo interpretation are given to distinguish various wetland classes and modifiers, including tone, texture, position in the landscape, elevation, and other features.<br>The Enhanced Wetland Classification (EWC) system is a comprehensive wetland inventory developed for the boreal forest region (Smith et al. 2007). The classification system recognizes up to 19 minor (detailed) wetland types that conform to the five major wetland classes (CWCS, NWWG 1997). The EWC uses medium-resolution satellite imagery as the most cost-effective and accurate way to provide resource managers, researchers, industry and other organizations with detailed information on the spatial distribution of wetland classes. The EWC focuses on wetland types and vegetation cover that are spectrally separable in satellite imagery in order to classify its wetlands. The methodology integrates two algorithms (i.e., a multi-resolution segmentation process and a classification process), giving more flexibility in the classification and allowing additional features beyond the spectral information of the satellite imagery to be used (i.e., additional datasets, proximity, texture, etc.). | Halsey et al., 2003<br>Smith et al., 2007 |
| | Standard releve (Braun-Blanquet) for emergent vegetation | A 100 m$^2$ plot is established in a "representative" location within the emergent plant community. Plants in the plot are inventoried and the cover class (abundance) of each plant taxon are estimated using cover classes. Similar sampling effort can also be made in the floating or submerged zones when they are present and wading is possible.<br>One advantage, or disadvantage, is that this sampling technique is restricted to the dominant vegetation community represented at a site. Therefore, it is not sensitive to spatially heterogeneous or complex communities. This approach is not as good at capturing how plants may position themselves with respect to changes in wetland water levels over time. | US EPA, 2002 |

| Metric | Method | Description | Reference |
|---|---|---|---|
| | Transect sampling “for sampling vegetation in herbaceous, shrub-scrub, or wooded wetlands.” | Numerous variations on the use of transects can be used for sampling vegetation in herbaceous, shrub-scrub, or wooded wetlands. The location of transects can be determined randomly or systematically. The systematic approach allows the observer to assess vegetation community changes over time.<br>Transects may be a single line, or a belted transect can be used in which data are recorded in a zone extending on either side of the line. Often a transect line is used in combination with quadrats at random or regular intervals along the line. | Bonham, 1989<br>US EPA, 2002<br>Ross, 2009 |
| | Quadrat methods | Quadrats of varying sizes have been used to measure cover. The most frequently used methods involve ocular estimates of percentage cover by species. This is usually accomplished by cover classes and the midpoint value of cover class for data analysis. Use of cover classes enables repeatable estimates to be made by different observers over several time periods. However, the data cannot be analyzed by standard statistical methods.<br>Communities or stands are often selected subjectively, but then sampled using randomly located quadrats (i.e., stratified random technique). Consideration should be given to selecting quadrat size, shape and number at a site. Long, rectangular quadrats tend to pick up more species than square or round quadrats. Smaller quadrats are not appropriate for locations where woody species are present. The number of quadrats will often be based on statistical needs. | Bonham, 1989.<br>Barbour et al., 1987<br>US EPA, 2002 |
| | Point-centered quarter method | Involves distances that are measured from a point to the nearest plant in each of four 90° sectors around a randomly or systematically established sampling point. The mean area occupied by the plant is determined by averaging the four distances of a number of observation points. Density is then determined by squaring the reciprocal of the average mean distance per point. This method can sometimes give biased results in clumped distributions, by over-estimating density in some cases by almost 60%. This may be most important in younger forests where smaller trees tend to cluster. | Cottam and Curtis, 1956<br>Bonham, 1989<br>US EPA, 2002 |
| | Bitterlich variable plot method | Bitterlich’s method is based on the relationship between the basal area of a tree and the basal area per acre that the tree represents. The variable plot method is most appropriate for sampling shrub canopy cover, but a modified gauge has been successfully used to measure bunchgrasses. Because counting is involved, it is not a suitable method to sample vegetation where the identification of individuals is difficult. Some inaccuracies can arise from failing to count distant plants obscured by large closer ones. Therefore, the method is not recommended where canopy cover is greater than 35%. | Cooper, 1957<br>Cooper, 1963<br>Fisser, 1961<br>Hyder and Sneva, 1960 |

| Metric | Method | Description | Reference |
|---|---|---|---|
| Frequency and cover | Mapping/ charting<br>area-list method<br>photographic<br>intercept/point intercept<br>grid-quadrat frame<br>cross-Wire sighting<br>line/point transect<br>step point | Frequency and cover are important characteristics of vegetation. Frequency is defined as the number of times a species is present in a given number of quadrats of a particular size or a given number of sample points. It is usually expressed as a percentage and helps describe the distribution of a species in a community. Size and shape of plots affect frequency determinations. For example, less common species may not be recorded at all. Also, if the shape and sample units differ between sites then data cannot be compared between sites.<br>While the concept of cover is simple, it is important to recognize that there is no single definition of the term. It often refers to the vertical projection of the plants or plant parts, humus, or litter on the ground when viewed from above for determining the percentage of ground surface covered by vegetation material. Care must be given when assessing ground coverage in locations where certain wetland species possess very different physical structures at their base. For example, one cattail plant may cover the same area as does 30 to 60 hardstem bulrush plants. | Bonham, 1989 |
| Frequency and composition | Timed meander vegetation survey | This sampling technique consists of walking around a site or assessment area and recording the “rapid species” present for a specified amount of time – with additional time added to the meander according to the complexity of the site and the rate that new species are observed. The approach is plotless, requiring no equipment or predetermined sampling location. Sampling effort is measured in terms of time. The technique allows for sampling complex areas that may also vary in size. Observers must be familiar with vegetation zones and communities in wetland types in order to assess the area properly. While valuable in rapidly assessing the composition of a vegetative community, other techniques may need to be used as well to more closely measure community and species development in the first few years of commissioning. | Minnesota Pollution Control Agency, 2014 |

**If the wetland vegetation** does not meet the goals of the project, a variety of remedial options are available based on the cause of the problem. Wetland water depths and water quality can be altered, weeds or other vegetation can be removed, or wetland plants can be added. Wetland vegetation, once fully established, will not be managed as assemblages will change over time.

**Wildlife habitat and wildlife use monitoring** helps document or predict which species use the wetland and adjacent areas as habitat. Permanent observation stations are often best for observing wildlife, but these may not provide the accuracy for monitoring all the species of interest on a project. Permanent observation locations may be situated in the open for long distance viewing, or behind screens and blinds for close up observations. A sampling procedure is established for observation consistency including the time of year, time of day, and study duration. Any additional wildlife structures installed during the construction phase are monitored for wildlife use to assess their value.

Measurements can be direct observation and/or signs of wildlife presence. A list of species of interest is developed and used to guide observation. Objectives in terms of relative abundance and community composition should be based on reference sites and/or local knowledge, and reflect the type of wetland being reclaimed. This will not necessarily be the same type of habitat as existed at the site before. Also, it will take some time for some organisms to colonize and establish at a reclaimed site. Colonization speed and success may be influenced by factors such as wetland quality (e.g., water quality, diversity and abundance of vegetation, etc.), distance from sources of colonizers (e.g., other wetlands), the nature of the terrestrial matrix in which the wetlands are embedded, and size of the wetland.

**If the wetland wildlife habitat and use vegetation** does not meet goals, there are opportunities to add habitat features, enhance vegetation, or adjust water quality.

#### 8.4.10.5 Infrastructure

Problems with infrastructure are usually readily apparent to the user and needed repairs can be documented on the action log. A checklist for an annual inspection is employed.

#### 8.4.10.6 Finance/other

Costs and action logs for operations and maintenance are tracked for each wetland (or group of wetlands within a block or area that will be certified) as further demonstration of declining levels of effort as the wetland matures and becomes self-sustaining. Periodic reviews of costs and action logs supply useful feedback for designers and managers as part of broad adaptive management. Table 8-11 provides an additional example of monitoring and maintenance activities (Ross, 2011).

**Table 8-11. Monitoring activities related to early site commissioning of a reclaimed marsh.**

| Objective | Performance measure | Year | Monitoring method | Scheduled management activities | |
|---|---|---|---|---|---|
| | | | | Maintenance | Contingency |
| Establish Wetland Hydrology | Soil saturated to the surface over 80% of the wetland during the summer. | 1, 3, 5 and 7 | Test pits and mapping | None | Adjust weir, regrade mitigation site, or create additional mitigation area. |
| | Create desired area of wetland. | 5 and 10 | 1987 Corps Manual | None | Adjust weir, regrade mitigation site, or create additional mitigation area. |
| Establish Native Vegetation | 100% survival of planted woody species after one year and year 3. | 1 and 3 | Percent survival | Replace dead individuals | Replace dead or dying plants. |
| | 4 plant shoots per meter. | 2 | Direct count | Weed | Replant with different species, relocate plants, water, fertilize or mulch. |

| Objective | Performance measure | Year | Monitoring method | Scheduled management activities | |
|---|---|---|---|---|---|
| | | | | Maintenance | Contingency |
| | 25, 50 and 75% cover by native herbaceous species in emergent areas. | 3, 5 and 8 | Percent cover | Weed planting rings | Replant with different species, relocate plants, water, fertilize or mulch. |
| | 25, 50 and 75% cover by upland native species. | 3, 5, and 7 | Percent cover | Weed planted areas | Replant the same or different species. |
| | 3 woody species with 5 percent cover will be identified in the created wetland. | 5, 7 and 10 | Percent cover | Weed planting rings | Plant additional species. |
| | Less than 10% coverage by non-native invasive species – uplands and wetlands. | 1, 3, 5, 7 and 10 | Percent cover | Hand weed or spray invasive plants | Increase planting density of native species. |

## 8.5 Minimum ecological management: planning for the long-term

Minimal ecological management (MEM) calls for taking actions that provide for the long-term sustainability of the hydrological cycles characteristic of the region and appropriate for the intended wetland. When projects are planned, designed and executed well, management interventions can be kept to a minimum.

For restored wetlands, the concept of MEM is to apply only those levels of management needed to restore and maintain the natural hydrological regime that originally sustained the wetland before it was degraded. Many reclaimed wetlands, however, present unique challenges that must be anticipated. Historically, the goals for most constructed wetlands were seldom stated. This was due, in part, to a lack of understanding of wetland functions, along with the difficulty and expense of quantifying wetland functions. It has taken some time for wetland science to catch up to our building of constructed wetlands. Also, project documentation and monitoring before construction and after completion of the wetland was often rare.

It is clear that for MEM to work a project's goals and objectives must be clearly outlined and the objectives measurable. Project goals will vary, but without clearly stated goals and a vision for success, project managers can only guess as to when management is required or success has been achieved. The project should also be designed and constructed with the appropriate hydrological conditions for sustaining and maintaining the desired flora and fauna.

### 8.5.1 Guiding MEM principles for project planning and management

**MEM guiding principles include:**

1. **Goal-setting:** Each wetland must have appropriate and achievable goals for management over both the short and long term.
2. **Management and Sustainability:** Wetlands should be designed and maintained within an ecological regime appropriate to the wetland through infrequent interventions that employ a minimum of artificial processes.
3. **Diversity:** For most freshwater wetlands, optimal conditions exist when a broad assortment of aquatic vegetation and aquatic species are established. Diversity can only be achieved through a clear vision of what is to be designed for the hydrological conditions to be created. Diversity builds robustness into a new wetland site and makes it more resilient against unexpected disturbances.

For MEM to be successfully executed on a wetland project, the following deliberations need to be considered (adapted from Ross (2011) and the Committee on the Restoration of Aquatic Systems (1992)):

Are the challenges regarding wetland reclamation (i.e., biological and logistical challenges, legal compliance, local acceptance) clearly understood and defined?

Is there consensus among all those involved on the project's mission and the definitions of success?

Have the goals and objectives been identified and, more importantly, are they measurable?

Has the reclamation project been planned with adequate scope and expertise?

Have adequate monitoring, surveillance, management, and maintenance plans been developed early on so that monitoring costs and operational details are planned for, and as a result minimized over time due to good initial planning?

Does the management plan have an annual or midcourse correction point in line with adaptive management procedures?

Are performance indicators (measurable biological, physical, and chemical attributes) directly and appropriately linked to the objectives?

Can the results of the monitoring program be used to guide and improve creation techniques on new projects (both locally and regionally)?

Has an appropriate reference system (or systems) been selected from which to extract target values of performance indicators for comparative evaluation?

Will sufficient baseline data be collected to facilitate and document before-and-after treatment comparisons? Information needs to be collected on both the construction site and from any plant donor sites if future comparisons are to be made correctly.

To minimize the risks of failure, have critical project procedures been anticipated, modeled, tested and accounted for (i.e., soils, hydrology, and infrastructure) prior to construction?

To minimize maintenance requirements, has the project been designed (i.e., with appropriate wetland hydrology, maintenance of vegetative growth and diversity, durable and lasting infrastructure) to make the created ecosystem as self-sustaining as possible?

Has thought been given and documented on how long monitoring will have to be performed before the created wetland can be declared successful and/or self-sustaining?

Have risk and uncertainty from all aspects (i.e., human, flora/fauna, financial, hydrological, infrastructure, legal/mitigative) been adequately considered in project planning?

## 8.6 Final steps: Preparation for reclamation certification

### 8.6.1 EPEA framework

According to Section 137(1) of the Alberta Environmental Protection and Enhancement Act (EPEA), "An operator must (a) conserve specified land, (b) reclaim specified land, and (c) obtain a reclamation certificate in respect of the conservation and reclamation." Section 138(1) goes on to say that "An application for a reclamation certificate must be made by the operator to the Director or an inspector in the form and manner and within the time provided for in the regulations." The process for preparing an application is provided by LCRC (1991).

What is often overlooked is that by the time of reclamation certification, it may be impractical to make significant changes to the reclaimed land. What happens when key indicators are missed? Is it too late? This guide assumes that the closure plan is used to set out specific goals and objectives for wetland design and performance. If the wetland can be shown to meet these goals and inspection criteria during the reclamation stage, it ought in most cases to be eligible for a reclamation certification and relinquishment to the Crown. The application for reclamation certification does not require that logical boundaries be selected, but there is benefit of certifying a wetland as part of its watershed or mining landform.

### 8.6.2 Reclamation certification in the oil sands

Syncrude received a reclamation certificate for the 104-ha Gateway Hill project at its Mildred Lake operation in 2008. The area certified was almost exclusively forested uplands and was based on the guidance provided by LCRC (1991).

To date, there have been no applications for reclamation certification in the oil sands that included reclaimed wetlands and there is uncertainty about the criteria for reclamation certification.

### 8.6.3 Other frameworks and considerations to address

Previous editions of this document have offered general guidance for certification (AENV, 2004, AENV, 2008). There are several documents that propose changes to the certification process, with a focus on criteria. Welham and Robinson (2006), Golder Associates (2007), Poscente (2009, 2011), and Poscente and Charette (2012) each provide a review and recommendations for enhancements or change. Creasey (2012) reports on the outcome of a recent workshop on the role of professional judgment.

Table 1-7 provides three broad objectives:

- Reclaimed landscapes are established that support natural ecosystem functions
- Natural ecosystem functions are established on the reclaimed landscape
- Reclaimed landscapes support an equivalent land capacity appropriate to the approved end land use

AENV (2008) provides three questions for wetlands:

- Is the wetland viable/sustainable in the long-term as a wetland ecosystem?
- Does the wetland have structural and functional integrity?
- Does the wetland have the capacity to support the intended functions and uses?

More basically, do the wetland design, construction, and performance meet the intent set out in the approved closure plan?

### 8.6.4 Timing of application

The monitoring program and schedule set out in this chapter suggest that the application for reclamation certification can be prepared after the periods of wetland establishment/active management, declining management, and certification qualification have been met. In principle, this could be done in as little as three years.

Some operators may choose to apply for reclamation certification for individual parcels of land or when the whole lease area is fully reclaimed, perhaps decades into the certification qualification period. The monitored performance may also dictate the timing of the reclamation certification application.

### 8.6.5 Contents of application

The application will contain the following text and drawings:

- The certification boundaries (legal survey)
- The regulatory history (applications, approvals, inspections)
- The goals and objectives agreed to in the closure plan and any subsequent agreements
- The predevelopment environment
- Details regarding design with respect to geotechnical and topography, groundwater, surface water, vegetation, fish and wildlife, and land use
- Details of historic and current wetland and watershed performance
- Analysis of construction and performance against the agreed upon goals
- Listing of reclamation inspections and how any concerns were addressed
- Analysis of lease and regional considerations

Much of the application contents can be prepared prior to applying for certification. Operators may consider preparing the content as early as practical and updating it annually as monitoring data become available and wetland performance is established and becomes sustainable.

## 8.7 Summary

No two wetland reclamation projects will have the same goals or objectives. Each comes with distinctive site characteristics and opportunities. It is difficult to apply one standardized approach to monitor and manage all wetland projects. Planning, design, post-construction monitoring, and adaptive management are interrelated activities that, when done well, help produce successful wetland reclamation projects. Adaptive management and the OMM manual provide an operational approach that is efficient and practical for the many wetlands that will be reconstructed in the oil sands landscape.

Project planning and design goals and objectives will set direction and help steer the course over the lifetime of the project. Monitoring is a crucial part of the reclamation process and begins immediately after a site is constructed. When compared with design objectives, it can provide early warnings that a site may not be performing or responding as intended, and supply the opportunity to perform maintenance and adjust performance. The intensity of the monitoring program will be driven by the project’s goals and by a desire to acquire new information that can be used to inform future reclamation projects. Finally, adaptive management strategies will help define and develop measurements for project accomplishments that are biologically meaningful, affordable, and useful for informing management actions, not only for the project in question but for future wetland reclamation projects as well.

# Appendix A

## Common Vegetation in Swamps

**Lisette Ross**
Native Plant Solutions

**Table A-1. Common tree, shrub, forb/herb and graminoid species in conifer swamps. See Smith et al. (2007), Halsey et al. (2004), Harris et al. (1996) and Locky et al. (2005).**

| | Smith et al. (2007) | Halsey et al. (2004)[1] | Harris et al. (1996)[2] | Locky et al. (2005)[3] |
|---|---|---|---|---|
| **Trees** | *Picea mariana*, *Thuja occidentalis*, *Abies balsamea* | Major species: *Picea mariana, Larix laricina*.<br>Minor species: *Abies balsamea, Betula papyrifera, Picea glauca, Pinus banksiana, Pinus contorta, Populus balsamifera,* and *Populus tremuloides* | *Picea mariana*, *Abies balsamea* | *Picea mariana* |
| **Shrubs** | *Chamaedaphne calyculata* *Betula pumila*, *Betula glandulosa*, *Gaultheria hispidula* *Kalmia polifolia*, *Ledum groenlandicum*, *Lonicera villosa*, *Oxycoccus microcarpus*, *Vaccinium myrtilloides* *Salix* spp. | *Alnus crispa, A. tenuifolia, Cornus canadensis, Cornus stolonifera, Ledum groenlandicum, Linnaea borealis, Rosa acicularis, Rubus idaeus, Viburnum edule, Vaccinium myrtilloides, Ribes* spp. and *Salix* spp. | *Gaultheria hispidula, Ledum groenlandicum, Vaccinium angustifolium, Vaccinium myrtilloides, Vaccinium oxycoccos, Kalmia polifolia, Chamaedaphne calyculata, Alnus incana* | |
| **Forbs/ Herbs/ Non-vascular** | *Caltha palustris*, *Cornus canadensis*, *Equisitem fluviatile*, *Galium* spp. | *Aralia nudicaulis, Lycopodium annotinum, Mertensia paniculata, Mitella nuda, Petasites palmatus, Rubus pubescens, Vicia americana, Equisetum* spp. | *Maianthemum trifolium, Cornus canadensis, Equisetum sylvaticum, Lycopodium annotinum* | Hummock indicators: *Equisetum sylvaticum, Petasites frigidus* var. *palmatus, Cornus canadensis, Linnaea borealis, Rosa acicularis, Moneses uniflora, Geocaulon lividum, Orthillia secunda, Equisetum arvense, Listera* |

| | Smith et al. (2007) | Halsey et al. (2004)[1] | Harris et al. (1996)[2] | Locky et al. (2005)[3] |
|---|---|---|---|---|
| | | | | *cordata, Mertensia paniculata*<br><br>Hollow indicators: *Rhizomnium pseudopunctatum, Rhizomnium gracile, Plagiochila porelloides* |
| **Graminoids** | *Calamagrostis canadensis*, *Carex* spp., *Typha latifolia* | *Calamagrostis canadensis, Carex* spp. | *Carex trisperma, Calamagrostis canadensis* | |

[1] Halsey et al. (2004) do not separate tamarack swamps for other conifer swamps; therefore, the species list below includes species that may be found in both conifer and tamarack swamps.

[2] Harris et al. (1996) species listed are from their ‘poor conifer swamp’ classification (black spruce/ Labrador tea/ *Sphagnum*).

[3] Locky et al. (2005) species listed include significant indicator plants found on hummocks and hollows in black spruce swamps. No additional tree, shrub or graminoid species are listed, as they were not found to be indicator species for black spruce swamps; however, this does not mean these groups are not found in black spruce swamps.

**Table A-2. Common tree, shrub, forb/herb and graminoid species in boreal tamarack swamps. See Smith et al. (2007), Halsey et al. (2004) and Harris et al. (1996).**

| | Smith et al. (2007) | Halsey et al. (2004)[1] | Harris et al. (1996)[2] |
|---|---|---|---|
| **Trees** | *Larix laricina* | Major species:<br>*Picea mariana, Larix laricina*<br><br>Minor species:<br>*Abies balsamea, Betula papyrifera Picea glauca, Pinus banksiana, Pinus contorta, Populus balsamifera, Populus tremuloides* | *Thuja occidentalis, Larix laricina* |
| **Shrubs** | *Andromeda polifolia*, *Betula papyrifera*, *Chamaedaphne calyculata*, *Lonicera villosa*, *Myrica gale*, *Potentilla fruticosa*, *Rhamnus alnifolia*, *Ledum groenlandicum*, *Salix* spp. | *Alnus crispa, A. tenuifolia, Cornus canadensis, Cornus stolonifera, Ledum groenlandicum, Linnaea borealis, Rosa acicularis, Rubus idaeus, Viburnum edule, Vaccinium myrtilloides*, *Ribes* spp., *Salix* spp. | *Rubus pubescens, Acer spicatum, Linnaea borealis, Lonicera canadensis, Ribes triste, Rosa acicularis, Sorbus decora* |

| | Smith et al. (2007) | Halsey et al. (2004)[1] | Harris et al. (1996)[2] |
|---|---|---|---|
| **Forbs/Herbs** | *Caltha palustris* | *Aralia nudicaulis, Lycopodium annotinum, Mertensia paniculata, Mitella nuda, Petasites palmatus, Rubus pubescens, Vicia americana,*<br>*Equisetum* spp. | *Trientalis borealis,*<br>*Aralia nudicaulis,*<br>*Mitella nuda,*<br>*Viola renifolia,*<br>*Clintonia borealis,*<br>*Cornus canadensis,*<br>*Maianthemum canadense,*<br>*Streptopus roseus,*<br>*Aster macrophyllus,*<br>*Athyrium filix-femina,*<br>*Coptis trifolia,*<br>*Gymnocarpium dryopteris* |
| **Graminoids** | *Calamagrostis canadensis*,<br>*Carex* spp.,<br>*Typha latifolia* | *Calamagrostis canadensis,*<br>*Carex* spp. | |

[1] Halsey et al. (2004) do not separate tamarack swamps for other conifer swamps; therefore, the species list below includes species that may be found in both conifer and tamarack swamps.

[2] Harris et al. (1996), species listed are from the rich conifer swamp: cedar (tamarack) classification.

**Table A-3. Common tree, shrub, forb/herb and graminoid species found in boreal shrub swamps according to Smith et al. (2007), Halsey et al. (2004) and Harris et al. (1996).**

| | Smith et al. (2007) | Halsey et al. (2004)[1] | Harris et al. (1996)[2] |
|---|---|---|---|
| **Shrubs** | *Alnus* spp.,<br>*Salix* spp.,<br>*Cornus stolonifera*,<br>*Rubus idaeus* | Salix spp.,<br>*Alnus tenuifolia,*<br>*Betula glandulosa* | *Alnus incana,*<br>*Salix petiolaris,*<br>*Cornus stolonifera,*<br>*Rubus idaeus,*<br>*Rubus pubescens* |
| **Forbs/Herbs** | *Caltha palustris*,<br>*Equisitem fluviatile*,<br>*Galium* spp.,<br>*Potentilla palustris* | *Caltha palustris,*<br>*Galium trifidium, Heracleum lanatum,*<br>*Potentilla palustris* | *Impatiens capensis,*<br>*Lycopus uniflorus,*<br>*Scutellaria galericulata,*<br>*Campanula aparinoides,*<br>*Equisetum sylvaticum* |
| **Graminoids** | *Calamagrostis canadensis,*<br>*Carex* spp., *Typha latifolia* | Carex spp., *Calamagrostis canadensis,*<br>*Typha latifolia* | *Calamagrostis canadensis* |

[1] As Halsey et al.'s (2004) description of a deciduous swamp is characterized by shrubby, rather than hardwood species, their list of common vegetation species found in deciduous swamps has been included with lists of other common species found in thicket swamps.

