GUIDELINE FOR WETLAND ESTABLISHMENT ON RECLAIMED OIL SANDS LEASES

Revised (2007) Edition

Recommended by the
Wetlands and Aquatics Subgroup, Reclamation Working Group,
Cumulative Environmental Management Association –
Wood Buffalo Region

Alberta

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Any comments, questions or suggestions on the content of this document may be directed to:

Regional Services, Northern Region
Alberta Environment
#111 Twin Atria Building
4999 – 98 Avenue
Edmonton, Alberta T6B 2X3
Fax: (780) 427-7824

Additional print copies of this document are available from:

Information Centre
Alberta Environment
Main Floor, Oxbridge Place
9820 – 106 Street
Edmonton, Alberta T5K 2J6
Tel: (780) 427-2700
Fax: (780) 422-4086
Outside of Edmonton dial 310-0000 for toll-free connection
Email: env.infocent@gov.ab.ca

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CEMA Reclamation Working Group
Wetlands and Aquatics Subgroup

Mission Statement
Support the creation of a range of sustainable wetlands for oil sand reclamation and restoration of disturbed wetlands in the Athabasca oil sands region, by advancing the development of guidelines

Vision
Design criteria and performance measurements for created wetlands that are accepted by industry, regulators and stakeholders

Title Page Photographs: *Right photo*: Tower Road natural wetland, Fort McMurray, AB. Courtesy of Kristina Norstrom (Albian Sands) 2005. *Left photo*: Peat Pond, Syncrude Mildred Lake lease (on saline, sodic overburden landform) – the first reclaimed wetland to use the Guidelines for Wetland Establishment on Reclaimed Oil Sands Leases (2000 [first] edition) during the planning and design phases of construction. Courtesy of Clara Qualizza (Syncrude Canada) 2006.

Executive Summary

This second edition of the wetlands guideline is an update of the state of knowledge regarding reclamation of wetlands in the oil sands region. It describes an integrated approach to the planning, design, construction, monitoring and adaptive management of reclaimed wetlands. The approach adopted by this guideline is founded on five basic principles:

- recognition of the critical function of wetlands in distributing and retaining water on the reclaimed landscape;
- recognition of the complex interaction of climate, hydrology, geology, ecology and time on wetlands creation and evolution in the oil sands region;
- recognition of the need for inter-disciplinary collaboration and coordination when working toward wetlands reclamation;
- recognition that good will, compromise and communication among stakeholders will be invaluable in the pursuit of a complex and dynamic result – healthy, functioning reclaimed wetlands that approximate natural systems as best as current knowledge and capabilities allow;
- recognition that best practices will evolve with continued research, monitoring, and adaptive management.

Although this edition focuses on reclamation on surface-mined oil sands leases, there is also information provided regarding restoration of altered wetlands on or adjacent to surface-mined leases or on in-situ mine sites. Wetland reclamation is defined as the creation of wetlands on disturbed land where they did not formerly exist or where their previous form has been entirely lost. Wetland restoration is a process of returning wetland function of a remnant wetland site, as it was before disturbance.

Wetland reclamation and restoration knowledge from other regions of North America and the world may be used to assist planning teams in the oil sands, but those experiences must be adapted and/or assessed for their applicability to the natural, traditional, industrial and regulatory environments of north-eastern Alberta. Section 3.0 provides these ecological, historical and regulatory contexts to the guidance in the remainder of the document.

Wetlands cover approximately half of the natural landscape in the oil sands region, and are, thus, a major component of the undisturbed boreal ecosystem. Wetlands are areas where the land is saturated with water for long enough periods to support wet-adapted processes and plants. They are shallow (≤2 m) with stagnant or slowly moving water. Wetland classes encountered in the oil sands region are bogs, fens, marshes, shallow open water wetlands and swamps. This guideline discusses riparian margins or fully aquatic systems (lakes and streams) only in relation to their interaction with wetlands on the whole reclaimed landscape.

Natural boreal wetlands are a critical habitat for many important wildlife species, including woodland caribou, moose, muskrat, beaver, waterfowl (particularly diving ducks) and amphibians. They are linked to the traditional way of life of local Aboriginal people, because of the economic importance of fur-trading and the cultural significance of many wildlife species (moose, muskrat, beaver) and wetland plants (Sphagnum moss, rat root, bog cranberry). Aboriginal knowledge and interpretations of wetland systems are based on long term empirical evidence and have much to contribute to western scientific research findings.

The surface mining of oil sands in north-eastern Alberta produces several landforms and materials that are relevant to wetlands reclamation:

- mining excavations produce end-pits, a wide range of gradients and overburden piles;
- extraction of bitumen from oil sands produces process-affected tailings containing water, sand, silts, clays, soluble organic chemicals (such as naphthenic acids and hydrocarbons), ammonia, heavy metals and salts;
- process-affected materials that cannot be recycled are stored in settling basins (up to tens of square kilometres in surface area), where subsequent settlement and redistribution produces sand edges, mature fine tailings and process-affected water;
- upgrading of bitumen to crude oil produces by-products like sulphur and coke that are stockpiled in a retrievable manner;
- the mining and extraction processes increase the volume of materials (natural soils and separated soil components like overburden and tailings) by 20-25 % over the initial pre-disturbance volume.

These changes fundamentally alter the topography, geochemistry and hydrology of the land. Reclamation must incorporate or accommodate these post-mining elements.

The reclamation of these disturbed areas to wetlands requires an awareness of the regulatory and planning policies of the region. These include legislated obligations (Alberta Water Act, Alberta Environmental Protection and Enhancement Act [EPEA]), management strategies ('Water for Life'), regional planning (Regional Sustainable Development Strategy, Fort McMurray regional management plan), and multi-stakeholder strategic planning (the mandate of the Reclamation Working Group of CEMA). A fundamental component of the EPEA is the reclamation objective of returning disturbed landscapes to 'equivalent land capability', which is defined as the ability of the land to support various land uses after reclamation that are similar but not necessarily identical to those that existed before mining. Wetlands will play an important functional role in meeting these regulatory requirements of reclaimed landscapes.

Reclamation efforts in the oil sands are large-scale, involving whole landscapes or watersheds; thus wetlands created in this context are fundamentally different from many of the wetland projects documented in the published literature. In this guideline, the planning and design of wetlands has been divided into landscape-scale and wetland-scale components. This recognizes that landscape-scale elements and design of uplands reclamation will largely determine what can be achieved at the level of the individual wetland. Guidance on wetlands planning at these two spatial scales is provided in section 4.0.

Landscape-scale planning must involve decision sequences that incorporate: the uses and functions required in the reclaimed wetland, wetland placement relative to other landforms, and aerial extent of wetlands in the closure landscape. Guiding recommendations that relate to this level of planning are provided in section 4.1.

Wetlands provide several important uses and functions:

- water storage
- groundwater recharge
- flood control (by detention or depression storage)
- storm runoff generation
- microclimate regulation
- shoreline stabilization
- water treatment
- carbon storage
- Aboriginal cultural use
- trapping of fur-bearers
- fishing and waterfowl hunting
- recreation
- wildlife habitat (wetland indicator species are moose, woodland caribou, muskrat, beaver, Canadian toad and ducks).

The key limiting landscape-scale and wetland-scale variables related to the provision of these uses and functions are listed in table 4.1.

The landscape setting will largely determine whether a reclaimed wetland will be suitable for its intended uses or functions. Various feasible landscape settings are documented in section 4.1.2. Landscape-scale planning and design must consider the following broad elements, as they relate to the desired uses and functions as well as to long-term sustainability of wetlands:

- climate
- hydrology
- geology
- topography
- succession

Wetlands need a water supply that can sustain hydrophytic plants and produce saturated soils for at least part of the year. Water in the reclaimed landscape may come from direct precipitation, surface runoff (including snowmelt), groundwater, or process-affected water. Because wetlands in the oil sands region persist in a near water deficit most years (precipitation < evapotranspiration), water inputs (from deep groundwater or surface flows) or dynamic storage properties are critical for sustaining them over the long term. It will be imperative to connect many of the wetlands on reclaimed landscapes with local or regional groundwater flows and to understand how water moves through reclaimed soils. Other wetlands perched above the water table may provide valuable functions in groundwater recharge or storm runoff generation, whereas shoreline wetlands connected to end-pit lakes or streams may be less complex hydrologically and useful in water treatment or as wildlife habitat.

The thick, layered, marine-derived nature of undisturbed surficial soils in the oil sands region complicates the hydrogeochemical design and placement of reclaimed soils. Salinity and sodicity are common issues with reclamation overburden, and have major implications for wetland vegetation viability and diversity. The layering of fine- and coarse-grained soils in natural systems produces complex interflow pathways. Creating subsoil layers of fine-grained and coarse-grained soils during construction of closure landscapes will increase the proportion of lateral interflow of water and may provide sustainable levels of surface runoff to perched wetlands.

The upland end land use and vegetation design must also be considered when estimating the long-term sustainability of constructed wetlands. Growth of forests on upland hill-slopes will likely reduce the surface runoff, particularly snowmelt, to wetlands. The actual rate of evapotranspiration can also change dramatically with succession to different grassland and forest communities. Section 4.1.4 suggests some potential landscape settings for sustainable reclaimed wetlands, accounting for regional hydrology, geology, topography, succession changes and natural watershed to wetland ratios. Site-specific landscape design may build upon these scenarios.

Once their placement within the reclaimed landscape has been determined, planning for individual wetlands should consider the following broad design elements:

- basin morphology
- sediment and substrate materials and properties
- hydrologic capacity
- water sources
- chemical properties
- vegetation communities
- invertebrate communities
- other habitat elements for wildlife and fish.

Recommendations for construction of wetlands are provided in section 4.2. There is more experience in constructing marshes and ponds than the other wetland classes, and thus there are more design recommendations available for these wetland classes (see table 4.3). Research into the hydrological conditions required for fens, and organic matter accumulation rates for vascular peat-forming species indicate that there is potential for fen reclamation. In the near future, this needs to be confirmed at the field experimentation level.

Monitoring and adaptive management of constructed wetlands are discussed in section 4.3. Monitoring is key to tracking wetland establishment and identifying issues threatening long-term sustainability. Effective monitoring incorporates the following principles:

- a program design that enables statistical validation of findings
- a comparison with similar reference wetlands
- identification and monitoring of the key structural and functional variables
- appropriate time-lines for monitoring
- progressive, well-communicated interpretation of the data
- integrated planning by monitoring teams.

Some potential physical, chemical and biological monitoring methods are outlined in figure 4.4. Where problems with the constructed system are encountered during monitoring, adaptive management may be able to overcome the identified obstacles. Section 4.3.2 describes some of the anticipated challenges and what management techniques might be applied in those cases. In some cases, there may be a need to retrofit the wetland to achieve intended functions. In others it may be that the functions are modified to suit the wetland established. Section 4.3.3 describes some of the lessons learned thus far during pilot-scale wetland reclamation research initiatives on Suncor and Syncrude oil sands mine leases.

Section 5.0 discusses restoration of altered wetlands, where the emphasis is clearly focused on monitoring the changes from pre-disturbance conditions and managing the magnitude of the changes until a full restoration plan can be implemented. Many of the techniques applied for monitoring and adaptive management are similar to those described in relation to constructed, reclaimed wetlands; however, the sequencing is changed from the reclamation scenario. Extensive monitoring must occur before and during the

anticipated disturbance, to ensure that the pre-disturbance ecosystem is adequately understood.

Criteria for certification of reclaimed wetlands have not been established. Thus, section 6.0 on certification only briefly outlines the following fundamental considerations for the structural and functional integrity of reclaimed wetlands, as possible criteria for evaluation:

- Will the wetland be 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?

The final section of this guideline addresses the uncertainty that remains for wetlands reclamation in the oil sands region, including the challenges facing mine closure teams, and the ongoing research needed to address the remaining knowledge gaps. The WASG research priorities in the next five years focus on studies that investigate (in no rank order):

- Reclamation of peat-forming wetlands, including fens
- Incorporation of societal values into wetland reclamation
- Hydrological mechanisms in wetlands reclamation
- Biological processes driving wetlands establishment
- Water treatment capacity of reclaimed wetlands
- Methods for monitoring efficacy of wetland ecosystem establishment.

This second edition of the wetlands guideline has incorporated knowledge gains that have occurred through an accelerated research program since the first edition was issued in 1999. Although there is still much to be learned about reclaimed wetlands, there is the potential for healthy, dynamic and valuable ecosystems on closure landscapes in the future. The third edition planned for in five years time should be able to extend the existing recommendations for marshes and shallow water wetlands and potentially include guidelines for fen creation.

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1.0 How to Use This Guideline

The Guideline for Wetland Establishment on Reclaimed Oil Sands Leases was designed to be used in tandem with other **reclamation** planning documents, including the Landscape Design Checklist[1] and the Guidelines for Reclamation to Forest Vegetation in the Athabasca Oil Sands Region[2]. The premise is that reclamation on **oil sands** leases requires an integrated approach from planning inception through to certification.

This guide considers wetlands (depth ≤2 m, see section 3.1); other aquatic elements such as end-pit lakes and streams are only discussed in relation to how they interact with wetlands.

An integrated approach requires the involvement of a multidisciplinary management team; wetlands cannot be built by any one discipline in isolation. Connell and Hayes[3] describe this need: "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 others' work and professional approach is much greater than in other projects". Wetlands reclamation planning, design and construction will require input from engineers, hydrologists, soil scientists, wetland botanists and ecologists, and earth-movers at the least.

This guideline is limited in scope to issues directly related to the practical application of reclamation techniques to **wetlands** creation. It is a **guideline** and not a **handbook**[4], which means that it outlines a general approach rather than a precise recipe for reclamation. This reflects both the early stage of reclamation in the oil sands and also the variable, site-specific nature of hydrological and geochemical processes within the surface mineable oil sands region. The body of the text contains recommendations and a minimal level of background material. The reader is, therefore, frequently directed to the appendices and other published literature for an extended discussion of the elements pertinent to wetlands reclamation.

A guideline is an outline of a course of action, whereas a handbook is a concise reference or manual for a process. Wetlands reclamation in the oil sands region is not yet developed to the point where a handbook is advisable.

The steps in the wetlands reclamation process are presented according to the following categories and colour codes: contextual material (blue), steps to plan, design, build and monitor (red), certification (yellow), and identification of uncertainty factors and ongoing research (burgundy). Words that are defined in the glossary appear in green bold upon first mention in the text. In recognition of the varied backgrounds and specialties of reclamation participants, some elaboration on key words and concepts is also given in the page margins.

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[1] CEMA 2005
[2] Oil Sands Vegetation Reclamation Committee 1998; other update documents include Geographic Dynamics Corp 2002, Axys 2003
[3] Connell and Hayes 2000
[4] for example, the wetlands handbook designed by the US Army Corp of Engineers (Hayes et al. 2000) is available online at: http://el.erdc.usace.army.mil/publications.cfm?Topic=techreport&Code=wetland

2.0 Guideline Objectives

2.1 Founding Principles for the Guideline

The approach to reclamation adopted by this guideline is founded on five basic principles:

- recognition of the critical function of wetlands in distributing and retaining water on the reclaimed **landscape**;
- recognition of the complex interaction of climate, **hydrology**, geology, ecology and time on wetlands creation and evolution in the oil sands region;
- recognition of the need for inter-disciplinary collaboration and coordination when working toward wetlands reclamation;
- recognition that good will, compromise and communication among stakeholders will be invaluable in the pursuit of a complex and dynamic result – healthy, functioning reclaimed wetlands that approximate natural systems as best as current knowledge and capabilities allow;
- recognition that best practices will evolve with continued research, **monitoring**, and **adaptive management**

These principles are inherent in the guideline's recommendations and in the direction currently taken by the Cumulative Environmental Management Association – Wood Buffalo Region (CEMA) to address future information needs.

2.2 Guideline Origins

This is the second edition of a document first prepared in 2000 by a multi-stakeholder initiative called the Oil Sands Wetlands Working Group[5]. The original guide arose out of a recognized regulatory need (see section 3.4), with the intent that it would be a working document subject to regular updates. This 2006 edition is an interim update, with a further extensive update planned for five years time, which will incorporate knowledge gained from current research initiatives.

The original guideline was published by Alberta Environment as a planning tool in support of wetlands reclamation on oil sands leases. To date, the guideline's recommendations have been used on one lease (Syncrude's Mildred Lake) to assist with the reclamation of one wetlands complex (Peat-Golden Ponds). The performance of the guideline in that instance has been evaluated and changes made to this edition where a need for further guidance was identified; for instance, hydrology was a topic area where additional information was required.

The original mandate of the Oil Sands Wetlands Working Group has been adopted by a subgroup of CEMA, specifically the Wetlands and Aquatics Subgroup (WASG) of the Reclamation Working Group. This subgroup was established in 2002, and their primary mandate was to revise the

[5] OSWWG 2000

published wetlands guideline. This second edition was produced by WASG members[6]. In addition to identifying information gaps in the first edition and improving guidance in those areas, WASG developed a strategic plan that identified outstanding fundamental wetlands reclamation needs. They have initiated studies to address several of these needs including research gaps (see section 7.2). The intention is that the findings from these studies will be available for incorporation into the third edition of this guideline (planned in approximately 5 years time).

Current research needs:
1. reclaiming fens / bogs
2. value of wetlands
3. hydrology
4. biological succession
5. water treatment
6. wetland indicators.

2.3 Key Intent of Guideline

This document was developed to guide the planning processes for design, construction, monitoring, management, and certification of wetlands reclaimed on surface-mined oil sands leases in the Regional Municipality of Wood Buffalo (RMWB; ie, the mineable oil sands, see Figure 2.1). **Restoration** of wetlands **altered** but not destroyed by surface mining is briefly discussed (section 5.0). A clear distinction is made between reclamation and restoration in this guideline; the two processes are compared and contrasted in section 3.5.

The information contained here is organized such that it will hold the most value if it is applied from project inception (at the environmental impact assessment stage) through closure planning, implementation, certification and mine closure.

The guidelines recommended here may also be applicable to the reclamation of other types of surface disturbances, such as *in-situ* oil sands operations. However, recommendations specific to these other circumstances are largely beyond the scope of this edition. Future editions should expand the breadth of the guidelines to encompass related wetlands restoration situations.