[2] Harris et al. (1996), species listed include both the speckled alder/bluejoint grass and tall willow thicket swamp classifications.

**Table A-4. Common tree, shrub, forb/herb and graminoid species in boreal hardwood swamps. See Smith et al. (2007) and Harris et al. (1996). Although Halsey et al. (2004) describe a deciduous swamp, their description is characterized by shrubby, rather than hardwood species. Therefore, Halsey et al.'s (2004) list of common vegetation species found in deciduous swamps is included with other thicket swamps in Table A-1.**

| | Smith et al. (2007) | Harris et al. (1996)[1] |
|---|---|---|
| **Trees** | *Populus balsamifera*, *Betula papyrifera* | *Fraxinus nigra, Populus tremuloides* |
| **Shrubs** | *Salix* spp., *Alnus* spp., *Cornus stolonifera*, *Rhamnus alnifolia* | *Rubus pubescens, Acer spicatum, Ribes triste, Corylus cornuta, Cornus stolonifera, Prunus virginiana, Lonicera canadensis, Rubus idaeus, Alnus incana* |
| **Forbs/Herbs** | *Corylus cornuta*, *Equisitem fluviatile*, *Galium* spp., *Rubus* spp., *Ribes* spp., *Salix* spp. *Cornus stolonifera* | *Aralia nudicaulis, Maianthemum canadense, Fragaria virginiana, Mitella nuda, Aster macrophyllus, Athyrium filix-femina, Streptopus roseus, Trientalis borealis, Dryopteris carthusiana, Circaea alpine, Caltha palustris, Gymnocarpium dryopteris, Equisetum sylvaticum* |
| **Graminoids** | *Calamagrostis canadensis*, *Carex* spp., *Typha latifolia* | *Calamagrostis canadensis, Carex gracillima, Carex intumescens, Cinna latifolia* |

[1] Harris et al. (1996), species listed include both the upland transition and riparian hardwood swamp classifications.

**Table A-5. Common tree, shrub, forb/herb and graminoid species found in boreal mixedwood swamps according to Smith et al. (2007).**

| | Smith et al. (2007) |
|---|---|
| **Trees** | *Populus balsamifera*, *Betula papyrifera*, *Picea mariana*, *Larix laricina*, *Thuja occidentalis*, *Abies balsamea* |
| **Shrubs** | *Salix* spp., *Alnus* spp., *Cornus stolonifera*, *Rhamnus alnifolia* |
| **Forbs/Herbs** | *Equisitem fluviatile*, *Galium* spp. |
| **Graminoids** | *Calamagrostis canadensis*, *Carex* spp., *Typha latifolia* |

# Appendix B

# Functional and Structural Attributes of Wetlands

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## B.1 Peatlands

Reclamation of peat-forming ecosystems requires basic understanding of the critical functions of these unique ecosystems. What follows is an overview of the key structural and functional attributes of peatlands that need to be considered during reclamation procedures.

### B.1.1 Peatland size and distribution

Peatlands in the Oil Sands Region are mostly less then one $km^2$ in size and have a perimeter ranging from 0.3 to 0.8 km. In general, they range from circular to elliptic in shape.

Watersheds in the oil sands region of Alberta are extremely variable in peatland cover. From an analysis of 50 watersheds, each centered on a RAMP (Regional Aquatics Monitoring Program) lake in the oil sands region, Bloise (unpublished data) determined that 68% of these watersheds were covered by peatlands, with 49% covered by fens and 19% by bogs. Overall cover in the forested area of the Province is approximately 40%.

### B.1.2 Flora and species richness

Total plant richness (gamma diversity) for Alberta peatlands ranges from 127 species in bogs to 150 species in acidic fens to 212 species in alkaline fens, overall increasing along this gradient (values are means for the peatland classes used by Halsey (2007). Vascular plant diversity also increases along the bog-fen gradient from 48 species in bogs, 84 in acidic fens, to 112 in alkaline fens, but bryophyte diversity remains constant varying from 79 species in bogs, 66 species in acidic fens, and 63 species in alkaline fens. The vascular plant/bryophyte ratio changes markedly across this gradient, from 0.7 in bogs, 1.3 in acidic fens, to 2.1 in alkaline fens. The decreasing importance of vascular plants as acidity increases in remarkable. Species richness of bryophytes at the site level (alpha diversity) is most closely correlated to the number of microhabitats (Vitt et al., 1995). Rich fens are rich owing to a relatively high number of species that have high fidelity to the calcareous conditions of the sites. In comparison, poor fens are relatively poor in differential species. Bogs have few if any of these fen indicators. Sjörs (1983) and Vitt and Chee (1990) provided lists of characteristic species from Sweden and Canada, respectively. Among numerous publications that provide listings of species for northern peatlands, Ruuhijärvi (1960) and Eurola (1962) both provide extensive lists of species for a variety of fen communities in Finland, Halsey (2007) provided lists of species from western Canada and Anderson and Davis (1998) provided a list for bogs in eastern North America.

### B.1.3 Acidification

Bogs and poor fens are naturally acidic with a pH range varying between 3.5 and 5.5. In 1963, Richard Clymo (1963) proposed that peatland acidity is produced by *Sphagnum* cell walls. The hydrogen ions of the carboxylic acid moieties of uronic acid cell wall components are exchanged for base cations found in the pore waters. In 1980, Harry Hemond recognized that this process occurs, but he thought that it was not sufficient to produce the acidity needed for the low pH's found in bogs. Hemond proposed that bog acidity is a result of hydrogen ion release from decomposition, releasing humic acids as DOC (dissolved organic carbon) into the pore waters.

The historical record clearly shows that the general successional pattern for boreal peatlands is from alkaline, basic, rich fens dominated by true mosses to succeed to acidic, poor fens dominated by *Sphagnum* species and subsequently through the development of an acrotelm (see hydrology section) to bogs (Kuhry et al., 1993). Peatland acidification may be regional dependent on a number of processes, including *Sphagnum* cation exchange (Clymo, 1963; Vitt, 2000), decomposition and production of humic acids (Hemond, 1980), or hydrological blocking of alkaline ground waters through peat accumulation (Soudzilovskaia et al., 2010).

### B.1.4 Carbon cycling

The basic concepts of long-term peat (and carbon) accumulation were first developed by Clymo (1984). In the Clymo model a peat core is considered as two-layered — a top, aerobic layer (the acrotelm) and an underlying anaerobic zone — the catotelm (terms from Ingram, 1978). The acrotelm is composed of the surficial ground layer of mosses and associated litter, roots, and decaying moss plants. The acrotelm is subjected to changes in climate, water level fluctuation, and plant productivity. The catotelm receives mass from the acrotelm, and undergoes slow anaerobic decomposition. The Clymo model assumes plant production remains constant and as that decomposition of the annual fractional mass loss of the catotelmic mass also is a constant, thus as the peat increases in thickness the amount of mass lost in total for the column every year also increases and the result, over thousands of years is a concave depth-age profile. Changes in acrotelmic inputs, owing to plant production and/or aerobic decomposition to the catotelm may change the shape of this age-depth curve (Yu et al., 2003). More recent models have enhanced our abilities to better predict carbon accumulation. For example, Frolking et al. (2001) developed a model that tracks annual input cohorts of vascular plants and non-vascular plants as they are buried and proceed through the peat profile. Bauer (2004) elaborated on this model to include additional plant functional types. Other enhanced models include those published by Frolking et al., 2010; Belyea and Malmer, 2004; LaFleur et al., 2003; and Hilbert et al., 2000.

### B.1.5 Methanogenesis

Despite the fact that peatlands are a long-term carbon sink storing approximately one-third of the world's soil carbon, they also are important methane sources to the atmosphere. Northern peatlands contribute about 34-60% of the global wetland $CH_4$ emissions (Bartlett and Harriss, 1993). Methane is formed as the terminal step in a long and complicated degradation process only under anaerobic conditions in the catotelm by methanogenic Archaea (Garcia et al., 2000), and can be subsequently oxidized in the aerobic acrotelm. Methane is formed either by acetate dissimilation or by bicarbonate reduction (Westermann, 1993). Variation in both vegetation and temperature contributes to which pathway dominates (reviewed in Vasander and Kettunen, 2006). Isotopic studies of C have shown a link between vascular plant root exudates and methanogenesis, and $C^{14}$-dated $CH_4$ collected directly from the peat column has been found to be 2,000 years younger than the surrounding peat suggesting that at least a part of the C in $CH_4$ originates from DOC in the pore water which in turn can be largely derived from root exudates (Charman et al., 1994). Variation in methane fluxes has been extensively studied and related to a large number of variables, with vegetation type and water level being of most importance (Kettunen, 2003).

### B.1.6 Nitrogen utilization

In general, peatlands are a sink for nitrogen and it has been estimated that boreal peatlands contain about 9-16% of the global pool of N (Limpens et al., 2006). Despite this abundance of N in peatlands most of it is unavailable to plants, and nitrogen is in short supply in peatlands, especially in ombrotrophic bogs wherein N is supplied only from atmospheric sources. As nitrogen is received by the peatland, it is sequestered by the ground layer, mineralized to DON (dissolved organic nitrogen), and redistributed to vascular plant roots and microbes. S*phagnum* redistributes some of the N upward to new tissue (Aldous, 2002a,b). Under pristine conditions *Sphagnum* can show increased growth with increasing nitrogen deposition (Rochefort et al. 1990); however, under heavy loads of nitrogen deposition *Sphagnum* shows reduced growth Limpens et al. 2011) and in a warmer environment the growth inhibition is expected to become stronger. Indeed Lamers et al., (2000) proposed the triphasic response model of *Sphagnum* to increased nitrogen loads and based on a regional survey of available data Vitt et al. (2003) suggested a critical load for bogs. Utilizing decades of research, the current view of nitrogen cycling in ombrotrophic bogs includes the following: nitrification rates are low owing to acidic conditions and denitrification is unimportant due to low $NO_3^-$ availability. Also, $N^-$inputs from $N_2$ fixation has been considered unimportant; however, recent findings in Canada that recent accumulation of N in peat was about four times greater than inputs via wet deposition suggest that there must be additional inputs from organic N deposition, dry N deposition, and/or $N_2$ fixation (Moore et al., 2004).

### B.1.7 Sulfate reduction

Sulfur occurs in peatlands in a number of different redox states and conversions between these states are the result of microbial transformations. The deposition of S from acid precipitation adds S to peatland systems. One important transformation is sulfate reduction wherein sulfate (deposited from the atmosphere) and plant carbohydrates are transformed to $CO_2$ and $H_2S$ gas. This transformation oxidizes plant material (peat) and over time could decrease the mass of carbon stored in a peat deposit (Vile et al., 2003). Although the S-cycle has been reviewed extensively for forest and aquatic systems the S-cycle in peatlands has only one critical modern review (Vile and Novak, 2006). In addition to deposited S being transformed, it also can be lost from peatlands during periods of high water flow (Bayley et al., 1986).

### B.1.8 Hydrology

Fundamental to the functioning of a peatland is water (hydrological section in Rochefort et al. (2012). The movement of water into, through, and out of a peatland is perhaps the most important driver of ecosystem functions in fens and bogs. Ingram's (1978) recognition that a peat column is made up of two layers — the oxic acrotelm and the anoxic catotelm has been fundamental to our understanding of processes in peatlands, especially affecting decomposition processes, gas exchange, and vegetation differences. The earlier recognition by C.A. Weber that bogs are three-dimensional organic landforms with unique hydrological properties also was key in the development of peatland science. However many questions remain as to how ground water, surface water, and atmospheric precipitation interact to produce such chemically different peatland types as rich fens and bogs. Vertical and horizontal flows in peatlands have long been puzzling to hydrologists as has the dynamics of water movement from vegetation and the upper peat column.

### B.1.9 Decomposition

Peatlands accumulate organic matter as peat due to decomposition and DOC export being less then plant production over the long term. Recently a global analysis of millennial carbon accumulation in peatlands of the boreal forest suggests that rates of carbon accumulation are strongly correlated to photosynthetically active radiation and rates of photosynthesis (Charman et al., 2012). However, decomposition is also an important process. As organic material is produced and as it passes through the acrotelm, rates of decomposition are largely determined by plant chemistry (Turetsky et al., 2008). Additionally, the amount of time that the material remains in the acrotelm is also important (Yu et al., 2003a). Catotelmic rates as predicted by the Clymo (1984) model are constant and relatively low.

### B.1.10 Summary

Natural peatlands in the oil sands area have a distinct size and perimeter range, with few outliers. Species richness is highest in alkaline fens, and lower but similar in bogs and poor fens. Acidity and the reduction and eventual complete absence of alkalinity are important developmental thresholds. Peatlands contain large stores of carbon, nitrogen, and sulfur. Increases in nitrogen and sulfur will strongly affect the abilities of peatlands to accumulate carbon. Likewise changes in water levels and water quality will affect these elemental stores and accumulation processes. From a reclamation perspective, the following may be important to consider.

- Size is important in emulating natural peatlands.
- Northern Alberta watersheds are extremely variable in peatland cover.
- Bryophytes are an important component of the flora with overall species richness low. Richness is not equally distributed along the bog fen gradient, with alkaline fens having a large number of bryophyte (and probably vascular plant species)..
- Bryophytes contribute a large amount of the organic material to the peat column due to species chemistry.
- Acrotelm/catotelm development is extremely important in providing for carbon accumulation processes.
- Changes in N inputs may change carbon accumulation processes.

- Increased S inputs will increase sulfate reduction and loss of carbon will occur.
- Plant photosynthesis as related to PAR may be an important determinant in development of an organic layer.
- Methanogenesis may be an important process in early peatland development.

## B.2 Marshes, shallow-water wetlands

### B.2.1 Water inputs and chemistries

Mitsch and Gosselink (2007) referred to hydrology as the “single most important determinant of the establishment and maintenance of specific types of wetlands and wetland processes.” Wetland hydrology influences many chemical and physical properties including soil and water salinity, soil oxidative state, sediment dynamics, nutrient availability, and substrate characteristics such as pH and texture (Holland et al., 1990; Lewis, 1995; Mitsch and Gosselink, 2000; Baker et al., 2009). It is therefore vital that the character and role of hydrology in a wetland system is understood prior to planning and management. Hydrology also affects the biotic component of the wetland ecosystem. As we will see, water depth and duration of inundation determine the type, extent and distribution of vegetation communities that can survive in marshes and shallow water wetlands in the western Boreal Plains. Hydrology is central to understanding wetland formation and evolution, and the ecological, physical and chemical processes operating within wetlands (Mitsch and Gosselink, 2007; Thompson and Finlayson, 2001). In effect it is the principal driver of wetland ecosystem functioning (Baker et al., 2009).

Canadian Boreal wetland water budgets are strongly influenced by seasonal weather, related to timing of precipitation; melt water inputs; evaporation and transpiration losses; vegetative cover relating to interception, infiltration and evapotranspiration; and connectivity to the local and regional hydrological network (Devito et al., 2012). The seasonal climatic trends for the oil sands area north of Fort McMurray consist of dry falls and winters, followed by wet summer periods when the evaporative and transpiration losses are greatest. As a result, surface water flow and spring runoff flow can be small contributors to the area hydrology (Devito et al., 2005b) unlike hydrologies for marshes and shallow water wetlands in more southern locations in Alberta and western Canada.

However, marsh and shallow wetland systems in the Boreal Plains do possess similarities and dissimilarities with wetlands of a similar type in other parts of Canada. As in other regions, evaporation (i.e. water loss from the water surface) and transpiration (i.e. water loss through the transpiration of plants) can play a significant role in water loss during the growing season. Precipitation, not surface runoff, provides the major water input. However the structure for maintaining saturation in these wetlands is varied.

In a comparison of wetland habitats in the Boreal Plains region, Whitehouse and Bayley (2005) characterized the plant communities surrounding small (<200 ha) ponds in boreal Alberta, General information on average pond depths was not collected. They found the wettest wetland communities were found at the pond edge where marsh systems were prevalent. The driest wetland communities were located in bogs. Their findings were further supported by mean depth to water table measurements. Water tables were closest to the surface in marshes at an average of 5.7 cm below the soil surface. Water tables furthest from the surface were in bogs at 42.4 cm. They found that wet open fens, dry open fens, and treed fens had mean water table depths of approximately 20 cm below the surface.

Bayley and Mewhort (2004) found that in a comparison of nutrients in the surface water of marshes versus fens in the western Boreal Plains that nutrients ($NH_4^+$, $NO_3^-$, TDN, SRP, and TP) were all significantly greater in marshes than in fens. The quotient of available N to P was also was significantly greater in marshes. Marshes, in general, exhibit higher surface water nutrient concentrations than fens. In general, concentrations of $SO_4^{2-}$, $Cl^-$, $Na^+$, $K^+$, $Ca^{2+}$, $Mg^{2+}$, and alkalinity, conductivity, and pH were higher in marshes than in fens.

### B.2.2 Hydroperiod and Water Depths

Water regime is considered the major determinant of plant community development and patterns of plant zonation in marsh and shallow water wetlands (Casanova and Brock, 2000). It can be described by the depth, duration, frequency, rate of filling and drying, timing and predictability of flooded and dry phases in a wetland (Spence, 1982; Bunn et al., 1997). Changes in water depth are associated with changes in a variety of environmental factors (e.g., light, soil nutrients and particle size, and gas exchange rates) that either physiologically constrain species' distributions (Keddy, 1982; Spence, 1982) or allow them to spread. Despite the importance of water depth, attempts to model the distribution of wetland plants based solely on adult water depth tolerances have generally been unsuccessful (de Swart et al., 1994). This suggests that additional factors (e.g., species' regeneration niches) are important in determining the structure of the coenoclines that form along the gradient of elevations in wetlands (Wilson & Keddy, 1985; de Swart et al., 1994; Seabloom et al., 1998).

### B.2.3 Hydroperiod

A number of early studies documented cyclical changes in the abundance and composition of vegetation and noted that the diversity and productivity of both wetland flora and fauna appeared to be driven by cyclic wet and dry periods in marsh type wetlands across North America (Weller and Spatcher, 1965; Weller and Fredrickson, 1974; Walker, 1959, 1965). These early studies raised many questions about the nature of these cycles and how wetland vegetation responds to both increases and decreases in water levels over time (van der Valk, 2000). Questions arose about why certain plant species were eliminated during years with high-water levels, while other species were eliminated when water levels were maintained at constant levels. Questions also arose about the role of droughts in driving wetland productivity and whether wetland plant communities could rebound when wetlands were reflooded after experiencing several years of drought conditions.

It was surmised at the time that water depth was generally the most important environmental determinant of the position of plant species along coenoclines in freshwater marsh and shallow water wetlands (Spence, 1982). Water levels in freshwater marshes, however, are far from constant whether they exist in the prairie pothole region or in the western Boreal Plains region. They can not only fluctuate seasonally, but many fluctuate cyclically over longer periods of 5 to

30 years (van der Valk, 1981, 1985; van der Valk, 1991) (Figure B-1). Although there was considerable literature describing the impact of water-level changes on wetland vegetation, much of it was descriptive until the 1990s.

**Figure B-1. Marsh wet-dry cycle proposed by van der Valk and Davis (1978).**

### B.2.4 Depth of flooding

Wetland plants position themselves within a basin based on their ability to survive certain water depths (Figure B-3). Various flooding depths within a marsh determine what will grow in a particular location and what will not. Depending on the type of marsh being designed (i.e. wet meadow marsh versus a shallow water wetland) water depths can be used to allocate the specific locations of where plants will grow. This ultimately allows one to create the wetland one would like depending on the objectives of the project. Numerous studies have examined the flooding thresholds of various aquatic species. The most visible effect of a prolonged increases in water levels (i.e. >1 yr and >1 m) is the elimination first of annual species, followed by emergent perennial species (Figure B-1 – lake stage) (van der Valk, 1994; van der Valk et al., 1994). Many researchers initially believed that wetland plants could survive deep flooding periods by extending shoot length above the water's surface. Research now shows that for most marsh plants this is not the case. Squires and van der Valk (1992) found that upper marsh species, such as *Carex spp*. and *Scolochloa festucacea*, were unable to adjust their shoot length to maintain sufficient shoot area above water if they were growing in water depths deeper than 20 cm. The same would hold true for other boreal wet meadow species such as *Calamagrostis canadensis* and *Cicuta maculata*. Lower marsh species, such as *Typha latifolia* and *Schoenoplectus spp*., are able to adjust shoot length up to a water depth of 70 cm, however both aboveground and belowground biomass will be greatly reduced (i.e. stressed) for the plants to accomplish this. When subjected to water levels beyond their upper flooding range many marsh species can be quickly eliminated in just one growing season. This has important implications for getting the hydrology right in reclaimed marshes. van der Valk (2000) studied the concept of plants being able to migrate upslope when water depths approached their depth limit. He found that marsh species already growing under stressed conditions do not have the energy needed for cloning growth into locations with more optimal water depths. Therefore, in marshes flooded too deep, there is no ability for *Typha latifolia*, *Schoenoplectus spp*., and *Sparganium eurycarpum* to move upslope into shallower flood locations. If flooded too deep for too long these species will simply disappear over time. van der Valk (2000) also observed that in most cases deeper emergent marsh plants were unable to compete with species such as sedges and grass species already existing in the shallower flooded areas. Ross (2010) provides guidance for the application of water depths in wetland designs.

**Figure B-2. Marsh cross-section indicating species placement along a coeincline.**

### B.2.5 Duration of Flooding

Not only does the depth of flooding dictate which plant species survive in marshes, but duration of flooding also impacts survival. Many species are intolerant of prolonged flooding even when grown at optimal water depths for the species of interest. Investigators have reported that *Schoenoplectus tabernaemontani* is intolerant of prolonged flooding (Walker, 1965; Macaulay, 1973; van der Valk and Davis, 1980; Neckles,1984; Neckles et al. 1985; Neill, 1990). Studies have shown that softstem bulrush clones live a maximum of 3 years when flooded no matter what water depth it is growing at (Shay and Shay, 1986; van der Valk and Davis, 1978; Squires, 1991). Meredino and Smith (1991) established that *Scolochloa festucacea* can begin to die after only 3 months when flooded to depths of 30 and 50 cm, but survives when flooded at 15 cm. In the same study, softstem bulrush populations declined significantly or were extirpated when flooded 50 cm. For both species, the younger the plants the greater the negative impacts of prolonged and stable flooding.

Long term stable flooding, regardless of the water depth, can reduce vegetation coverage over time in marshes. Approximately 35 to 45% of emergent vegetation can be eliminated within 3 to 4 years following a marsh drawdown. This is particularly true if water levels are restored to stable water depths of 60 cm or more (van der Valk, 2000). In the case of designing shallow water wetlands in the western Boreal Plains, stable and deep water depths can be used to create the depths necessary for the central open water portion to develop. A lengthening of time between drawdowns will be critical in order for this to develop. What is important to note is that regardless of the marsh or wetland being designed, once a marsh or shallow water wetland begins to enter the degenerating stage of an ever expanding open water area versus emergent or wet meadow vegetation, it is virtually impossible for these systems to revegetate themselves until they enter into another drought phase. Therefore, careful consideration of the system being designed and the length between naturally occurring drawdowns must be considered.

### B.2.6 Drought

Very few wetland plant species have the ability to expand their presence in wetlands that are continuously flooded, particularly if water depths are kept stable. Therefore, periodic drought conditions become important for the germination and reestablishment of many aquatic species in marshes and shallow water wetlands (Figure B-2). As water levels decrease during drought conditions, part or all of a wetland’s bottom substrate is exposed and seeds from terrestrial, mud-flat annuals and emergent plants are allowed to germinate (Harris and Marshall, 1963). When wetlands reflood, mud-flat annuals and terrestrial plants die-off and become replaced by emergent and submersed aquatic vegetation adapted to more hydric conditions within the very first growing season (Euliss et al., 2004).

How often a drawdown should occur depends on the type of wetland being created and the biological objectives of the project. Wet meadow marshes require drought conditions on a much more frequent basis than shallow water wetlands or marshes possessing deeper emergent plant species such as cattails and bulrushes. Species composition of a developing plant community is determined in part by the seed bank present in the substrate at the time of drought (van der Valk and Davis, 1978) and by the environmental conditions on the substrate surface during drawdown (Welling et al., 1988a). While we often do not have control on the severity of a drawdown condition, studies have shown that the length and severity of drought conditions impacts both the diversity of species that germinate and their numbers. van der Valk (2000) states that soil moisture and salinity can significantly affect seed germination and that these factors can be sometimes be managed or designed in such a way as to encourage different responses. Normally, the drier the drawdown condition the greater the soil salinity at the soil surface. Galinato and van der Valk (1985) and Seabloom et al. (1998) found that the germination of emergent species was inhibited by dry soils, whereas the germination of annual seeds was inhibited by slightly flooded conditions or very moist soils.