2.4 Key User Groups and Stakeholders

The intended audience for this document includes those who may apply the guide's recommendations to reclaim wetlands (oil sands mine closure planning teams), the government agencies responsible for evaluating and regulating reclamation (Government of Alberta) and those who will live beside and possibly use reclaimed wetlands after lease closures. Possible use of the guideline by these key stakeholders includes the following:

Mine closure teams

- Managers may use the whole document and integrate its recommendations with the requirements of regulators and desires of other stakeholders;

[6] a list of WASG members (current at the time of preparation of this manual) is provided in Appendix A

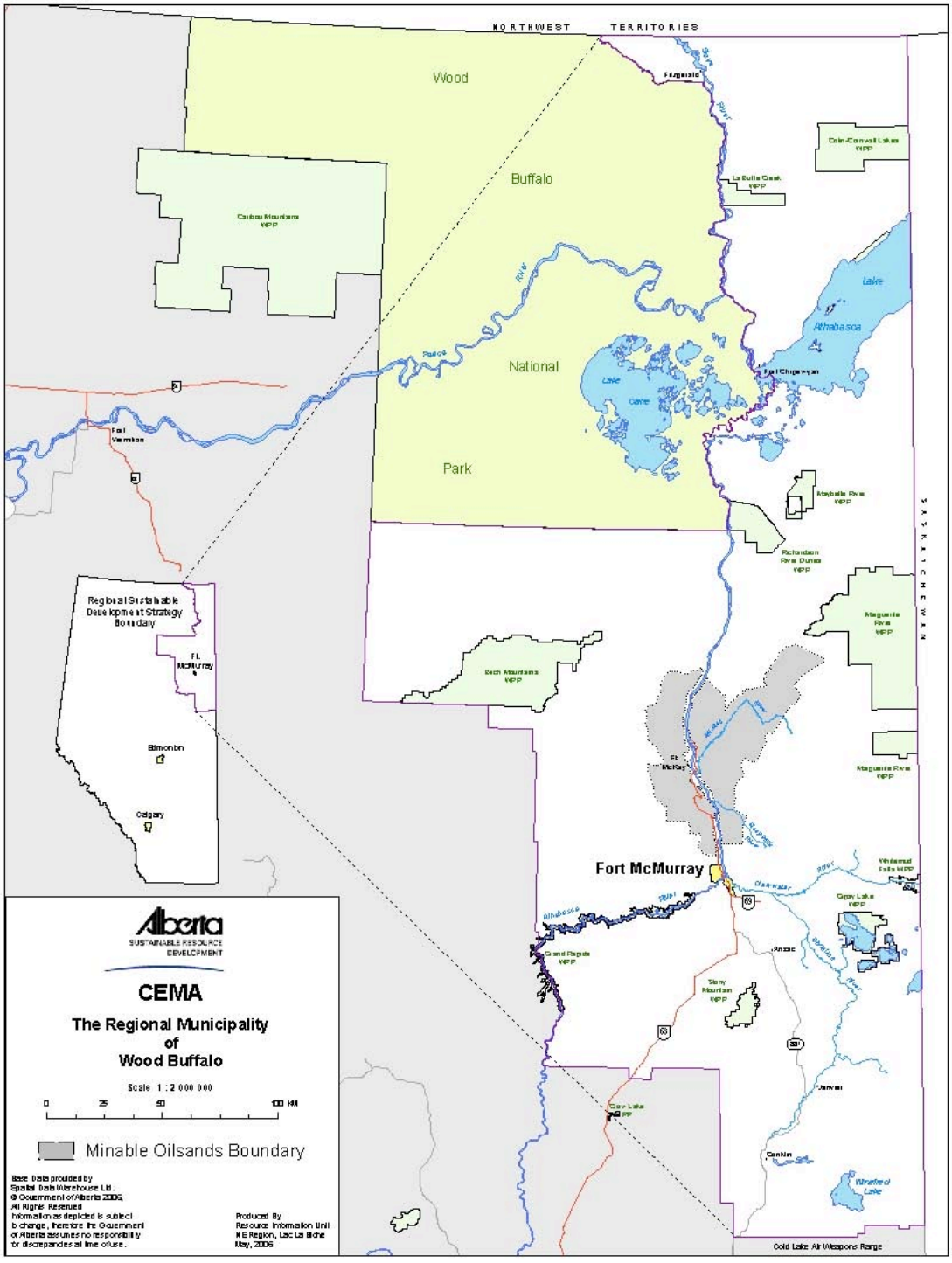

Figure 2.1 The geographic boundaries of the Cumulative Environmental Management Association (CEMA) and its subgroups correspond to those of the Regional Municipality of Wood Buffalo. This map also shows the area of surface mineable oil sands (shaded expanse north of Fort McMurray), of which this guideline is principally concerned.

- Planners may find section 4 useful for identifying the most practical and functional setting for wetlands in the reclaimed landscape;
- Engineers, hydrologists, soil scientists and biologists may find sections 4 and 7 useful for adapting the design and construction of reclaimed wetlands to specific reclaimed landscapes, using the most current knowledge available.
- Scientists monitoring the structure and function of reclaimed or altered wetlands may find sections 4 and 5 useful for understanding how their area of expertise is connected to the other elements of the whole landscape.

Regulators

- Government staff may use this guideline as a tool for advising mine lease holders, to assist in reviewing mine development applications, and as a resource in the eventual evaluation and certification of reclaimed wetlands.

Communities

- Interest groups can use the guideline as a resource to identify the current state of the science regarding wetland reclamation in the region;
- **Aboriginal people** from the region may refer to it when communicating their specific needs for wetland **habitat** to mine lease holders or when determining how they wish to be involved in and contribute to the processes of reclamation and restoration;
- Interest groups and individuals may find the guideline useful for identifying which types of wetlands could satisfy their recreational and/or economic requirements.

3.0 Background

3.1 Environmental Context and Wetlands Classification

The natural environment overlying the **surface mineable oil sands** of northern Alberta is variously defined by hydrologists, ecologists, Aboriginal people and others according to their key interests. Hydrologists and geologists recognize the area as part of the boreal plain or the Western Canadian sedimentary basin. Foresters and ecologists recognize most of it as central mixed-wood natural sub-region of the extensive northern boreal forest region[7]. Aboriginal people identify with the principal habitat of **muskeg**; Fort McKay's Cecilia Fitzpatrick states that "the muskeg is why the earth breathes"[8].

The climate of the region is sub-humid, which means that precipitation is less than or equivalent to **potential evapotranspiration** (PET). The **bedrock** is sedimentary and deep (often > 50 m below the ground

[7] all of the sub-regions are described by Wiacek et al. 2002; Alberta Environment 2006
[8] Fitzpatrick 2003

surface). The surficial soils reflect ancient processes of **riverine** deposition, estuarine encroachment, invasion of marine waters and **sediments**, and finally glaciations. The **topography** is flat to gently rolling with a deeply incised Athabasca River valley. Water movement patterns through this land contrast strongly with those for other regions of Canada, in that the influence of surface **runoff** in regional hydrological systems is minimal compared to that of soil storage and **groundwater flow**. Vertical movement of water through the soil dominates over horizontal movement[9].

Sub-humid Climate (water deficit) → *plan* → good water storage

Wetlands cover around 50 % of the natural landscape in the oil sands region[10]. Wetlands are areas where the land is saturated with water for long enough periods to support wet-adapted processes and plants, including **hydrophytic** vegetation[11]. They are differentiated from lakes by having a mid-summer water depth of ≤2 m, and from streams or channels by having a non-linear morphology and little to no **flow** for most of the year (swamps and fens may have surface sheet flow periodically). This guideline will use the Canadian Wetland Classification System[11] to describe the wetland forms currently and potentially attainable by reclamation initiatives. The Canadian system was chosen over other formal classification systems used in southern Alberta[12], because it is more suited to distinguishing the **natural wetland analogues** present in the boreal forest[13]. According to the Canadian system, there are five major classes of wetlands (see Figure 3.1 and Appendix B). In the oil sands region, the **peat-forming** classes, namely **fens** and **bogs**, cover a significant area of boreal terrain (43 % of the total landscape), compared to **marshes** (2 %, also may be peat-forming in northern Alberta), **shallow water wetlands** (1 %) and **swamps** (<1 %)[14].

Sedimentary geology (marine & freshwater deposits) → *consider* → coarse- or fine-grain salt content

Topography (flat to rolling) → *map* → groundwater-surface intercepts

Even though classification of wetlands is a critical planning and communication tool for conducting cross-disciplinary endeavours like reclamation, it is also important to acknowledge that neither natural nor constructed wetlands are static systems through time. Depending on long-term trends in biogeoclimatic conditions, a wetland may or may not transform into a different class type. For instance, fens typically begin as marshes and they may retain the fen dynamics or ultimately evolve into a bog[15]. The time-scale for natural **succession** tends to be in hundreds or thousands of years. Succession in constructed systems may occur in a much shorter period, because of elements intentionally or unintentionally introduced during or after construction. For instance, the **compression** of upland or wetland soils still settling after reclamation placement affects the morphology and depth of a wetland, which will in turn alter vegetation and nutrient regimes. Intensive planting of wet-adapted vegetation will

This guideline describes shallow water wetlands as ponds (inland) or open water wetlands (shoreline). The descriptor 'shallow' is misleading, as this class tends to include the deepest wetlands (1 – 2 m), dominated by submergent (below-surface) vegetation.

[9] Appendix C1-2 (Devito & Mendoza; Devito et al.)
[10] Kuhry et al. 1993; Vitt et al. 1996; Bayley 2003
[11] National Wetlands Working Group 1997; Alberta Environment 2003a
[12] Cowardin et al. 1979; Stewart and Kantrud 1971; both are USGS systems recommended in Alberta Environment 2005; available online at: http://www.npwrc.usgs.gov/resource/wetlands/ (followed by either classwet/classwet.htm or pondlake/pondlake.htm)
[13] Bayley and Mewhort 2004
[14] Bayley 2003
[15] Mitsch and Gosselink 2000; Vitt 1994; Vitt 2003

accelerate the natural processes of plant colonization and community stabilization. Fort McKay Elders refer to beaver (*Castor canadensis*) as the 'builders of the land'[16]. Establishment of beaver can dramatically change the form and function of a wetland and/or create wetlands in a short period[17]. Adaptive management can anticipate or enhance the processes of succession, incorporate flexibility and diversity into wetland reclamation, and is therefore an important aspect of the work.

Other commonly used wetland names: the term slough is often used to describe a marsh; prairie pothole is a regional type of marsh in southern and central Alberta.

Wetlands are a critical habitat for several of the indicator wildlife species identified by CEMA stakeholders[18]. These species were chosen because of their ecological importance, niche representativeness, abundance or resource use value[19]. Woodland caribou (*Rangifer tarandus caribou*) rely on the cover provided by bogs and fens to evade their primary predator, wolves (*Canis lupis*); they also depend on lichens found in these habitats as food for most of the year. Although moose (*Alces alces*) are **habitat generalists**, they particularly seek out fens during spring calving and use wetlands and riparian margins in late winter to access green browse high in energy value. Muskrat (*Ondatra zibethicus*) and beaver use marshes and open water wetlands, where their preferred species of **emergent** and riparian vegetation are also present. Canadian toads (*Bufo hemiophrys*) require some form of still or slow-moving water to breed, and will use almost anything wet that is adjacent to sandy upland **overwintering** sites. Ducks, particularly diving ducks like canvasback (*Aythya valisineria*), redhead (*A. americana*) and ring-necked ducks (*A. collaris*) and sea-ducks like bufflehead (*Bucephala albeola*) and common golden-eye (*B. clangula*), use marshes and open water wetlands in the oil sands region for nesting, **moulting** and during spring and fall **staging**. Of these indicator species, moose might be considered as a cultural **keystone species**, because of its significance to Aboriginal people[20].

succession

↓

expect effects from

↓

vegetation of uplands
soil compaction
climate change
land slips or slides

vegetation of wetland
substrate consolidation
change in water sources
beaver, muskrat activity

Boreal pond in Utikuma Research Study Area (Credit: Suzanne Bayley 2005)

[16] Garibaldi 2006a
[17] Naiman et al. 1994
[18] Wiacek et al. 2002; Axys 2003
[19] Oil Sands Vegetation Reclamation Committee 1998
[20] Garibaldi and Turner 2004; A. Garibaldi personal communication

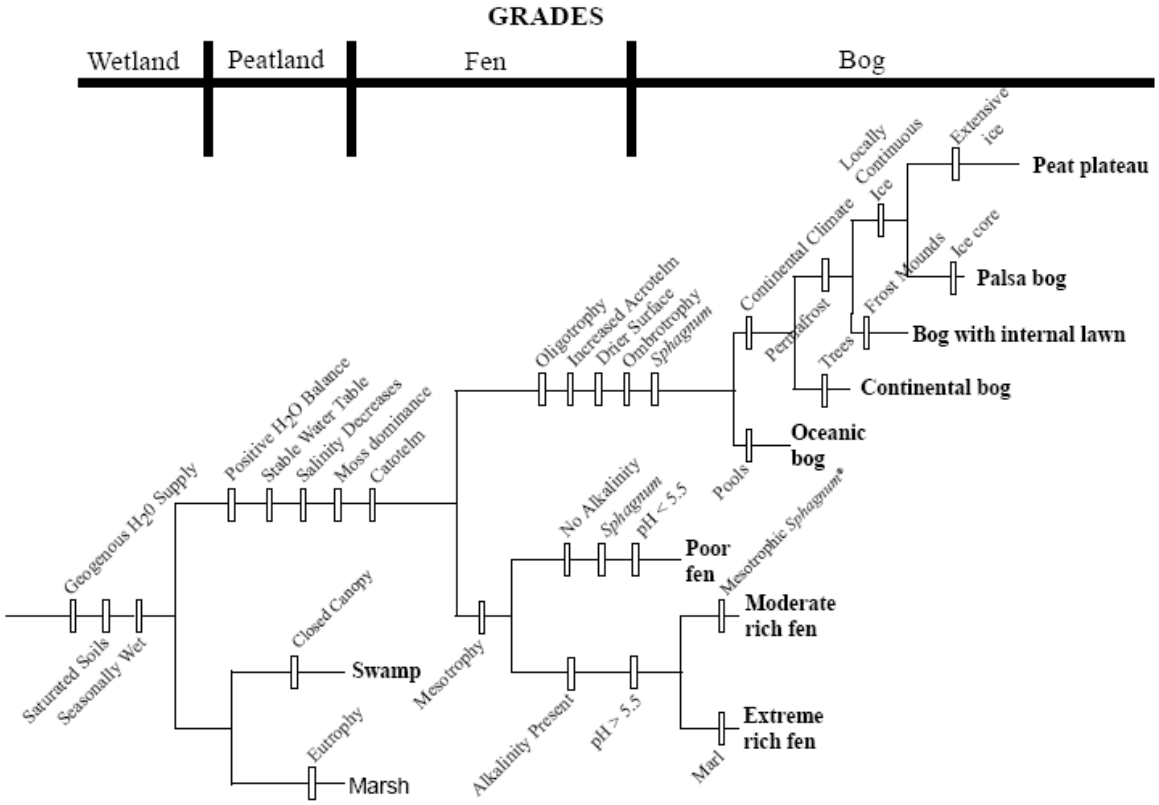

Figure 3.1 A clade of wetlands naturally occurring in boreal ecosystems of North America (reproduced with permission from Wieder and Vitt 2006). With reference to wetlands reclamation and restoration, the greater the number of conditions identified along the clade pathway, the more complicated is the process of wetland establishment. Shallow water wetlands are not shown, but would occur at the first point of diversion (requiring only a geogenous water supply, saturated soils and seasonal wetting). Bogs are the most complex wetland systems, and also the most difficult systems to reclaim.

3.2 Aboriginal Use Context

Wetlands in the oil sands region are indelibly linked to the traditional way of life for local First Nations and Métis communities. Some Elders of Fort McKay recall the muskeg where the Mildred Lake and Steepbank mine leases are as being particularly spongy and rich with life[21]. Moose, the main food for generations then and now[22], were there in abundance.

Muskeg is another name for peat-forming wetlands (bogs and fens). Some First Nations may also use it to describe the dominant forms of moss associated with bogs and fens.

People of the Fort McKay, Anzac and Fort Chipewyan communities continue to use wetlands for subsistence hunting and trapping, for food and medicinal plant collection, and for spiritual well-being. Spirituality for people from these communities is inherent in the interaction of the people with their land[24]. A number of culturally significant plant and animal species are exclusively or often associated with wetlands[25]. Rat root (sweet flag, *Acorus calamus*) is one example of a culturally significant wetland plant, used regularly as a natural remedy for a number of aches, pains, colds and flus[26]. In the past, moose meat was stored in the naturally cold muskeg, where the frost never retreated. Moss was collected and dried for toilet paper, diapers, mattress stuffing and house insulation[8].

"Water supplies the air, water supplies food for the plants, water supplies food for the people that live…around here. Everything water. That's what you've got to test all the time." Elder from Anzac, March 22, 2005, TEK Workshop[23]

Trapping, mainly of muskrat and beaver, is an important economic and cultural winter activity in the region. Traditionally, Aboriginal people from the oil sands region lived isolated lives in small family units and survived by trapping. Trap-lines lie at the heart of the connection of the people with the land. They may still be handed down from generation to generation, linking young people with Elders in a practical and spiritual sense. The lines also provide year-round circuits to hunt, fish, collect plants and educate young people about muskeg and the larger natural landscape. Increasingly, however, trap-lines are disappearing or are being fragmented and isolated from dispersing fur-bearers by expansion of surface mining operations[27].

Elders from Fort McKay have noted that water levels appear to be lower in the region compared to pre-mining levels.[23]

Regional Elders and others actively practicing a traditional lifestyle have a vast store of knowledge about the wetland habitats of the oil sands region, and the life histories of the culturally significant species that inhabit them. This valuable knowledge could provide great insight when designing and reclaiming wetlands on closure landscapes. It is critical that Aboriginal consultation is included at every stage of wetland reclamation, from planning to building to monitoring. Open communication and knowledge-sharing will strengthen the integrity of the work and its value to all stakeholders. In addition, the participation of local young people in building reclaimed wetlands may help strengthen cultural integrity. In order to maintain a connection with the new landscape, recognition of the

[21] Fort McKay First Nation 1996; Fitzpatrick 2003
[22] Wein et al. 1991; Fitzpatrick 2003
[23] excerpt from Shared Learnings (Garibaldi 2006b)
[24] a conversation between A. Garibaldi and C. Fitzpatrick
[25] Appendix F (Gulley & Garibaldi)
[26] Fort McKay First Nation 1996; Garibaldi 2006a
[27] Tanner et al. 2001

value of reclaimed wetlands and ultimately a desire to use the areas by Aboriginal residents will be critical.

That said, as long as a lease remains active, unstructured access for anyone will not be feasible due to safety concerns. By the time of mine closure, at least some of the wetlands should have had time to develop as viable habitat used to sustain wildlife populations. At this stage in the research, it seems likely that the coverage of peat-forming wetlands on the reclaimed landscape will be reduced from pre-mining abundance, because of the current scientific limitations to fully reclaiming bogs and fens, and because of the effects of reclamation to a steeper topography on the upland: wetland ratio (see sections 4.1, 7.2). However, the local populations of some important waterfowl and fur-bearing species, such as ducks and muskrat, may benefit from expanding the area in marshes and open water wetlands.

Another issue that must be resolved for reclamation wetlands before re-establishment of their full use by local communities relates to potential **contaminant** levels in plants and animals. Research to-date suggests that food species collected from reclaimed wetlands on operating leases have negligible (undetectable) levels of metals[28]. However, monitoring will need to occur routinely at each mine site as reclamation progresses to ensure the ongoing safety of country foods.

3.3 Oil Sands Mining Context

Large-scale surface mining of oil sands in Alberta began in 1967 about twenty kilometres north of Fort McMurray. A second mine opened in 1978, then four others opened between 1998 and 2002. Since 2000, the oil sands industry has expanded significantly, and production now exceeds one million barrels crude oil per day[29]. The total area deemed suitable for surface mining is approximately 2535 km^2 (253,500 ha), and in 2006, 55 oil sands lease agreements cover 90% of that area[30]. Active development is occurring on over 250 km^2 (25,000 ha)[31].

Those first two early mines, Suncor's lease 86 and Syncrude Canada's Mildred Lake lease, are currently proceeding with progressive closure of reclaimed landscapes. Experimentation with wetlands reclamation at these two sites has been underway since the early 1990s. Closure landscapes with wetland elements have begun to take shape. The last surface mines may still be in operation beyond 2050.

Naphthenic acids are surfactants (detergents). They can be highly toxic to aquatic plants and animals, because they disrupt respiration by altering the outer living membranes.

Surface mining of oil sands produces several landforms and materials that are relevant to wetlands reclamation:

- mining excavations produce end-pits, a wide range of gradients and **overburden** piles;
- extraction of bitumen from oil sands (using an aqueous process) produces process-affected tailings containing **sand**, **silts** and **clays**

[28] Golder Associates 2002
[29] Government of Alberta 2005; includes *in-situ* production as well as surface mining
[30] Alberta Environment and Alberta Sustainable Resource Development 2005
[31] Oil Sands Consultation Group 2006

in suspension, soluble organic chemicals (such as **naphthenic acids** and **hydrocarbons**), ammonia, **heavy metals** and salts;
- process-affected material that cannot be recycled is stored in settling basins (currently representing a cumulative surface area approaching 100 km^2), where subsequent settlement and redistribution produces sand edges, mature **fine tailings** and **process-affected water**;
- upgrading of bitumen produces by-products like sulphur and coke that are stockpiled for later retrieval, and which may directly or indirectly affect wetlands (chemically);
- the complete mining process increases the volume of materials (tailings and separated soil components like overburden and muskeg) by 20-25 % over the initial pre-disturbance volume.

The topography of the mined landscape exhibits greater relief than the surrounding natural landscape, particularly where high sand or clay overburden deposits are formed. The increased gradients and increased volumes of waste deposits lead to interruptions or redirections of groundwater **aquifers** and will influence where wetlands can be created on reclaimed landscapes. Water movement through this altered environment may be dramatically different than it was pre-disturbance.

Saline soil has a high salt content, resulting in an electrical conductivity >2 dS_m^{-1}. Salty inputs to freshwater alter the balance of salts inside and outside of the plants or animals living there. Some can't adapt and their ability to take up water and essential minerals and nutrients is affected.

Overburden may be **coarse-grained** (sand or shale), **fine-grained** (silt or clay), non-saline, **saline** or **sodic** depending on whether it originated from soils in the Pleistocene layer or the Clearwater Formation[32]. Saline and sodic leachates are a challenge for wetlands reclamation, in that many species of boreal wetland plants show significant levels of sensitivity to elevated **conductivity** and sodium[33]. **Peat** materials are valuable **topsoil** for wetlands reclamation.

Sodic soil has a high concentration of sodium ions, which causes soil particles to disperse. This affects how water moves on, under and through the landscape, because it changes the size of spaces between the solid particles in the soil.

The silts and clays from tailings streams delivered to settling basins eventually become mature fine tailings or **soft (consolidated) tailings** when dewatering is chemically accelerated. These materials may form bottom **substrates** for open water wetlands or marshes. The sands that settle out around the edges of the settling basins may be used to control or direct groundwater flow in a reclaimed landscape. The process-affected water itself may influence wetlands and end-pit lakes for a time, as chemical elements are modified to meet water quality standards for release off-site.

3.4 Regional Regulatory and Planning Context

This guideline was produced within the context of well established legislated responsibilities for developers regarding water management and environmental protection. Relevant regional strategic planning is in place as well, although some changes in focus are being discussed that have ramifications for wetlands reclamation. There are large volumes of planning and policy documentation that discuss reclamation in the oil sands. This section distils all of that material down to four main

[32] CEMA 2005
[33] Howat 2000; Crowe et al. 2002; Vitt 2003; Purdy et al. 2005

approaches to reclamation regulation, planning and assessment that are used by federal, provincial and municipal bodies:

- 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;
- Multi-stakeholder strategic planning – non-binding strategies, such as this guideline, developed by communities working with government to address priority information needs. This planning may result in recommendations to government that can become binding if incorporated into project approvals.

Acts of Parliament are enforceable laws. Plans and strategies identify common goals and outline means of achieving them.

In the case of wetlands reclamation, all four of these approaches are used to direct the planning and evaluation of water management and landscape development. The rationale and structure upon which this guideline originated is placed in the context of these approaches in Figure 3.2 and in the following text.

Binding legislation (laws governing reclamation goals)

- The Alberta government is largely responsible for regulating water use and wetlands protection, except where there are issues that cross boundaries or otherwise have national significance for fisheries or **biodiversity;** they then fall under joint or federal jurisdiction. Relevant federal legislation includes the Canada Water Act, the Canadian Environmental Protection Act (1999) and the Fisheries Act.
- The Alberta Water Act (1999) and the Alberta 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 the preparation of an environmental impact assessment, when mitigation and reclamation measures must be detailed. They are subsequently defined in project approvals.
- A fundamental component of the EPEA is the reclamation objective of returning disturbed landscapes to '**equivalent land capability**'. This concept of equivalency recognizes that some **ecosystems** may not be returned to exactly the same ecosystem as before, but the acceptable standard for **end land use** and environmental functional integrity is nonetheless very high.

Equivalent land capability means that the ability of the land to support various land uses after reclamation is similar to the ability that existed prior to mining, although individual land uses will not be identical.

Management strategies (with water conservation objectives)

- In 2003, Alberta Environment introduced the 'Water for Life' strategy, recognizing three key goals of safe, secure drinking water, healthy **aquatic** ecosystems, and reliable, quality water supplies for a sustainable economy[34].
- Their strategy for achieving those key goals involved addressing gaps in the areas of knowledge and research, collaborative partnerships, and water conservation policy.

[34] Alberta Environment 2003b

- Short-term objectives of the strategy (to be met before 2007) included development of a wetland policy[35] and supporting action plan as well as development of better monitoring systems in general.
- Medium-term objectives (to be met before 2010) include the establishment of planning and advisory councils for the Athabasca and Peace **watersheds**.
- The 'Water for Life' strategy gives wetlands, as fundamental components of watersheds, a high priority for conservation.
- It also indicates that watershed plans will be developed for the oil sands region in the near future; therefore it is to be expected that the structural and functional health of reclaimed wetlands will be considered within a landscape-scale action framework.

Regional planning (addressing sustainable development)

- The Regional Sustainable Development Strategy for the Athabasca Oil Sands Area (RSDS) was produced in 1999, and identified 72 regional environmental issues that needed further research and action in order for economic development to continue in a **sustainable** way[36].
- The strategy recommended a path forward based on principles of environmental protection, effective resource management, continual learning and shared stewardship.
- More recently and building on the RSDS, the older regional management plan for the Fort McMurray area[37] was updated with draft discussion documents which proposed a strong shift from **cumulative** effects management of oil sands development, towards integrated management of all development within the oil sands region.
- the response to these discussion documents resulted in the formation of the Oil Sands Consultation Group, who have recommended that planning for oil sands development occur on a much broader, integrated scale (including the geographic boundaries of the Peace and Cold Lake deposits as well as the Athabasca) using a multi-stakeholder committee structure and a consensus-based approach[38].
- This group also recommended that consultation be completed by June 2007, to develop a clear strategic plan for managing oil sands development in an integrated and enduring manner.
- Thus, there is an indication that regional planning for the mineable oil sands area will soon be directed by a much broader strategic plan for all oil sands development in northern Alberta.

Multi-stakeholder strategic planning (problem-solving issues)

- Within this context of increasing regulatory direction over the past five or six years, a number of multi-stakeholder initiatives have been

[35] policy currently does not exist, although recommendations were made for a policy framework in 1994 (Alberta Water Resources Commission 1994) and consultation on a draft policy is scheduled to occur late in 2006.
[36] Alberta Environment 1999a
[37] Alberta Environmental Protection 1996
[38] Oil Sands Consultation Group 2006; available online at: http://www.environment.gov.ab.ca (under "What's new")

undertaken[39]. These groups contain representatives from the oil industry, provincial and federal government, Aboriginal people, and sometimes forestry interests, academics and consultants.

- The common objectives have been to prioritize the information gaps that impede reclamation work and to fund studies, including research, that address those gaps.
- Initially, the Oil Sands Mining End Land Use Committee made guiding recommendations on closure land use that included wetlands as critical components of natural and conservation areas[40].
- These were followed up by the Athabasca Oil Sands Reclamation Advisory Committee (1999), who recommended the release of the first edition of this guideline, produced by another multi-stakeholder group, the Oil Sands Wetlands Working Group.
- Eventually, the reclamation advisory committee was integrated into CEMA and continues to exist as a stand-alone working group within CEMA. The function of these multi-stakeholder initiatives has been and continues to be to problem-solve a path forward to sustainable reclamation of closure landscapes.

Thus, this guideline is the result of several multi-stakeholder initiatives that responded to information needs identified by the Government of Alberta, industry and Aboriginal communities. It seeks to provide people in the oil sands region with the best tools of knowledge for reclaiming wetlands on closure landscapes. It acknowledges and incorporates the principles of existing legislation where appropriate (see Figure 3.2).

WASG field trip to Syncrude Mildred Lake lease (Credit: Carol Jones 2003)

[39] include CEMA, Canadian Oil Sands Network for Research and Development (CONRAD), and Regional Aquatics Monitoring Program (RAMP)
[40] Oil Sands Mining End Land Use Committee 1997

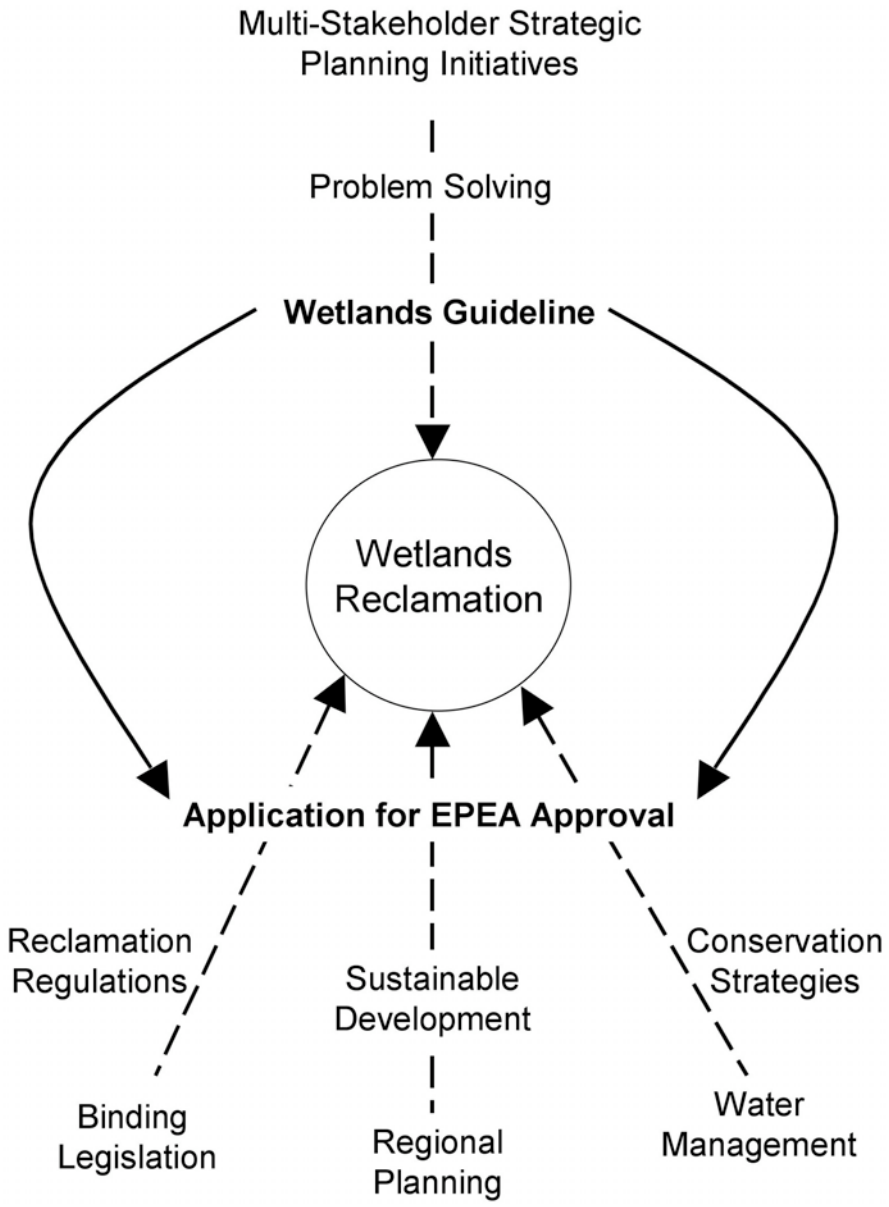

Figure 3.2 Avenues of regulation and planning for wetlands reclamation in the surface mineable oil sands region of northern Alberta. During initial mine EPEA approval processes, environmental impact assessments (EIAs) must consider the appropriate laws governing water and land use, their protection or reclamation, and also the regional and provincial strategies adopted to manage water use and sustainable development. This wetlands guideline is a resource that may be used to determine what is currently possible with respect to wetlands reclamation in the oil sands region.

3.5 Reclamation Context

There is considerable interchange of the terms 'reclamation' and 'restoration' in the published literature; however, for the purposes of this guideline, there will be a clear distinction made between the two. Wetland reclamation is defined here as the creation of wetlands on disturbed land where they did not formerly exist or where their previous form has been entirely lost. Wetland restoration is a process of restoring wetland function to a remnant wetland site, as it was before disturbance. Surface mining in the oil sands region leaves no remnants of wetlands to recover, except perhaps on lease boundaries where the original land surface is still intact.

Although the end result of both reclamation and restoration is intended to be healthy wetlands, reclamation starts with a blank canvas (ie., no remnant ecosystem), whereas restoration starts with a damaged but still existing residual wetland.

This distinction is relevant when mine closure teams go to the literature to search for examples of wetlands reclamation to adapt to the unique environment of the oil sands region. The volume of information available on wetlands restoration is reasonably large[41], but much of it will have limited usefulness here, either because of differences in the magnitude of disturbance (complete versus partial wetland removal) or because of differences in the environmental setting (climate, geology, hydrological cycle).

The most relevant examples of previous experiences with wetlands restoration or reclamation are listed below, with caveats.

Peat-forming wetlands

Peat-forming wetlands are more difficult to reclaim or restore than marshes or ponds (refer Figure 3.1), because peat formation requires the presence of a specific vertical structure (the acrotelm - catotelm) and more specific chemical conditions.

- Much has been learned about restoration of bogs in eastern Canada, through the work of the Peatland Ecology Research Group (PERG) on sites harvested for horticultural supplies of peat. Research has been conducted for over ten years in some places[42]. Although some lessons can be taken from these studies, there are two important distinctions to make with the situation in the oil sands. First, these bogs were restored, not reclaimed, thus there was some remnant bog left on the landscape to recover. Second, the relatively wet climate of eastern Canada makes it easier to regain hydrological function there than in northern Alberta.
- Fens in the Rocky Mountain and Cascade Ranges of the western United States have also been restored after peat-harvesting[43]. In some cases, the approach taken has been more akin to reclamation, where the groundwater flow was completely reconstructed and substrate and vegetation placement took place 'from scratch'. The sub-humid climate is also more similar to that of the oil sands region than the examples from eastern bogs. The main differences between these projects and wetlands reclamation in the oil sands relate to geographic scale of impact. The area to be reclaimed is much larger on oil sands leases. In addition, the results of the US projects are

[41] refer to CEMA 2003; Price et al. 2003; Rochefort et al. 2003; Society of Ecological Restoration web-site (www.ser.org) for synopses.
[42] Quinty 2003; Rochefort et al. 2003; Campeau et al. 2004; Cobbaert et al. 2004, Price et al. 2005a
[43] Cooper and MacDonald 2002; Cooper 2003

often difficult to obtain in any summarized, 'how-to' format (present mostly in the unpublished literature, but see Appendix D).

Marshes and shallow open water wetlands

- Knowledge on restoration of **prairie potholes** in Alberta and Saskatchewan is now well advanced[44]. Because many projects in these wetlands were focussed on recovering waterfowl habitat, there is detailed data regarding the habitat requirements of ducks and geese, including the germination of seeds during drawdown in the critical near-shore emergent zone. Once again, the intensity of disturbance (altered function versus lost structure) and the relative size of the projects (small, individual wetlands) are not comparable with the oil sands. Also, the hydrology in these mainly **ephemeral** and semi-permanent depression (basin-like) wetlands is largely driven by surface runoff from small, grassland catchments. The water inputs, outputs and seasonal hydroperiod tend to be derived from a more predictable set of variables than is present in watersheds in the oil sands region.
- Coal and metals mining in eastern Canada provide examples of reclamation that are similar to the oil sands in terms of the spatial magnitude of disturbance[45]. The key differences between these examples and the oil sands is the relative simplicity in re-establishing a hydrological cycle; many of the reclaimed mine sites occur on shield bedrock (thus, on shallow soils with predictable groundwater flow) in regions where precipitation is greater than potential evapotranspiration. There is not the water deficit to consider as there is in the sub-humid oil sands region.

This guideline focuses on reclamation of wetlands, because the surface mining process will typically necessitate the complete construction of wetland ecosystems, beginning with the establishment of an appropriate and sustainable water supply. The following section 4 is concerned, therefore, with reclamation design and techniques. Section 5 discusses restoration briefly, and should be consulted where existing wetlands on lease boundaries have been altered by mine activities and need to be restored to a pre-disturbance condition. Restoration may be most applicable to *in-situ* oil sands operations.

[44] Galinto and van der Valk 1986; Green and Salter 1987; Galatowitsch and van der Valk 1994; Gray et al. 1999; Butterworth 2003

[45] Beckett 2003; Ontario Mineral Industry Cluster Council web-site (www.omicc.ca)

4. Steps to Creating Reclaimed Wetlands

Reclamation of wetlands in the oil sands region differs from many of the situations documented in reclamation handbooks and published literature, in that it must be conducted in the context of larger-scale reclamation of whole landscapes or watersheds. Thus, mine closure teams commencing the planning and design process for wetlands must first consider and work with their counterparts who are planning the layout of the adjacent upland and aquatic areas. Each group must ensure that their plans do not preclude those of others, and approach landscape reclamation from a holistic perspective. Failure to do so will have severe repercussions for wetlands, which occur at the interface of terrestrial and deep or flowing aquatic environments.

At the time of planning integration, there should be communication of wetland designs with Aboriginal communities and other stakeholders. This consultation may elicit additional important design considerations.

In this guideline, the planning and design of reclaimed wetlands has been divided into landscape-scale and wetland-scale components, in recognition that landscape-scale elements and design of uplands reclamation will largely determine what can and cannot be achieved at the level of the individual wetland. Landscape-scale planning is discussed in section 4.1, whereas landform-scale (wetland) design is discussed in section 4.2.

Figure 4.1 shows a decision sequence that summarizes the steps and key environmental elements to consider throughout the planning and design stages. Each step is described in greater detail in the following text and in further decision sequences (Figures 4.2 and 4.3) throughout section 4.

4.1 Landscape-scale Planning

Before mining commences and the original landscape is re-arranged, mine closure teams should ask themselves three key questions with respect to reclaimed wetlands:

- What uses and functions do we want reclaimed wetlands to provide? (refer section 4.1.1)
- Where can we place reclaimed wetlands relative to other landforms so that those uses and functions will be sustained over time? (refer section 4.1.2)
- What proportion of the closure landscape in wetlands is optimal to ensure the integrity of the whole system? (refer section 4.1.3)[46]

Wetlands and aquatic complexes are locations where several distinct wetlands, lakes and connecting water-ways occur in close proximity to each other. These complexes are common in watersheds of the oil sands region and provide excellent habitat for many mammals and waterfowl.

This section will address these questions and make recommendations based on the current state of knowledge on reclamation in the oil sands region.

[46] Additional questions that may be posed, but which are not directly addressed in this guideline are: _ what approaches to mining can be used to ensure that the wetland types and functions that exist in the region can be reclaimed? _ how can this site be mined and reclaimed so that hydrologic disturbance is minimized and the pre-mining hydrologic regime can be recovered?