Marshes and shallow water wetlands can dry at different times of the year. Often they either enter the spring in a drier condition that results from a previously dry fall and winter or they gradually go dry by early summer (i.e., late June through mid-July). Studies examining the timing of drawdowns on recruitment show that the germination of seeds in marshes and the resulting recruitment of seedlings from a seed bank can be significantly affected by the initiation date of the drawdown. May drawdowns can result in 600% more seedling growth compared to drawdowns initiated in July and August (Merendino et al., 1990; Merendino and Smith, 1991). Overall, shoot densities have been shown to be higher with spring drawdowns, as is the survivability of these new shoots when reflooded. Spring drawdowns can also reduce the recruitment of potential problem species, such as certain *Typha* species. Numerous studies have shown that it is difficult to predict which species will respond to a drawdown in any given year. Ultimately, understanding the ecology of the plants and documenting species dominance and diversity throughout the project's life will greatly improve one's predictive capabilities when a drawdown does eventually occur.

One of the important considerations when designing and constructing a reclaimed marsh or shallow water wetland is the length of drought required in order to get the best plant response once reflooding reoccurs. It was initially thought that longer drawdowns would provide a longer recruitment period for the germination of seeds. It was also thought that plants recruited during longer drawdowns would be hardier and therefore better able to survive when reflooding did occur. Studies have since shown no practical difference in vegetation response between and 1- and 2-year drawdowns (Welling et al., 1988 a, b). Most plant recruitment has been observed to occur during the first few months of a drawdown with the survival of emergent seedlings no different whether the drawdown lasts one or two years.

The long-term hydrological regimes of marsh and shallow water habitats drives plant community responses and diversity in wetlands. This regime, coupled with the depth and duration of flooding, are important considerations in wetland design. The following section begins to discuss the different plant, microbial and algal communities that exist in wetland habitats and considerations for the wetland designer in terms of wetland function, productivity and resiliency.

### B.2.7 Foundational Species

Foundational species in marshes and shallow water wetlands include wet meadow and shallow marsh species such as *Mentha arvensis*, *Juncus spp.* and *Carex spp*., deeper emergent species such as *Schoenoplectus spp*.and *Typha latifolia*, and submersed and floating vegetative species such as *Potamogeton spp*. and *Nuphar lutea ssp. variagatum* (Table 2). In addition to these vegetation communities are the algal and bacterial populations that not only play an important role as nutrient pools, but also as a source of nutrients for the higher order organisms within these systems, such as invertebrates, fish and wildlife.

In the western boreal region, fens and marshes are not always visually distinct, causing difficulties in describing sites. Most wetlands in the western boreal region have substantial peat deposits, and many wetlands support sedge, reed, and rush growth without obvious distinctions among wetland classes (Bayley and Mewhort, 2004). Despite the apparent similarities of these sites, different species assemblages exist likely as a result of differences in the physical settings of each wetland (i.e., elevation, basin morphology, and hydrological inputs and frequencies). These can ultimately lead to differences in water chemistry (Hill and Devito, 1997), and, in turn, promote different plant communities (Nicholson and Vitt, 1994).

The wetland plants occurring in marshes and shallow water wetlands in the western Boreal Plains are not that different from wetland vegetation common to most Canadian marshes (Bayley and Mewhort, 2004). Plant assemblages occurring such as sedges, rushes, and aquatic vascular species agree with the list of wetland vegetation common to Canadian marshes (Vitt, 1994; National Wetlands Working Group, 1997).

Extensive investigations by Whitehouse and Bayley (2005) on marshes in the western boreal region have found a variety of species that include *Tephroseris palustris*, *Typha latifolia*, *Epilobium leptophyllum*, *Bidens cernua*, *Sium suave*, and *Sparganium eurycarpum*. In their work they found that communities differed depending on whether the wetland was in a flooded state or in a state of drawdown. Annual mudflat marshes were dominated by *Tephroseris palustris* and *Bidens cernua* while the reed–sedge marshes were dominated by *Carex aquatilis* and *Typha latifolia*. What was interesting in their findings was the species diversity between fens and marshes in the region. They found that total community diversity was lowest in marshes (26 species) and highest in treed fens (86 species). Marshes represented the wettest of the systems they studied, while bogs represented the driest. Not surprisingly, the vegetation of bogs and marshes were the most dissimilar.

What makes marshes and shallow water wetlands unique from the other wetland systems discussed here is the development of bands or zones of vegetation depending on the flooding depths that occur within the wetland. Bands or zones of vegetation (coenoclines) at a variety of scales are common features of most marshes (Spence, 1982), including boreal marsh and shallow water systems. Stewart and Kantrud (1971) do a very good job of describing these zones based on water depths and water permanence. They also include an extensive list of various species that occur within these zones. While their classification system was designed for marsh wetlands in the prairie region of western Canada, many of these same species can be found in the marshes and shallow water wetlands in the western Boreal Plains region as well. Wetland ecologists have spent a great deal of time describing and investigating these zones to determine why and how they develop (van der Valk and Davis, 1978; Spence, 1982; Snow and Vince, 1984; Keddy, 1982; van der Valk, 2000). Wetlands can be designed and restored based on the positioning of these specific plant zones.

It is important to note that some emergent aquatic species are very efficient at outcompeting other species. *Phalaris arundinacea* (reed canary grass) should never be included in the plant community of any wetland design. While considered native to North America, it can readily outcompete many of the species associated with the wet meadow wetland plant community. It is also very resistant to herbicide control. *Phragmites australis* is also considered native to North America, yet it grows very aggressively and often overtakes the wet meadow, shallow and deep marsh zones of marshes. Like *Phalaris*, it is also very resistant to herbicide control. Many studies have looked at controlling *Phragmites* through burning, water level manipulation and harvesting. Very little success has been achieved with any of these management approaches. *Typha spp.* should also be handled with caution in wetland designs. While the plant offers many habitat and water quality benefits, it can easily spread and take over both shallow and deep flooded marsh zones. Therefore it is very important that wetland designers understand the habitat requirements, and water depth limitations, of both *Typha latifolia* and *Typha angustifolia*.

### B.2.8 Plant zonation

Four major mechanisms for the establishment of vegetation zones in these systems have been described in van der Valk and Welling (1988). These include: (1) the differential distribution of seeds along elevational gradients; (2) the differential recruitment of species along elevational gradients; (3) differential survival of seedlings and adults along elevation gradients during a drawdown event; and (4) differential survival of adults after reflooding occurs. Seed dispersal patterns are normally not responsible for the development of vegetation zones. Generally over time, seeds of all species tend to be more evenly dispersed across elevational gradients (van der Valk and Davis, 1978, 1980; Poiani and Johnson 1989). Some emergent species may have higher seed germination percentages along some sections of an elevational gradient than others (van der Valk, 2000). For example, *Typha latifolia* and *Schoenoplectus tabernaemontani* seedling densities can be higher at slightly lower elevations during a drawdown event than that at which their seeds are most abundant. Plant species adapted to growing in shallower water depths will often germinate more successfully, and in greater numbers, higher up on the elevation gradient.

During coenoc1inal development, different combinations of factors may influence the final position of a species along an environmental gradient, and no one factor (e.g., dispersal, recruitment, or competition) is responsible for the final distribution of all species (van der Valk, 2000). For example, differential seed germination is primarily responsible for the distribution of *Phragmites australis* along the new coenocline, whereas a combination of seed dispersal, differential seed germination, and seedling and adult mortality is responsible for the position of *Scolochloa festucacea*. Understanding the recruitment attributes of individual aquatic species is key for designing wetlands in the western Boreal Plains that are both resilient and diverse.

### B.2.9 Algal communities

In most wetland reclamation plans, it is the emergent and wet meadow plant species, such as *Schoenoplectus*, *Carex spp*., and *Juncus spp*. that are the focus of wetland designs and construction activities. Algal communities and the role they play in supporting food web dynamics and primary productivity in marshes and shallow water wetlands is almost always overlooked as an important component of both newly developing systems and mature wetland systems. Algae are significant contributors to total primary productivity in marsh and shallow water wetland systems, and as such, they can support much of the secondary production (Robinson et al., 2000).

For many years it has been claimed that wetland food webs (i.e., secondary consumers such as fish and invertebrates) were fueled primarily by the macrophytic detritus, which is produced through the decomposition of emergent wetland plants. We now know that algal and bacterial production in marsh systems is important to secondary consumers for a variety of reasons. First, algal communities are more or less available throughout most of the year. Secondly, compared to plant detritus, algae and bacteria are relatively easy to ingest by other aquatic organisms because of their higher nutritional values (low carbon: nitrogen ratio) and softer cell walls (Robinson et al., 2000).

How do algal communities compare to aboveground emergent plant growth in marshes and shallow water wetlands? In one of the most extensive studies on marshes in western Canada, aboveground macrophyte biomass was found to be about 93 g $m^{-2}$, while belowground growth and roots represented 560 g $m^{-2}$. After conversion of algal chlorophyll data to equivalent dry weight in the same marshes, it was estimated that mean total algal biomass was about 244 g $m^{-2}$ over the same period. While the total amount was less than that of total macrophytes, the authors mentioned it was worth considering that the preferential allocation of macrophyte biomass with belowground parts precludes its entire use by herbivores in the water column; from the standpoint of providing resources to aquatic invertebrates and fish in wetlands (Robinson et al., 1997a). If one only considered biomass production within the water column and not within the sediments, then algal production would have accounted for more than 70% of the biomass produced within these marsh systems overall. What is also important to note is that turnover times for algal biomass is considered in days as opposed to macrophyte turnover times which is measured in months or years.

Four algal communities exist in boreal marsh and shallow water wetlands. These include phytoplankton, epipelon, epiphyton, and metaphyton. Phytoplankton, as we’ve discussed in chapter 4 for shallow water wetlands, are algae entrained in the water column. Epipelon inhabit the soft surficial sediments found in the upper soil layers in marsh and shallow water boreal wetlands. They often display diurnal migrations towards the upper surface sediments by day, retreating deeper into the surface sediments by night (Round, 1981; Robinson et al., 2000). Epiphyton colonize aquatic surface of submersed and emergent plants, and are often the slimy outer layer that one feels on the surface of emergent vegetation. Metaphytic algae most commonly occur as floating mats of entangled filamentous and epiphytic algae on the water surface. They are often buoyed to the surface because of the air bubbles trapped within them. There is considerable structural overlap between the four assemblages; phytoplankton is derived, in part, from detached epiphyton and epipelon suspended from the sediments during high winds. Metaphyton originates from epiphyton and gradually detaches from it as biomass increases (Robinson et al., 1997a).

Their presence at any given time is determined by habitat characteristics, flooding regimes, water depths and competition for available nutrient resources by other plants, zooplankton and fish (Norlin et al., 2005; 2006). As in most shallow, eutrophic waterbodies (Moss, 1998), nutrient loading in western boreal shallow-water wetlands and marshes is probably dominated by internal processes; therefore, recycling of nutrients from organic sources may be of particular importance for algal growth in these systems (Norlin et al., 2005).

For wetland designer and managers, Robinson et al. (1997a) proposed a model of algal abundance in marshes and shallow water wetlands that comprises four alternative stable states dominated, alternately, by epipelon, epiphyton, metaphyton, or phytoplankton. Their model's four states mirror those of van der Valk and Davis' (1978) vegetation model. It includes a

1. "Dry wetland" (epipelon dominant) state characterized by low water levels, exposed mudflats and abundant terrestrial vegetation.
2. An "open wetland" (epiphyton dominant) state possessing deeper water and an abundance of submersed and emergent macrophytes.
3. A "sheltered wetland" (metaphyton dominant) state in which macrophyte abundance is reduced allowing for the development of intermittent open water areas sheltered from wind.
4. A “lake wetland" (phytoplankton dominant) state typified by large areas of open shallow water.

In this model, one would expect that shallow water wetlands in the boreal would be dominated by phytoplankton communities in the central open water areas of the wetland, epiphytic algae growing on the macrophytes established around the outer edges of the pond, and epipelic algae in the upper layers of the bottom sediments. Wetlands undergoing a drying out period would still possess epipelic algae in the moist bottom sediments, and possibly mats of dead metaphytic algae covering the sediments in areas where it had established in open water areas prior to drawdown. What we do know is that wetlands can be designed and managed for optimal algae production depending on desired outcomes of the project. Benthic algae can be abundant in lakeshore wetlands, while metaphytic algae may flourish when a drawn down wetland is reflooded. Epiphyton dominance (the "open wetland" state) may be achieved by maintenance of moderate water levels, abundant macrophyte stands, and representative consumer populations (Robinson et al., 1997a; 1997b).

### B.2.10 Bacterial populations

Bacterial communities in wetlands play a critical role in regulating the cycling, retention, and release of major nutrients and soil carbon in freshwater wetlands, demonstrating large effects on water quality and global carbon cycling (Hartman et al., 2008). They are generally accepted as the main decomposers of organic carbon and regenerators of minerals in aquatic ecosystems. They directly utilize dissolved organic carbon (DOC), incorporating it into their biomass and remineralizing up to 50% for primary production (Azam et al., 1983). In turn, they are fed upon by various microbial and macro-grazers and in this fashion energy, carbon and nutrients are cycled up food chains to higher trophic levels (Robarts and Waiser, 1998).

While plant decomposition has often been suggested as the major control point in phosphorous (P) cycling and its availability in northern marshes (Chapin et al., 1978), other studies have pointed to the fact that the seasonal patterns and releases of P and nitrogen (N) from decomposing vegetation is mismatched between the amount of inorganic nutrients required by the plants in the spring for new growth versus what is readily available for plant uptake. Therefore, it is suggested that sediment bacteria are an important major pool of P (>70%) and N (>50%). Gachter and Meyer (1993) researched the role of bacteria in P cycling at the sediment-water interface and found that sediment bacteria contain as much P as settles with organic detritus in any one year in eutrophic systems. Others have wondered how sediment bacteria in colder climates have been able to supply enough nutrients to growing wetland plants in the spring when cooler temperatures should limit their productivity. However, Cole and Pace (1995) and Chapin et al. (1978) both found that anaerobic bacterial populations were in general larger in cold hypolimnia and more productive than those in warmer, aerobic environments.

In newly designed and constructed marsh systems the issue of substrate limitation on bacterial growth needs to be considered. Even though most wetland sediments are highly organic, much of that organic matter may not be suitable as a substrate for some microbial activities. And all organic matter may not be the same. Sander and Kalff (1993) and Kerner (1993) found that bacterial processes could be limited in spite of the availability of abundant organic matter in the sediments. This may be more related to the amount of DOC available (Waiser and Roberts, 1997, 2004). Besides the importance of DOC in fueling microbiall food chains, too much DOC can also limit the amount of soluble reactive phosphorous (SRP) needed for microbial processes (Waiser and Robarts 1995).

In situ changes can occur with bacterial populations as newly constructed wetlands mature. Shifts in the composition of whole bacterial communities, and the abundance of specific taxonomic groups with environmental gradients may reflect changes in biogeochemical cycling, hydrological cycling, soil chemistries and pH. Hartman et al. (2008) found that soil pH broadly altered the composition of bacterial communities and their diversity of their wetland soils. The amount of peat and the effect of pH on decomposition mediated the shifts. Mineral soils supported different communities. Song et al. (2010) found that hydrologic pulse including water level drawdown and subsequent flooding could have an impact on both biogeochemical processes and the denitrifying microbial communities in wetlands, particularly if repeated and severe drying and reflooding occurred regularly. Shorter term drawdowns, however, may have less of an impact on bacterial communities in riparian wetlands than in bogs and fens. Kim et al. (2008) found that a short-term drought experiment led to significant decline in bogs and fens, but not in the riparian wetlands. This may demonstrate marshes and shallow water wetlands proclivity for intermittent drawdowns to restore productivity as opposed to the impacts of drawdowns in fens and bogs.

Consideration of the chemical nature of the soils placed in newly reclaimed marshes and shallow water wetlands must also be addressed in any discussion of the bacterial communities in these systems. Native wetland communities in the vicinity of the Athabasca oil sands are naturally exposed to low levels of bitumen and its associated components, including naphthenic acids (NA) (Headley et al., 2000). Wetlands that receive process-affected water or remnant soils from operations are expected to have some differences from natural bacterial communities (Hadwin et al., 2006; Rezanezhad et al. 2012). First, because processing does not recover all available bitumen, newly restored wetlands may be exposed to higher levels of bitumen than would naturally occur in native wetlands. Secondly, it can be expected that they may be exposed to up to 30x higher levels of naphthenic acids (Pollet and Bendell-Young, 2000). Salt (Na) also increases significantly following the processing of oil sands and the increased concentration of Na flowing through peat can also decrease microbial activity (Rezanezhad et al. 2012). Lastly, wetlands will generally be established on land that has been significantly disturbed by mining operations, and may include little or no vegetation during the early phases of microbe establishment (Hadwin et al., 2006). What Hadwin et al. (2006) found first in their comparisons of native marshes versus newly constructed marsh systems in the oil sands region was that very little variability in bacterial communities within wetland sites existed. This is unlike bacterial community structure in marine environments where communities can change drastically within centimetres of one another (Scala and Kerkhof, 2000). Secondly, while they found differences in community structure between non-impacted and impacted wetland sites, they also found that the communities in impacted sites shifted to ones that were more capable of metabolizing naphthenic acids. They suggest it may be advantageous to seed newly reclaimed marsh sites with sediments from communities known to bacterial communities with higher NA degradation potential.

## B.3 Marsh/shallow-water systems: Nutrient pools through a wetland's wet/dry cycle

### B.3.1 Net primary productivity (NPP)

Understanding the net primary productivity (NPP) and movement of nutrients between pools in marshes and shallow water wetlands is an important consideration in wetland design. Depending on the system being designed, it helps to define when hydrological changes need to occur, and how often they should occur. Once wetlands are constructed, it also helps to provide insight for those responsible for managing these systems how even small changes in vegetation can have big implications for where nutrients are pooled and stored. Understanding nutrient pools and the movement of nutrients within individual plants also indicates to us when it is safe to transplant vegetation and when it is not. Shrubby swamps and non-peat accumulating marsh wetlands tend to produce more biomass annually through the process of NPP than do peatlands. Where systems differ is in the amount of plant biomass that can be sequestered on an annual basis. While we know that peatlands, such as bogs and fens accumulate more carbon, Vitt et al. (2001) estimate that on average the total for above- and belowground NPP of non-peat accumulating marshes is approximately 1344 g $m^{-2}$ $yr^{-1}$. While marshes and shallow water wetlands tend to represent only a small percentage of the wetlands present in the boreal region, their contribution to productivity in the region cannot be overlooked (Vitt et al., 2001).

The quantitative description of the inputs, outputs, and internal cycling of materials in an ecosystem is called an ecosystem mass balance (Whigham and Bayley, 1979; Nixon and Lee, 1986). If the material being measured is N, P, or C, then the mass balance is termed a nutrient budget (Mitsch and Gosselink 2007). Mass balances provide a useful framework for organizing information about nutrient inputs and outputs and changes in nutrient pools and fluxes among these pools within an ecosystem. Understanding these elements and the sharing of resources between pools is important for coordinating construction schedules of restored marshes and shallow water wetlands in terms of transferring vegetation or seeding new vegetation at the right times of the year.

The nutrient pools in marshes and shallow water wetlands are partitioned between the water, the plant tissues, and the peat/soil. Water has different levels of nutrients depending on the source and flow pattern (ground water, surface water, precipitation), and marshes generally have higher levels of nitrogen (N) and phosphorus (P) in the water relative to fens (Thormann and Bayley, 1997, Bayley and Mewhort, 2004). Nutrients inputs into wetlands are primarily through precipitation and surface and groundwater inflows (Kadlec, 1983; Neely and Baker, 1989). Primary outputs are through surface and groundwater outflows. Long-term loss of nutrients to the sediments is also considered an output and, in some cases, exports to the atmosphere may be important (e.g., loss of N through denitrification) (Neely and Baker, 1989). Intrasystem cycling is the flux or exchange of nutrients among pools within the wetland (Mitsch and Gosselink, 2007).

Generally, there are two distinct cycling periods to consider when discussing the movement of and pooling of nutrients within marshes and shallow water wetlands. The timing of these cycling periods should be considered when coordinating reclamation schedules and construction activities. On an annual basis there are three discrete periods when nutrients are being exchanged between aboveground and belowground plant pools: late spring-early summer (early June to early August); late summer-fall (early August to early October); and winter-early spring (early October to early June). These three periods are distinct because of macrophyte growth and production. Late spring-early summer is usually the period of maximum macrophyte growth when nutrients are being transferred into above ground growth of the plants. Late summer-early fall is the period of maximum standing crops of macrophytes followed by senescence as fall proceeds (Murkin et al., 2000; Bayley and Mewhort 2004). It is during this period that nutrients are being transferred back into the roots for plant overwinter survival and storage. Winter to early spring is the period of minimal macrophyte production, representing the dormant winter period and the early spring period when the marshes begin to thaw but before much macrophyte growth occurs. During this time most of the plants nutrients are stored in their roots. Wetland plants are most vulnerable to being moved or relocated from one site to another during those periods when nutrients are being transferred between their aboveground and belowground growth.

The second distinct cycling period to consider is the nutrient transfers that occur as marshes and shallow water wetlands cycle through periods of sustained flooding to drawdown followed by reflooding (Murkin et al., 2000). One of the reasons that marshes are as productive as they are in terms of plant growth and biodiversity is because of the nutrient transfers that occur as systems cycle through a wet-dry cycle (Figure B-1). When marshes are in a flooded state the transfer of nutrients occurs in a manner similar to what was described in the preceding paragraph. Nitrogen (N) and phosphorous (P) uptake occurs mainly between the belowground roots and rhizomes to the aboveground growth, while carbon (C) uptake occurs mainly by aboveground plant tissues (Murkin et al., 2000). In the early period following the reflooding of a system, large flushes of N and P can be transferred into surface waters as annual plant species that have grown on the mudflats die and their aboveground biomass enters into the aboveground litter pool. The aeration of the sediments resulting in increased decomposition and release of nutrients from the sediments is also considered as another reason for this early increase in productivity (Kadlec, 1962). Algal populations during this early phase of reflooding are extremely important for capturing available nutrients in a way that young growing aquatic vegetation cannot (Robinson et al., 1997a,b). Decomposing vegetation not only releases additional nutrients into their available nutrient pools, it also provides an abundance of surface areas for grazing invertebrates and bacterial populations. As a result, an important consideration for the long term viability and productivity of reclaimed marshes and shallow water wetlands in the Western Boreal Plains is occasional occurrence of the wet-dry sequence.

The longer flooded conditions remain in a marsh the more likely that deeper emergent species, such as cattails and bulrushes, begin to die back In the early part of the degenerating stage wetlands tend to be very productive. Habitat complexity is increased as certain vegetative species disappear and open water areas begin to develop. This change in structure supports a broad range of both primary and secondary consumers (Murkin et al., 2000). With a decline in the major aboveground and belowground macrophyte nutrient pools, the dominant fluxes associated with the macrophytes (uptake, translocation, leaching, and litter-fall) are reduced over time. Nutrient pools that at one time received nutrients from macrophytes decrease in size as well. These pools include surface water, algae, and invertebrates.

What does continue as marshes and shallow water wetlands become more dominated by open water habitat is the ongoing input of nutrients to the pore-water inorganic pools through mineralization. With the elimination of plant uptake as the major flux of dissolved inorganic nutrients from the pore water and continued microbial activity within the sediments (mineralization), the pore-water pool increases over time to eventually become one of the largest pools in the system. Nutrients in these pools remain "locked" in the pore water and sediments until emergent vegetation and associated plant uptake are once again reestablished to move the nutrients from these belowground pools to aboveground pools (Murkin et al., 2000). Because of this, the latter stages of constant flooding is often considered to be the period of lowest overall productivity in terms of exchanges between various nutrient pools within the system. This is why it is key to occasionally cycle wetlands through the wet-dry cycle in order to maintain its productivity over the long term.

When marshes and shallow water wetlands experience a drought phase, a combination of mudflat annuals and newly recruited emergents begin to germinate and grow. For many wetlands species, this is the only time when these communities can reestablish themselves from seed within the wetland system. Major fluxes associated with macrophytes, most notably nutrient uptake, leaching, and litter-fall, are reestablished as important components of the nutrient budgets and pools during this dry stage. Translocation generally remains low because the vegetation is dominated primarily by annual species that do not translocate nutrients between above and belowground tissues to any great degree. What is important to note is that the aboveground biomass of annuals during the dry marsh stage can equal or often exceed that of emergent vegetation during the regenerating stage of the wet-dry cycle (van der Valk and Davis, 1978). This means that a lot of the nutrients captured within these annuals are poised for release to the water column when water returns. An important difference to note between annuals and emergents is the much lower belowground production of annual species. Although emergent macrophytes became established during dry stage, the development of their belowground tissues is relatively slow. Therefore, nutrient pools associated with below ground roots and rhizomes remain much lower than the aboveground pools of both annuals and emergent vegetation combined during the dry marsh stage.