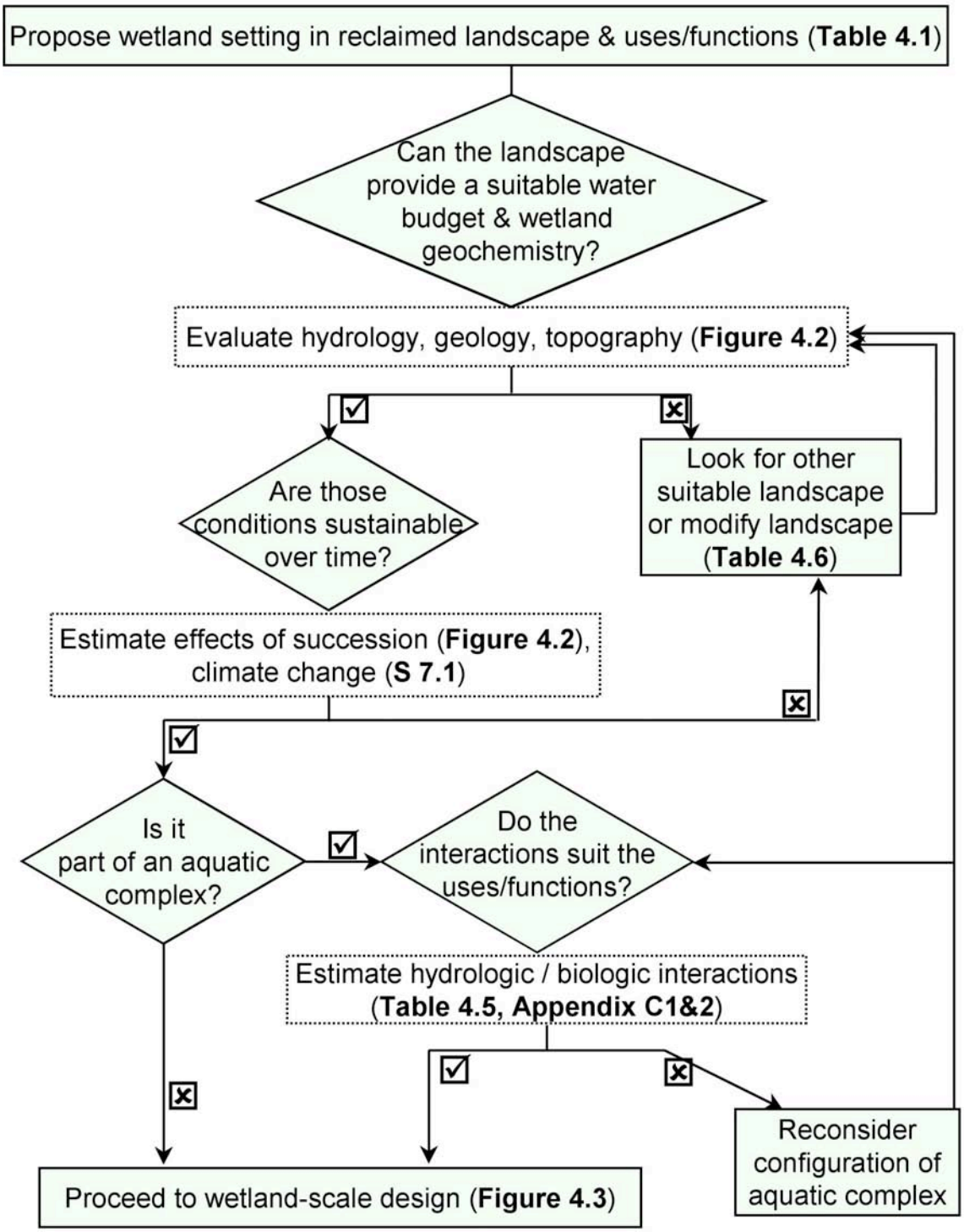

Figure 4.1 Decision sequence for the planning and design of reclaimed wetlands within closure landscapes of the oil sands region. Inherent in this sequence is the desire to make frequent referral back to the intended uses or functions of the system, and the need to apply adaptive management throughout. Uses and functions are discussed in section 4.1.1 and adaptive management in section 4.3.2 (particularly Table 4.6).

4.1.1 Potential uses and functions provided for by reclaimed wetlands

Table 4.1 gives some indication of which classes of wetlands can fulfill the variety of uses and functions desirable on closure landscapes. In some situations, wetlands other than those indicated might also provide the desired function or use at a less than optimal capacity. The landscape setting will largely determine whether a wetland will be suitable for its intended use or function; settings and functions are described in the next sections 4.1.2 to 4.1.4. Also there are elements of each wetland that must be specifically designed with regard to the intended use; these are discussed in detail in section 4.2.

At this stage, it may not be possible to predict nutrient and other geochemical fluxes into wetlands from reclaimed uplands. These loadings or fluxes will impact on functionality. This is a critical area for further research.

The ability to achieve the five classes of wetlands that exist in northern Alberta on reclaimed landscapes is variable. At this time, marshes and ponds have been constructed on reclaimed oil sands mines, whereas reclamation of fens, bogs and swamps has yet to be attempted. However, research continues to pursue the feasibility of peatland reclamation. In particular, CEMA (through WASG) is currently funding two studies that investigate the environmental conditions required for peat formation in reclaimed wetlands. One of the studies is examining the potential for wetland vegetation to grow and accumulate **organic** matter (peat) under current climatic conditions and in the presence of saline soil or water[47]. The other study is using a model to evaluate the hydrological feasibility of creating fens on reclaimed landscapes[48].

Ponds are an inland form of shallow water wetland; however, the term 'shallow' is misleading, as these tend to be the deepest class of wetland (1–2 m). The prevalence of open water habitat reflects the depth restriction on emergent plant species.

Shrubby and open fen (Credit: Suzanne Bayley, 2005)

[47] Refer to section 7.2, project title 'Effects of salinity on vegetation and organic matter accumulation in natural and oil sands wetlands'.
[48] Refer to section 7.2, project title 'Creating a fen peatland on a post-mined oil sands landscape: a feasibility modelling study (phase 2)'.

Table 4.1 Functions and uses of the five classes of wetlands present in the natural environment of the oil sands region, and the key limiting elements that determine their efficacy. These elements are defined and discussed in sections 4.1.2 and 4.2.[a]

	Optimal / preferred wetland	Key limiting landscape-scale elements (S. 4.1)	Key limiting wetland-scale elements (S. 4.2)
Storage of water	fens, marshes, open water	▪ catchment size	▪ size & depth profile ▪ soil saturation ▪ beaver activity
Groundwater recharge	bogs, fens, marshes	▪ elevated topography	▪ permeability of sediment, substrate
Storm runoff generation	fens, swamps	▪ slope ▪ groundwater discharge	▪ vegetation density ▪ size
Flood control[b]	marshes, fens	▪ aquatic complexes ▪ elevation & slope	▪ size & shape ▪ soil saturation ▪ vegetation density
Shoreline stabilization	marshes, open water	▪ shoreline setting ▪ high energy waves ▪ inverted shoreline	▪ fetch ▪ soil cohesion ▪ emergent density
Water treatment	marshes, open water, fens[c]	▪ shoreline setting ▪ water sources	▪ hydraulic retention time (HRT) & flow path ▪ anaerobiosis, microbial community
Carbon storage	bogs, fens	▪ watershed : wetlands ratio[d]	▪ peat volume ▪ peat saturation
Indigenous cultural use	bogs, fens, marshes	▪ connectivity	▪ plant community ▪ contaminants
Trapping of fur-bearers	fens, marshes, open water	▪ connectivity ▪ aquatic complexes	▪ emergent & riparian vegetation
Fishing	open water	▪ shoreline setting ▪ access barriers	▪ contaminants ▪ spawning habitat
Low-impact recreation	all classes	▪ access	▪ ecological sensitivity
Habitat for:			
• **moose**	bogs, fens, swamps	▪ connectivity ▪ predator access	▪ browse in winter & spring
• **woodland caribou**	bogs, fens	▪ connectivity ▪ predator access ▪ disturbance	▪ lichen ▪ concealing cover
• **muskrat**	marshes, open water	▪ aquatic complexes	▪ water level stability ▪ plant community
• **beaver**	swamps, open water	▪ riparian vegetation ▪ aquatic complexes	▪ water level stability ▪ water depth
• **Canadian toad**	all classes	▪ sandy upland soils	▪ flow velocity ▪ gradients
• **ducks**[e]	marshes, open water	▪ aquatic complexes ▪ migration routes	▪ nesting & loafing safety ▪ forage diversity (plants, benthos)

[a] listings under the 'optimal / preferred' column are based on published information; 'open water' refers to shallow water wetlands, either shoreline open water or inland pond forms; with respect to preferred habitat, knowledge specific to the oil sands region was considered[49]; the key limiting elements are by no means the only determinants of efficacy, but are rather the most critical ones.
[b] refers to depression storage in mid-slope ephemeral basins and detention storage in large, lowland peatlands
[c] fens are likely not appropriate where water for treatment is sub-saline or saline
[d] limiting for fens, not bogs
[e] by extension, includes elements important for waterfowl hunting

The importance of wetlands in the movement and retention of water on the natural boreal landscape cannot be overstated. Boreal Plains forests persist in a near water deficit most years, in large part because of water stored in groundwater reservoirs and an abundance of wetlands on the landscape. Bogs and other **perched** wetland basins can contribute to **groundwater recharge** by slow percolation of stored water through low permeability sediments. Peat-forming wetlands hold water throughout the year (they may be as much as 95% water), and saturated fens located on gentle slopes can be an important source for storm runoff, with the associated redistribution of nutrients down-slope[50]. During dry periods, water held in peat-forming wetlands may provide a source of water to adjacent vegetation through capillary action or root uptake[51]. Marshes and shallow waters may function in water storage, but (like lakes) can enhance water losses as well, through evapotranspiration[50]. An average loss of water from a northern Alberta marsh is 25 to 30 cm each year[52]. The flood control capacity of wetlands has been over-stated in the literature[53]. Flooding of forested landscapes in the sub-humid climate of the oil sands region occurs every twenty years on average[54]; however, newly reclaimed and sparsely vegetated landscapes or those with steep, simple contours may experience more frequent overland flow flooding events.

'Recharge' refers to the process where water percolates through the surficial soils to add to the total volume held in groundwater aquifers.

'Discharge' refers to the process where ground-water exits into springs, wetlands, lakes, streams or rivers, as the water table intersects the soil surface. This is often called base flow in a wetland.

Water **treatment** is a critical function that must occur in some of the wetlands and end-pit lakes on the closure landscape, for an extended, albeit finite, period. Wetlands receiving process-affected water will still need to be designed to eventually function as habitat in reclaimed boreal ecosystems. This will support reclamation certification and minimize the need for retrofits at closure.

In this guideline, water treatment refers to the removal of mining-related soluble chemicals: salts, naphthenic acids, metals, PAHs, ammonia.

There are a few broad options related to water treatment that must be considered at the early planning stages. Treatment may be achieved for some materials, such as low molecular weight organic acids, through biodegradation to other biologically-inert compounds[55]. Although not all naphthenic acids appear to biodegrade at the same rate, aging in wetlands does seem to reduce the associated toxicity. CEMA (through WASG) is currently funding further study of the differing toxicities

[49] Hayes et al. 2000; Wiacek et al. 2002; Axys 2003; CEMA 2003
[50] Appendix C1 (Devito & Mendoza)
[51] Appendix C1 (Devito & Mendoza); Petrone et al. 2006
[52] K. Lumbis pers. comm.. in OSWWG 2000
[53] Price et al. 2005c
[54] K Devito, pers. comm.
[55] Clemente et al. 2005; Scott et al. 2005

associated with natural naphthenic acid mixtures of varying age and chemical make-up[56]. Some materials, such as salts, cannot be degraded and must be otherwise treated by dilution or geochemical reactions in the sediment. It is uncertain whether local wetland vegetation can be effective in removing a significant portion of salts from solution by plant uptake (called **phytoremediation**)[57]. This approach may also only delay attainment of a long-term solution, since the affected vegetation and associated salts would eventually need to be removed from the watershed. The effect of upland landform type, climate change and wetland morphology on far-future concentrations of salts and organic acids in treatment wetlands has been modelled. The salt concentrations in 100-year old treatment wetlands are predicted to be greater in the Tar River watershed compared to the Muskeg, Firebag and Steepbank River watersheds[58].

The cultural significance of bogs and fens to Aboriginal people is described in section 3.2. There are numerous valued plant species that are only found in these classes of wetlands[59]. This has provided some of the incentive for the current research on the practicality of reclaiming fens[60]. However, marshes and open water wetlands can provide some opportunities for trapping and fishing. These latter systems are favoured by muskrat and beaver, particularly when there are good **aquatic** connections to streams or small lakes, and when water levels in the wetland are relatively stable. Connectivity also promotes their use by fish as spawning habitat.

Staging refers to the habit of migratory birds stopping en route to or from breeding grounds to briefly rest and feed. During these stops, each species congregates in flocks.

Many of the wildlife species chosen as indicators of sustainable ecosystems by CEMA[61] are **habitat generalists.** They may use a variety of uplands and aquatic habitats, and require good **connectivity** within boreal ecosystems via extensive travel corridors. The key exception is the woodland caribou, a **habitat specialist** which requires predominantly bogs and fens for cover and forage. Other protected species like sandhill crane (*Grus canadensis*) also use bogs and fens extensively. The whooping crane (*G. americanus*) breeds in marshes of the Peace-Athabasca Delta and likely uses wetlands in the oil sands region for **staging**. Most ducks prefer to stage and **moult** on larger lakes[62], but use smaller wetlands with open water and extensive riparian cover for nesting and brood rearing. Waterfowl in general prefer to use wetlands-lake complexes, with multiple aquatic units present within a few square kilometres[63]. Further information is available in Appendix E on the use of wetlands by fish and wildlife species integral to boreal ecosystems.

Moulting refers to the period after breeding when waterfowl shed and replace their primary feathers. For a period of a few weeks, they cannot fly and are vulnerable to predators.

[56] refer to section 7.2, project title 'The role and effectiveness of wetlands for mitigation of oil sands impacted waters'.
[57] Renault 2001; Kernaghan et al. 2002
[58] Golder Associates 2006a
[59] Appendix F (Gulley & Garibaldi)
[60] refer to section 7.2
[61] Wiacek et al. 2002; Axys 2003; Ursus 2003
[62] Wiacek et al. 2002
[63] Golet 1976; Brown and Dinsmore 1986; McKinstry and Anderson 2002

4.1.2 Sustainable placement of reclaimed wetlands

The placement of wetlands relative to uplands and aquatics elements on closure landscapes has the potential to affect not only their own longevity, but also the health and form of adjacent riparian and upland vegetation communities. The setting for wetlands will be influenced by climate, and interacting controllable factors related to:

- hydrology
- geology
- succession, and
- topography

Wetlands need a water supply that can sustain hydrophytic plants and produce saturated soils (e.g., an anaerobic root zone) for at least part of each year.

Hydrological setting

Wetlands cannot persist without water. Water in the reclaimed landscape may come from direct precipitation, surface runoff, groundwater, or, for an undefined time after mine closure, from process-affected waste-water in end-pit lakes. **Inland** wetlands that are disconnected from groundwater **discharge** by the presence of an impermeable soil lens are called 'perched'. Many of the reclamation scenarios described in the first edition of this guideline, and in a virtual reclaimed mine used as a reference by the oil industry[64] would likely be perched systems in practice. There are **natural analogues** for such a setting in the oil sands region[65], but there are risks to sustainability associated with perched systems, such as climate change that may incrementally dry up the landscape. However, there is value in creating some perched systems to function in groundwater recharge and early **seral** flood control[66].

A natural analogue is a wetland that is found in an undisturbed setting and which is comparable in structure and function to what a constructed wetland was designed to become. If a constructed system does not look or act like any natural analogue in the region, it is likely that it is not sustainable under existing conditions.

The first edition of this guideline assumed that surface runoff would be the dominant contributor of water to wetlands. This is certainly typical for many other regions of North America, but does not necessarily apply to the oil sands region. Surface runoff coefficients (the amount of runoff relative to precipitation) in the surface mineable zone are less than 20%[67]. This is a function of climate, geology and topography. In forested areas of the boreal plain, rainfall events of 20 – 25 mm or more are needed before any runoff or soil infiltration will occur. Based on precipitation data from Fort McMurray, daily rainfall exceeding 25 mm occurs less than 2% of the time[67].

Promoting groundwater recharge in perched systems will help alleviate the build-up of salts created by ET.

The major precipitation events typically occur in late spring or summer (Jun-Aug), which coincides with high vegetation water demands and peaks in evapotranspiration (ET). Snow melt and early spring rains are not the largest contributors to surface runoff on forested terrain, as is the case in the southern prairies and elsewhere[68].

In small newly constructed systems where upland vegetation has not fully developed, snow melt over frozen ground may sustain some perched wetlands in the short term. This is currently the case for Bill's Pond, an

[64] http://www.osern.rr.ualberta.ca/Virtual_Mine; Golder 2000
[65] Appendix C1 (Devito & Mendoza); Devito and Mendoza 2003
[66] Peters et al. 2006
[67] Appendix C1 (Devito & Mendoza); Woo and Winter 1993
[68] van der Kamp et al. 2003

opportunistic marsh wetland on Syncrude's Mildred Lake lease[69]. Grassland hill-slopes surrounding Bill's Pond are composed of shale overburden covered with till and peat of varying thicknesses (35 cm – 100 cm). Soil hydrology studies show a short snow-melt period of a few days, during which runoff events of up to ~40 mm occur. **Interflow** measured on the north-facing slopes from 1999 – 2006 averaged 1.8 mm (100 cm soil cover, range of 0.1 – 6.4 mm), 0.6 mm (35 cm soil cover, range of 0.04 – 2.0 mm) and 0.4 mm (50 cm soil cover, range of 0.04 – 1.1 mm) each year on three 1 ha plots[70]. These interflow rates alone are likely not sufficient to maintain permanent wetlands. It is unlikely that this wetland will persist once mature forests develop on upland **slopes**[69]. Trees, particularly conifers, will intercept snow deposition (sublimation effect), reduce rates of snow melt, and influence frost patterns[71]. Thus, the timing and amount of water received from the adjacent hill-slope will change, and likely be reduced. The depression storage capacity will determine if the wetland can persist through long dry periods.

Groundwater may be local, regional, above the water table (interflow in the vadose zone) or below (aquifer). See Appendix C1 for a description of boreal settings where local groundwater occurs.

Research on natural analogues indicates that groundwater discharge to wetlands is a significant source of water, especially for those in topographically low locations in coarse-grained soils, and for large fens[72]. Wetlands with a groundwater connection also tend to exhibit moderated water-level changes during wet-dry climate cycles. This suggests that they would be more likely to persist over the long-term and through dryer periods.

Groundwater will be a critical source of water sustaining many wetlands on closure landscapes. It is imperative to map where aquifers are and know how water moves through the reclaimed soils.

Process-affected water will seep from sand dykes, soft tailings and mature fine tailings for an undetermined number of years. In addition, water may be channelled through treatment wetlands associated with end-pit lakes from operational holding facilities like tailings ponds. This water source may augment natural sources during the establishment of marshes and ponds and through dry years, provided salinity **toxicity** thresholds are not exceeded. However, the initial design must also plan for the eventual disappearance of this mining water source.

The association of wetlands with lake and river systems influences how the varying water sources (runoff, groundwater and process-affected water) enter and exit. Wetlands in such settings are defined as being **shoreline**, as they are influenced by **riverine** or **lacustrine** processes and take on the water levels and **hydroperiod** of those other systems[73]. The distinction between shoreline wetlands and **littoral zones** is sometimes blurred, but Appendix C1 provides some solid means of defining the boundaries. Shoreline wetlands may form in protected bays on lakes or behind spits, bars or islands in rivers and lakes. Thus, they form where there is protection from prevailing winds (so **sediment** deposition outweighs erosive forces) and where there is morphological complexity (i.e. not around bowl-shaped, uniformly curved lakeshores).

Riverine and lacustrine are terms that describe physical and chemical processes characteristic of rivers and lakes, respectively.

[69] Devito and Mendoza 2003
[70] Elshorbagy et al. 2005; L Barbour & A Elshorbagy, unpublished data (pers. comm.)
[71] Woo et al. 2000 and Woo and Marsh 2005 are comprehensive reviews of snow hydrology in boreal ecosystems; Buttle et al. 2000, 2005 provide corresponding reviews of forest hydrology
[72] Appendix C1 (Devito & Mendoza); Devito and Mendoza 2003
[73] Appendix C1 (Devito & Mendoza); Mitsch and Gosselink 2000

Geological setting

Groundwater **flow** and water retention in wetlands is directed by the properties of surficial soils. In the oil sands region, the soils (overburden, oil sands and muskeg) above the bedrock are thick and highly variable in texture and chemistry[74]. These soils may be broadly defined as coarse-grained (sands and gravel) or fine-grained (silt and clay). Soft tailings are intermediate in texture and grain-size[75]. Coarse-grained soils encourage flow through, while fine-grained soils act as horizontal or vertical barriers to water flow. Texture controls not only **porosity** and **permeability**, but also influences chemical activity. Smaller particles, and particularly clays, have greater potential for chemical exchange with groundwater[76].

Littoral zones are the shallow edges of lakes, where light penetrates and rooted plants grow. Some shoreline wetlands occur in littoral zones, but not all littoral zones are wetlands.

Riparian margins are areas of land adjacent to rivers, streams, lakes and wetlands where soils are influenced by water. Wetlands that occur adjacent to rivers or streams are sometimes said to exhibit a 'riparian regime'.

Knowledge gained from research on natural wetland analogues in the region suggests that there may be significant benefits to incorporating layers or lenses of coarse- and fine-grained materials in the closure landscape, to help direct interflow laterally and allow perched wetlands to persist[77]. Provided that issues of soil stability can be addressed, such changes to upland soil placement standard practice could greatly increase options for sustainable wetlands settings and uplands use.

In the oil sands region, the marine origin of the Clearwater Formation shales (and the glacial tills derived thereof) creates chemistry-related challenges to the design of effective groundwater recharge and discharge regimes. This saline and sodic overburden is generally used for landform construction, but its effect on groundwater must still be anticipated and addressed during planning. A high **concentration** of sodium in sodic overburden restricts soil permeability and groundwater recharge, and increases the lateral flow of water in the **vadose zone**. There are natural analogues of saline wetlands and dry meadows (transition zones to uplands) in the oil sands region. Comparative research at some of these sites and Bill's Pond (affected by sodic and saline overburden) on Syncrude's Mildred Lake lease suggests that salinity in reclaimed wetlands and upland landscapes on that lease is intermediate (sub-saline) between freshwater and strongly saline natural analogues[78].

Creating subsoil layers of fine- and coarse-grained soils during construction of closure landscapes can increase the proportion of lateral interflow of water and direct water to perched wetlands.

The vadose zone is the unsaturated region of soil located just above the water table, where water from the surface (called interflow) travels laterally and horizontally.

Succession setting

Succession-induced changes to vegetation on the closure landscape will require a shift in management focus over time from one of upland flood and **erosion** control to one of water retention and storage. Designs for the former should not preclude adaptive management for the latter.

[74] Appendices C1 (Devito & Mendoza) & C2 (Devito et al.); except in the extreme north-east, where the shallow soils of the Canadian Shield begin
[75] CEMA 2005
[76] Smith and Pizalotto 2000
[77] Appendices C1 (Devito & Mendoza) & C2 (Devito et al.); Stein et al. 2004
[78] Purdy et al. 2005

Initially, bare or newly-planted upland terrain which may still be settling or shifting, poses an erosion risk to lowland environments, including wetlands. Surface runoff may contribute more water to wetlands, but precipitation peaks in late spring or summer when grounds are unfrozen could also lead to unsustainable **sedimentation** rates[79]. Sedimentation of just 0.25 cm_y^{-1} impaired seed emergence in prairie pothole marshes[80]. High sediment loads can quickly infill small marshes. A hummocky-shaped landform with many unconnected, ephemeral depression wetlands may provide the optimal setting for flood and erosion control in these young environments. Simple slope contours, clay tills and young vegetation on reclaimed landforms may increase the risk of channelling and slumping, whilst carrying water away from pioneer forest stands[81].

Succession is a natural evolution of plant communities. It happens because plant growth alters the surrounding environmental conditions, which in turn affects the kinds of plants that will grow in the same community.

Vegetation on uplands and wetlands affects how much water is available to the boreal ecosystem as a whole, through processes of interception of precipitation and evapotranspiration. As closure landscapes develop, the water budget will change to reflect succession processes. Forests will intercept more snow and rain and accelerate rates of evapotranspiration. Modest growth of grasses and **shrubs** will reduce snow melt runoff[82]. In mid- to late-seral boreal forests, the first 20 – 25 mm of each precipitation event is intercepted by vegetation and surficial organic topsoils; thus, rainfall events greater than 25 mm will be required to initiate groundwater recharge or surface runoff[83].

The end land use and upland vegetation design must be accounted for when estimating the long-term sustainability of constructed wetlands in the catchment. The rate of actual evapotranspiration (AET) can change dramatically with the succession of different plant communities.

If peat-forming wetlands can be established on reclaimed landscapes, more water could be stored and less evaporated. The development of an **acrotelm** – **catotelm** vertical structure in peat creates a micro-environment that enhances the water retention capacity of the soil. The **anaerobic**, lower catotelm is where peat is formed; it will hold water as the upper acrotelm dries during a drought and act as a water source for the live **mosses** and sedges in the wetland. Peat is thermally insulative, and will freeze deeply and remain frozen for longer, thereby protecting water from evaporation[84]. Thus, fens and bogs in sub-humid north-eastern Alberta can persist through long periods of water deficits, where other wetlands cannot[85]. Peat vegetation also produces lower rates of **transpiration** than emergent **macrophytes**. Evapotranspiration in peat-forming wetlands typically accounts for 50-70% of precipitation, whereas in marshes it can be >90%[86].

Topographical setting

To date, closure landscape planning has largely been conducted using a topographic model to define **watershed** or catchment boundaries; that is, the limits of individual catchments were considered to be the topographic

[79] Faubert and Rochefort 2001; Gleason et al. 2003
[80] Galinto and van der Valk 1986
[81] K Devito, pers. comm.
[82] van der Kamp et al. 2003
[83] Appendix C1 (Devito & Mendoza)
[84] most peatlands in the region freeze at the surface in winter, and those without thick peat accumulations also freeze internally; uncommonly, fens connected to springs do not freeze (L Halsey, pers. comm.)
[85] Price 2003
[86] Mitsch and Gosselink 2000

highs on the landscape. The first edition of this guideline applied this common modeling approach, which assumes the dominance of surface runoff sources for water. However, research on natural catchments in the oil sands region indicates that catchment boundaries are often defined by more complex interactions of topography with climate, geology and vegetation[87].

Topography is one factor to consider in creating watersheds, and closure landscapes should be designed to fall within the normal range of elevations, slopes and **aspects** present in the region. Elevation generally varies by 40 m or less, with the exception of areas like the Birch Mountains and Muskeg Mountain. Slopes are gradual and terrain is hummocky, rolling or flat. Slope gradients are shallow, typically less than 15 %; slope lengths are generally less than 300 m[88]. The properties of simple and complex landforms in the oil sands region have been documented in a recent CEMA report[88]. Common landforms include drumlins, eskers, flutings, kettles (often containing lakes or swamps), dunes, gullies, river valleys with flood-plains and **terraces**, and undulating and hummocky complexes (often containing depression wetlands).

Slope angle and length have less influence on sedimentation rates and subsequent infilling of wetlands than upland vegetation cover[89], but nonetheless contribute to surface runoff coefficients. Hummocky terrain often exhibits poor surface connectivity that impedes surface runoff and leads to accumulation of water in wetland depressions. Gently rolling terrain to the windward side of a wetland may reduce the **actual evapotranspiration rate** (**AET**) by as much as 30%[90], thereby protecting the wetland from unsustainable water losses. Wetlands on terraces are a risk to slope stability and not advised for reclaimed settings. Wetlands may be situated on plateaus at topographical highs, on gentle slopes (<3%), or on lowland flats[90]. To date, upland landform reclamation has produced steeper gradients than were present in the pre-disturbance landscape.

Large wetlands will probably need to be set in low-lying areas, where there is access to groundwater discharge. Wetlands in high elevation, perched settings will likely be smaller (<5 ha) to reflect limited water inputs.

4.1.3 Proportional representation of reclaimed wetlands

There has been conflicting advice on the watershed : wetlands ratio required to create sustainable ecosystems in the oil sands region. The first edition of the wetlands guideline recommended ratios between 5:1 and 20:1, depending on the desired function; that translates into 17% and 5% of the watershed in wetlands, respectively. However, these figures were derived from research conducted on prairie pothole systems, where the climate and geology are different from the oil sands region. In particular, surface runoff is a critical water source that establishes the permanence of a prairie wetland; that is usually not the case in the oil sands region. Research on natural analogues in northern Alberta has shown that ratios can vary from <1:1 to 10:1[90]. Based on these more

[87] Appendix C2 (Devito et al.); Devito et al. 2005; Petrone et al. 2006
[88] MacMillan et al. 2006; exceptions to these typical gradients and slope lengths occur in gullies, stream channels and river valleys
[89] Tajek et al. 1985
[90] Appendix C1 (Devito & Mendoza)

relevant reference systems, an average ratio of 2:1 was derived. This translates into 33 % of the watershed in wetlands, which is still less than the cover or abundance of wetlands in the region prior to mining[91].

Achieving an optimal proportion of wetlands on a closure landscape may be done by creating many small wetlands or fewer large ones. Natural peat-forming wetlands in the region can be very large; for example, the McClelland Lake wetland complex covers ~3,500 ha[92]. It is unlikely that constructed sizes could approach those values, even if research can eliminate the current obstacles to fen and bog reclamation, because of the changes to topography that limit the continuity of low-lying, relatively level expanses. Large marshes and ponds also may not be desirable, since the larger open surface areas increase rates of evapotranspiration. Thus, a greater number of moderate-sized (5-50 ha) wetlands with a high degree of connectivity may be the most practical management approach at this time for most sites and to meet the variety of desired uses/functions.

Bill's Marsh, an opportunistic wetland on Syncrude's Mildred Lake lease with Bison Lake in background (Credit: Clara Qualizza 2006)

[91] Bayley 2003
[92] Vitt et al. 2003a

4.1.4 Potential landscape settings for reclaimed wetlands

Table 4.2 is a collation of the current knowledge on landscape-scale variables, as presented in the previous three sub-sections. These are generalized scenarios for sustainable wetlands on reclaimed landscapes. They are intended to be used as a starting point for closure planning and design, and they will need to be adapted to fit the site-specific conditions present at each mine lease. Hydrology is the greatest determinant of wetland sustainability within a given landscape setting, and there are three main hydrological scenarios to consider: perched systems; groundwater discharge systems; and coastal or shoreline systems. Figure 4.2 shows decision sequences for each of these scenarios, elaborating further on Figure 4.1 and considering the information documented in sections 4.1.2 and 4.1.3.

The hydrological setting – perched, groundwater discharge or shoreline – will greatly influence what functions or uses are feasible and what other variables will drive the wetland system.

In the boreal ecosystem of the surface mineable oil sands region, wetlands most often occur as complexes. That is, several types of wetlands occur in close proximity, with surface or groundwater links. Fens may have internal bogs and be surrounded by a perimeter of treed swamps and marshes. Marshes and open water wetlands are often transitional to lakes. The creation of wetlands complexes on reclaimed closure landscapes would be optimal for increased biodiversity of vegetation types, habitats and wildlife.

To make the best use of these recommendations, some preliminary estimates of environmental parameters would be helpful. It is advantageous to have some site-specific knowledge of the following variables when planning landscape-scale design of reclaimed wetlands:

- depths / locations of existing aquifers, all hydrologic flow paths and volumes;
- the direction of prevailing winds, rates of precipitation and PET;
- storm frequencies, magnitudes and seasonal timing;
- the range of sodicity and salinity values in sources of overburden;
- the nature of water quality issues (i.e. will treatment be required for naphthenic acids, heavy metals, salts, PAHs, or other compounds);
- the presence of existing travel corridors for wildlife in adjacent boreal ecosystems, which could be connected to reclaimed wetlands complexes;
- the **mineral** and **nutrient** characteristics of groundwater and interflow;
- the proximity to natural analogue wetlands, and subsequent probabilities for natural seeding of wetland vegetation and **dispersal** of colonizing **aquatic invertebrates**.

Table 4.2 Possible generalized hydrogeological and topographical settings for reclaimed wetlands[a]

Landscape setting	Wetland class	Functions / uses[b]	Main issues to resolve
▪ Inland, perched ▪ Fine-grained soils (non-saline, non-sodic) ▪ Plateaus	Bogs Marshes	▪ Groundwater recharge ▪ Habitat for birds ▪ Cultural use ▪ Carbon storage[B] ▪ Recreation	▪ Minimize AET (protect from prevailing winds) ▪ Maximize water storage (with basin shape) ▪ May be ephemeral ▪ Probably isolated ▪ Maximize relative output to groundwater recharge (with depth & substrate porosity)
▪ Inland, perched ▪ Fine-grained soils or coarse-grained lens on fine-grain pan (non-saline, non-sodic) ▪ Mid-elevation (very low gradient)	Bogs Marshes Fens	▪ Groundwater recharge ▪ Storm runoff generation[B,F] ▪ Flood control[M] ▪ Habitat for moose & caribou ▪ Cultural use ▪ Carbon storage[B,F] ▪ Recreation	▪ Minimize AET (protect from prevailing winds) ▪ Maximize water storage (with basin shape) ▪ May be ephemeral ▪ Travel corridors required
▪ Inland, groundwater discharge zone ▪ Coarse-grained soils or coarse-grained lens on fine-grain pan ▪ Lowlands or mid-elevation (very low gradient)	Fens Swamps Marshes Ponds	▪ Water storage[F,M,P] ▪ Flood control[F,Sw] ▪ Storm runoff generation ▪ Cultural use[F,M] ▪ Trapping[F,M,P] ▪ Habitat for muskrat, beaver, toad, ducks ▪ Carbon storage[F] ▪ Recreation	▪ Peat or fine-grained soil lens required to prevent water losses to recharge for some functions (except flood control) ▪ Many uses require high connectivity with uplands & other aquatic systems
▪ Shoreline, lake connection (adjacent) ▪ Fine-grained soils or coarse-grained lens on fine-grain pan ▪ Lowlands	Marshes Open water	▪ Water treatment ▪ Water storage ▪ Fishing[Sh] ▪ Trapping ▪ Habitat for muskrat, beaver, ducks, moose ▪ Recreation	▪ Minimize AET and erosion (protect from prevailing winds) ▪ Plan for a succession of uses ▪ Connect to end-pit lake for optimal treatment of water
▪ Shoreline, river or stream connection ▪ Fine-grained soils ▪ Mid-elevation (very low gradient)	Swamps Marshes	▪ Water treatment[M] ▪ Water storage[M] ▪ Flood control ▪ Trapping ▪ Habitat for beaver, moose ▪ Recreation	▪ Protect from extreme rates of sedimentation ▪ Connect to end-pit lake up- or downstream for optimal treatment of water ▪ Plan for a succession of uses

[a] see Appendix C1 (Devito & Mendoza) for further details

[b] functions / uses may be provided by all wetland classes identified, unless superscripts denote that they are specific to a subset of wetlands; **B** = bog, **F** = fen, **M** = marsh, **Sh** = open water, **Sw** = swamp, **P** = pond (pond & open water are forms of the shallow water wetland class)

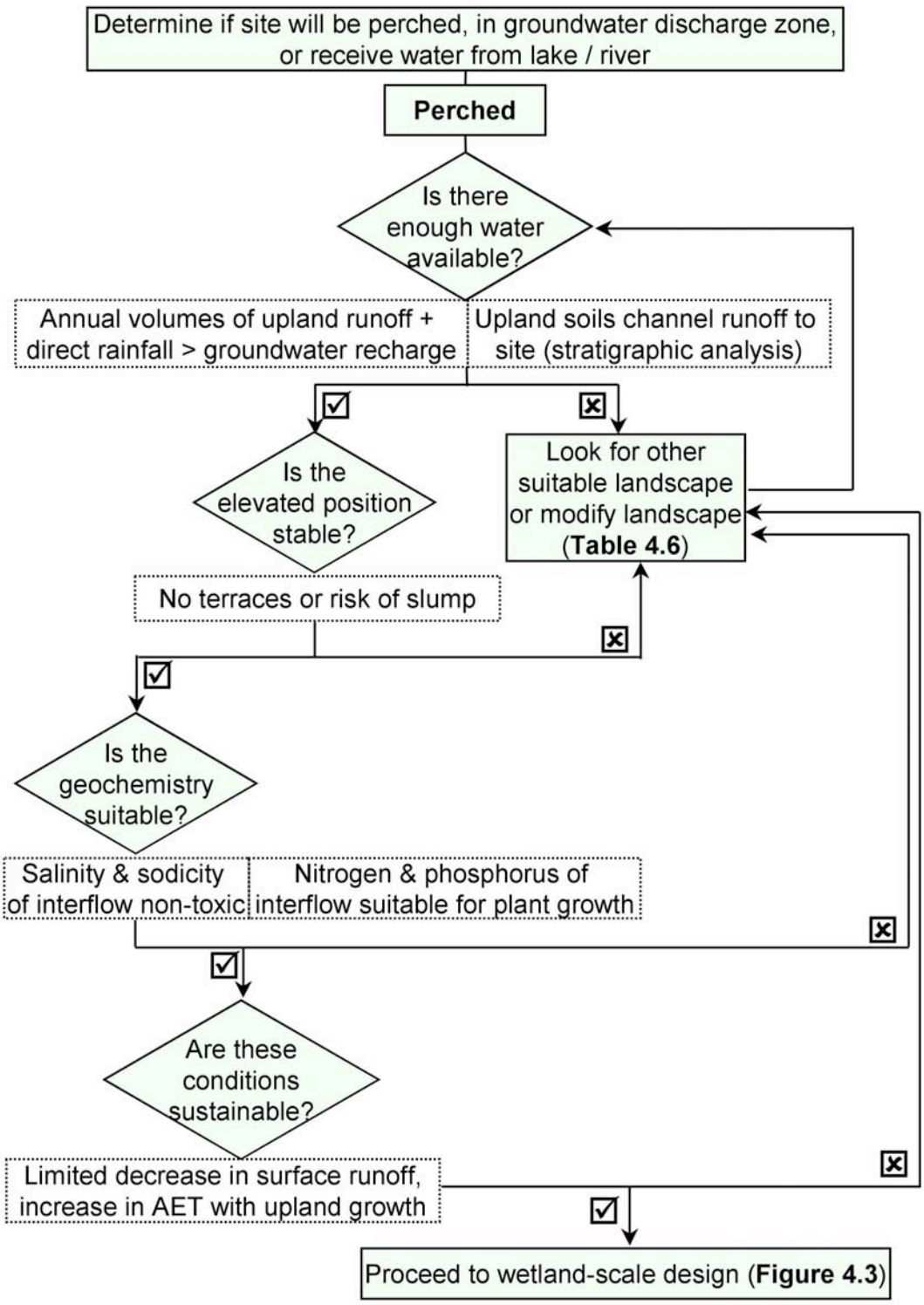

Figure 4.2(a) Decision sequence for the landscape-scale planning of reclaimed wetlands that are perched on closure landscapes of the oil sands region. For each question posed, refer to the box(es) directly beneath for guidance on how to investigate the answer (& review text in 4.1). Throughout this sequence, it is prudent to refer back and confirm the suitability of the site for the intended uses / functions (see section 4.1.1). Adaptive management is discussed in section 4.3.2.

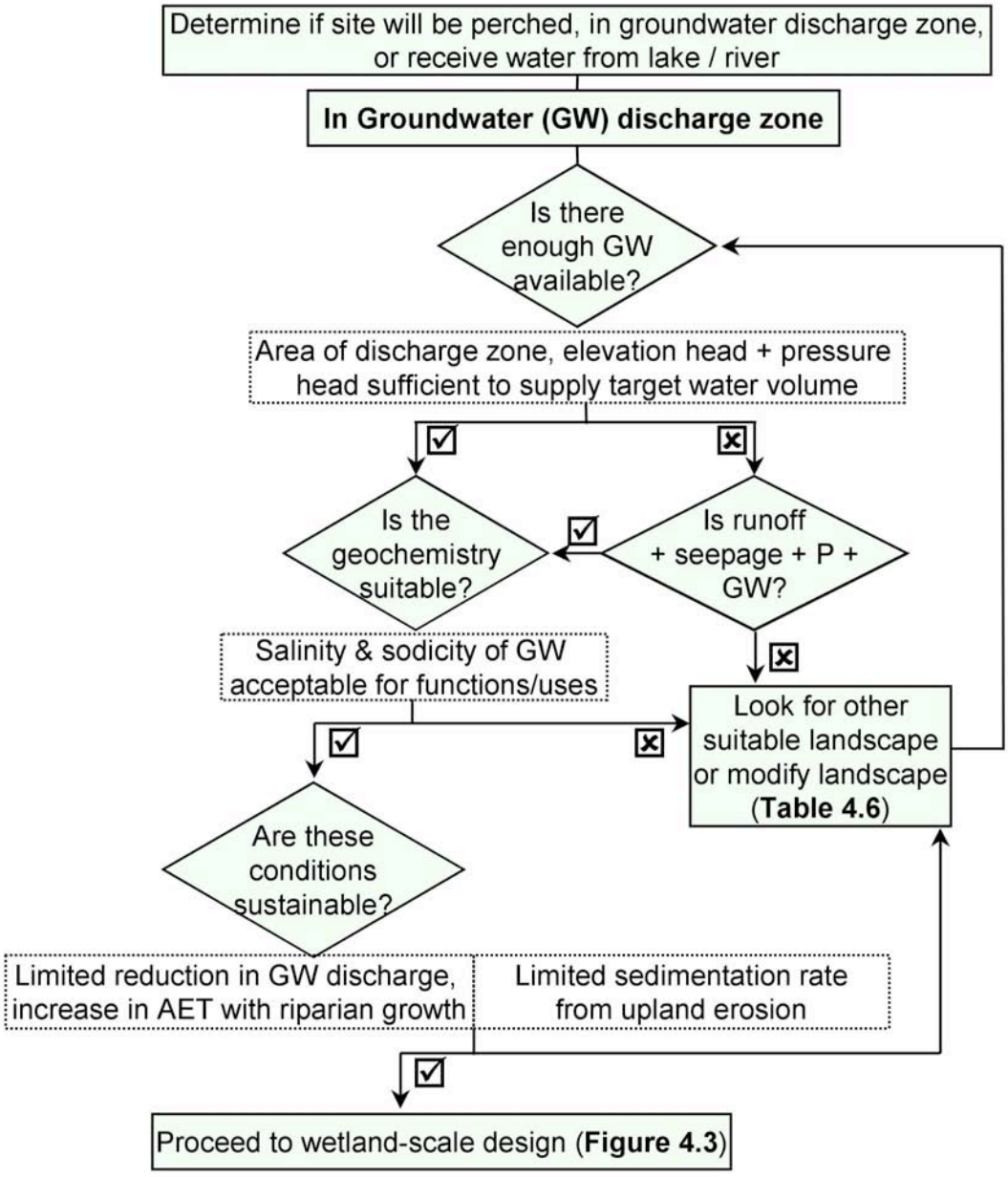

Figure 4.2(b) Decision sequence for the landscape-scale planning of reclaimed wetlands that occur in a groundwater discharge zone on closure landscapes of the oil sands region. For each question posed, refer to the box(es) directly beneath for guidance on how to investigate the answer (& review text in 4.1). Throughout this sequence, it is prudent to refer back and confirm the suitability of the site for the intended uses / functions (see section 4.1.1). Adaptive management is discussed in section 4.3.2.