### B.3.2 Plant production/decomposition rates influence on ability to survive flooding

Evidence from a variety of wetland ecosystems suggests that, in general, litter decomposition is much less rapid at sites that are never flooded compared to sites that are inundated for at least a portion of the growing season (Bell et al., 1978; Ewel and Odum, 1978; Merritt and Lawson, 1979; Day, 1982; Bartsch and Moore, 1985; Shure et al., 1986; Farrish and Grigal, 1988; Gorham, 1991). The decomposition of macrophyte litter that is submerged by flooding also proceeds faster than that of standing litter (Boyd, 1970; Davis and van der Valk, 1978; Bruquetas and Neiff, 1991). Inundation influences decomposition directly by controlling leaching and soil moisture and indirectly by influencing other environmental conditions that affect microbial activity, such as soil pH, oxygen levels, temperature, and dissolved nutrient ability (Neckles and Neill, 1994). Decomposition is a complex process that includes nearly all changes in organic matter that has undergone senescence or death (Brinson et al., 1981). Leaching of soluble organic matter precedes losses due to the removal by animals or assimilation by micro-organisms (Thormann and Bayley, 1997). Decomposition is completed with the loss of physical structure and changes in the chemical constituents of the remaining organic matter (Clymo 1984). Litter quality, or the physical structure of the plant, also affects the rate of decomposition (Brinson et al., 1981; Bridgham and Richardson, 1992; Szumigalski and Bayley, 1996; Thormann and Bayley, 1997; Thormann et al., 2001).

Decomposition is often suggested to be greater in marshes than fens (Vitt 1994; Hansen et al., 1995; Zoltai and Vitt 1995); however, actual mass loss rates reported in the literature are inconclusive (Davis and van der Valk, 1978; Bartsch and Moore, 1985; Morris and Lajtha, 1986; Ohlson, 1987; Verhoeven and Arts, 1992; Szumigalski and Bayley, 1996; Aerts and de Caluwe, 1997; Thormann and Bayley, 1997). Bayley and Mewhort (2004) studied the rate of mass loss of litter in fens and marshes in the Boreal Plain and found that long-term decomposition rates for the mass loss of vegetation were significantly greater in marshes than in fens. They concluded that hydrologic conditions and not surface-water nutrient concentrations promoted faster decomposition in northern marshes than in fens

Why consider decomposition and decomposition rates when designing wetlands for reclamation? We do so because certain species of plants are very sensitive to flooding depths when flooded at depths beyond their acceptable water depth limit. This is particularly true for sedges and wet meadow grasses that are better suited to growing in shallow flooded environments. The physical structure of sedges and grasses tends to be less robust than cattails and bulrushes, making them less tolerant of deeper water depths and much more prone to quicker decomposition. The most common effect of a prolonged (i.e., more than one year) increase in water depth often is the elimination of emergent vegetation. For many species one growing season of water depths being their limits will result in the loss of the entire community (van der Valk, 1994). Keep in mind that few wetland species possess the ability to re-grow under water, even if water depths are lowered. Therefore the the only way to restore vegetation to a wetland whose standing vegetation has been lost is to have it re-enter a drawdown state.

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# Appendix C
# Wetland Mapping and Application

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Native Plant Solutions

## C.1 Introduction

Wetland mapping and remote sensing products can be a valuable tool in the wetland reclamation process, both to understand the types, distribution and interconnectivity of wetlands that exist within a region and to inform the reclamation process at the watershed level. However, like any well-run project, understanding the objectives prior to undertaking any mapping exercise is key to acquiring useful data. Is the goal of mapping to inventory the extent and proportions of wetland types within a particular area? Or is the desire to better understand the key characteristics and functions, including vegetation and hydrology, which structure a particular wetland system or type? Each goal is a question of scale (spatial and temporal) and the resolution of the data required. By better understanding what questions are being asked, the classification system, type of imagery, resolution of imagery and timing of imagery to be used can be appropriately selected to help provide the desired results.

## C.2 Overview of mapping products/approaches in the region

The first step to any wetland mapping exercise is to decide the classification system to be followed. As outlined at the beginning of this chapter, a number of wetland classification systems exist and are of different levels of applicability, depending on the user’s needs and information requirements. When choosing a classification system to follow for a wetland inventory, it is important to ask: Will I have a definition of all wetland types I am trying to model or inventory? When working with remote sensing data, whether you are using aerial photography or satellite imagery, you are interpreting visual or spectral information from a distance. In order to appropriately classify what you’re looking at, you need a reference point (i.e., a classification system) to standardize how you define a particular wetland type, as well as a classification methodology to highlight what key attributes or indicators you look for. The ability to interpret these indicators, although important, depends on the imagery being used and its resolution. For satellite imagery, indicators of wetland type may include variations in textures, colours and spectral responses. On the other hand, for aerial photography, indicators may include elevations, vegetation species or vegetation height. These differences in indicators between remote sensing types are different due to the scale at which the data is collected; therefore, it is important to clarify the objectives of the mapping products at the beginning and determine the wetland classification, type of imagery and scale you are trying to acquire for mapping purposes.

In the oil sands region, the more commonly used classification systems include the Canadian Wetland Classification System (CWCS; NWWG, 1997) and Cowardin et al. (1979). However, in terms of their application to GIS and remote sensing products, the most applicable include the Alberta Wetland Inventory (AWI; Vitt et al., 1996; Halsey et al., 2003) and the Enhanced Wetland Classification (EWC; Smith et al., 2007), which follow methodology for remote sensing mapping. In this chapter we will focus on these two approaches, providing a background on each classification method. Both the AWI and EWC serve a dual purpose as an ecological guide in the field and a remote sensing based guide for the image analyst. Although the AWI and EWC both conform to the CWCS at the major class level (i.e., bog, fen, marsh, swamp and shallow water wetland; NWWG, 1997) and focus on vegetative characteristics to classify wetlands, each method has its strengths and limitations, depending on the mapping exercise to which it is applied.

### C.2.1 Alberta wetland inventory

Developed by Vitt et al. (1996), the Alberta Wetland Inventory (AWI) is a classification system structured specifically for Alberta wetlands, with a focus on peat-based wetland ecosystems. Followed by a second edition by Halsey et al. (2003), the classification scheme contains sublevels that describe the vegetation and landform type, from the wetland complex (meso-level) to the local wetland element (micro-level). These three subclasses include a vegetation modifier (i.e., forested, wooded and open), a wetland complex landform modifier (i.e., presence of permafrost or patterning) and a local landform modifier (including both landform and vegetative characteristics). The AWI has summarized wetland distribution by type across Alberta (Vitt et al., 1996), Saskatchewan (Vitt et al., 2001) and Manitoba (Halsey et al., 1997).

The AWI uses aerial photography as the primary remote sensing imagery input, with visual delineation of polygons around different wetland types. In Halsey et al. (2003), visual cues for aerial photo interpretation are given to distinguish various wetland classes and modifiers, including tone, texture, position in the landscape, elevation, and other features. This is in addition to on-the-ground interpretation of vegetation structure, both vertically (i.e., canopy and understory vegetation layers) and spatially (i.e., distribution of microhabitats).

### C.2.2 Enhanced wetland classification

Created by Ducks Unlimited Canada (DUC) and Ducks Unlimited, Inc. (DUI), the Enhanced Wetland Classification (EWC) system is a comprehensive wetland inventory developed for the boreal forest region (Smith et al., 2007). The classification system recognizes up to 19 minor (detailed) wetland types that conform to the five major wetland classes (CWCS; NWWG, 1997), as described in Smith et al. (2007). This wetland classification is currently used to help meet the data requirements of various government-led initiatives, including Water For Life, Land Use Framework Regional Planning, Alberta NAWMP, and the pending provincial wetland policy (Kershaw et al., 2011; in prep.).

Due to the complexity and diversity of wetlands in the boreal forest region of Alberta, the developers of the EWC chose to use medium resolution (30 $m^2$) satellite imagery (Landsat TM/ETM) as the most cost-effective and accurate way to provide resource managers, researchers, industry and other organizations with detailed information on the spatial distribution of wetland classes. The EWC focuses on wetland type and vegetation cover that are spectrally separable in remote sensing data in order to classify its wetlands. Described in Ducks Unlimited (2005), the methodology integrates two algorithms (i.e., a multi-resolution segmentation process and a classification process), giving more flexibility in the classification and allowing additional features beyond the spectral information of the satellite imagery to be used (i.e., additional datasets, proximity, texture, etc.). A decision hierarchy included to guide the wetland classification not only serves as a remote sensing-based guide for the image analyst, but also as an ecological guide to be used in the field.

### C.2.3 AWI/EWC classification strengths and limitations

Depending on the objectives of the mapping exercise and the scale of detection required, both the AWI and EWC have different strengths and limitations on the final products. The AWI, because it uses aerial photography as the primary remote sensing input, it is able to provide information at a much higher resolution, as compared to the EWC and its use of medium resolution satellite imagery (i.e., Landsat TM/ETM). Therefore, a mapping exercise for reclamation purposes that requires information at a more detailed level (i.e., wetland sizes, common attributes and where wetlands are distributed on the landscape) may be more suitable to the AWI and the use of higher resolution types of aerial photography. However, a number of disadvantages exist for using aerial photography, as opposed to medium resolution satellite imagery. Cost in general can be higher for aerial photography versus satellite imagery. In addition, because aerial photography provides a much higher resolution image, the complexity of the mapping exercise increases, resulting in a more intensive detailed look at a smaller geographic area. Using aerial photos does not allow for more automated processing, increasing overall mapping time. Finally, for remote areas in northern Canada, satellite-based imagery is often the sole data source available for classification. Therefore, the use of the AWI is restricted to where aerial photography is available. In comparison, by using medium resolution imagery, the EWC results in a more cost-effective product when mapping the complexity and diversity of boreal wetlands across a larger region. The EWC is better at capturing all the different wetland types in the boreal and their spatial extent in an area, particularly swamp systems (Ross et al. 2012). Although the 30 $m^2$ resolution of EWC is lower than can be mapped by the AWI, by providing high accuracy and detailed wetland information, the EWC provides a more comprehensive review across the boreal region and guides selection, and proportion, of the types of wetland to be focused on in a region or watershed for the reclamation process.

### C.2.4 Advantages and disadvantages of remote sensing data for wetland reclamation planning

A number of advantages and disadvantages must be considered when using wetland classification based on remote sensing data in the reclamation planning and wetland construction process. As a main advantage, any GIS data acquired for information purposes can be used in conjunction with other data sets - including geotechnical, hydrological, or topographical - to better inform the selection of wetland type to be reclaimed at the regional level, as well as the key characteristics to be reclaimed at the watershed and micro-level. In addition, wetlands can be classified specific to a region by identifying key vegetation patterns and therefore inform wetland reclamation potential appropriate to a particular landscape.

However, key limitations do exist with the use of GIS mapping products for reclamation purposes. Inferred products, including relative nutrient regime, soil moisture regime and hydrodynamic regime, can be created based on general groupings of wetland types (DUC, 2011). However, caution should be used when assigning wetland types to characteristic regimes, as there is an exception to every rule. For example, when considering open water wetland systems, a range of nutrient regimes exist (DUC, 2011). In addition, digital elevation models (DEMs) that map topography of the landscape are often used to give an understanding of the water-holding potential, or gradient of wetness, in an area. However, in the low-relief boreal plains, surficial geology and groundwater are more important controls on hydrology than topography and therefore need to be considered. These important controls are currently being studied in the boreal plains through on-the-ground research (Devito et al., 2012); however, GIS information describing these characteristics is limited at this time.

**Table C-1. Wetland class comparison between the Alberta Wetland Inventory (Halsey et al., 2003), Enhanced Wetland Classification (Smith et al., 2007), Cowardin et al. (1979) and National Wetland Classification System (NWCS; NWWG, 1997). Table modified from Smith et al. (2007).**

| AWI[6] | DU - EWC | Cowardin[7] | NWCS |
|---|---|---|---|
| Provincial | Ecozone | National | National |
| **Bog**, *Forested/ Wooded* | **Treed Bog** | **Palustrine**, *Forested Wetland*, Needleleaf Evergreen | Bog (w/subforms[1]) |
| **Bog**, *Open*, Shrub, | **Shrubby Bog** | **Palustrine**, *Shrub/Scrub*, Broad-leafed Evergreen or Needle-Leaved Evergreen | Bog (w/subforms[1]) |
| **Bog**, *Open*, Graminoid, | **Open Bog** | **Palustrine**, *Moss/Lichen or Shrub/Scrub*, Moss or Lichen or Broad-leafed Evergreen or Needle-Leaved Evergreen | Bog (w/subforms[1]) |
| **Fen**, *Forested/ Wooded*, | **Treed Rich Fen** | **Palustrine**, *Forested or Shrub Scrub*, Needle-Leaved Deciduous, Needle-Leaved Evergreen or Broad-leaved Deciduous | Fen (w/subforms[2]) |

| AWI[6] | DU - EWC | Cowardin[7] | NWCS |
|---|---|---|---|
| **Provincial** | **Ecozone** | **National** | **National** |
| | | (Shrub only) | |
| **Fen**, *Forested/ Wooded* | **Treed Poor Fen** | **Palustrine**, *Forested or Shrub Scrub,* Needle-Leaved Deciduous, Needle-Leaved Evergreen or Broad-leaved Deciduous (Shrub only) | Fen (w/subforms[2]) |
| **Fen**, *Open*, Shrub | **Shrubby Rich Fen** | **Palustrine**, *Shrub Scrub*, Needle-Leaved Deciduous, Needle-Leaved Evergreen, or Broad-Leaved Deciduous | Fen (w/subforms[2]) |
| **Fen**, *Open*, Shrub | **Shrubby Poor Fen** | **Palustrine**, *Shrub Scrub or Moss/Lichen*, Needle-Leaved Deciduous, Needle-Leaved Evergreen, or Broad-Leaved Deciduous or Moss | Fen (w/subforms[2]) |
| **Fen**, *Open*, Graminoid | **Graminoid Rich Fen** | **Palustrine**, *Emergent*, Persistent | Fen (w/subforms[2]) |
| **Fen**, *Open*, Graminoid | **Graminoid Poor Fen** | **Palustrine**, *Emergent or Moss/Lichen*, Persistent or Moss | Fen (w/subforms[2]) |
| **Swamp**, *Forested/ Wooded* | **Conifer Swamp** | **Palustrine**, *Forested*, Needle-Leafed Evergeen | Swamp (w/subforms[3]) |
| **Swamp**, *Forested/ Wooded* | **Tamarack Swamp** | **Palustrine**, *Forested*, Needle-Leafed Deciduous | Swamp (w/subforms[3]) |
| **Swamp**, *Forested/ Wooded* | **Mixedwood Swamp** | **Palustrine**, *Forested*, Needle-Leaved Evergreen, Broad-Leaved Deciduous | Swamp (w/subforms[3]) |
| **Swamp**, *Forested/ Wooded* | **Deciduous Swamp** | **Palustrine**, *Forested*, Broad-Leaved Deciduous | Swamp (w/subforms[3]) |
| **Swamp**, *Open*, Shrub | **Shrub Swamp** | **Palustrine**, *Shrub Scrub*, Broad-Leaved Deciduous | Swamp (w/subforms[3]) |
| **Marsh**, *Open*, Graminoid | **Emergent Marsh** | **Palustrine, Riverine, or Lacustrine**, *Emergent*, Persistent or Nonpersistent | Marsh (w/subforms[4]) |
| **Marsh**, *Open*, Graminoid | **Meadow Marsh** | **Palustrine, Riverine, or Lacustrine**, *Emergent*, Persistent or Nonpersistent | Marsh (w/subforms[4]) |
| Shallow-water | **Aquatic Bed** | **Palustrine, Riverine, or Lacustrine**, *Aquatic Bed*, Rooted Vascular or Floating | Shallow Water (w/Subforms[5]) |

| **AWI[6]** | **DU - EWC** | **Cowardin[7]** | **NWCS** |
|---|---|---|---|
| **Provincial** | **Ecozone** | **National** | **National** |
| | | Vascular | |
| Shallow-water | **Open Water** | **Palustrine, Riverine, or Lacustrine**, *Rock Bottom or Unconsolidated Bottom or Streambed*, Bedrock or Rubble or Cobble-Gravel or Sand or Mud or Organic | Shallow Water (w/Subforms[5]) |
| Shallow-water | **Mudflats** | **Palustrine, Riverine, or Lacustrine**, *Unconsolidated Shore*, Mud or Organic | Shallow Water (w/Subforms[5]) |
| Shallow-water | **Algae/ Eelgrass** | **Palustrine, Marine, Estuarine, Riverine, or Lacustrine**, *Aquatic Bed*, Algal or Rooted Vascular | Shallow Water (w/Subforms[5]) |

[1] NWCS Bog Subforms (Palsa, Peat Mound, Mound, Domed, Polygonal Peat Plateau, Lowland Polygon, Peat Plateau, Plateau (Atlantic and Northern), Collapse Scar, Riparian, Floating, Shore, Basin, Flat, String, Blanket, Slope, and Veneer)

[2] NWCS Fen Subforms (String, Northern Ribbed, Atlantic Ribbed, Ladder, Net, Palsa, Snowpatch, Spring, Feather, Slope, Lowland Polygon, Riparian, Floating, Stream, Shore, Collapse Scar, Horizontal, Channel, Basin)

[3] NWCS Swamp Subforms {Tidal (Freshwater, Saltwater), Inland Salt, Flat (Basin, Swale, Unconfined), Riparian (Lacustrine, Riverine, Floodplain, Channel), Slope (Unconfined, Peat Margin, Lagg, Drainageway), Mineral Rise (Beach Ridge, Island, Levee, Mound, Raised Peatland)

[4] NWCS Marsh Subforms {Basin (Discharge, Isolated, Linked), Estuarine (Bay, Delta, Lagoon, Shore), Hummock, Lacustrine (Bay, Lagoon, Shore), Riparian (Delta, Meltwater Channel, Floodplain, Stream), Slope, Spring, Tidal (Basin, Bay, Channel, Lagoon)

[5] NWCS Shallow Water Subforms {Basin (Discharge, Isolated, Linked, Polygon, Thermokarst, Tundra), Estuarine Water (Basin, Bay, Channel, Delta, Lagoon, Shore), Riparian Water (Delta, Floodplain, Meltwater, Stream), Tidal (Basin, Bay, Channel, Lagoon, Shore)

[6] AWI Subclasses (local landform modifier) here pertain primarily to peatland classes only.

[7] Consideration for System (**Bold**), Class (*Italic*), and Subclass (Normal) only; Sub-system (applies only to emergent, aquatic bed, and open water BPWCS classes), Dominance Type, and Modifiers (Water Regime, Water Chemistry, Soil, Special) were not considered for this table for the sake of brevity and the detail of information required.

### C.2.5 Using temporal coverage of remote sensing products

When utilizing any remote sensing product, whether it's aerial photography or satellite imagery, one consideration to be made is the use of temporal coverage, in addition to spatial resolution. A remote sensing image provides landscape information at a single point in time; however, multiple images of the same location collected over time (i.e., ice free period) provide additional information on changes in the landscape. The temporal coverage of any imagery/remote sensing product can provide additional information on variables such as hydroperiod, vegetation cues, and land use changes; however, it is also a useful tool to ensure areas are mapped correctly. In the case of aerial photography, the temporal coverage that can be acquired is limited only by budget. In comparison, the temporal coverage at which satellite imagery can be collected is dependent on the platform being used and whether it is passive (i.e., a signal receiver) or active (i.e., a signal sender). Landsat satellite imagery, although free, collects images on a scheduled basis and may or may not be suitable to the mapping project's design, depending on the resolution required and the limitations that cloud cover or season might place on acquiring images. Various high resolution commercial satellites (e.g., WorldView), on the other hand, can be programmed to collect images on a scheduled basis, at a cost. However, collection is dependent on a number of factors, including weather and cloud cover, a key limiting factor in the north. Therefore, there is no guarantee for successful collection for pre-programmed schedules.

Medium resolution satellite imagery can provide a broad sense of the hydroperiod to expect in different wetland types. For shallow open water systems or marshes in the boreal where there is significant hydrological variability, remote sensing imagery collected over time can provide additional hydrological information. However, hydrological changes are harder to detect in wetland systems where there is limited surface water (e.g., conifer swamps, bogs). Clark et al. (2009) demonstrated the ability of European Remote Sensing (ERS) satellites to map the probability of hydrologically sensitive areas (HSAs) within a watershed. However, where knowledge of hydroperiod of a specific site is required in the reclamation process, mapping products are not a substitute for, and can be enhanced in conjunction with, on-the-ground fieldwork and hydrological monitoring in an area.

Temporal coverage in any mapping product can provide additional confidence in correctly identifying wetlands in the boreal landscape. As wetland classification systems identified in this chapter (i.e., AWI, EWC) focus on vegetation as one of the defining characteristics of wetland type, the timing of remote sensing products is key to classifying correctly. For vegetated wetland types, focusing on imagery during the peak growing season (i.e., July/August), prior to the start of senescence, is important in order to receive the appropriate spectral response signature from vegetation. For example, often into September (depending on latitude and year to year climatic differences), the leaves of bog birch have turned, resulting in a change in their spectral response. However, in the case of tamarack swamps, capturing imagery later in the fall during senescence, but prior to leaves falling off, can aid in the interpretation. Treed wetlands may also be more easily identified from uplands using imagery in early winter, to detect spruce/pine coverage, and then integrating a DEM to identify low lying areas. Overall, the quality of the imagery collected, and one's ability to discern certain features to be interpreted, will be affected by atmospheric conditions and sun angle, which can vary by season. Therefore, timing of collection is an important consideration for any mapping product.

The temporal coverage of the imagery being used may also aid in wetland classification in areas with recent burns, which are difficult areas to map. Fires don't discriminate between upland and most wetland areas, and different types of wetland vegetation burn. This leads to the new spectral response of the region limiting not only the identification of the type of wetland that previously existed, but also where the wetland occurred, as compared to an upland area. In addition, although knowledge of the type of wetland that was present prior to a burn may exist, occasionally changes in wetland type follow post-burn. Going back to dated imagery prior to a burn is possible to address this limitation. Therefore, special consideration regarding classification needs to be made in burn areas.

### C.2.6 Gap analysis of remote sensing in the boreal region of Alberta

Valuable information on the type and distribution of wetlands in an area can be achieved with quality wetland mapping. This information can be used not only to guide wetland reclamation activities, but has aided in various boreal projects, including site selection and development of a regional wetland monitoring program in the oil sands area (Ciborowski et al., 2012) and calving habitat selection of boreal caribou (DeMars et al., 2011). However, in order to assist in the reclamation process, a number of gaps exist that limit the applicability of GIS mapping products at this time.

For all classifications and their mapping products, there are spatial levels at which each system's resolution presents limitations of use. One example of this are small, temporal boreal wetlands that exist within upland forested areas. These systems are currently unmapped and potentially un-mapable using remote sensing, because of tree cover; however, they have been identified as being critically important (i.e., similar to prairie systems), in terms of hydrology, by linking the water table from wetland to upland systems. By missing these small wetland systems at the watershed level, properly identifying these links with the water table may be difficult with medium resolution. However, the possibility of identifying these links can be enhanced by incorporating analyses focused on hydrologic responses along with higher resolution imagery and other techniques such as stereo-pairs or radar.

More detailed information on the extent, configurations, sizing and distribution of wetlands by type in the mineable oil sands region is also lacking, although potentially useful in the reclamation process. As wetlands in the boreal region are interconnected, existing largely as complexes, in addition to individual basins, their complexity leads to difficultly in defining these systems not only at a regional scale, but also a watershed scale. Although the reclamation process requires information at the watershed level, as well as the relationship between surficial geology, regional groundwater and vegetation response, all GIS mapping systems are currently limited at providing this detailed information. A concerted, focused effort may have existed in specific oil sands leases to map key information and features using high resolution imagery, in order to help guide reclamation opportunities. However, caution should be used when making comparisons across different site-specific inventories, as inconsistencies may exist, in terms of the classification system used and the imagery interpretation of what was there by different groups.

## C.3 Recommendations for mapping in the oil sands region

After consideration of the current limitations that exist with respect to wetland mapping in the oil sands region, the following is a summary of recommendations to follow prior to acquiring remote sensing data for reclamation purposes:

1. Outline the wetland mapping goals and objectives: In order to provide the desired results from any wetland mapping product, outlining the goals and objectives will assist in the appropriate selection of a classification system, type of imagery, resolution of imagery and timing of imagery.

2. Consider the scale of work: The scale of mapping, for any wetland mapping exercise, should provide an understanding of not only the site specific area but also consider the regional context necessary to understand the wetland system.

3. Integrate other spatial information: Additional spatial information where available, including geotechnical, topographical or hydrological information, can aid in the classification process. However, any inferred product should be used with caution and attention to their methods of generation and purpose, as not all wetland types fit into characteristic regimes.