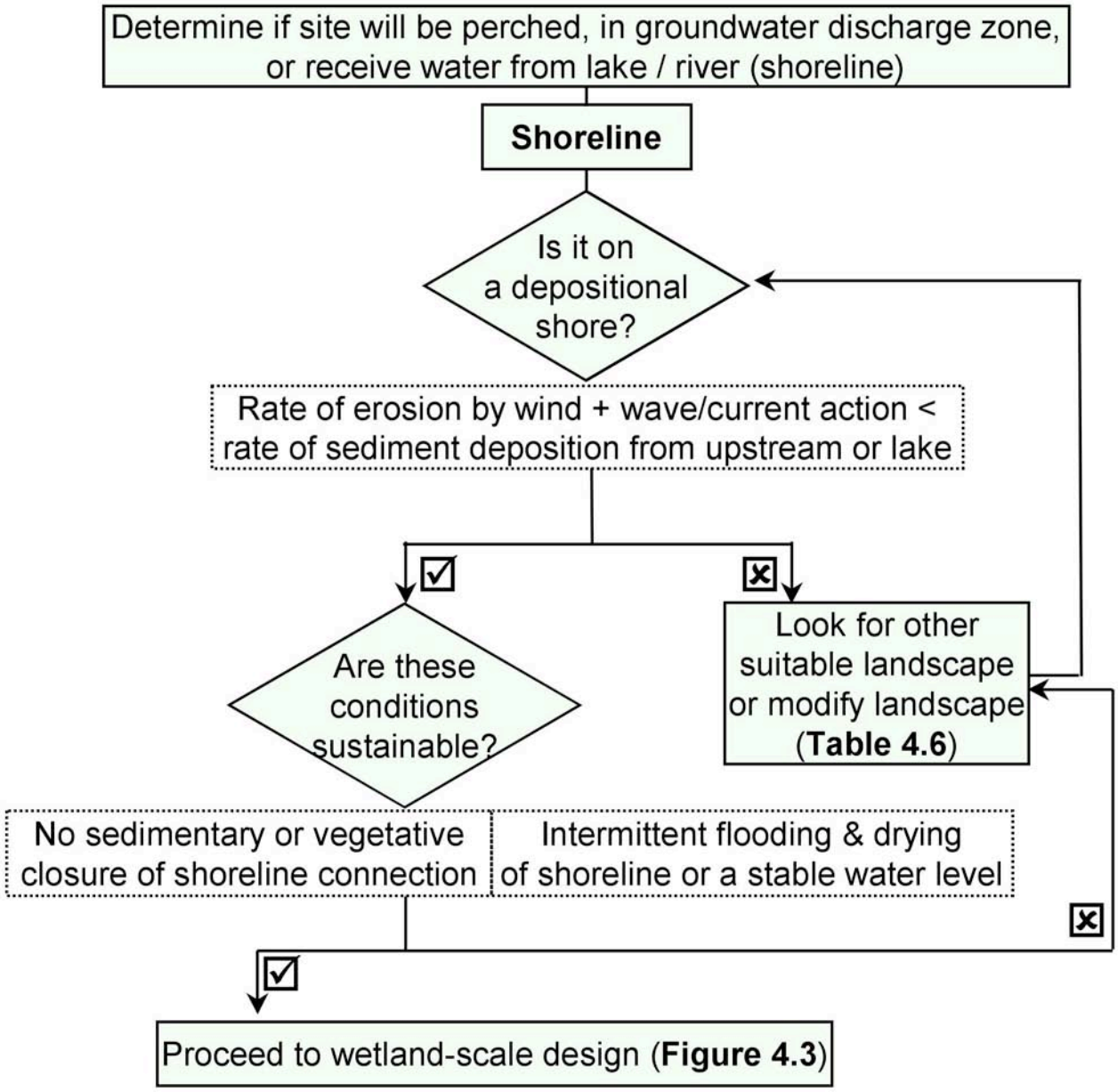

Figure 4.2(c) Decision sequence for the landscape-scale planning of reclaimed wetlands that occur in a shoreline setting on closure landscapes of the oil sands region. For each question posed, refer to the box(es) directly beneath for guidance on how to investigate the answer (& review text in 4.1). Throughout this sequence, it is prudent to refer back and confirm the suitability of the site for the intended uses / functions (see section 4.1.1). Adaptive management is discussed in section 4.3.2.

4.2 Building Individual Wetlands

Once the range of wetland types and their position in the reclaimed landscape has been established, the next step is to design and plan the construction of each system. This section makes recommendations about how to build each class of wetland, based on the functions it is being designed to provide. The timing of and activity sequence for wetland construction is discussed at the end of this section.

To build a wetland, the following broad elements must be considered:

- Functions / uses (see section 4.1);
- Landscape setting (see section 4.1);
- Basin morphology;
- Sediment and substrate materials;
- Hydrologic capacity;
- Water sources and chemical properties;
- Vegetation communities;
- Invertebrate communities;
- Other habitat elements for vertebrates.

When naming wetlands, use the correct class category (i.e. Bill's Pond would be Bill's Marsh); in the long term, it will aid communication across disciplines.

Much of the remainder of this section is organized by wetland class, with all of the wetland- (or landform-) scale elements described as much as possible for each class. Figure 4.3a-b shows a decision sequence that identifies one stepwise process of building a design for a reclaimed wetland, using marshes and ponds as an example. This sequence considers the design of key limiting structural, hydrological and geochemical variables first, then proceeds to refinement of secondary structural elements and functional (biological) elements. The hydrology and geochemistry at the wetland-scale is contingent on so many interacting variables that it is difficult to consider just one design element at a time. The challenge for design teams will be to envision how the proposed system will function as a whole.

Again, it is important to recognize that the state of knowledge on reclamation and establishment times of the five classes of wetland is variable. The greatest level of knowledge exists for reclamation of marshes and ponds. Vascular plants and zoobenthos may establish relatively quickly and develop a community structure similar to natural analogues within ~15 years[93]. The level of knowledge for bogs, fens and swamps is considerably less[94]. Reestablishment of fen or bog structure, that is groundwater flow, attainment of saturated soils and establishment of peat-forming vegetation, requires approximately 5 years at restored sites[95]. Fen reclamation may or may not require more time. It is not known to what extent peat will accumulate (production > **decomposition**) in the boreal environment as a whole, with an expected greater frequency of dry years[96].

[93] Ciborowski 2003
[94] CEMA 2003
[95] Cooper 2003; Quinty 2003
[96] preliminary study suggests that natural analogues in the region have been accumulating 0.3 – 1.6 mm peat per year over the last 80 years (Trites & Bayley, unpublished data)

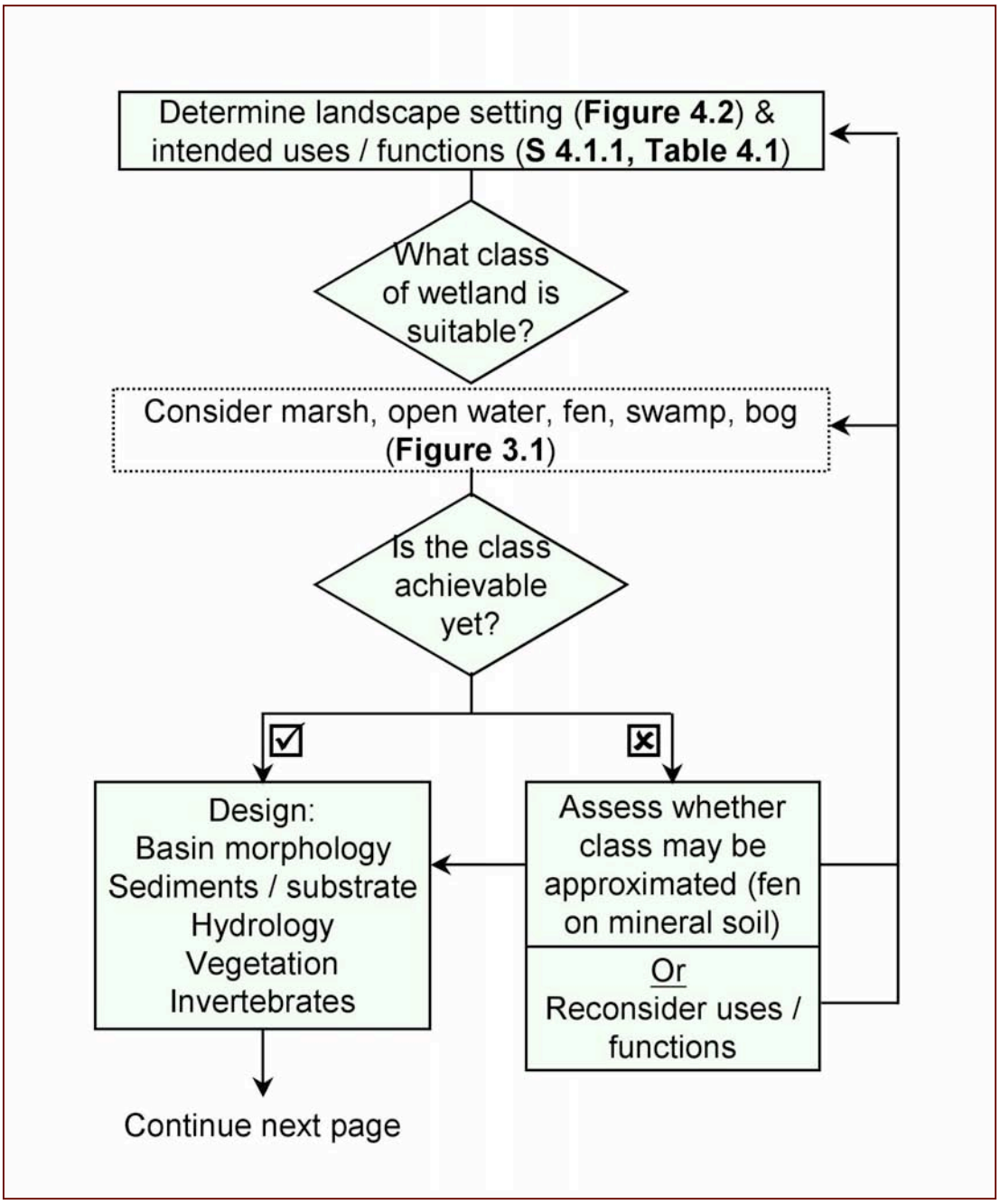

Figure 4.3(a) Decision sequence for proceeding from landscape-scale to wetland-scale design of reclaimed wetlands in the oil sands region. Wetland-scale design for inland marshes and shallow open water wetlands (ponds) continues on the next page.

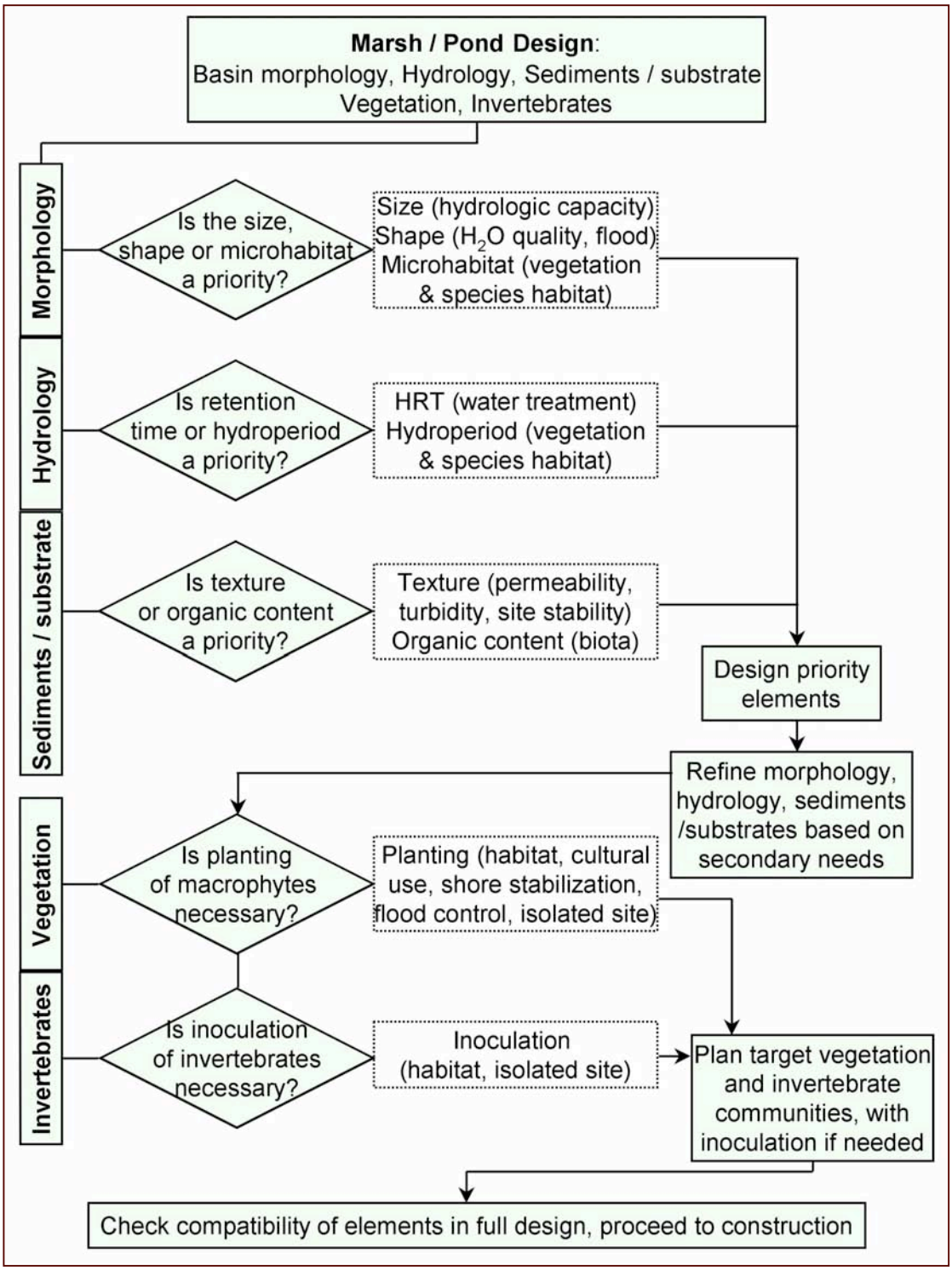

Figure 4.3(b) Decision sequence for the wetland-scale design of reclaimed wetlands on closure landscapes, using inland marshes and ponds as an example. This sequence uses a stepwise process, where key limiting variables (referred to as priorities) are considered first, then the structural design is further refined by considering secondary variables before proceeding onto functional (biological) element design.

4.2.1 Building marshes and open water wetlands

Marshes are wetlands dominated by reeds, rushes and sedges (**herbaceous** water plants) rather than mosses or trees. They are periodically inundated by standing or slowly moving water, and have a neutral to basic pH[97]. The national classification system defines them as not peat-forming (i.e. <40 cm peat accumulated); however, there are examples in northern Alberta where they are peat-forming, particularly where they exist as a fringe around ponds, small lakes or fens[98]. Thus, substrates may be a mixture of mineral material, peat and **gytjja**. Water may enter marshes from direct precipitation, runoff, seepage or groundwater flow. Where present, standing water tends to be **eutrophic** and supports a diversity of submerged and floating vascular plants. Inland marshes (**terrigenous**) in the boreal forest appear to exhibit wet-dry cycles similar to prairie pothole systems, where levels of standing water vary significantly from one year to the next[99]. Shoreline marshes (**littogenous**) are also present in the boreal forest and are less subject to water draw-down effects. Marshes can be sustained under a wide range of hydrologic and nutrient regimes[100]. There are natural analogues in the region for several variants, including **alkaline** (high in calcium and bicarbonate) and saline (high in sodium and sulphate) marshes[101].

Gytjja is a flocculent, mineral-rich soil with organic components like decomposed sedges, pondweeds & algae; it can be found at the bottom of lakes and wetlands. The organic content is not as high as peat (80+%).

Shallow open water wetlands are often located as ponds within wetland complexes that are predominantly made up of other wetland classes[102]. To be recognized as a distinct class within such inland complexes, they should be larger than 8 ha in size[103]. Ponds are distinguished from marshes by having at least 75% of total surface area in open water during the summer. In shoreline settings, they occur along a continuous gradient, as a transition zone (~1 – 2 m depths) between riparian margins or marshes and lakes. Vegetation in the open water zone is restricted to submerged and floating forms. **Phytoplankton** may dominate the plant community in some instances[104].

While the terms inland and shoreline are used to distinguish hydrological settings for wetlands, the terms terrigenous and littogenous describe the corresponding wetland forms. Terrigenous forms are connected to surface or groundwater inflows. Littogenous forms are connected to riverine or lacustrine sources of water.

In reclaimed landscapes, it is likely that marshes and open water wetlands or ponds may form wetland complexes. For this reason, and because many of their design specifications overlap, this section groups them together. Table 4.3 provides recommendations for their design. Basin morphology may be varied within each wetland to address multiple objectives. When land use objectives conflict, construction materials and biotic components will likely need to be varied among numerous wetlands for optimal targeted design.

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[97] Appendix B (Halsey); National Wetlands Working Group 1997; Mitsch and Gosselink 2000
[98] National Wetlands Working Group 1997; Bayley and Mewhort 2004
[99] Butterworth 2003; Peters et al. 2006
[100] Bayley and Mewhort 2004; Whitehouse and Bayley 2005
[101] Appendix B (Halsey); Golder Associates 2003; Purdy et al. 2005
[102] Whitehouse and Bayley 2005
[103] National Wetlands Working Group 1997
[104] Bayley 2003

The acceleration of vegetation establishment (by seeding or planting) and invertebrate colonization (by inoculation) may be critical to the early success of habitat wetlands. The 'build it and they will come' philosophy for wetland creation only works when the reclaimed or restored site is well-connected spatially to healthy, remnant natural wetland complexes[106]. Some wetland plants like sedges and saline seep species produce few seeds and rely on rhizome growth to expand into neighbouring areas[107]. Invertebrates like gastropods (snails), bivalves (mussels) and crustaceans (aquatic sow-bugs, scuds) have limited capacities to disperse overland or by air. If these species cannot reach the constructed system to colonize it, the new wetland may become colonized by a few vigorous species or otherwise be limited in diversity relative to natural analogues.