4. Consider the history: Temporal coverage of imagery can provide additional information on variables such as hydroperiod, vegetation cues, and land use changes, as well as be a useful tool to ensure areas are mapped correctly. However, with wetland reclamation in the oil sands, considering the temporal coverage of imagery can provide a wetland inventory of the pre-disturbance landscape. Reclamation interests should factor in the landscape that was originally there, particularly for hydrological considerations, in terms of discharge areas vs. recharge areas.

5. Consider connectivity: As wetlands in the boreal region are interconnected, existing largely as complexes, understanding connectivity (i.e., surface and subsurface) and how it functions on the landscape is an important consideration in the reclamation success of wetlands and their ability to exist and function properly.

6. Ground-truthing: Mapping products should not be considered as a substitute for on-the-ground fieldwork. Therefore, ground-truthing is important to confirm the accuracy of wetland mapping.

## C.4 Next steps for wetland mapping

Currently, there is a definite gap between the details required for on-the-ground decisions for wetland reclamation and what is available from wetland mapping data. This gap exists largely due to differences in expectations of the wetland reclamation design team and current technical constraints of remote sensing products. Being able to typify one wetland over another wetland is not only fraught with ecological/biological challenges but there is also difficulty in incorporating any system or watershed functioning. The increased availability of remote sensing data and more sophisticated feature extraction methods are leading to more accurate mapping that will continue to provide more detailed wetland and upland mapping products. However, in order to aid in the use of remote sensing products for wetland reclamation in the boreal region, there are a number of next steps to be taken:

- Details needs to be provided on classification methodology and its accuracies: As described in this chapter, a number of wetland classification methodologies exist for the Alberta boreal region. By providing detail on classification methodology and the associated accuracies, comparisons between inventories can more easily be made. In addition, by having an understanding of each classifications current limitations or inaccuracies, prioritizations for furthering wetland mapping for reclamation can be made.

- Standardized classification should be used, including the pending Alberta Wetland Classification System. Coordinated wetland mapping/monitoring projects are essential to understand wetland systems in the boreal. By setting mapping standards (i.e., scale, classification, accuracies and minimum mapping unit) and ensuring the classification used is exclusive and exhaustive for the region, a focus on the advancement of wetland mapping to aid in reclamation planning can be made.

# Appendix D
# Wildlife in Wetlands

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## D.1 Habitat for culturally important species and species-at-risk

One of the overarching goals for reclamation in the mineable oil sands region of Alberta is that there is no net loss in habitat for species-at-risk. Further, reclamation should serve the needs of aboriginal peoples by re-establishing habitat for culturally important species, such as moose and beaver. Fifty-three sensitive, at-risk, and culturally important species in the mineable oil sands region of Alberta have been identified from multiple sources (Table D-1). Since each species has its own niche and therefore its own habitat requirements (Hutchinson, 1957, 1959; Chase and Leibold, 2003; Holt, 2009), it is impractical to design reclaimed wetlands to explicitly meet each species' needs. Moreover, the "Field of Dreams" hypothesis to reclamation – which assumes that if you create the physical structure of a wetland, then the appropriate biotic community will develop (e.g. "if you build it, they will come") – is often ineffective; Hilderbrand et al. (2005) describe this as one of the myths of restoration ecology. Eaton and Fisher (2011) offer an empirical approach to designing wetlands that may maximize the chances of having a focal species recolonize a reclaimed wetland, but this approach requires extensive analysis and design recommendations tailored for each species. Further, designing a wetland for one species might make it unsuitable for another, though equally desired, species.

The problem of designing reclaimed wetlands for specific species is also one of scale. For most species in Table D-1 wetlands are one small component of their total habitat requirements. Many species use habitats at spatial scales beyond those captured in reclaimed wetland design. Most notably, whooping crane, bison, moose, and caribou populations are influenced by factors measured at spatial scales well beyond the reclaimed wetland (Wallace et al., 1995; Fortin et al., 2003; Dussault et al., 2005, 2006; Boyd et al., 2008). Indeed, for caribou functional habitat is lost due to increased predation (Wittmer et al., 2005; Wittmer et al., 2007; Sorensen et al., 2008; Latham et al., 2011; Whittington et al., 2011) – a regional-scale problem that no reclaimed wetland design can fix.

Throughout this manual we advocate a practical, holistic, wildlife community-based approach that seeks to maximize the chances that diverse communities will recolonize a reclaimed wetland and its landscape: a functional wetland has high structural complexity, habitat heterogeneity, and high biodiversity (Zedler, 2000; Zedler and Kercher, 2005; Reich et al., 2012). Reclaimed wetlands designed to emulate these characteristics are more likely to support local wildlife populations; they are also expected to increase chances of colonization by sensitive and at-risk species. Importantly from a regulatory perspective, none of the community-scale recommendations is expected to exclude sensitive or at-risk species from reclaimed habitats. The argument can therefore be reasonably made that by reclaiming for diverse, functional wetlands, we are reclaiming *potential* habitat for these focal species. Realistically, given the relatively poor state of our existing knowledge of wetlands in boreal Alberta (Eaton and Fisher, 2011), this is the best we can presently do, but it provides a good basis for reclamation and future research on techniques and strategies that would enhance the probability of reclaimed wetlands supporting focal species. An iterative cycle of designing, implementing, monitoring, assessing and modifying approaches is an integral part of an adaptive management approach and is one which we strongly advocate for wetland reclamation.

A brief analysis of the most sensitive, aquatic-dependent species illustrates that the best wetland design recommendations for these species are generally the same as those we recommend for maximizing biodiversity as a whole. In addition, landscape-scale considerations are critical for many wetland-dependent species that rely on other habitat types (e.g. upland forest) to fulfill many of their needs (e.g. foraging habitat, overwintering sites); these include many culturally important species and species-at-risk.

Here we provide a brief account of the habitat needs of several species, or species groups. The approach we advocate is to consider general wetland and landscape design principles that would support a functional, biodiverse ecosystem, then examine the habitat needs of species of interest to determine if additional actions are necessary to increase the chance these species will colonize and persist in the reclaimed wetland or landscape. Note that this approach will not exclude any species, which could occur if a species-specific approach to reclamation was adopted.

### D.1.1 Beavers

Beavers (*Castor canadensis*) forage on land but live in water, making the wetland-terrestrial interface critical to their survival. Beavers require minimum water depths for overwintering, and will often engineer their environment to provide that habitat (Naiman et al., 1988). Beavers also require sufficient trees for forage. In Ontario boreal forests, Barnes and Mallik (1997) found that upstream watershed area and stream cross-sectional area were more important predictors of beaver dam occurrence than streamside vegetation. However streamside vegetation is still considered important by most researchers. Gallant et al. (2004) examined beaver selection of tree species in boreal forests of New Brunswick, and showed that some species are selected by beavers over others.

Gallant et al. (2004) also demonstrated that beavers' selection of plant species changed with increasing distance from the pond, suggesting that tree species distribution with respect to the pond edge can influence beaver foraging. Though the Maritime Plain forests where Gallant et al.'s (2004) research occurred has a greater deciduous diversity than Alberta boreal forests, willow (*Salix* spp.), trembling aspen, pin cherry, beaked hazelnut, and *Rubus* species all occur extensively in northern Alberta, are highly selected by beavers, so are candidate species for wetland reclamation.

### D.1.2 Muskrats

Very little pertinent empirical information exists on muskrat (*Ondatra zibethicus*) habitat selection. Virgl and Messier (1997) found that food was not a key limiting factor of muskrat demography. Muskrats occur in most wetland types across their range, living either in burrows or constructed lodges, and habitat selection may vary based on which shelter they use. Nadeau et al. (1995) found that bank slope, percent of floating and submerged vegetation, soil type, and width of shore vegetation were important predictors of burrowing muskrat occurrence. Slow-moving rivers represented preferred habitats. The site characteristics established by Nadeau et al. (1995) could be applied to generate wetland reclamation requirements for muskrats in boreal Alberta, though the outcome of this application is highly uncertain given the paucity of knowledge of muskrats' habitat requirements in general. Monitoring of sites with different characteristics would be required to determine the efficacy of habitat reclamation designs.

### D.1.3 River Otters

River otters (*Lontra canadensis*) are semi-aquatic mammals inhabiting rivers, streams and lakes across North America. They are generalist predators, and so will consume a variety of prey. In northeastern Alberta, fish (mostly abundant shallow-water fish such as catostomids and cyprinids) dominate river otters' diets (Reid et al., 1994). In summer they also eat insects, molluscs, crustaceans, and occasionally waterfowl, but in winter are restricted mostly to fish. Reid et al. (1994) suggested that access to prey was more limiting to otter occurrence than the abundance of any prey species, and hypothesized (but did not prove) that winter selection of water bodies with access to prey – characterized by shoreline substrate and morphology – predicted otter occurrence.

Gallant et al. (2008) instead suggested that shelter (for predation avoidance and thermal regulation) was the primary driver of otter occurrence. Though otters forage in water they require terrestrial shelters, so the water-land interface is key to river otter persistence. Shelters are typically naturally existing landforms such as hollows, animal burrows, and tree-root overhangs. Gallant et al. (2008) examined winter habitat selection by otters in boreal New Brunswick and found that river otters occurred less frequently in areas where open habitats (fields) extended to the water edge; otters selected areas with a high degree of vegetation and treed cover adjacent to the water's edge. Beaver ponds were the important predictor of otter occurrence, though in conjunction with streamside vegetation characteristics. LeBlanc et al. (2007) also found that otter activity on the same beaver ponds in New Brunswick was associated with the presence of beavers, pond size, and vegetation cover. Beavers impound water and create a stable water reservoir, generating a prey base for otters as well as a heterogeneous bank that provides shelter sites.

Quantitative stream- or pond-bank characteristics are associated with higher otter occurrence in boreal systems and are available from the literature (Leblanc et al. 2007; Gallant et al. 2008). Together these indicate that the most likely predictor of otter occurrence post-reclamation is the persistence of beavers and active dams with relative deep water levels, stable impoundment, and a densely vegetated and treed stream bank.

### D.1.4 Moose

Much research has been devoted to the habitat preferences of moose (*Alces alces*). Moose prefer young stands with abundant browse, whether they are of post-fire or post-harvest origin (Fisher and Wilkinson, 2005). Moose abundance in a stand is highest in the first decade following disturbance, then decreases through time, but increases again in old-growth stages when the canopy breaks up and understory vegetation is re-introduced in the stand (Fisher and Wilkinson, 2005). The stand types that moose select change as their availability on the landscape changes; deciduous uplands are selected in some areas of boreal Alberta whereas open conifer wetlands are selected in other areas (Osko et al., 2004). Habitat selection also differs between males and females, and across spatial scales (Dussault et al., 2006; Herfindal et al., 2009). At the landscape scales, predation risk and snow shelter are also important predictors of moose habitat (Dussault et al., 2005), though the relationship between these parameters and forest-stand characteristics is not easily extrapolated across landscapes.

Several models exist that relate stand vegetation characteristics to moose occurrence or abundance, though these remain quite general in nature. Allen et al. (1987) and Osko et al. (2004) devised HSI models for moose that have been subsequently modified for northeastern Alberta by J. Fisher (2004; unpublished) for CEMA-SEWG, and by Kirk et al..(2008) for Alberta's Lower Athabasca Regional Plan. In general terms, this model assumes:

- Forage occurs most abundantly in young seral stage deciduous stands, < 20 years old.
- Forage and cover also occurs in upland mixedwood forests > 20 years old.
- Cover is optimum in conifer stands > 20 years old.
- Untreed wetland provides alternative forage such as bog-dwelling or aquatic plants (see also MacCracken et al., 1993).
- Habitat is unsuitable adjacent to dwellings, road access, snowmobile routes, and communities.

### D.1.5 Woodland Caribou

Woodland caribou (*Rangifer tarandus caribou*) are the subject of extensive conservation efforts and controversy in Alberta. The boreal ecotype occurs throughout Alberta's northeast, including the oil sands region, and was a primary consideration in Alberta's Lower Athabasca Regional Planning process. As a controversial species that is listed as at-risk throughout much of its range, much research has been devoted to caribou habitat selection (e.g., Courtois et al., 2007; Fortin et al., 2008; Hins et al., 2009).

Hins et al. (2009) found that caribou avoided younger seral stages and selected for mature forest. Similarly, disturbed landscapes increased home-range size (thus increased energy demands and reduced reproduction of caribou in boreal Quebec (Courtois et al., 2007). Fortin et al. (2008) showed that Quebec woodland caribou habitat selection changes across latitudinal and longitudinal gradients. Caribou selected lichen habitats in the east and avoided them in the west. Caribou selected mature conifer forests in the north and avoided them in the south. Fortin et al.'s (2008) findings demonstrate the sometimes ecosystem-specific nature of habitat relationships, and why it is often unreliable to extrapolate habitat relationships from one area to another.

Woodland caribou in Alberta primarily eat lichen through the winter, so the availability of lichen has been suspected to influence caribou distribution (Dunford et al., 2006). However, food availability generally does not limit caribou survival and reproduction (e.g., Courtois et al., 2007). It is now widely recognized that predation risk, not food, limits caribou populations (McLoughlin et al., 2003; Bergerud, 2006). This may be reflected in habitat selection by individual caribou; in Québec, Briand et al. (2009) found that female caribou selected habitat based on both food availability and predation avoidance.

Sorensen et al. (2008) modelled caribou population change and functional habitat loss for six populations of boreal caribou in Alberta. They found that rate of caribou population change was best explained by the percentage area of caribou range within 250-m of anthropogenic footprint and the percentage of caribou range disturbed by fire in the last 50 years. This was confirmed by additional modelling by S. Boutin and C. Arienti for the LARP process (Fisher et al., 2009). Predation is a range-wide ecological process, not a local site-specific process, so could not realistically be managed by designing reclaimed wetland habitats. Sorensen et al. (2008) and the accumulating body of similar work show that the best way to increase caribou occupation of reclaimed lands is to isolate these lands from anthropogenic footprint – by reclaiming disturbed lands over large areas within caribou ranges.

### D.1.6 Waterfowl

The boreal region of Alberta is an important area for waterfowl for nesting and brood rearing, moulting, and migrating in the spring and fall periods. Waterfowl that occur on a regular basis in the mineable oil sands region include dabbling ducks, diving ducks, geese and swans (Wiacek et al., 2002). Densities of breeding birds, including waterfowl, in boreal areas of western Canada have declined in recent years (Cumming et al., 2001; Corcoran et al., 2007; Haszard and Clark, 2007), resulting in increasing research into the habitat needs of waterfowl species in the boreal region, where relatively little of this work has been done.

More specific information relevant to the boreal region is recently appearing in the literature. For example, recent work on the white-winged scoter has indicated that scoters avoid graminoid habitat for nesting, but select for sites nearly randomly within scrub and forest habitats, as long as those sites have certain local attributes (e.g. dense cover, close to edge (< 120 m) and water (mean of 142.7 m); Safine and Lundberg, 2008). Use of wetlands by white-winged scoter pairs and broods was also related to abundance of amphipods in a lake, with higher levels of scoter abundance on wetlands with high amphipod abundance (Haszard and Clark, 2007). Together these results suggest that both prey availability and predator avoidance are key components of white-winged scoter habitat.

Abundance of amphipods was also found to influence water body use of lesser scaup in the Northwest Territories; pond area and depth, probably related to availability of habitat and larger populations of invertebrate prey, also had strong influences on wetland use by this species (Walsh et al., 2006). Fast et al. (2004) found a similar pattern, as well as a positive association between scaup abundance and the occurrence of yellow water lily at a site. In the boreal forest of Alaska, Corcoran et al. (2007) found that nest success was highest on wooded creeks, and lower on small (<10 ha) and large (>10 ha) wetlands. However, creeks were rarely used as brood rearing habitat, and hens sometimes moved their broods from creeks and small wetlands to larger wetlands for rearing (Corcoran et al., 2007). As for scoters, scaup appear to select habitats that provide prey and minimise predation risk.

Developing recommendations for waterfowl habitat reclamation based on species-habitat associations will be complex, as each species has its own habitat requirements – a fundamental tenet of niche theory. However, some general patterns relating groups of species to habitat characteristics have been discovered. For example, Lemelin et al. (2010), working in boreal Quebec, found that small (!8 ha), connected ponds were selected by 10 species of breeding waterfowl, and that seven of these species made extensive use of wooded streams as well; islands on lakes were also selected by several species, potentially as predator-free nesting sites. An examination of the presence of waterbirds on 113 lakes in the boreal transition zone of Alberta found that different groups responded to different lake parameters (Found et al., 2008). Logistic regression models of occurrence for several waterfowl species revealed that presence of fish, extent of lakeshore where emergent macrophytes occurred, lake depth, water clarity, and presence of a riparian buffer were major explanatory variables (Found et al., 2008). Similar associations between aquatic bird guild composition and lake parameters (lake area, maximum depth, water color, pH, fish assemblage, and slope of the lake catchment) were found for 41 eutrophic lakes at the southern edge of Alberta's boreal forest (Paszkowski and Tonn, 2006).

These studies, taken together, suggest that there are statistical species-habitat relationships for guilds of waterbirds that quantify the effect of general habitat variables on occurrence. These may be mediated by more specific needs for individual species. Designing wildlife habitat reclamation guidelines for aquatic landforms will be informed by both guild and individual species habitat associations.

### D.1.7 Canadian Toad

Few amphibians occur in the mineable oil sands region of Alberta (Russell and Bauer, 2000). Of those that do, the Canadian toad (*Anaxyrus hemiophrys*, formerly *Bufo hemiophrys*) has the most specific habitat needs, and is therefore the most vulnerable to disturbance. This species requires standing water for breeding, habitat for foraging, and corridors to allow movement between these habitats. The Canadian toad is not a freeze tolerant species, and so requires very specific habitat for hibernation (Kuyt, 1991). Recent research from Alberta suggests that toad hibernation sites may be limiting (Garcia et al., 2004; Golder, 2005a, b; Constible et al., 2010), and that toads may move up to 1 km from ponds to reach these sites (Garcia et al., 2004). The low dispersal ability of Canadian toads (Beiswenger, 1986), the need for suitable overwintering sites (Kuyt, 1991), and their extensive use of upland forested habitat (Constible et al., 2010) may make them vulnerable to changes in terrestrial habitats (Hamilton et al., 1998; Constible et al., 2010).

To support habitat management to conserve Canadian toad populations in the Athabasca Oil Sands Region, as well as to provide an understanding of habitat requirements for this species during the reclamation of mining areas, Golder (2006) summarized habitat association information available on the Canadian toad to date and used this information to develop a regional Habitat Suitability Index (HSI) model for this species in northeast Alberta. Golder (2006) based their regional HSI model on spatial data for a number of landscape features, including surficial geology, soil textures and parent materials, vegetation data (Alberta Vegetation Inventory – AVI), and hydrography with updated stream order classification (Strahler Order). The Golder model describes year-round suitability for Canadian toads, with over-wintering habitat being given a higher weighting than breeding habitat. The model makes the following assumptions: (1) over-wintering habitat is a critical factor determining toad distribution; (2) over-wintering habitat is defined solely based on the availability of coarse-textured soils; (3) optimal toad habitat occurs within 1000 m of over-wintering habitat; (4) all waterbodies within 1000 m of over-wintering habitat are suitable for breeding; (5) permanent waterbodies are more likely to support successful toad reproduction, and are therefore given higher suitability ratings; ephemeral waterbodies suitable for breeding are difficult to detect using remote sensing, so overwintering habitat without a water source within 1000 m is still considered to provide toad habitat.

The Canadian toad requires very specific habitat for hibernation, usually consisting of loose sand or gravel substrate in which individuals can burrow (Kuyt 1991). Coarse-textured soils are likely the only substrates suitable for over-wintering by the Canadian toad, and the Alberta Vegetation Inventory (AVI) database was used to model the occurrence of these substrates. Since Canadian toads breed in most types of water bodies, potential breeding habitat was modeled as all permanent waterbodies and vegetation types associated with standing water in the spring. The habitat needs of Canadian toads outside of the breeding season and for overwintering are not fully understood, but radio-tracking studies have suggested that toads are often found in areas with at least 25% graminoid and forb cover (Golder, 2005b). Therefore, 25% graminoid and forb cover was used as the lower threshold for optimal post-breeding forage/cover habitat in the HSI model (Golder, 2006). These habitat types were modelled using vegetation types derived from AVI data.

Recent work using radio-tracking to document habitat use by Canadian toads in north-eastern Alberta (Constible et al., 2010) suggests that adult toads spend significant amounts of their active period in wetlands (" 44.4%), but also use upland habitats (e.g. forest, cutblocks) much of the time. Upland forests may be important for hibernation habitat and as corridors for toads moving between wetlands. These authors observed three toads at putative hibernacula; these sites had firm packed sandy soil, little tree cover, and were elevated above the surrounding area on significant slopes. These sites were 654 – 1386 m from the local breeding lake, suggesting toads move considerable distances between hibernacula and breeding habitats.

Work in the boreal foothills of Alberta on other amphibian species (wood frog, western toad (*A. boreas*)), suggests that beaver ponds are important as breeding habitat (Stevens et al., 2007); therefore, creation of ponds by beaver may result in establishment of healthy amphibian populations in an area. Older beaver ponds are especially attractive as amphibian habitat, so increased local amphibian density would be expected as reclaimed sites age (Stevens et al., 2006). The importance of beaver ponds to amphibians has been documented elsewhere as well; Karraker and Gibbs (2009) found that these habitats could produce 1.2–23 times as many wood frogs as vernal pools did in their study area in the northeastern United States.

In summary, existing information on Canadian toad habitat needs suggests that reclamation of oil sands mining areas must include wetlands suitable as breeding sites interspersed with forested uplands that provide overwintering habitat. A number of studies suggest that a range of wetland sizes and hydroperiods are necessary to support the full amphibian community across a landscape (Lehtinen and Galatowistsch, 2001; Pechmann et al., 2001; Baldwin et al., 2006b; Petranka and Holbrook, 2006). In addition, these types of habitats must be linked with suitable corridors for amphibian movement, which will be essential not only for reaching overwintering sites, but also for connectivity between local populations (Harper et al., 2008). These factors should be taken into account when designing wetland reclamation projects, especially at a landscape scale.

### D.1.8 Horned grebe

Horned grebes are diving birds that do not walk well on land, making them a wetland-dependent species (as reviewed in Kuczynski, 2009). They are generalist predators that feed on both fish and invertebrates; they forage and nest in the water. Despite some basic natural history (Stedman, 2000), little is known of horned grebes' habitat requirements. In Alberta, expansive, undisturbed emergent vegetation at the wetland edge is key habitat for nesting grebes (Kuczynski, 2009; Kuczynski et al., 2012). Lower densities of submerged macrophytes increases the chances that grebes use reclaimed ponds; grebes may also avoid active beaver ponds (Kuczynski, 2009).

In summary, based on what little we know, a wetland with a variable-depth basin profile and hydrologic connectivity will provide deep areas for fish and shallow areas for insects and emergent vegetation; together these will maximise the chances of supporting horned grebes. These wetlands should have an irregular shape to maximize the perimeter-to-area ratio, with gently sloping peripheries that allow abundant emergent vegetation. These design characteristics are also recommended for maximizing plant, insect, bird, and amphibian diversity.