Mallard ducklings preferentially feed on large predaceous beetles (Coleoptera, Dytiscidae) and caddisflies (Trichoptera) in boreal wetlands[105].

Although this scenario may not be an issue for systems designed to provide water treatment, it is a problem for habitat systems designed to accommodate breeding waterfowl, fur-bearers or moose. For example, many nesting duck species require a varied diet of plants, snails, insects, worms, and crustaceans[108]. A wetland with a benthos dominated only by midges (Chironomidae) may not provide brooding hens and young ducklings with the same quality nutrition[109]. Inoculation of many functional groups of invertebrates needs to occur after the establishment of an appropriate submergent macrophyte community[110]. The various, general options for vegetation establishment are discussed in section 4.2.5 and Appendix D.

Hydroperiod refers to the seasonal pattern of flooding and drying in a wetland. It is likely to be most varied in perched systems or those connected to local groundwater flows.

Hydroperiod is another important consideration for many intended uses. Marshes with seasonally fluctuating water levels provide desirable habitat for many waterfowl, whereas beaver and muskrat prefer a less variable regime [108]. Vegetation planting or seeding will also need to consider the preferred hydroperiod and saturation zone for each species[107]. For instance, some seeded sedges establish best with an initial drawdown scenario, while other closely related species are intolerant of small water level changes[111]. Studies of water management in restored wetlands indicate that spring draw-downs are most beneficial for seed germination in the emergent zone of wet-dry marshes[112]. In the short-term, it is possible to manipulate water depth using dams and berms[113]. The mature landscape setting must be sufficient to create the desired hydroperiod in the long term. CEMA (through WASG) is currently funding a study tasked with identifying natural marsh vegetation community assemblages in the oil sands region and the typical water depth zone of each species[114].

Consider the interaction of elevated salinity and hydroperiod. Fluctuating water levels will compound salinity issues, because saline crusts will form when water evaporates or is otherwise drawn down.

[105] Hornung and Foote 2007
[106] Brady et al. 2002; Wiacek et al. 2002; Appendix E (Lumbis et al.)
[107] Appendix D (Cooper et al.); Golder Associates 2005a
[108] Butterworth 2003; Wiacek et al. 2002
[109] Gurney et al. 2005
[110] Brady et al. 2002; Hornung and Foote 2006
[111] Budelsky and Galatowitsch 2000; different species of *Carex* sedges were tested
[112] Taft et al. 2002; Kaminski et al. 2006
[113] Taft et al. 2002
[114] see section 7.2, project title 'An analysis of existing information on wetland vegetation in the oil sands region – marshes'

Resources for traditional use may be provided for in marsh reclamation by optimizing habitat for moose, muskrat and beaver, and by planting vegetation holding cultural significance. An important medicinal plant is rat root (*Acorus calamus*, sweet flag), which may be established in the emergent zone of marshes using **propagules** (plants or rhizomes) planted in the fall or spring[115]. Bulrushes (*Scirpus* sp.), cattail (*Typha latifolia*), itch plant (*Myrica gale*, sweet gale), and twisted stalk (*Streptotus amplexifolius*) also have cultural applications[116].

The presence of fish, muskrat and beaver in marshes and ponds can profoundly alter wetland dynamics. Fish, particularly predatory species, affect benthic invertebrate, plankton and macrophyte assemblages[117]. Boreal wetlands inhabited by brook stickleback (*Culaea inconstans*), for instance, have reduced biomass of grazing and predatory invertebrates[118]. Muskrat can produce channels through marshes and affect the proportion of open water through grazing, while beaver influence the size, depth and organic makeup of wetlands[119].

Trophic refers to the position of organisms in the food chain. Low trophic status is given to plants and high trophic status is given to predators like kestrels.

Suncor pond containing tailings water on overburden (Credit: Wayne Tedder, 2005)

[115] see Appendix D (Cooper et al.) for further details
[116] see Appendices D (Cooper et al.) and F (Gulley & Garibaldi)
[117] Gould 2000; Hornung and Foote 2006
[118] Hornung and Foote 2006
[119] Appendix E (Lumbis et al.); Butterworth 2003; Naiman et al. 1994; Devito and Dillon 1993

Table 4.3 Design guidance for constructing marshes and shallow water ponds on reclaimed landscapes.

Key design element and parameter	Design guidance for marshes and shallow water ponds
Basin morphology	
Size	▪ Minimum sizes for waterfowl are 0.2 ha (within larger complex of wetlands) or 5 ha (isolated)[120] ▪ Minimum size for beaver is 1.3 km^2 marsh[121] ▪ Volume of recharge is often directly proportional to surface area[122] ▪ Large surface areas increase evaporation and concentrate salt ions in treatment wetlands[123]
Shape & forms	▪ Convoluted shorelines increase use by territorial species[124] ▪ Islands provide protected nesting areas for ducks[124] ▪ Shoreline complexity index >1.6 preferred by breeding waterfowl[125] ▪ Length:width of 10:1 increases water treatment efficiency[126] ▪ Long fetches may resuspend sediments (& sediment-bound contaminants), but aid volatilization of water-borne contaminants (like ammonia)[122]
Depth	▪ 1.5 to 2 m for open water habitat, oxygenated water treatment, over-wintering by fish, muskrat & beaver[127] ▪ <1.5 m for submergent vegetation (moose forage), microbes[128] ▪ 0.1 to 0.5 m for emergent vegetation[128] ▪ > 25 cm for diving ducks, 5 – 25 cm for dabbling ducks, < 18 cm for waders (shorebirds)[129] ▪ Temporary weirs increase winter depths, HRT and allow for some water treatment processes to occur under ice[123] ▪ Deep areas should be contiguous to prevent entrapment of fish or fur-bearers during water level fluctuations[127] ▪ Deep water produces stronger piezometric gradients, which encourages groundwater recharge & discourages discharge[122]
Shoreline gradient	▪ Slopes of 15:1 horizontal(H):vertical(V) or flatter[130] ▪ Submerged slope of 0.5% optimal for emergent plants[131] ▪ Low banks required for access to forage by moose & beaver (<1 m, <10˚)[127] ▪ High banks required for winter denning by muskrat & beaver

[120] Lokemoen 1973; Wiacek et al. 2002
[121] Allen 1982 cited in Wiacek et al. 2002
[122] Hayes et al. 2000; landscape position is a greater controlling factor of recharge (Appendix C1[Devito & Mendoza], section 4.1)
[123] Golder Associates 2006a; concentrations of ammonia, TP & TN may still increase under-ice (Devito and Dillon 1993)
[124] Appendix E (Lumbis et al.)
[125] Jalkotzy et al. 1990
[126] Kadlec and Knight 1996
[127] Wiacek et al. 2002; Axys 2003
[128] Appendix D (Cooper et al.); Golder Associates 2005a
[129] Appendix E (Lumbis et al.); Taft et al. 2002
[130] Kentula et al. 1992
[131] Steiner and Freeman 1989

Key design element and parameter	Design guidance for marshes and shallow water ponds
	(maximum 5H:1V, <2 m high)[127]
Bottom gradient	▪ <1% is optimal for flood control, with deeper channels[132] ▪ Irregular bottom provides frictional resistance for flood control or sediment retention & increases HRT[133]
Percent open water	▪ <75% for marshes, >75% for shallow open water ponds ▪ 50% optimal for breeding waterfowl & ammonia degradation[134] ▪ <50% optimal for other wetland birds (rails, etc)
Inlets & outlets	▪ Restrict outlet to increase HRT, control floods, or increase groundwater recharge (relative to ET)[133] ▪ Increase inlet width to disperse suspended sediments[133]
Sediment & substrate	
Substrate type	▪ Organic substrate can bind metals and enhance nitrogen cycling[135] ▪ A peat–mineral mix with 15 to 20% organic matter is optimal for root penetration and turbidity control[136] ▪ Muskrat require a firm substrate for house-building (soft tailings would not be appropriate)[137]
Substrate depth	▪ Transplanting 6-7 cm organic soil from natural marsh enhances vegetation with native species[138] ▪ 20 cm substrate is optimal for root penetration at water depths < 45 cm[139]
Sediment type	▪ Fine-grained if marsh or pond is perched and isolated, or for water treatment wetlands ▪ Deep organic sediment (> 2 m) common in natural analogues[140], increases total water holding capacity of wetland
Sedimentation rate	▪ <0.25 cm_y^{-1} to allow wetland seed emergence[141] ▪ High suspended sediment loads limit macrophyte, plankton & fish growth[142]; incorporate sediment trap above habitat marshes ▪ 0.16 mm_y^{-1} is acceptable for habitat wetlands[143]
Hydraulic capacity	
Retention time* *HRT (days) = wetland volume (m^3) ÷ outflow (m^3_d^{-1})	▪ Several months for the labile (more toxic) fraction of naphthenic acids[144] ▪ Several years for the refractory fraction of naphthenic acids[144] ▪ ~4-6 weeks for ammonia[145] ▪ Temporary weirs may be used to increase HRT

[132] Appendix C1 (Devito & Mendoza); Mitsch and Gosselink 2000
[133] Hayes et al. 2000
[134] Golet 1976; Weller 1978; Bishay and Nix 1996
[135] Zedler and Langis 1991
[136] Stauffer and Brooks 1997; Luong 1999
[137] Wiacek et al. 2002; Ursus 2003
[138] Brown and Bedford 1997
[139] Hammer 1989; Brown and Bedford 1997
[140] Bayley 2003; Bayley and Mewhort 2004
[141] Galinto and van der Valk 1986
[142] Harris 2001
[143] Golder Associates 1998
[144] Scott et al. 2005; Golder Associates 2005a; M. MacKinnon, pers. comm.
[145] Golder Associates 2005a

Key design element and parameter	Design guidance for marshes and shallow water ponds
Hydroperiod	▪ Spring drawdown & re-flooding by 15 – 45 cm enhances waterfowl habitat[146] ▪ Germination of emergent plants requires species-specific water level fluctuations[147] ▪ Stable water levels required for beaver (<1 m_y^{-1}) & muskrat[127]
Loading rate	▪ 2.5 to 5 cm_d^{-1} for water treatment[148]
Water chemistry	
Nutrients	▪ Nitrogen is a limiting nutrient in boreal emergent-dominated marshes and natural saline marshes & fens[149] ▪ Phosphorus may be the limiting nutrient in sub-saline reclaimed marshes[150] ▪ Phosphorus availability increases with catchment area[151] ▪ Adding phosphorus (<100 μg_L^{-1}) enhances initial water treatment rates[152], but may favour weedy vegetation[147] ▪ Natural analogues contain 10-50 μg_L^{-1} N, 25-100 μg_L^{-1} P[153] ▪ Anoxic conditions under ice may lead to build-up of N & P[154]
Naphthenic acids	▪ Marshes can be associated with end-pit lakes to extend HRT ▪ Larger wetland volumes (by increased depth not surface area) will increase HRT and extend potential for biodegradation[155]
Salinity	▪ Electrical conductivity >10 dS_cm^{-1} in soil & > 2 mS_cm^{-1} in water limits vegetation to saline-tolerant species; EC <3-4 dS_cm^{-1} in soil allows establishment of non-saline riparian vegetation[156] ▪ Flow-through, restricted hydroperiod or limited AET required to prevent salt crust formation ▪ Larger wetland surface area increases salt concentrations as a result of additional ET[155] ▪ Greater depth will ameliorate concentration of salts under the ice in winter (salt rejection)[155]
Ammonia	▪ Open water aeration and a healthy bacterial population promotes removal[145] ▪ Under-ice concentrations may increase as dissolved oxygen decreases[154]
Hydrocarbons	▪ Largely substrate- and sediment-bound ▪ Increase water depth to reduce flow & shear stresses, promote sedimentation and limit resuspension[157] ▪ Increase frictional resistance with dense submergent vegetation and irregular bottom to limit suspension of particulate-bound

[146] Taft et al. 2002; Kaminski et al. 2006
[147] see Appendix D (Cooper et al.) for requirements of species in the oil sands region
[148] Mitsch and Gosselink 2000
[149] Bayley 2003; Trites and Bayley, unpublished data; may be true for *Sphagnum fuscum* moss in local bogs (Vitt et al. 2003b)
[150] Trites and Bayley, unpublished data
[151] Prepas and Trew 1983
[152] Reed 1990
[153] Bayley 2003
[154] Devito and Dillon 1993
[155] Golder Associates 2006a
[156] Purdy et al. 2005; Appendix D (Cooper et al.)

Key design element and parameter	Design guidance for marshes and shallow water ponds
Metals	▪ Mo, B, Fe, Al, Cu, Zn present in soft tailings, possibly above water quality guidelines[158] ▪ Maintain neutral - basic pH to limit mobilization of metals ▪ Co, Cu, Mn, Ni, V, Zn are released quickly from coke; pre-rinsing coke with water and crushing it to reduce particle size before placement as substrate may reduce associated toxicity[159]
Vegetation & phytoplankton	
Submergent	▪ Phytoplankton dominate ponds >1.5 m deep ▪ Macrophytes dominate ponds < 1.5 m deep ▪ >21 % cover preferred by breeding waterfowl as forage[160] ▪ 30 mg_L^{-1} NAs and 1000 μS_cm^{-1} are thresholds above which phytoplankton community composition is altered (thereby changing the structure at the base of the aquatic food web)[161] ▪ Macrophytes (pondweed) and floating plants (yellow pond lily roots) are high-quality summer foods for moose[162]
Emergent	▪ Transplant densities are species-specific[163] ▪ Water table depths for planting are species-specific and may vary from natural settings in process-affected soils[163] ▪ Saline tolerant species are often not proximate to reclamation sites and will not self-seed; need to transplant in donor wetland soil (seed bank) or plant propagules from saline sources[164] ▪ Cattail monocultures help retain nutrients[165], but limit habitat ▪ 30 – 90 % cover preferred by waterfowl for nesting & brood-rearing habitat[160] ▪ Muskrat prefer reedgrass for house-building and cattail, rat root, burreed, bulrush and sedges for foraging[166] ▪ A weed-free seed bank reduces competitive stress for plants[164]
Riparian	▪ Aspen & willow <15 cm in diameter and close to water (<100 m) will enhance beaver habitat[167] ▪ Willow, water birch and black spruce are tolerant of CT-associated salinity and sodium (EC 4440-7910 μS_cm^{-1})[168] ▪ Canadian toad prefer >50% aspen cover[160]

[157] Evans 1994; Hayes et al. 2000
[158] Golder Associates 2005a; Mo=molybdenum, B=boron, Fe=iron, Al=aluminum, Cu=copper, Zn=zinc
[159] Squires 2005; Co=cobalt, Mn=manganese, Ni=nickel, V=vanadium
[160] Wiacek et al. 2002; toad requirements (riparian) may be a function of sandy hibernaculum soils
[161] Hayes 2005
[162] Wiacek et al. 2002; Garibaldi 2006b; pondweed (*Potamogeton* spp.), yellow pond lily (*Nuphar variegatum*; Aboriginal name = beaver pineapple)
[163] see Appendix D (Cooper et al.) for recommended densities for a number of native species; Golder Associates 2005a
[164] Appendix D (Cooper et al.); Purdy et al. 2005; Golder Associates 2005a
[165] Cronk and Fennessy 2001; CEMA 2003
[166] Wiacek et al. 2002; Garibaldi 2006b; reedgrass (*Phragmites* spp.), cattail (*Typha latifolia*), rat root (sweet flag, *Acorus calamus*), burreed (*Sparganium* spp.), bulrush (*Scirpus* spp.), sedges (*Carex* spp.)
[167] Wiacek et al. 2002
[168] Renault et al. 1998

Key design element and parameter	Design guidance for marshes and shallow water ponds
Invertebrates	
Benthic & Nektonic	▪ Submergent vegetation and channel edges increase snail densities[169] ▪ Habitat structural complexity (plants, submerged logs, detritus) are required to support invertebrate community diversity[170] ▪ Introduction of natural wetland sediments can be used to inoculate benthos; consider inoculation or stocking to establish poor dispersers [171] ▪ Presence of fish will alter zoobenthic community composition[172] ▪ Gatherer, predator, shredder & piercer functional invertebrate groups are reduced where submergent vegetation is dominated by dissected leave plants like milfoils[173]
Planktonic	▪ 1.1-9.0 mg_L^{-1} naphthenic acids influences zooplankton community composition and may thereby alter food web structure (invertebrates and fish)[174]
Other habitat for vertebrates	
Fish	▪ Spawning may occur in shoreline marshes among emergents ▪ Suitable for introduction to phytoplankton-dominated ponds[175]
Waterfowl	▪ Spring staging requires shallow (<0.5 m), open wetlands (often connected to lakes) with an early spring thaw[176] ▪ Breeding requires emergent vegetation with a significant vertical dimension and convoluted shorelines[176]
Muskrat	▪ Critical ice-water depth for winter survival is 75 cm under water[177] ▪ Optimal habitat contains 40-75% emergent vegetation cover and >75% submergent vegetation cover[178]
Canadian toad	▪ Wetland should be within 50 m of hibernacula (burrows on south-facing 40˚ slopes, un-vegetated with loose sand)[179]

[169] Olson et al. 1998
[170] Hornung and Foote 2006; invertebrate biomass is positively related to the proportion volume of submerged plants
[171] Brady et al. 2002; innoculate once a submergent macrophyte community is established
[172] Gould 2000; Hornung and Foote 2006
[173] Hornung and Foote 2006; milfoil (*Myriophyllum* spp.)
[174] McCormick 2000
[175] Bayley 2003
[176] Appendix E (Lumbis et al.); Wiacek et al. 2002
[177] Ambrock and Allison 1972 cited in Wiacek et al. 2002
[178] Jalkotzy et al. 1990 cited in Wiacek et al. 2002
[179] Axys 2003

4.2.2. Building fens and bogs

Fens are peat-forming wetlands and the dominant wetland class in natural environments of the oil sands region[180]. In fens, the water table is relatively stable, at or slightly above the soil surface. 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 mosses** (rich fens) or Sphagnum mosses (poor fens), with less dense assemblages of vascular plants like sedges and shrubs[181]. 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 are extremely variable in physiognomy and are divided into sub-classes of poor, rich and extreme-rich based on water chemistry and vegetation[182].

Bogs, like fens, are peat-forming wetlands; however, bog hydrology is driven solely by precipitation in a perched setting. They are rich in humic and fibric **acids** (pH <4.5) and poor in phosphorus and other base cations. The dominant vegetation, Sphagnum moss, further acidifies the environment and is a poor heat conductor, thereby assisting in the establishment of a micro-environment that is unsuitable for most competing vascular plants[182]. In the boreal forest, bogs also commonly contain lichens (which are critical forage for woodland caribou), **ericaceous shrubs**, and black spruce.

At the present time, reclamation of fens or bogs in the oil sands has not been attempted. There are some examples of successful reclamation of fens in the western US to draw upon[183]. Preliminary findings from a recent CEMA-funded study suggest that some saline-tolerant sedge and reed species from the oil sands region may be able to accumulate organic matter and produce peat[184]. This study is also measuring historic and recent rates of peat accumulation in saline boreal wetlands of the oil sands region, with the aim of predicting how many years it will take to produce peat in reclaimed wetlands. Another current CEMA (WASG)-funded study aims to predict the feasibility of creating the hydrological conditions required for a fen wetland on oil sands reclaimed landscapes[185]. A previously constructed model[186] will be used with new inputs of recent hydraulic and soil permeability parameters derived from reclaimed landscapes[187]. The hydrological patterns in natural fens from the region suggest that many fen wetlands are connected to local

[180] Vitt 1992; Vitt et al. 1996; Bayley 2003
[181] Bayley and Mewhort 2004; Vitt 2003
[182] National Wetlands Working Group 1997; Appendix B (Halsey)
[183] Cooper and MacDonald 2000
[184] see section 7.2, project title 'Effects of salinity on vegetation and organic matter accumulation in natural and oil sands wetlands'
[185] see section 7.2, project title ' Creating a fen peatland on a post-mined oil sands landscape: a feasibility modelling study (phase 2)'
[186] Price et al. 2005b
[187] Devito and Mendoza 2003; Elshorbagy et al. 2005

groundwater flow (small catchments) and may experience seasonally and annually variable recharge and discharge rates[186]. The model identified liner material permeability and water retention properties of the replaced peat as being critical variables controlling the provision of sufficient groundwater. Hence the current study will also examine the effects of disturbance, such as caused by stockpiling of muskeg, on the water retention capacity of replaced peat.