**Table D-1. A list of sensitive, at-risk, and priority species potentially occurring in reclaimed wetland habitats in the mineable oil sands region. Note that species occurrence, as presented here, may not reflect recent information collected by the monitoring programs of individual companies operating in the oil sands region, data collected during EIAs, or other sampling efforts. Species occurrences in this table are limited to the sources in the footnotes. .**

| Common Name | Scientific Name | AESRD Status[1] | COSEWIC Status[2] | CEMA priority species[3] | | Species of cultural value[4] | Observed in OSR wetlands[5] |
|---|---|---|---|---|---|---|---|
| | | | | #1 | #2 | | |
| **Amphibians** | | | | | | | |
| **Canadian Toad** | *Anaxyrus hemiophrys* | May be at risk | Not at risk | x | | x (toads as a group) | x |
| **Western Toad** | *Anaxyrus boreas* | Sensitive | Special Concern | | | x (toads as a group) | |
| **Northern Leopard Frog** | *Lithobates pipiens* | At risk | Special Concern | | | x (frogs as a group) | |
| **Reptiles** | | | | | | | |
| **Red-sided Garter Snake** | *Thamnophis sirtalis* | Sensitive | | | | | x |
| **Birds** | | | | | | | |
| **Common Loon** | *Gavia immer* | Secure | Not at risk | | | | x |
| **Pied-billed Grebe** | *Podilymbus podiceps* | Sensitive | | | | | x |
| **Western Grebe** | *Aechmophorus occidentalis* | Sensitive | | | | | x |
| **Horned Grebe** | *Podiceps auritus* | Sensitive | Special Concern | | | | x |
| **American White Pelican** | *Pelecanus erythrorhynchos* | Sensitive | Not at risk | | | | x |
| **Great Blue Heron** | *Ardea herodias* | Sensitive | | | | | x |
| **American Bittern** | *Botaurus lentigenosis* | Sensitive | | | | | x |

| Common Name | Scientific Name | AESRD Status[1] | COSEWIC Status[2] | CEMA priority species[3] | | Species of cultural value[4] | Observed in OSR wetlands[5] |
|---|---|---|---|---|---|---|---|
| | | | | #1 | #2 | | |
| **Ducks and Geese (as a group)** | | | | | x | x | x |
| **Canada Goose** | *Branta canadensis* | Secure | | | | | x |
| **Mallard** | *Anas platyrhynchos* | Secure | | | | | x |
| **Northern Pintail** | *Anas acuta* | Sensitive | | | | | x |
| **Green-winged Teal** | *Anas crecca* | Sensitive | | | | | x |
| **Blue-winged Teal** | *Anas discors* | Secure | | | | | x |
| **American Wigeon** | *Anas americana* | Secure | | | | | x |
| **Northern Shoveler** | *Anas clypeata* | Secure | | | | | x |
| **Redhead** | *Aythya americana* | Secure | | | | | x |
| **Ring-necked duck** | *Aythya collaris* | Secure | | | | | x |
| **Lesser Scaup** | *Aythya affinis* | Sensitive | | | | | x |
| **Common Goldeneye** | *Bucephala clangula* | Secure | | | | | x |
| **Bufflehead** | *Bucephala albeola* | Secure | | | | | x |
| **White-winger Scoter** | *Melanitta fusca* | Sensitive | | | | | x |
| **Bald Eagle** | *Haliaeetus leucocephalus* | Sensitive | Not at risk | | | | x |
| **Northern Harrier** | *Circus cyaneus* | Sensitive | Not at risk | | | | x |
| **Osprey** | *Pandion haliaetus* | Sensitive | | | | | x |
| **Sandhill Crane** | *Grus canadensis* | Sensitive | | | | | x |
| **Sora** | *Porzana carolina* | Sensitive | | | | | x |
| **Yellow Rail** | *Coturnicops noveboracensis* | Undetermined | Special concern | | | | |
| **Upland sandpiper** | *Bartramia longicauda* | Sensitive | | | | | |
| **Buff-breasted Sandpiper** | *Tryngites subruficollis* | Secure | Special Concern | | | | |
| **Black Tern** | *Chlidonias niger* | Sensitive | Not at risk | | | | x |
| **Caspian Tern** | *Hydroprogne caspia* | Sensitive | | | | | x |
| **Forster's Tern** | *Sterna forsteri* | Sensitive | Data deficient | | | | |

| Common Name | Scientific Name | AESRD Status[1] | COSEWIC Status[2] | CEMA priority species[3] | | Species of cultural value[4] | Observed in OSR wetlands[5] |
|---|---|---|---|---|---|---|---|
| | | | | #1 | #2 | | |
| **Short-eared Owl** | *Asio flammeus* | May be at risk | Special concern | | | x<br>(owls as a group) | x |
| **Common Nighthawk** | *Chordeiles minor* | Sensitive | Threatened | | | | x |
| **Least Flycatcher** | *Empidonax minimus* | Sensitive | | | | | x |
| **Olive-sided Flycatcher** | *Contopus cooperi* | May be at risk | Threatened | | | | x |
| **Purple Martin** | *Progne subis* | Sensitive | | | | | |
| **Tennessee Warbler** | *Vermivore peregrine* | Secure | | | x | | x |
| **Cape May Warbler** | *Dendroica carulescens* | Sensitive | | x | | | x |
| **Black-throated Green Warbler** | *Dendroica virens* | Sensitive | | x | | | x |
| **Blackburnian Warbler** | *Dendroica fusca* | Sensitive | | | | | |
| **Common Yellowthroat** | *Geothlypis trichas* | Sensitive | | | | | x |
| **Canada Warbler** | *Wilsonia canadensis* | Sensitive | Threatened | | x | | x |
| **Rusty Blackbird** | *Euphagus carolinus* | Sensitive | Special concern | | | | x |
| **Mammals** | | | | | | | |
| **American Beaver** | *Castor canadensis* | Secure | | | x | x | x |
| **Moose** | *Alces alces* | Secure | | x | | x | x |
| **Muskrat** | *Ondatra zibethicus* | Secure | | x | | x | x |
| **Northern River Otter** | *Lutra canadensis* | Secure | | | x | x | x |
| **Wood Bison** | *Bison bison athabascae* | At risk | Special concern | | | | x |
| **Woodland Caribou** | *Rangifer tarandus caribou* | At risk | Threatened | x | | x | x |

[1] Alberta Environment and Sustainable Resource Development (AESRD) general status of wildlife; http://esrd.alberta.ca/fish-wildlife/species-at-risk/albertas-species-at-risk-strategy/general-status-of-alberta-wild-species-2010/default.aspx. Accessed January 15, 2014.

[2] Committee of the Status of Endangered Wildlife in Canada (COSEWIC) status; http://www.cosewic.gc.ca/eng/sct5/index_e.cfm. Accessed January 15, 2014.

[3] Westworth Associates Environmental Ltd., 2002; URSUS Ecosystem Management Ltd., 2003.;

[4] AENV, 2008a; Fort McKay Environment Services Ltd., 1997; Garibaldi Heritage and Environmental Consulting, 2006; O'Flaherty, 2011.

[5] Alberta Biodiversity Monitoring Institute (ABMI) data (obtained December 16, 2013) from field surveys within the Lower Athabasca and Central Athabasca - Lower ABMI defined watersheds; AENV, 2008b.

# Appendix E
# Considerations for Vegetation Establishment Using Seeds

**Lisette Ross**
Native Plant Solutions

## E.1 Considerations for seed harvest

Seed costs for unique wetland species can range from $100 to $200 per pound depending on availability and the method of collection. Commercial nurseries may be able to provide seeds and the adult plants of selected wetland species, though varieties and quantities may be limited. The quality of the seed supplied can also vary (van der Valk, 2009). For example, seeds are sometimes collected from local wetlands by native plant nurseries, but the viability of this seed is rarely tested and as a result the TZs (Tetrazolium test for seed viability) can be very low (van der Valk et al., 1999). Hand collecting seeds from desirable species may provide one of your best options, but this can be time consuming and the resources to do so must be available when the seeds are ready for collection. Conversely, not all seeds are viable for the same length of time. Many seeds from wet meadow species are only viable for one or two storage seasons. Therefore, understanding what you are collecting, how it should be stored, and the conditions needed to stimulate germination are critical for successful germination in the field (Galatowitsch and van der Valk, 1998).

Seed availability of native species is being addressed by a group of companies in the mineable oil sands through the Oils Sands Vegetation Cooperative. This group is open to all mineable and in situ oil sands operators interested in participating. Native seeds are harvested by local operators in compliance with the Forest Genetic Resources Management Standards. By segregating collections by harvest location, genetic variability is maintained and seedlings can be deployed in appropriate seed zones. Seeds are extracted and tested at certified extraction facilities and registered and stored by the AESRD’s Tree Improvement and Seed Centre under controlled conditions.

Timing of harvest is an important factor in viability. Some species can be harvested while green and seed will continue to ripen after harvest, notably members of the composite family. However, for the best results, seed should be harvested at the peak of ripeness, just as the first seeds are beginning to drop naturally. An experienced harvester can recognize this stage and coordinate harvest efforts to collect many species in close succession.

Not all seeds should be planted at once. Those species most capable of competing with aggressive weeds be sown first. Galatowtisch and van der Valk (1998) provide a list of species for various stages of revegetation. The challenge is that time and site restrictions may not allow for seeding and inspections to occur over many years. If this is the case then it is recommended to use seed mixes and seed populations with as many genotypes and as much genetic variation as possible. It is also beneficial to use phenotypically plastic species with wide ecological amplitudes (Lessica and Allendorf, 1999). Sites where it is possible to direct drill the seed into the soil the fall before spring flooding occurs will see the best results. Unfortunately, not all new wetland sites lend themselves to this practice.

## E.2 Considerations for seed germination

Many believe that seed dispersed in a wetland will automatically germinate. This is far from the truth. In fact, many wetland seeds persist in wet or moist soil environments for years before they are provided the opportunity to germinate. The chemical and physical forces of this environment help to prepare the seed for when drawdown occurs and germination is allowed to begin. When seeds are collected in the field and stored in cold and dry conditions this chemical and physical action is missing. Many species of *Carex*, for example, are not viable if stored in dry-cold conditions (Budelsky and Galatowitsch, 1999). For many species cold-wet stratification and physical scarification are required. These help to mimic the natural range of environmental factors that conceivably affect germination, such as soil texture (Keddy and Constabel, 1986), litter, moisture (van der Valk, 1981; Keddy and Ellis, 1985), and burial by sediment (van der Valk et al., 1983).

## E.3 Breaking seed dormancy and seed coat

Many wetland seeds will be unable to germinate without first breaking seed dormancy and the outer coat of the seed. For many species, dormancy in temperate regions can be broken by a combination of stratification at low temperatures and scarification of the outer coat (Schütz, 2000). This step is known as conditional dormancy. Cold stratification represents a natural mechanism that ensures germination occurs in the spring for most plant species (Probert, 1992). Our challenge lies in the extent to which this combination of stratification and scarification needs to occur to initiate germination for each wetland species. For many species cold stratification and scarification tend to be very specific. Once dormancy is broken, seeds gain the ability to germinate over an extended range of conditions (Baskin and Baskin, 1998).

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This initial avoidance of immediate germination improves the chance that a seed becomes incorporated into the seed pool (Grime et al., 1981) and it germinates at a favourable time of year. In terms of seeding a site it is important to note that most species of temperate regions appear to avoid germination in summer and autumn (Roberts, 1970; Baskin and Baskin, 1988, 1998). Germination during the summer bears a higher risk of seedling loss due to drought, salt intolerance or shading by the leaf canopies of other annual species growing on mudflats. In autumn seedlings are vulnerable to a reduced growing period and to frost (Schütz, 2000).

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Seed coat inhibition is apparently the primary mechanism for seed dormancy. Scarification, or abrasion at the micropylar end, enables or enhances germination, especially for large-seeded species such as *Carex* (Schütz, 2000). Artificial scarification can be accomplished using acids, abrasive surfaces like sandpaper or tumbling with gravel or grit. Scarification mimics the natural weathering away of the outer seed coat. It is this weakening of the outer seed coat that finally allows germination to occur. This may explain why it takes two or more years of this weathering before many species can germinate.!

## E.4 Seed germination and water

Water relations are rarely a source of concern with nursery production, but a major consideration when attempting to spread and germinate seed on reclaimed sites. Water affects seed viability in two ways: the inability of seeds to germinate under water, and a lack of viability the longer a seed remains flooded. The seeds of wetland plants cannot germinate when under water. It is only during the drought-induced period of a wetland that the germination of deposited seeds begin and the transformation or revegation of the wetland is initiated (van der Valk, 1981; Keddy and Reznicek, 1982; Smith and Kadlec, 1983; Leck, 1989). Consequently, it is only when a wetland experiences a drought period that seed germination and revegetation of an existing site is promoted (Wilson et al., 1993). This is why cyclical drought periods are an important consideration in the hydrological design of reclaimed marshes and shallow open-water wetlands. In addition to complete inundation, soil moisture at the time of drawdown may also impact the total number of seeds, and the relative proportion of seeds that germinate from an existing seed bank (van der Valk et al., 1992). When drawdown soils are drier it is expected that terrestrial annual species will dominate germination at a marsh site. When soils contain more moisture, emergent and wet meadow species are expected to dominate germination. Unfortunately, in most marsh drawdown situations there is very little control over the extent to which soils go dry.

While it only requires drawdowns of one growing season for adequate germination and revegetation to occur, the number of viable seeds in the seed bank may be reduced the longer a wetland’s soil remains inundated. This is one of the reasons why we observe such high plant biodiversity in wet meadow marshes, and such low biodiversity in the open water areas of shallow-water wetlands. It is in those zones where inundation and drought periods cycle often that seed viability remains high. For many species of *Carex*, fresh seeds produced from the previous growing season will likely produce the best germination response (van der Valk, 1999; Casanova and Brock, 2000). Although many of the seeds of annual, emergent and submersed species die within a few years after entering the seed bank (Lewis, 1973), seeds of certain species can survive for decades (Roberts, 1970, 1981; Fenner, 1985; Galatowitsch and van der Valk, 1998). These often include emergent species such as *Typha* and *Schoenoplectus*, which are adapted to growing in deeper water that often undergo fewer drawdown events. However, breaking dormancy and seed coat on these particular species can sometimes be the most difficult because they are adapted to sitting in moist soils for very long periods of time.

Just as the number of species in the seed bank declines the longer a wetland remains drained (Weinhold and van der Valk, 1989), the same holds true for wetlands flooded for extended periods of time (i.e., >15 years). Hopfensperger (2007) examined the time between disturbance events for forest, grasslands and marsh wetlands. She found that disturbances were a common mechanism driving community composition in all ecosystems. Similarities between above-ground species and seedbank compositions decreased the most with time since disturbance in forest and wetland ecosystems and the least in grassland habitats.

## E.5 Temperature and light requirements for seed germination

Among the environmental factors controlling the timing of germination in temperate regions, temperature is very important (Baskin and Baskin, 1988, 1998). Temperature has a dual role in regulating the timing of germination. First, the dormancy level of seeds is generally temperature dependent. Second, non-dormant seeds have specific temperature requirements for germination (Bouwmeester and Karssen, 1993; Vleeshouwers, 1997). High minimum temperatures for germination are a typical requirement for most wetland plants (Grime et al., 1981; Baskin and Baskin, 1998). Studies on Carices indicate that almost none are able to germinate at temperatures of 10°C (Schütz and Rave, 1999). Most seeds require a period of temperature stratification between 10°C and 25°C in order to germinate. This happens in natural wetland environments, but must be forced when using seed to revegetate newly reclaimed wetland habitats. Wetland seeds possess a depth sensing mechanism that allows them to detect increased amplitudes in soil surface temperatures when inundated soils experience a drawdown and soil surface temperature rises (Thompson and Grime, 1983). These temperature increases are the first indication to the seed that germination is possible. Increased soil temperatures also help to detect gaps in surface vegetation, since temperature amplitudes are smaller under a leaf canopy than in exposed soils (Schütz, 2000). This decreases competition from other plants and improves the survival of seeds germinating in exposed locations.

Light is a requirement for germination in many plant species (Grime et al., 1981; Schütz, 2000). For those species whose seeds have broken dormancy, many remain unable to germinate in darkness (Thompson, 1969, 1974; Grime et al., 1981; Thompson and Grime, 1983; Pons and Schröder, 1986; Baskin et al., 1989, 1996; Clevering, 1995; Baskin and Baskin, 1998). Species with small seeds often require more light for germination than do larger-seeded species. This is likely a protective measure so that smaller seeds can reach the soil surface (Pons, 1992). Species such as *Carex* spp., *Rhododendron groenlandicum* and *Acorus americanus* require light for germination (Wood pers. Comm, USDA NRCS 2013; Smreciu et al. 2013; van der Valk 1999). Plants belonging to the *Carex* genus, more than almost all other genera, display a marked requirement of light to germinate (Schütz and Rave, 1999).

## E.6 Sedimentation and seed germination

The combination of low light and oxygen caused by sediments results in poor germination of many wetland and riparian plants (Galinato and van der Valk, 1986). Sedimentation in newly reclaimed or existing wetland habitats occurs through a variety of mechanisms (Ross, 2009). One mechanism is the deposition of excess soil and nutrients into outer wetland margins as a result of surrounding land-use or construction practices. Wind and water soil erosion can be a naturally occurring process on all land (Brady and Weil, 2002), particularly when soil surfaces are unprotected. Water erosion is affected by runoff and rainfall factors, which include the amount of vegetative cover on the surface and a soil's ability to resist erosion. Wind erosion is affected by factors such as soil particle size, surface roughness, climate, vegetative cover in the surrounding watershed and unsheltered distance. In newly reclaimed landscapes, sedimentation from water erosion is a much more damaging process to seed germination than sedimentation through wind erosion.

Steps should be outlined in the wetland design methodology to minimize excessive sedimentation wherever possible during construction and in the first few years of wetland development. Cover crops planted on upper slopes, native grasses planted within the watershed, and soft berms constructed just above the riparian zones of wetlands are practices that can help minimize sedimentation. Ghaffarzadeh et al. (1992) found an 85% reduction of sediments within the first 3 meters of a grassed buffer surrounding a wetland edge. Neibling and Alberts (1979) showed a 90% reduction in sediment discharge within the first 5 meters of a grassed buffer, while Magette et al. (1989) found a 66% reduction in sediments passing through a 4.6-metre grass buffer.

While the accumulation of excess sediments has created much concern for the water quality and health of aquatic life in wetlands (Gleason and Euliss Jr., 1998), little attention has been given to the effect additional sediments have on plant communities. Evidence suggests that only small portions of incoming sediments reach the deeper areas of the wetland basin and that most sediment remains, or settles, in the outermost margins of a wetland. Even small amounts of overlying soil can impact seed germination and species richness and diversity (Galinato and van der Valk, 1986; Dittmar and Neely, 1999; Werner and Zedler, 2002). Galinato and van der Valk (1986) studied the germination of wetland/riparian plant seeds covered by 0, 1, 2, 3, 4, 5-cm of soil and found that seed germination decreased from 79% to 38% for annuals and from 71% to 20% for perennials when covered by only 1-cm of soil. Only *Hordeum jubatum*, an invasive perennial, was able to establish successfully under all soil depths. Mahaney et al. (2004) found all plant seeds collected from pristine wetlands in Pennsylvania were impacted by 1-cm of overlying sediments while invasive species collected from impacted wetlands, such as reed canary grass (*Phalaris arundinacea*) and Canada thistle (*Cirsium arvense*) were not.

Plants belonging to the *Carex* genus, more than most other genera, display a marked requirement for light to germinate (Schütz and Rave, 1999). This is a concern since *Carex* species are an essential plant community in the outer margins of many marsh and shallow-water wetland habitats (Trites and Bayley, 2009). Most species in this genus have difficulty germinating in conditions that are both low in oxygen and light due to an accumulation of overlying sediments (Fenner, 1987; Bewley and Black, 1994; Baskin and Baskin, 1998). For wetland and riparian plants with small seeds, the combination of low light and oxygen also make germination even more difficult when buried by sediments (Galinato and van der Valk, 1986).

## E.7 Seeding Rates

The seeding rates used, and the mixture of the seed, depends on the marsh zones being seeded (i.e., wet meadows versus deep emergent) and one's confidence that the seeds will actually germinate in a particular location. Certain species in seed mixes can be increased to provide initial coverage (i.e., slough sedge, *Beckmannia syzigachne*), while slower germinating wetland species are allowed to establish. Seeds should be distributed in locations where the soil surface is exposed and the soil surface is tacky. Contact between the seed and the soil is very important. Because of the cost of wetland seed, one should also be careful not to distribute seeds where flooding of the soil surface may occur before seeds germinate. This will quickly destroy any chance the plant will take hold in that location.

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# Appendix F
# Wetland Reclamation Theory

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## F.1 Introducing Theory

In ecology, the present is a time of the search for mechanisms and interrelationships of a multitude of ecosystem components. Unfortunately, ecology is complicated and patterns are often messy leaving one with the unsatisfactory feeling of wondering if rules indeed do exist. Even though they may be disguised, indeed they do exist, and furthermore they are important for our understanding of natural patterns. As we explore these ecological rules for organization and functioning of natural communities and ecosystems, we also need to recognize that these same rules govern the reclamation and restoration of disturbed areas, and in particular we need to utilize these rules to rebuild communities on the boreal landscape. Although most, if not all, of the ideas and theory for ecological rules relating to restoration also apply to reclamation, these terms apply to different situations and disturbance regimes on the landscape. Here we address the establishment of vegetation on previously mined areas of the oil sands region wherein all of the original ecosystem components have been destroyed by the mining processes. Our attempts at reclamation should attempt to re-establish the landscape to the state at which it was before disturbance. At a minimum, reclamation should lead to a local set of ecosystems that are robust, productive for the local and migratory lifeforms, resilient, and in harmony with their surroundings.

## F.2 Ecological Theory for Oil Sands Reclamation

Ecologists have long been interested in how communities change over time (Pickett et al*.,* 2008). Perhaps the earliest studies were those of Henry Cowles who observed floristic changes from lakeshore inland along Lake Michigan and interpreted these as representing community change, or succession, through time (Cowles, 1899). Succession is the shift in dominant plant assemblages of a localized region via a progression of plant species following a perturbation or disturbance and has been commented on many times in the literature (Clements, 1916; Egler, 1954; Connell and Slatyer, 1977; Noble and Slatyer, 1980). Succession is dynamic, occurring as different states in different regions and times (Egler, 1954; Connell and Slatyer, 1977; Crawley, 1997). Given no further disturbances, plant communities are driven by a combination of internal (autogenic) and external (allogenic) factors. In reclamation we can set the stage for future autogenic changes and control many, but not all (e.g., climate), of the allogenic factors.

Early concepts (Clements, 1916) viewed discrete assemblages of species arriving, assuming dominance, and shifting in discrete phases until a final ‘climax’ community was attained in a predictable manner (often called ‘floristic relay’). This view suggests that a community would regenerate its pre-disturbance composition in an orderly, predictable series of species replacements following a disturbance and is analogous to an ontogenetic progression, where each species of the community modifies the environment so it is less suitable for its own persistence and more suitable for its successor, until the final community is able to reproduce itself indefinitely. These shifts; however, may not be reflective of Clements' ideas on 'floristic relay,' but instead the gradual emergence and dominance of species initially present, but inconspicuous following the disturbance. Egler (1954) proposed that what was once thought to be the common pattern of succession, such as the floristic relay, might be much less frequent then once thought and emphasized that species dominance may be established by life history characteristics of individual species and site occupancy by these species. This view is more in line with that of Henry Gleason (1917), who proposed that succession is a matter of individual species arriving and responding dynamically to their environment, with a variable, often non-predictable successional progression and end point.

*Models of Succession.* Colonizing ability, growth responses, longevity -- (Noble and Slatyer, 1980; Drury and Nisbet, 1973), along with associated allogenic and autogenic environmental factors (Connell and Slatyer, 1977) are responsible for progression of species through succession. From these characteristics, general patterns that describe the order of species dominance can be ascertained and are usually repeatable (Glenn-Lewin and van der Maarl, 1992). Focusing on life history traits, in 1977, Connell and Slatyer proposed three general models of succession. In general, they argued that the interactions of resource availability and site history provide a set of circumstances for a set of species arrivals, these arrival species establish, grow, and interact with one another. These events exhibit one of three outcomes: 1) facilitation - whereby species modify their surroundings and make conditions suitable for the next group of species, 2) tolerance - whereby late arrival species are not affected by early arrivals, or 3) inhibition - whereby early arrivals suppress or exclude late arriving species.

The facilitation model is similar to floristic relay, whereby later successional species rely on early successional species to create a suitable environment. As the ontogeny analogy suggests, this model implies directional development (Odum, 1969) and a high degree of organization in the communities (Connell and Slatyer, 1977).

The tolerance model describes succession as leading to communities composed of species most efficient at gathering resources. These species thrive in the presence of other species and resources limit these populations. In this model, the habitat modifying characteristics of relay floristics mostly alter the environment to be less favorable for other species. Even though both late successional and early successional species are present after disturbance, the early colonizers dominate due to differences in growth rates and other life history characteristics (Connell and Slatyer, 1977; Noble and Slatyer, 1980). Later successional species may have traits allowing them to survive in the presence of associated species. Different species become dominant through time, modifying the site little by little, until eventually the presence and subsequent establishment of the previous assemblage of species are excluded (Egler, 1954; Connell and Slatyer, 1977). This cycle repeats until an irreplaceable climax (final) community persists (Crawley, 1997).

The inhibition model describes succession as having no superior competitive species, with the community composed of the first species to colonize and establish. Although over time modifications to the site make conditions less favorable for early successional species, these early species prevent any other species from becoming dominant. Replacement may occur by invasion of a new colonizer, although the individual would need to provide its own resources (e.g. seed with stored energy), unless there was either damage or death, which releases new resources. Thus, the community shifts gradually and inevitably toward species that live longer, since the ability to live longer suggests the species have defenses against all inevitable hazards (Connell and Slatyer, 1977).

Although each model exemplifies different pathways, all three models are capable of existing in nature. The facilitation model demonstrates primary succession of “newly formed” habitats (e.g., from receding glaciers). Tolerance and inhibition models represent secondary succession situations, involving the return of the ecosystem to its former state of equilibrium.

### F.2.1 Novel and Hybrid Ecosystems

Disturbances such as many of those in the oil sands region include the removal of natural soil and changes in the local hydrology and result in both major changes in the abiotic environment and a decrease in the available diaspore bank from the original species pool, both of which can prevent the re-establishment of pre-existing species assemblages. Ecosystems containing new combinations of species that arise through human action have been termed ‘novel ecosystems’ or ‘emerging ecosystems’ and result when species occur in combinations and relative abundances that have not occurred previously within a given biome. Key characteristics are novelty, in the form of new species combinations that have the potential for changes in ecosystem functioning (Hobbs et al., 2006). These novel ecosystems can be the result of deliberate human action, but do not depend on continued human intervention for their maintenance. These novel species associations early in oil sands reclamation may be necessary in order to initialize the early plant communities along a wetland successional gradient.

## F.3 Wetland Classification Within the Context of Oil Sands Reclamation

### F.3.1 Historical Framework: Concepts from Europe and the Canadian Wetland Classification

In 1911, C.A. Weber used the term ‘ombrogenous’ for peatlands that he thought received all of their water from rainfall. These Hochmoore (or bogs) are then defined based on source of the water supply or hydrology and differ from peatlands with topogenous (influenced by stagnant waters), soligenous (influenced by seepage, or limnogenous (influenced by flood waters from water courses) (original terms mostly from von Post and Granlund, 1926). These fens then are peatlands that have waters that contain dissolved ions derived from mineral soils and have nutritional and buffering effects. DuReitz (1954) introduced the term minerotrophic to express this situation and the bogs are thus ombrotrophic in this ecological sense.

The division for peatlands into ombrotrophic and minerotrophic systems began in Germany and the Netherlands (Weber 1911 was perhaps the first). This simple division based originally on hydrology has been adopted nearly worldwide. The ombrotrophic bogs, dominated by oligotrophic species of *Sphagnum* (e.g., S. fuscum, S capillifolium) are on one end of a water chemistry gradient while a series of variable fen types make up the remainder of the gradient. *Sphagnum*-dominated, acidic fens with a rather poor flora were designated 'fattigkarr' or poor fens by DuReitz (1942), while basic and alkaline fens with a much richer flora largely dominated by brown (true) mosses were termed 'rikkarr' by DuReitz. Fens dominated by a set of calcareous species were termed 'extremrikkarr' or extremely rich fens while those with less exacting species were called 'medelrikkarr' or moderately rich fens (earlier called transitional rich fens by DuReitz). In 1952, Hugo Sjörs correlated pH and electrical conductivity to this set of fen types and introduced 'mellankarr' or intermediate fens to the spectrum of fen types, these being characterized by a distinctive suite of species less tolerant of strong acidity and an intermediate ionic chemistry. Thus poor fens and rich fens are generally recognized based on both floristic and water chemistry (pH and base cations) criteria.

Rich fens are rich owing to a relatively high number of species (especially true mosses) that have high fidelity to the calcareous conditions of the sites. In comparison, poor fens are relatively poor in differential species. Bogs have few if any of these fen indicators. Sjörs (1983) and Vitt and Chee (1990) provided lists of characteristic species from Sweden and Canada, respectively. Among numerous publications that provide listings of species for northern peatlands, Ruuhijärvi (1960) and Eurola (1962) both provide extensive lists of species for a variety of fen communities in Finland, Vitt and Belland (1995) for bryophytes and Anderson and Davis (1998) provide lists for bogs in North America. These species in addition to the original defining features proposed by DuReitz (1954) characterize the principle peatland types: poor fens are acidic, have low concentrations of base cations, no or little alkalinity (bicarbonate ion), and are dominated by *Sphagnum,* while rich fens are basic to neutral, have higher concentrations of base cations, have bicarbonate as a dominant anion, and are dominated by true mosses and some mesotrophic species of *Sphagnum* (reviewed in Vitt and Chee, 1990). Each of these peatland types are vegetationally (structurally) diverse, and each can be dominated by species in the tree layer, the shrub layer, the field layer (sedges, forbs, and grasses), or the ground layer (mosses), thus vegetation does not add to the definition of the peatland types. In contrast, non-peat forming wetlands are well-distinguished by either being dominated by species in the field layer (marshes) or species in the tree layer (swamps).

In summary, it is generally recognized that boreal peatlands can be divided into three types – bogs, poor fens, and rich fens (these composed of two subordinate types and non-peat forming wetlands into two types – marshes and swamps. This was recognized in the Canadian Classification of Wetlands (Zoltai and Pollett, 1983; National Wetlands Working Group, 1988; CFCW 1997), and conceptualized by Vitt 1994 (Figure F-1). This classification reflects for peatlands a base cation, alkalinity, acidity gradient, and associated change in plant species (flora). It is noteworthy that vegetation (structure) is not associated with this gradient. Also important to recognize is that the terms 'poor' and 'rich' were not originally defined to include either a change in nutrient (N, P) status nor overall species richness, but only indicate the number of plant species having high fidelity to each peatland type. Although species richness does not increase at the site level across this peatland gradient, overall richness for each site type does (Vitt et al., 1995). Furthermore, this classification divides non-peat forming wetlands from peatland types along a nutrient and water stability gradient.

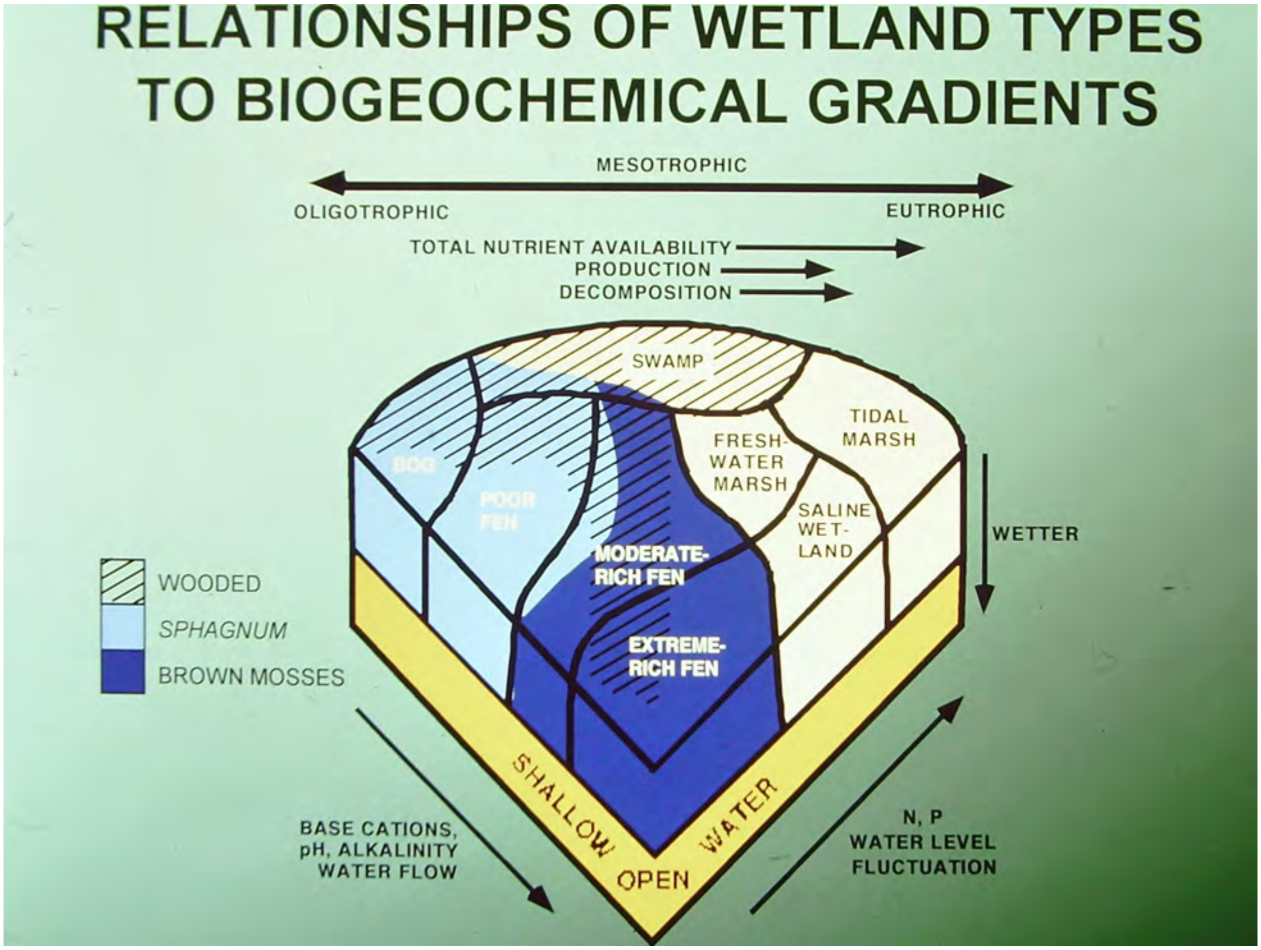

**Figure F-1. Wetland types and their relationship to important environmental gradients (modified from Vitt, 1994).**

### F.3.2 Peatland Initiation and Development in Alberta

Fundamental to wetland reclamation is to understand the processes of wetland and peatland initiation. These processes can be best understood using the historical record. Peatlands in continental western Canada began to initiate soon after the retreat of glaciers, some 12,000 to 15,000 years ago, by primary peat formation directly on wet, mineral soils. Also, the retreating glaciers stagnated leaving isolated blocks of ice scattered on the landscape that were soon covered by eroding mineral soil. When these blocks of ice melted there remained depressions with steep sides and these “kettle holes” soon filled with water. Surrounding these depressions, wetland vegetation developed and over time the water-filled basins were filled in by decomposing peaty materials, thus forming a peatland vegetative cover from terrestrialization. Both primary peat formation and terrestrialization were common processes in the early Holocene and primary peat formation continues to be a common initiation process in the Hudson Bay Lowland today as isostatic rebound provides new unvegetated surfaces. However, the modern landscape of western Canada and Alaska is largely the result of a third peatland initiation process that is termed paludification, or the swamping of previously dry mineral soils with upland vegetation. Most of the peatland-dominated landscape of the boreal region of the continent has an ever-increasing cover of peatland landforms. This paludified landscape began to develop relatively late in the Holocene in western Canada, whereas it began earlier in the east. Thus in general, peatlands are older in eastern Canada and younger in the west (Glaser and Janssens, 1986). Rates of paludification, especially in the dry western portion of Canada were cyclic, with several episodes of paludification (Campbell et al., 2000), and these paludification events appear to be climate-related with higher rates of paludification associated with wetter, cooler climatic periods.

After initiation, peatland development in western Canada proceeded along one of two successional pathways. First, early initiation from either infilling of ponds and from drier uplands resulted in the rapid development of marshes and then of either rich fens or poor fens with these persisting to the present time (Kubiw et al., 1989; Bauer et al., 2003), with little successional change. In this case, allogenic factors of climate and local water chemistry have over-riding effects and the fen communities persist for millennia (Yu et al., 2003). Secondly, initiation of marshes or fens on wet ground may persist for some time, but autogenic changes such as peat buildup leading to isolation of the peat surface from the local surface and ground waters, acidification, and oligotrophication may provide the critical drivers and rapid succession from rich fen to poor fen to bog may occur. Peatland landforms (bog islands, water tracks, patterning) evolve over time, and are secondary features of complex peatlands (Nicholson and Vitt, 1990). This development of secondary landform features is strongly influenced by both allogenic and autogenic drivers (Glaser, 1983).

# Appendix G
# CFRAW Research Program Summary

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## G.1 Introduction

The CFRAW project began in 2005 as collaboration among 5 researchers who had worked together on wetland-related projects for several years. This project was one of the first to receive support from a consortium of oil sands partners (Syncrude Canada, Ltd., Suncor Energy, Inc., Canadian Natural Resources Ltd, Albian Sands (now Shell Canada), Total E&P Ltd., Imperial Oil Resources, and Petro-Canada (now Suncor). Additional funding was provided by NSERC through a Collaborative Research and Development grant. The objectives were to:

1. Track the movement of carbon to describe the dynamics and food web structure in constructed wetlands of differing ages and material additions;
2. Assess the effects of mine process materials and their interactions in constructed wetlands on the environmental condition of selected components of wetland food webs; and; and
3. Document the qualitative changes in the distribution of carbon, relative abundance and dispersal of potentially toxic elements/compounds in constructed wetlands.

Sixteen “focal” wetlands, representing a factorial suite of contrasting age since formation including younger (<7 yr) and older (>8 yr), the use or absence of oil sands process water and/or tailings in construction, and the present vs. absence of sediment amendments with an organic carbon-rich capping layer of terrestrial or hydric origin. Supplemental observations were made from a larger suite of up to 40 wetlands within and adjacent to the oil sands lease areas.

## G.2 Macrophyte production and community composition

The plant community was surveyed in all wetlands for several years. The species richness of submergent and emergent aquatic plants in OSPM-affected wetlands was lower than in non-affected wetlands (Slama, 2010; Roy, 2014). Submergent vegetation biomass in OSPM-affected wetlands was approximately 20% of that in reference wetlands of equivalent age (Slama, 2010). The wet meadow region of constructed wetlands supported more species than such areas in natural wetlands, due to the prevalence of weedy species in the constructed wetlands (Roy, 2014). The architecture of constructed wetlands also resulted in much smaller wet meadow zones than occur in natural wetlands. The influence of oil sands process-affected water and sediments on plant community composition and on above- and below-ground production and respiration of *Typha* was experimentally measured across several years. Mollard, et al. (2013) found that OSPW induced physiological changes in cattails but that these weren't necessarily reflected in altered plant production. Sedge growth, however, was inhibited by OSPW (Mollard et al., 2012). Overall, the application of peat-enriched soil to constructed wetlands enhanced the extent and rate of development of emergent vegetation, but did not influence either the richness or biomass of SAV.

## G.3 Microbial production

Seasonal and spatial trends in production and stable isotope signatures of microbial primary producers were studied by various researchers at the University of Waterloo (Hayes, 2006; Farwell et al., 2009, Videla et al., 2009; Chen, 2010; Boutsivongsakd, 2013). In general, nutrient supplementation resulted in transient increases in algal production and biomass. Adding small quantities of peat resulted in slower but more persistent periphytic and planktonic responses. Zoobenthos were unaffected by nutrient supplements (Chen, 2010). Parallel work on biofilm production produced comparable results (Frederick, 2011). Generally, reference wetlands supported significantly greater concentrations of chlorophyll-*a* than OSPW-affected wetlands. Biomass of aquatic invertebrate grazers was strongly correlated with periphyton biomass.

Productivity studies of bacterio-plankton (Daly, 2007) and benthic microbes (Gardner Costa, 2010) indicated that relatively little $CO_2$ and methane were produced relative to quantities typical of natural North American wetlands. Reference wetlands characteristically produced more methane but less carbon dioxide than OSPM-affected wetland sediments (Gardner Costa, 2010). Elevated concentrations of sulphate in the water and sediment of OSPM-affected wetlands likely promote dominance by sulphur-reducing bacteria, which inhibit development of methanogenic bacterial communities. Sediment oxygen demand (SOD) in each wetland was independently estimated (Slama, 2010). OSPW-affected wetlands exhibited both greater net primary production (daytime increase in DO) and greater SOD (DO loss during dark conditions) than reference wetlands. Approximately 80% of SOD in constructed wetlands is due to chemical oxygen demand. This is consistent with patterns observed in young, constructed wetlands elsewhere in North America. Detrital decomposition rates did not vary between OSPM and non-OSPM constructed wetlands (Wytrykush and Hornung, unpubl).

## G.4 Invertebrate biomass and secondary production

Ganshorn (2002), Baker, (2007), Thoms (2009), Kennedy (2012), and Williams (2014) estimated aquatic insect emergence and abundance at selected wetlands by aquatic sampling, collecting floating exuviae on the wetland surface, sweep-netting emergent wetland vegetation, and setting out sticky traps. Much greater biomass occurred in the water than in or over wetland vegetation. Marshlands supported more biomass than fens (Williams, 2014). OSPW-affected wetlands often had equivalent or greater biomass (but lower taxa richness) than reference wetlands. However, growth rates and production tended to be lower in OSPW wetlands than in their reference counterparts. The addition of peat to OSPW-affected wetlands did not mitigate the effects of OSPW on zoobenthic abundance or community composition (Baker, 2007; Barr, 2009).

## G.5 Overall trends in carbon dynamics and food web characteristics

Kovalenko et al. (2013) summarized biomass changes among food web compartments of young vs. older, and reference vs. OSPW-amended wetlands as identified over the course of the CFRAW project. Overall, young OSPM-affected wetlands had lower invertebrate biomass, microbial biomass and production, and macrophyte biomass. Older OSPM-affected wetland compartments were more similar to reference wetlands (benthic and planktonic invertebrates, macrophytes and bacterial production). However, differences in food webs. Dissolved carbon pools in OSPM wetlands may be dominated by recalcitrant carbon, limiting energy transfer to higher trophic levels.

Carbon storage and transfers within constructed wetlands were low relative to natural wetlands. OSPM reduced carbon turnover but not necessarily biomass. Respiration was lower in constructed wetlands than in natural wetlands. Production and biomass accumulation rates of some compartments appeared to be increase with age. Although data were limited, few processes or compartments reached asymptotes by 20-25 years.

## G.6 Community composition

All groups of organisms studied (aquatic plants and invertebrates, amphibians, birds) exhibited marked change in community composition as wetlands aged and are thus suitable as biological indicators of change. The rate of convergence in composition of OSPM-affected wetlands relative to reference-constructed wetlands depended on the size and generation time of the community studied. Few species had converged with reference conditions by age 20 y, likely because of constraints of the water chemistry and condition of the surrounding landscape.

Community composition is expected to slowly become more natural over time. Using peat as a topsoil supplement speeds emergent plant establishment but has slight if any mitigative influence on the effects of salts or naphthenic acids (NA) in water. Salinity limits diversity and production and slows succession. Full-scale constructed wetlands must be designed such that hydrological processes will result in the eventual dilution of salts if the desire is to mimic the community structure and processes of the dominant natural wetlands of the area.

## G.7 Summary toxicity of mine process constituents

The weight of evidence of multiple lab-based toxicity tests and in situ investigations suggest that OSPW is toxic when it comprises 25-68% of water volume (depending on its source and age. NA is toxic at 5-30 mg/L, depending on taxon and developmental stage considered; salts (measured as conductivity) are toxic at 1-3 mS/cm, depending on the taxon. Ni and V ions associated with coke leachate can be toxic, depending on pH of the water. PAHs are not bio-accumulated. As and Se do not pose a risk in oil sands wetland food webs. NA toxicity declines with age. The half-life is variable, ranging from 0.25-12 y). Peat used in wetland construction may bind trace metals and PAHs but have limited effects on salts or NA.

**Table G1. Known properties of natural and reclaimed wetlands included in the CFRAW research program.**

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Bridge Wetland | | 463545E 6332825N | Natural | N/A | Natural | Natural | Surface | Natural |
| Fort McKay Wetland | | | Natural | Natural | Natural | Natural | Surface | Natural |
| Horseshoe Lake | | | Natural | N/A | Natural | Natural | Surface | Natural |
| Katie's Sedge Meadow | | 458278E 6317693N | Natural | N/A | Natural | Natural | Surface | Natural |
| Maqua Fen | | | Natural | N/A | Natural | Natural | Surface | Natural |
| Moose (Tower Road) | | 469444E 6289133N | Natural | N/A | Natural | Natural | Surface | Natural |
| Muskeg River Wetland | | 463655E 6332742N | Reference | 1978 | Natural | Natural | Surface | |
| Rhyno's Watering Hole | | 479425E 6274201N | Natural | N/A | Natural | Natural | Surface | Natural |
| Saline Lake [Saline L. 2 in Golder Rep] | | 468492E 6325376N | Natural | Natural | Natural | Natural | Surface | Natural |
| Sam's Rodeo | | 481462E 6278833N | Natural | N/A | Natural | Natural | Surface | Natural |
| Seeps W side of Hwy 63 | | | Natural | Natural | Natural | Natural | Surface | |
| Shipyard Lake | | 473500E 6313000N | Natural | N/A | Natural | Natural | Surface | Natural |
| Tower Rd. 1 | | 469750E 6289121N | Natural | N/A | Natural | Natural | Surface | Natural |

| **Wetland Name** | **Original purpose** | **UTM** | **Wetland type** | **Year of construction** | **Origin** | **Sediment placed/ type** | **Water** | **Peat substrate placed** |
|---|---|---|---|---|---|---|---|---|
| Tower Rd. 2A | | 464520E 6290829N | Natural | N/A | Natural | Natural | Surface | Natural |
| Tower Rd. 3 (channel) | | 462410E 6291038N | Natural | N/A | Natural | Natural | Surface | Natural |
| Tower Rd. 3 (marsh/beaver pond) | | 463128E 6290751N | Natural | N/A | Natural | Natural | Surface | Natural |
| Tower Rd. 5 | | 462410E 6291038N | Natural | N/A | Natural | Natural | Surface | Natural |
| Barge Marsh | Borrow pit | 458148E 6326614N | Reference | 1978 | Constructed | Natural | Surface | |
| Beaver Creek Reservoir | Surface water diversion around lease area | | Reference | 197* | Natural | Natural | Surface | Natural |
| Crane Lake | | 466403E 6316924N | Reference | 1976 | Opportunistic | Natural | Surface | Natural |
| Crane Road Marsh | | | Reference | 1996 | Opportunistic | Overburden | Surface | Natural |
| Crane Road West Wetland | | | Reference | 1996 | Opportunistic | Natural | Surface | Natural |
| High Sulphate (Crane L Duck Pond) | Watershed reclamation ecosystem processes | 466387E 6317227N | Reference | 1985 | Opportunistic | Lean oil sand | Surface | 15 cm PMM |
| Highway 63 Wetland | | 471058E 6312780N | Reference | Hwy Const date | Opportunistic | Natural | Surface | Natural |
| Hwy 63 Intersection Wetland | | | Reference | ?1978 | Opportunistic | Natural | Surface | Natural |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Poplar Creek Reservoir | Surface water diversion around lease area | | Reference | 1975 | Opportunistic | Natural | Surface | Natural |
| Poplar Creek Outflow | Surface water diversion around lease area | | Reference | 1975 | Constructed | Natural | Surface | |
| Ruth Lake | Surface water diversion around lease area | 465627E 6316229N | Reference | 1975 | Constructed | Natural | Surface | Natural |
| South Boundary Beaver Pond? | | | Reference | | Opportunistic | Overburden | Surface | |
| Tower Rd. 4 | | | Natural | N/A | Opportunistic | Natural | Surface | Natural |
| Lower Beaver Creek Wetlands | Original channel of Lower Beaver Creek | | OSPM | Natural | Natural | Natural | Surface | Natural |
| Suncor Floodplain | | | Natural | 1970 | Natural | Natural | Surface | |
| Suncor Weir 11 | | | Reference | | Constructed | | Surface | |
| Suncor Weir 7 | | | Reference | | Constructed | | Surface | |
| Suncor Fort Hills No Net Loss Lake | | | Reference | 2013 | constructed | natural | surface | PMM |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Suncor Millennium Compensation Lake | | | Reference | 2009 | Constructed | | surface | PMM |
| Suncor Millennium Interceptor E Impound (Sed. Pond) | Sedimentation pond for diversion water | 477050E 6304050N | Reference | 2000 | Constructed | Natural | Surface | Natural |
| Suncor Nikanotee Fen Watershed | Watershed reclamation ecosystem processes | | Reference | 2013 | Constructed | liner + coke + tailing sand | surface + groundwater | 2m peat |
| Suncor Nikanotee Outlet Pond | Watershed reclamation ecosystem processes | | Reference | 2013 | Constructed | overburden (K-spec) | surface | |
| Suncor Sand Pit (Crescent) | Watershed reclamation ecosystem processes | | Reference | 2004 | Constructed | Natural sand quarry | Surface | 21 cm PMM |
| Suncor South Tailings Pond Wetland 1-4 | Compensation wetland | | Reference | 2006 | Constructed | natural | surface | Natural |
| Suncor V-notch Weir | Reference for Suncor 4-m CT Wetland | | Reference | 2000 | Constructed | Overburden | Surface | |
| Suncor Wapisiw | Watershed reclamation ecosystem processes | | Reference | 2010 | Constructed | Liner + 30 cm tailings sand | Surface | 20 cm PMM |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Suncor Leggett Creek Upstrm | | | Reference | 2000 | Natural | | Surface | Natural |
| Suncor McLean Creek Wetland | Natural Reference for 4-m CT wetlands | | Reference | Natural | Natural | Natural | Surface | Natural |
| Suncor Construction Camp Pond | | | Reference | 2001 | Opportunistic | overburden | surface | |
| Suncor Dyke 4 Seepage Pond | | | | 2000 | Opportunistic | Overburden | Dyke seepage + runoff | |
| Suncor Fee Lot 2 Wetland | | | Reference | 2012 | Opportunistic | Natural; former gravel pit | surface | 50 cm PMM |
| Suncor Leo's Pond | | | Reference | 1999 | Opportunistic | Overburden | Surface | |
| Suncor Loon Lake Wetland (Weir 1) | Reference water for Suncor Trench toxicity tests | 471820E 6314971N | Reference | 1974 | Opportunistic | Natural; former gravel pit | Surface | |
| Suncor MD-5 | | | Reference | 2009 | Opportunistic | Overburden | Surface | 50 cm PMM |
| Suncor MD5 Wetland North | Watershed reclamation ecosystem processes | | Reference | 2009 | Opportunistic | overburden | surface | 50 cm PMM |
| Suncor MD5 Wetland South | Watershed reclamation ecosystem processes | | Reference | 2009 | Opportunistic | overburden | surface | 50 cm PMM |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Suncor North Steepbank Dump North Wetland | Watershed reclamation ecosystem processes | | Reference | 2013 | Opportunistic | overburden | surface | 20 cm PMM |
| Suncor North Steepbank Dump South Wetland | Watershed reclamation ecosystem processes | | Reference | 2013 | Opportunistic | overburden | surface | 20 cm PMM |
| Suncor Pond 5 Wetland | Watershed reclamation ecosystem processes | | Reference | 2005 | Opportunistic | Natural sand deposit with natural lean oil sand | surface | |
| Suncor Reclamation Area 8 Wetland | Watershed reclamation ecosystem processes | | Reference | 1987 | Opportunistic | Lean oil sand overburden | surface | 16 cm PMM |
| Suncor Salt Marsh (Saline Marsh; Species Donor E Wetland) | | 467457E 6316844N | Reference | 1991 | Opportunistic | Overburden | Surface | |
| Suncor SE Dump Cattail Wetland | | | Reference | 2008 | opportunistic | overburden | surface | LFH |
| Suncor SE Dump Wetland | | | Reference | 2005 | opportunistic | natural | surface | |
| Suncor Tar Island Dyke Ratroot Pond | | | Reference | 1970 | Opportunistic | natural | surface | Natural |
| Suncor Waste Area 11 (Duck Pond) | | | Reference | 1984 | Opportunistic | Overburden | Surface | |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Suncor 12-m CT | CT & OSPW degradation potential | | OSPM | 2005 | Constructed | CT | OSPW | |
| Suncor 12-m CT - Coke Zone | CT & OSPW degradation potential | | OSPM | 2005 | Constructed | Coke over CT | OSPW | |
| Suncor 12-m CT - CT Zone | CT & OSPW degradation potential | | OSPM | 2005 | Constructed | CT | OSPW | |
| Suncor 12-m CT - Peat Zone | CT & OSPW degradation potential | | OSPM | 2005 | Constructed | CT | OSPW | PMM |
| Suncor 4-m CT Wetland No Peat | CT & OSPW degradation potential | | OSPM | 1999 | Constructed | CT | OSPW | N/A |
| Suncor 4-m CT Wetland - Peat zone | CT & OSPW degradation potential | | OSPM | 1999 | Constructed | CT | OSPW | PMM |
| Suncor 1-m CT Wetland | CT & OSPW degradation potential | | OSPM | 1999 | Constructed | CT | OSPW | PMM |
| Suncor 4-m CT | CT & OSPW degradation potential | | OSPM | 1999 | Constructed | CT | OSPW | |
| Suncor Experimental Trenches | OSPW degradation rate | 469100E 6315610N | OSPM | 1988 | Constructed | liner + 45 cm sand | Various | 15 cm PMM |
| Suncor Jan's Pond | OSPW degradation potential & | | OSPM | 1999 | Constructed | overburden + 30 cm CT | OSPW | |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| | rate | | | | | | | |
| Suncor Sustainability Pond (MFT-N) | OSPW degradation potential | | OSPM | 1992 | Constructed | MFT | OSPW | |
| Suncor Sustainability Pond (MFT-S) | OSPW degradation potential | | OSPM | 1992 | Constructed | MFT | OSPW | |
| Suncor East Nat. Wetlands | | | OSPM | 1987 | Opportunistic | | Dyke seepage + runoff | |
| Suncor Hummock Wetland | OSPW degradation & toxicity assessment | 468498E 6315392N | OSPM | 1988 | Opportunistic | tailings sand | Dyke seepage + runoff | 15 cm PMM |
| Suncor Natural Wetland | OSPW degradation & toxicity assessment | 468985E 6315344N | OSPM | 1987 | Opportunistic | tailings sand | Dyke seepage + runoff | 15 cm PMM |
| Suncor Natural Wetland East | | | OSPM | early 1980s | Opportunistic | tailings sand | Dyke seepage | PMM |
| Suncor WA11 - Pond C | | | OSPM | ?1996 | Opportunistic | Overburden | Surface | |
| Suncor WA11 - Pond D | | | OSPM | ?1996 | Opportunistic | Overburden | Surface | |
| Syncrude Mildred Lake | | | Reference | Natural | Natural | Natural | Surface | |
| Syncrude Southwest Sands | | 456519E 6315878N | Reference | N/A | Natural | Natural | Surface | Natural |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Beaver | | | | | | | | |
| Syncrude Southwest Sands Beaver Pond #2 | | | Reference | Natural | Natural | Natural | Surface | Natural |
| Syncrude Bill's Lake | | 462848E 6317412N | Reference | 1997 | Opportunistic | Overburden | Surface | PMM |
| Syncrude Test Pond 1 (Whelly: RTP) | Reference for MFT Degradation /densification rate | 458029E 6327071N | Reference | 1989 | Constructed | Overburden | Surface | |
| Syncrude "Black" Pond | Watershed reclamation ecosystem processes | | Reference | 2000 | Opportunistic | Overburden | Surface | PMM |
| Syncrude North Wetland | | | Reference | ?1996 | Opportunistic | Natural | Surface | |
| Syncrude NWID Big Beaver (North) | | | Reference | 2005 | Opportunistic | Natural | Surface | Natural |
| Syncrude NWID Small Beaver (South) | | | Reference | 2005 | Opportunistic | Natural | Surface | Natural |
| Syncrude South Bison Ditch | | | Reference | N/A | Opportunistic | Overburden | Surface | Natural |
| Syncrude South Bison Pond | Watershed reclamation ecosystem processes | 463421E 6317177N | Reference | 1975 | Opportunistic | Clay & organic | Surface | PMM |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Syncrude South Boundary Ditch | | | Reference | 1985? | Opportunistic | Overburden | Surface | |
| Syncrude South Ditch | | | Reference | 1980 | Opportunistic | Overburden | Surface | |
| Syncrude South Hydro Line East Wetland (Paige's Pond) | | | Reference | | Opportunistic | Overburden | Surface | |
| Syncrude South Hydro Line West Wetland | | | Reference | | Opportunistic | Overburden | Surface | |
| Syncrude South Hydro Line Upland Wetland | | | Reference | | Opportunistic | Overburden | Surface | |
| Syncrude South of South Boundary Ditch | | | Reference | | Opportunistic | Overburden | Surface | |
| Syncrude Deep Wetland (SWSD) | Reference for Syncrude Test Ponds | | Reference | 1992 | Constructed | Overburden | Surface | |
| Syncrude Golden Pond | Watershed reclamation ecosystem processes | | Reference | 2000 | Constructed | Overburden | Surface | Marsh mud |
| Syncrude Northwest Wetland - WID | Borrow Pit | | Reference | ?1977 | Constructed | Natural | Surface | |
| Syncrude Peat Pond | Bison watering Pond | 462066E 6316804N | Reference | 2000 | Constructed | Overburden | Surface | PMM |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Syncrude Sandhill Fen | Watershed reclamation ecosystem processes | | Reference | 2013 | Constructed | Overburden | Surface | PMM |
| Syncrude Shallow Wetland | Reference for Syncrude Test Ponds | 458159E 6326713N | Reference | 1989 | Constructed | Pl/Pg clay | Dyke seepage | |
| Syncrude Shallow Wetland South Ditch | Reference for Syncrude Test Ponds | | Reference | 1992 | Constructed | Overburden | Surface | |
| Syncrude South Hydro Line Beaver Dammed Ditch | | | Reference | 2000 | Constructed | Overburden | Surface | |
| Syncrude U-shaped Cell (=Envirotest #5) | | | Reference | 1995 | Constructed | None (geocloth) | Surface | |
| Syncrude West Interceptor Ditch | Surface water diversion around lease area | 463635E 6323189N | Reference | 1978 | Constructed | | Surface | |
| Syncrude West Interceptor Ditch Pond (?Whelly North Pond) | Borrow Pit | | Reference | 1992 | Constructed | | Surface | |
| Syncrude: Bison Viewing Pond | Bison watering Pond | | Reference | | Constructed | | Surface | PMM |
| Syncrude CT Pond (Mike's | CT water degradation | 458714E 6330045N | OSPM | fall 1997 | Constructed | Clay | CT water | |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Pond) | rate & potential | | | | | | | |
| Syncrude CT Prototype | CT degradation rate & potential | | OSPM | 1992 | Constructed | Syncrude CT | Dyke seepage | |
| Syncrude Envirotest Pond #1 | OSPW degradation rate & potential | | OSPM | 1995 | Constructed | None (geocloth) | OSPW | |
| Syncrude Envirotest Pond #2 | OSPW degradation rate & potential | | OSPM | 1995 | Constructed | None (geocloth) | OSPW | |
| Syncrude Envirotest Pond #3 | OSPW degradation rate & potential | | OSPM | 1995 | Constructed | None (geocloth) | OSPW | |
| Syncrude Envirotest Pond #4 | OSPW degradation rate & potential | | OSPM | 1995 | Constructed | None (geocloth) | OSPW | |
| Syncrude Test Pond 2 | MFT Degradation /densification rate & toxicity | 458006E 6327058N | OSPM | 1989 | Constructed | MFT | Surface | |
| Syncrude Test Pond 3 | MFT Degradation /densification rate & toxicity | 458006E 6327058N | OSPM | 1989 | Constructed | MFT | Surface | |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
| Syncrude Test Pond 4 | MFT Degradation /densification rate & toxicity | 457976E 6327082N | OSPM | 1989 | Constructed | MFT | Surface | |
| Syncrude Test Pond 5 | MFT Degradation /densification rate & toxicity | 457893E 6327004N | OSPM | 1989 | Constructed | MFT | Surface | |
| Syncrude Test Pond 6 | MFT Degradation /densification rate & toxicity | 457909E 6326991N | OSPM | 1989 | Constructed | MFT | Surface | |
| Syncrude Test Pond 7 | MFT Degradation /densification rate & toxicity | 457932E 6326971N | OSPM | 1989 | Constructed | MFT | Surface | |
| Syncrude Test Pond 8 (=Shallow Pond) | MFT Degradation /densification rate & toxicity | 458063E 6326923N | OSPM | 1992 | Constructed | MFT | OSPW | |
| Syncrude Test Pond 9 (=TPW Pond) | OSPW degradation rate & potential | 457991E 6327068N | OSPM | 1992 | Constructed | Clay | OSPW | |
| Syncrude Test Pond 10 (Demo Pond) | MFT Degradation /densification rate & | 458352E 6326665N | OSPM | 1992 | Constructed | MFT | Surface | |

| Wetland Name | Original purpose | UTM | Wetland type | Year of construction | Origin | Sediment placed/ type | Water | Peat substrate placed |
|---|---|---|---|---|---|---|---|---|
|  | toxicity |  |  |  |  |  |  |  |
| Syncrude East Toe Berm Pond | Dyke seepage collection location |  | OSPM | 1999 | Opportunistic | Overburden | Dyke seepage |  |
| Syncrude Seepage Control Pond | Dyke seepage collection location |  | OSPM | 1978 | Opportunistic | Overburden | Dyke seepage |  |
| Syncrude Southwest Sands Bench wetland |  |  | OSPM | 1987 | Opportunistic | Overburden | Dyke seepage | Natural |
| Syncrude S-Pit |  | 460910E 6329488N | OSPM | 1975 | Opportunistic | tailings sand | Dyke seepage |  |
| Syncrude SW Sands Berm Pond |  |  | OSPM | Natural | Opportunistic | Overburden | Surface | PMM |
| Syncrude SWSS Flood |  |  | OSPM | 2009 | Opportunistic | Overburden | Dyke seepage |  |
| Syncrude SWSS North 1 |  |  | OSPM | 1987 | Opportunistic | Overburden | Dyke seepage | PMM |
| Syncrude SWSS North 3 |  |  | OSPM | 1987 | Opportunistic | Overburden | Dyke seepage | PMM |
| Syncrude SWSS South 1 |  |  | OSPM | 1987 | Opportunistic | Overburden | Dyke seepage | PMM |
| Syncrude SWSS South 2 |  |  | OSPM | 1987 | Opportunistic | Overburden | Dyke seepage | PMM |

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# Appendix H
# Ecological Considerations for Wetland Reclamation

**Brian Eaton, and Jason Fischer**, Alberta Innovates - Technology Futures;
**Lisette Ross**, Native Plant Solutions; and
**Théo Charette**, CPP Environmental

## H.1 General principles

A number of general design principles are relevant to reclamation of wetlands in the mineable oil sands region. Many are based on ecological principles articulated by Lewis et al. (1995), Zedler (2000), and Mitsch and Jørgensen (2004).

- Wetlands should fulfill multiple goals, by setting one or more major objectives with several secondary objectives. These goals are listed below. The design principles listed here provide over-arching guidance; more detailed information on design for individual wetland types is provided elsewhere in this guide.
- Wetland systems should require minimal maintenance, and feature general resilience to perturbation.
- Wetlands should be consistent with the hydrological and ecological landscapes in which they are being created.
- Climate, and potential impacts of climate change, should be considered.
- The effect of time during wetland reclamation must be acknowledged; it can take many years for some functions and organisms to appear in a constructed wetland, and this lag time should be considered when assessing reclamation success, and the need for intervention.
- Wetlands should be designed for function, not form, when possible.
- Do not design wetlands as rectangular basins, rigid structures, and regular morphology; mimic natural systems, where possible.
- Nature is variable; embrace that variability in design and outcomes for wetland reclamation.
- Some disturbance events (e.g., wet – dry cycles) are normal in wetlands and can enhance species richness; they should be considered as positive events, if they are within the natural range of variation for the region.
- Wetlands should be designed for functional connectivity to source populations. Connectivity and the availability of source populations are critical for the biotic communities that develop at reclaimed wetlands, and the rate at which this occurs.

- When designing wetlands to encourage biodiversity, both environmental condition of the site, and life-history traits of species must be considered.
- It is important to plan not only the wetland itself, but also the terrestrial matrix in which it is embedded.
- Trajectories for the development of wetlands following reclamation will follow complex paths, in most cases, that are difficult or impossible to predict (Zedler and Callaway, 1999). Therefore, boundary conditions under which a reclamation project is deemed successful should be established. Multiple potential outcomes should be encompassed within these boundaries as a functional wetland can take on many forms, and can still be considered a success, even if the wetland that eventually forms is not necessarily the type originally targeted. This is especially true when wetland reclamation is considered at a landscape scale, as diversity at this scale will influence biodiversity at a regional scale. Therefore, it is not a failure if a wetland planned as a fen ends up as a marsh, as long as that does not happen every time.
- Every reclamation project should be seen as a field experiment, with proper planning, implementation, monitoring and assessment. This is part of an adaptive management cycle, in which lessons learned from each project will inform future reclamation efforts and improve their chances of success in reaching targets. For this reason, the inclusion of experimentation as part of reclamation (e.g., using different wetland inoculation to add species to a reclamation site) should be formally supported in closure plans and the certification process.

## H.2 Specific design guidance

The general principles of design outlined above should be adopted for reclamation of both wetlands, and the landscapes of which they are a part. The primary design consideration for reclaimed wetlands is to design for local heterogeneity, where appropriate, to embrace spatial and temporal variability in wetlands, and to design wetlands that cover the range of natural variation exhibited by wetlands in the mineable oil sands region. At a landscape scale, reclamation strategies should plan for landscape complexity and connectivity among wetlands, and between wetlands and their terrestrial matrix.

From these general principles, two key points emerge:

1. The natural variability observed in boreal forest landscapes should be emulated in wetland design. The best information on variability of size, shape, and composition of wetlands should be garnered from the landscape and used to guide reclamation planning.
2. The concept of *biodiversity* must be broadened to include diversity in the types of wetlands within a landscape, diversity in the placement of wetlands within a landscape, and diversity in the successional trajectories of different wetlands through time (Ward

and Tockner, 2001). A standard "boilerplate" landscape design, or conversely, an *ad-hoc* site-specific approach, will be unlikely to achieve the objective of an ecologically functional wetland within an equally functional landscape.

In general terms, complexity can be achieved by planning for multiple wetland types within a landscape, juxtaposed with different upland habitat types. Complexity is key to maximizing beta diversity, but also for ensuring that different habitat requirements are available for different species, since not all species respond to the same habitat patches and environmental conditions. A reclaimed landscape should include ephemeral and permanent wetlands juxtaposed with upland forest stands and patches of emergent and shrubby vegetation. This recommendation echoes suggestions for wetland-landscape conservation for birds (Haig et al., 1998; Naugle et al., 2001), amphibians (Dodd and Cade, 1998; Semlitsch and Bodie, 1998; Houlahan and Findlay, 2003; Semlitsch and Bodie, 2003), reptiles (Buhlmann and Gibbons, 2001; Joyal et al., 2001; Gibbons, 2003; Roe and Georges, 2007) and beavers (Eaton et al., 2013). Moreover, the size, shape, and placement of wetlands within a landscape all have a marked effect on the ecological function of wetlands and their ability to support biodiversity. Multiple wetlands should be placed in proximity as they provide ecological stepping stones that increase connectivity between wetlands, lowering extinction rates and increasing colonization rates, thereby increasing population stability (Levin, 1974; Forman, 1995). In summary, the primary design consideration for reclaimed wetland landscapes is to emulate the structure, function, complexity, and biodiversity of natural wetlands in Alberta's boreal forest.

As for the landscape scale, a standard wetland design employed across reclaimed landscapes will not achieve objectives. The choice of wetland type to be constructed – marshes, swamps, peatlands, beaver ponds, intermittent and ephemeral wetlands – will of course be limited by site characteristics. But within those limitations, wetland design must be informed by the composition and structure of natural wetlands (Eaton and Fisher, 2011). Further, effort must be made to design a wetland that is different in these characteristics from previously reclaimed wetlands in the landscape.

In general terms, natural wetlands can be emulated by planning for wetland types with structural attributes similar to those in undisturbed landscapes, including wetland type, size, shape, profile, hydrology, vegetation, and riparian zone. Biodiversity follows from these attributes (provided that landscape-scale design has allowed for juxtaposition and connectivity). There are three approaches to designing wetlands for wildlife habitat: (1) the species introduction approach, (2) the biocoenosis restoration approach, and (3) the function approach (Ramseier et al., 2009). The species-introduction approach designs wetlands around habitat requirements for specific species, usually species-at-risk. However, in designing a wetland for one species the needs of other species, as well as general ecological function, may not be met. The biocoenoses approach designs wetlands for entire communities that were formerly present. The problem is in setting a baseline for restoration (Ramseier et al., 2009), but perhaps more importantly, in engineering a radically-altered site to conform to the geomorphic and hydrologic requirements of its former biotic community. This might be particularly evident when trying to replace peatland systems that took thousands of years to evolve. In contrast, the functional approach designs wetlands to provide ecological function, such as carbon accumulation or nutrient flux, without the constraints of exactly mirroring former vegetational communities (but still using native species). We maintain that by emulating structural attributes and biotic communities of natural boreal wetlands, objectives related to biodiversity and ecological function can both be met.

In specific terms, some rules can be extracted from our current knowledge of wetlands and biodiversity. Note that design considerations provided here should be thought of as probabilities, rather than as absolutes. For example, if wetlands are at least 1 km from a road it will increase the probability that they exhibit functional connectivity to the surrounding landscape. This does not mean that a wetland that is less than 1 km from a road will not be connected, just that there is an increased chance that it will be impacted by the presence of the road.

Wetland and landscape-scale design considerations:

1. The hydrologic regime and hydrologic connectivity will dictate the type of wetland to be constructed at a site.

2. The soil used should be appropriate for the wetland type, although the wetlands will build appropriate soil over time if the vegetation can thrive in initial conditions and the substrate can retain the appropriate hydrologic regime.

3. Vegetation planted should emulate the communities naturally occurring in the wetland type to be designed.

4. Different plant and animal communities occur in different wetland classes; a diversity of wetland types across the landscape will therefore maximize biodiversity at larger spatial scales.

5. Zones of emergent vegetation are an important component of many wetland types, and designs for these types (e.g., swamps, marshes) should include provisions for the development of such zones.

6. All wetlands should be bordered by a riparian zone of trees and shrubs to provide sediment and nutrient interception, nesting and foraging sites.

7. Wetlands should always be bordered by natural vegetation within at least 250 m of the wetland edge. This border should include vegetation characteristic of riparian zones.

8. Amphibians – which typically display poor dispersal abilities relative to other vertebrate species (Duellman and Trueb, 1986; Marsh and Trenham, 2001) – should set the bar for determining maximum distance between wetlands: < 1.0 km. Small ephemeral wetlands should be constructed between larger wetlands; they play an especially critical role in

connectivity, as they form stepping stones across the landscape between larger, more complex wetlands, allowing individuals to move between populations and to recolonize breeding sites following local extinctions (Semlitsch and Bodie, 1998; Gibbs, 2000).

9. Wetlands should be separated from roads by at least 1 km to facilitate hydrologic and ecological connectivity.
10. Wetlands should have high shoreline complexity; this increases edge habitat and provides a greater variety of habitat for wildlife.
11. The basin profile should emulate natural basins, with the objective of maximizing habitat for most species. If possible, construct variable basin profiles, as well as islands. Islands provide important refuge areas for waterbirds, and local irregularities in the contour of the wetland bottom will increase habitat heterogeneity (Alsfeld et al., 2009). A variety of depths should be constructed, including deeper water that will provide overwintering habitat for semi-aquatic mammals and small-bodied fish.
12. Coarse woody debris should be added to reclaimed wetlands, where appropriate, to provide habitat for aquatic invertebrates (Alsfeld et al., 2009), which are important prey items for wildlife species and important to wetland function. Information on naturally-occurring wetlands of the type being reclaimed should be used as guidance for determining site-specific reclamation actions.
13. Wetlands should have extensive shallow littoral zones, as these are important areas for many species including most aquatic vegetation, wading birds, and breeding amphibians.
14. Isolation of wetlands reduces immigration of reproductive propagules (plants, zooplankton, phytoplankton, microbes). Connectivity is critical for colonization of reclaimed wetlands.
15. Fluctuating water levels are important for many wetland types. This can control aquatic predator communities, dominant plant assemblages, access to prey, etc. Wetlands should be designed to allow changes in water levels, if appropriate for the wetland type.
16. Passive immigration of propagules is critical to facilitate succession at a site, especially if minimal ecological management is to be employed. The dispersal ability of organisms varies, and it must be realized that significant time may pass before some groups are able to reach a reclaimed wetland (Cáceres and Soluk, 2002).
17. Active inoculation of a site with vegetation, soil, and/or plankton from local wetlands of appropriate types may facilitate development of diverse biotic communities at constructed wetlands. This provides propagules of organisms which are poor dispersers, including plants and invertebrates (Brady et al., 2002), groups which form the base of the food web that supports wildlife species, and also provide much of the biological

function of wetlands. Note, however, that potential inoculants (e.g. plant material, soil cores) should be tested to ensure they are an effective means to introduce appropriate flora and fauna to a reclaimed wetland (Brady et al., 2002; Taillefer and Wheeler, 2013).

18. Design wetlands to support a community, rather than simply specific species. Where specific species are desired, or where regulations stipulate that habitat for specific species must be created (e.g., for a species-at-risk), identify what *additional* management steps are necessary (e.g., provision of overwintering habitat) after designing the wetland to support a functional community first. Realize that providing habitat for some species at a wetland will require a landscape-scale approach, rather than just the reclamation of a single wetland.

19. A reclaimed landscape should include ephemeral, intermittent and permanent wetlands juxtaposed with upland habitat.

20. Multiple wetlands should be placed in proximity as they provide ecological stepping stones that increase connectivity, thereby increasing stability and long-term persistence. Small wetlands, even if they are ephemeral, can provide important connectivity during the spring breeding migration of amphibians.

21. The presence of fish, even small-bodied fish such as stickleback, will alter the aquatic invertebrate community such that potential prey for waterfowl is reduced in abundance (Hornung and Foote, 2006). Fish should not be actively added to reclaimed wetlands; fish should be allowed to colonize these systems naturally, after the wetland system develops and can sustain natural colonization. This gives other elements of the biotic community time to establish at a reclaimed wetland, and ensures that fish are able to reach a wetland naturally to provide gene flow between populations in the future.

22. Migratory waterfowl use wetlands with a variety of hydroperiods, including ephemeral wetlands as spring pair habitat, and more permanent wetlands for nesting and brooding; these habitats should be within 3.2 km of each other.

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## Chapter 3

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## Chapter 4

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