Table 4.4 provides a summary of the current state of knowledge on the creation of fens. Although there is insufficient guidance here for demonstration-scale construction, this collation may prove useful in the design of smaller-scale (<1 ha) replicated research projects.

Bog reclamation may prove very difficult to achieve. Bogs require specific environmental conditions and represent a mature seral state in peatland formation (refer Figure 3.1). Lessons learned from fen reclamation research in the oil sands may be further applied to perched settings (see Table 4.2 for probable landscape-scale parameters) to investigate the feasibility of creating bogs on closure landscapes.

Treed poor fen on Suncor's Millenium lease (Credit: Wayne Tedder 2005)

Table 4.4 Fen reclamation and associated environmental conditions

Design element	State of knowledge
Basin morphology	▪ Microtopographic heterogeneity in the form of hummocks, hollows and flats is important for water retention, soil temperature gradients, vegetation diversity, nutrient partitioning and microbial activity[188]
Sediment & substrate	▪ Underlain by peat at least 50-100 cm deep, tapering shallower on upland slopes to allow for paludification ▪ Must establish aerobic-anaerobic layers (acrotelm-catotelm), with living peat above decomposing peat ▪ Fens have been established on mineral soils including in the boreal after the last glaciation[189]
Hydraulic capacity	▪ Water table must stay near the soil surface throughout seasons and vary by <20 cm[190]; grade site to within 20 cm of mapped level of groundwater aquifer[191]
Water & peat chemistry	▪ Electrical conductivity maximum is 300-400 μS_cm^{-1}, pH range 4-8[192] ▪ Phosphate fertilizer application (2 g_m^{-2}) prior to vegetation enhances establishment of vascular plants like sedges[193] ▪ Nitrogen from current oil sands air emissions (~4 $kg\_ha^{-1}\_y^{-1}$ for Steepbank) enhances Sphagnum moss growth, but growth inhibition occurs at higher N levels (~14 $kg\_ha^{-1}\_y^{-1}$)[194]
Vegetation	▪ Community assemblages, key indicator species are well known[195] ▪ Vascular sedges and possibly some mosses may be established by collecting peat substrate with diaspores from natural analogues in the spring; take top 10 cm, break up and spread[196] ▪ Straw mulch application (3000 kg_ha^{-1}) may protect vegetation from fluctuating temperature and drying soil moisture regimes during establishment[197] ▪ Awned sedge, seaside arrow-grass and bulrush are salt-tolerant and may accumulate organic matter sufficiently to form peat[198] ▪ Indigenous knowledge of Sphagnum mosses may provide insight on local optimal growing conditions

[188] Bruland and Richardson 2005
[189] Halsey et al. 1998; Amon et al. 2005
[190] Gignac et al. 1991; Zoltai et al. 1999
[191] Nicholson et al. 1996; Cobbaert et al. 2004; Whitehouse and Bayley 2005
[192] Vitt 2003; Whitehouse and Bayley 2005
[193] Rochefort et al. 2003; Cobbaert et al. 2004
[194] Vitt et al. 2003b; implies that *Sphagnum fuscum* in region may be nitrogen-limited
[195] Vitt and Slack 1975; Gignac and Vitt 1994; Vitt 1994; Vitt et al. 2003a; Whitehouse and Bayley 2005
[196] Cobbaert et al. 2004
[197] Price et al. 2003; Cobbaert et al. 2004
[198] S. Bayley and M Trites, preliminary results; awned sedge (*Carex atherodes*), seaside arrow-grass (*Triglochin maritima*), bulrush (*Scirpus paludosus*)

4.2.3. Building swamps

Swamps are forested wetlands with 30% or more tree cover and a water table at the soil surface. They may have shallow peat soils (<40 cm) and are often influenced by lateral water movement inward from their margins. They are not prominent in aerial coverage in the boreal forest surrounding the oil sands region. Where present, they are typically situated between a fen and a drier upland environment.

From a reclamation perspective, swamps have two valuable functions. They are the preferred wetland class for beavers[199], and they are also effective for flood control in some settings. There have been no attempts thus far to reclaim swamps in the oil sands, and WASG do not consider their creation to be a research priority because of their uncommon status. They can add value as flood control elements around low-lying marshes or fens. Where beaver activity is being encouraged, swamps could add value around marshes or fens in riverine settings where gradients are low. Planning for swamps at this point in time is largely limited to establishing appropriate marsh margin settings (saturated soils, intermittent flooding, vegetation with water birch, willows, tamarack and / or black spruce) and monitoring succession changes.

4.2.4 Building connectivity into wetland complexes using riparian margins and streams

Technically, **riparian margins** and riverine systems are not wetlands; however, they form critical links to uplands and between wetlands and lakes. Therefore, this guideline discusses them briefly and provides limited guidance on their construction, as it relates to wetland function. Table 4.5 lists some rudimentary considerations for design of effective connecting environments.

Littoral zones in lakes encompass the shoreline aquatic region as deep as light will penetrate; therefore, they include many different habitats and few of these could be considered wetlands. Wetlands existing in association with lakes and their littoral zones are described as shoreline. Planning and design elements unique to this type of wetland have been discussed in sections 4.1 and 4.2.1, under shoreline landscape settings. A broader discussion of littoral zones is left for future guidance documents related to end-pit lake construction.

[199] Searing 1979

Table 4.5 Design guidance for vegetated watercourses and riparian margins to wetlands

Key design element and parameter	Design guidance
Morphology	
Shape	▪ Two-level channels mimic many natural systems (narrow central channel – bank – wider outer channel – bank) ▪ Beaver use streams >0.8 km long & <5 m wide[200]
Gradient & velocity	▪ Submerged slope range is 1.5H:1V (fine-grained sediment) to 4H:1V or flatter (coarse-grained sediment)[201] ▪ Beaver use streams with low slope (<15%)[200] ▪ Water velocity should be ≤10 m_min^{-1} for muskrat[202] ▪ Beaver dam streams with <10 % riffles[203]
Sediment & substrate	
Sediment type	▪ Zones of rock/cobble on steeper gradients intercept suspended sediments and provide micro-habitat ▪ Peat-mineral mix must be protected from resuspension by gradual initial filling of channel and rapid vegetation growth ▪ Beaver use streams with fine-grain, stable banks[203] ▪ Shoreline banks with clay-loam soil (not peat) are suitable for muskrat burrows[204]
Vegetation	
Submerged	▪ Rapid establishment of macrophytes and periphyton is necessary for erosion control; planting of propagules (plant plugs or rhizomes) is advised
Riparian	▪ Moose browse species that are tolerant of moist soils include red osier dogwood (saline-tolerant), Saskatoon berry, choke-cherry and willow[203] ▪ Beaver prefer aspen and willow[203]
Habitat	
Fish	▪ Waterfalls may be constructed to prevent fish from reaching upstream sensitive wetlands

[200] Bovar 1996; Wiacek et al. 2002
[201] Golder 1998
[202] Nadeau et al. 1995 cited in Axys 2003
[203] Wiacek et al. 2002
[204] Axys 2003

4.2.5 The construction phase in wetlands reclamation

This guideline outlines some general considerations that should be planned for during the construction period. The process of construction can affect the functional integrity of the finished wetland system in a detrimental way if activities take place without careful planning. Such a plan should include consideration of:

- Timing of earth-works
- Movements of earth-moving equipment
- Grading and contouring strategies
- Temporary control of hydrology, particularly groundwater
- Substrate acquisition and placement
- Vegetation establishment

Timing of earth-works

Any excavation or movement of sub-grade soils at the wetland site should be scheduled when soils are dry or frozen, to minimize impacts on the hydrology of the edges and bottom and to control erosion. This is particularly the case in low elevation areas, where natural pooling of runoff, seepage or discharge occurs.

Movements of earth-moving equipment

Porosity and permeability of sediments and substrates are important design elements for several hydrological functions and vegetation establishment; thus, unforeseen changes due to compaction can seriously alter the hydrological and biological processes in the completed wetland. Designated travel corridors for heavy equipment may alleviate this problem. Also, subsequent tilling or loosening of the sub-grade may be necessary after excavation is complete[205].

Grading and contouring strategies

In some cases, where the groundwater discharge zone must be precisely intersected for instance, excavation and grading to an exact soil depth is important. However, some intended functions and uses would benefit more from leaving a rough bottom that offers frictional resistance to water flow (flood control is one example). Therefore, what might seem an insignificant factor, the smoothness of the finished surface, should be planned according to end wetland uses and functions. The final shape of the wetland, with bays, points, differing depths and bottom gradients, and islands should also be design elements built with minimal movements of equipment.

Temporary control of hydrology

Depending upon the existing hydrology at the site, seasonal patterns at the time of construction and the end wetland uses, it may be necessary to dewater the area temporarily during construction by pumping water away, diverting it, draining it with temporary tile drains or holding it nearby. Whatever the need, the construction team needs to be confident that the

[205] see Spigolon 2000 for a more in-depth discussion of types of heavy equipment and their various roles in wetland reclamation

solution they choose will not have a lasting detrimental effect on the wetlands hydrology. Once the structural elements are in place, further control of hydroperiod may need to be considered during vegetation establishment. The mechanisms used for control in both phases may be compatible to reduce costs and time.

Substrate acquisition and placement

The substrate is the upper layer of soil at the site, which will act as a rooting and growth medium for wetland vegetation. Depending on the intended uses of the wetland, it may be composed of peat, hydric soils salvaged from other wetlands in the area, upland-sourced mineral topsoils or some combination thereof. Timing of donor soil transport should be such that erosion and aeration are limited. Stockpiling also affects the geochemistry and seed viability of some substrates. For instance, the viability of some wetland plant seeds contained in peat and hydric soils could be lost if the soil is stockpiled for several years. These materials begin to compost when piled and left[206]. If fresh sources of such soils are available off-site, it may be worthwhile increasing transport distances to acquire them.

When substrate is placed, it is important to consider how it might move once inundated with water. In sites constructed with deep areas or islands, some substrates may tend to 'creep' down-slope. Shallow gradients and use of substrates with low slide tendencies can help overcome the problem[206].

Vegetation establishment

In constructed wetlands where there is some uncertainty about the resulting hydroperiod, water table depth and/or geochemistry, it may be necessary to first build the basin and monitor these conditions before choosing species assemblages to plant[207]. Vegetation may be established by:

- Natural (unaided) colonization from nearby reference wetlands (by wind, seed rain and biotic dispersal mechanisms)
- Direct placement of soils with intact seed banks
- Direct seeding with locally-sourced seeds of desired wetland plant species
- Planting of roots, rhizomes or soil plugs collected from local reference wetlands, or
- Planting of containerized plants grown from local seed in nursery/ greenhouse conditions.

Appendix D discusses the advantages and disadvantages of each approach.

Vegetation establishment in reclaimed wetlands may take several years, depending on the methods used. During that time, extreme fluctuations in hydroperiod may need to be prevented and minor fluctuations controlled to allow for germination of some target species and growth of others[208].

[206] Gilbert 2000
[207] Appendix D (Cooper et al.)
[208] see Appendix D (Cooper et al.) and Davis and Gandy 2000 for further details on establishment methods and species requirements

Where such control is necessary, it may be simpler to place temporary weirs or other control mechanisms during the construction phase.

During establishment when young plants are most vulnerable, it may also 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. The drying effects of wind may be virtually eliminated by planting in shallow depressions, mulching with (weed-free) straw, or establishing nurse plants prior to other plantings[209]. Wave action and grazing (by muskrats in particular) may be addressed using temporary barriers such as fences for muskrats and woody nurse plants or bank armouring for waves.

Vegetation establishment will also be more successful if mycorrhizal associations with wetland plant species can be maintained. The protection of mycorrhizae may be achieved by planting any stock-piles of muskeg or topsoils with N-fixing crops like clover or alfalfa, by not mixing planted organic soil with mineral **amendments**, and where plants are nursery-grown from seed, by always using some natural soil in the growth mix[209].

Wetland vegetation in Natural Wetland on Suncor lease 86 (Credit: Carol Jones 2003)

[209] Appendix D (Cooper et al.)

4.3 Monitoring, Maintaining and Modifying

Once the wetland construction is completed, a monitoring program should be established to track wetland structural and functional development. In some instances, maintenance may be required to optimize hydrological elements or ensure a healthy colonization with plants and animals. Good pre-construction planning will reduce the need for major adaptive management changes later in the process, but minor reworking may occasionally be necessary where unforeseen circumstances influence structural or functional integrity (such as muskrat or beaver activity, refer section 7.1). Aboriginal input to the monitoring program may help in the development of a robust process, by offering different valuation methods (such as the efficacy of traditional medicinal plants). This section recommends monitoring methods and adaptive management techniques where required.

4.3.1 Monitoring methods

Effective monitoring is necessary to track wetland establishment and to identify any issues threatening long-term sustainability. Unplanned, poorly designed monitoring programs can lead to uncertainty and 'more questions than answers'.

Monitoring is different from hypothesis-driven research; both have a role to play on reclaimed landscapes. Monitoring uses well-defined methods to evaluate temporal and spatial trends in structure and function of wetland systems. Hypothesis-driven research is a more intense investigation of questions that arise during the reclamation process.

Effective monitoring includes the following elements or principles:

- A design that allows statistical validation of findings;
- A comparison of reclaimed with similar natural analogue (reference) systems;
- Identification and monitoring of the key structural and functional variables for each wetland or wetland complex;
- Appropriate time-lines for monitoring;
- Progressive, well-communicated interpretation of the data;
- Integrated planning by monitoring teams.

Designs that allow statistical validation

It is clear from existing research on natural wetlands in the boreal region and from experiences thus far on reclaimed lease sites that wetland creation is, and will be, a challenging endeavour. Given the magnitude and number of sources for environmental variability in such a landscape, it is not an option to design a monitoring program that cannot be subjected to robust interpretive techniques. Without the benefit of statistical compartmentalization of variables, there is little chance that cause-effect relationships can be identified and subsequent solutions to problems found. Important elements of a testable design are: replicated sampling, use of quantitative measures, samples sizes large enough to provide sufficient power, limited reliance on variables that are not normally distributed (proportions, ratios, indices, presence / absence), falsifiable multiple hypotheses stated *a priori*, and above all, consistency in sampling procedures.

Comparison with similar natural analogue (reference) systems

Reclaimed wetlands and their natural analogues in the oil sands region are dynamic systems that are continuously responding to local- and regional-scale changes on the landscape. Comparing constructed wetlands to natural analogues ensures that effects caused by reclamation processes can be distinguished from effects caused by climate change and other broad-scale variables. However, comparisons will only be meaningful and effective if the wetland systems are categorically similar. For instance, constructed marshes should be compared to natural marshes, not natural fens. In addition to wetland class, choice of appropriate reference systems should also consider dominant hydrological inputs (is the system perched or connected to groundwater, subject to significant seasonal drawdown or not), salinity gradients, and wetland age groupings (<5 y, 5-10 y, >10 y) where possible. Established natural analogues that have been 'reset' to an earlier seral state may also be appropriate for comparison with young reclaimed systems. For example, a peatland that burned down almost to the depth of mineral soil may serve as a reference for a newly reclaimed fen. Comparisons of constructed and reference systems without consideration of these broad categories of class, age, hydrology and salinity may incorporate such high levels of natural variability that the collected data becomes un-interpretable.

Within these broad categories, it is not advisable to rely on one natural analogue for comparison, also because of the variability inherent in natural systems. Two or three comparable reference systems should be monitored. WASG recently compiled an inventory of potential reference wetlands (and some deeper water systems) in the oil sands region that may be useful in choosing appropriate reference sites[210].

Identification and monitoring of key structural and functional variables

It is not practical or advisable to monitor every detail about a reclaimed wetland and its set of natural analogues. A good monitoring plan will identify a manageable number of key variables, with a set of secondary variables chosen to further investigate issues of concern if they arise. Development of province-wide 'performance indicators' for Alberta wetlands is currently underway[211]; however, the unique nature of the oil sands environment may necessitate a more region-specific approach. CEMA (through WASG) is currently funding two studies of potential biological indicators specific to reclaimed landscapes in the oil sands region. One is evaluating the habitat suitability of process-affected wetlands for amphibians, using several measures of survival and fitness[212]. The other is assessing the use of reclaimed and altered wetlands by birds and the reproductive success of those species found breeding[213]. The results of these studies should be available by late 2007.

[210] see section 7.2, project title 'Identification of reference wetland sites (natural analogues) in the oil sands region'; Golder Associates 2006b

[211] an Alberta Environment initiative undertaken by Suzanne Bayley (UAlberta)

[212] see section 7.2, project title 'Amphibians as indicators of performance of wetlands in oil sands reclamation areas'

[213] see section 7.2, project title 'Bird assemblages as integrators and indicators of reclamation effectiveness in oil sands operational areas'

The majority of end uses and functions of reclaimed wetlands depend on attaining healthy, diverse, productive systems. Therefore, the monitoring strategy should focus on community composition, productivity or reproductive success, and the key physicochemical drivers of ecological function. Figure 4.1 provides some suggestions for primary and secondary monitoring measures. The primary methods reflect standard monitoring techniques. The secondary methods represent a phase-in of **hypothesis-driven research**, applied where standard monitoring indicates a potential problem with the constructed system. At the highest **trophic levels**, key indicator species (as defined by CEMA, refer section 3.1) may be used to assess ecological function, provided that those species reflect localized conditions. Appropriate species with temporally- and spatially-defined territories include, but are not limited to, amphibians (Canadian toad, northern leopard frog), breeding waterfowl, other birds that will use nest boxes (tree swallows, kestrels) and bats.

Appropriate time-lines for monitoring

Some of the variables monitored in a reclaimed wetland will change as the system ages. For instance, it should be reasonably evident within the first five years whether or not the constructed wetland is structurally sound. Conversely, it may not be helpful to monitor benthic invertebrates until the fourth year after construction; younger communities cannot always convey whether the mature assemblage will be a diverse and stable one. Figure 4.1 provides some broad recommendations on time-lines for primary monitoring measures. In the first five years, monitoring should focus on structural soundness – does the wetland look like the system it was designed to be? In subsequent years, there may be a shift in focus to functional monitoring – does the wetland act like the system it was designed to be?

An alternative to time-bracketing some monitoring would be to vary the frequency of sampling. For instance, water samples destined for chemical analysis may be collected more intensively during the first five years post-construction, at which point a pattern of enrichment and/or contamination should be evident. Variable intensity sampling is suitable for some of the physicochemical variables; however, it should be applied more cautiously to ecological variables, because their statistical evaluation can be compromised by changes to the sampling regime.

Progressive, well-communicated interpretation of the data

The greatest gains in knowledge regarding appropriate wetlands reclamation originate from studies conducted on or near oil sands leases. To avoid learning the same lessons over and over again, it is imperative that research and monitoring results be well-communicated, preferably in a peer-reviewed format.

To date, many of the studies conducted on reclaimed wetlands have been contracted to consultants or academics. This may be a cost-effective and high quality approach, but it is not without flaws. The data interpretation often remains obscured in internal reports which are not always well circulated. Also, there has been a lack of collation of the multiple facets of each study, where each facet is undertaken by different researchers. That

makes it difficult to obtain the big-picture perspective. One means of gaining ground on the first issue is to write in a contractual obligation to publish. Increasingly, academic institutions require that graduate students submit theses in a publishable format. With regard to the second matter, it would be useful for monitoring teams to produce an annual summary of progress, as an exercise in self-evaluation. A formal technology transfer process can greatly assist in the review and determination of research and monitoring learnings[214].

Integrated planning by monitoring teams

Monitoring teams will likely be composed of a diverse group of specialists, who speak different technical languages and operate under different sets of premises and assumptions. It is easy to see how the activities of one group may impact unintentionally on those of another. Planning for initial monitoring study design and any maintenance along the way needs to be integrated across professional boundaries. Regular communication in the form of trouble-shooting workshops or monitoring and planning synopses is essential.

Peat Pond, a reclaimed open water wetland on Syncrude's Mildred Lake lease (Credit: Clara Qualizza 2006)

[214] such a process is planned for this 2007 fiscal year by CONRAD to collate the research findings to date for the CT Wetland (Suncor lease 86)

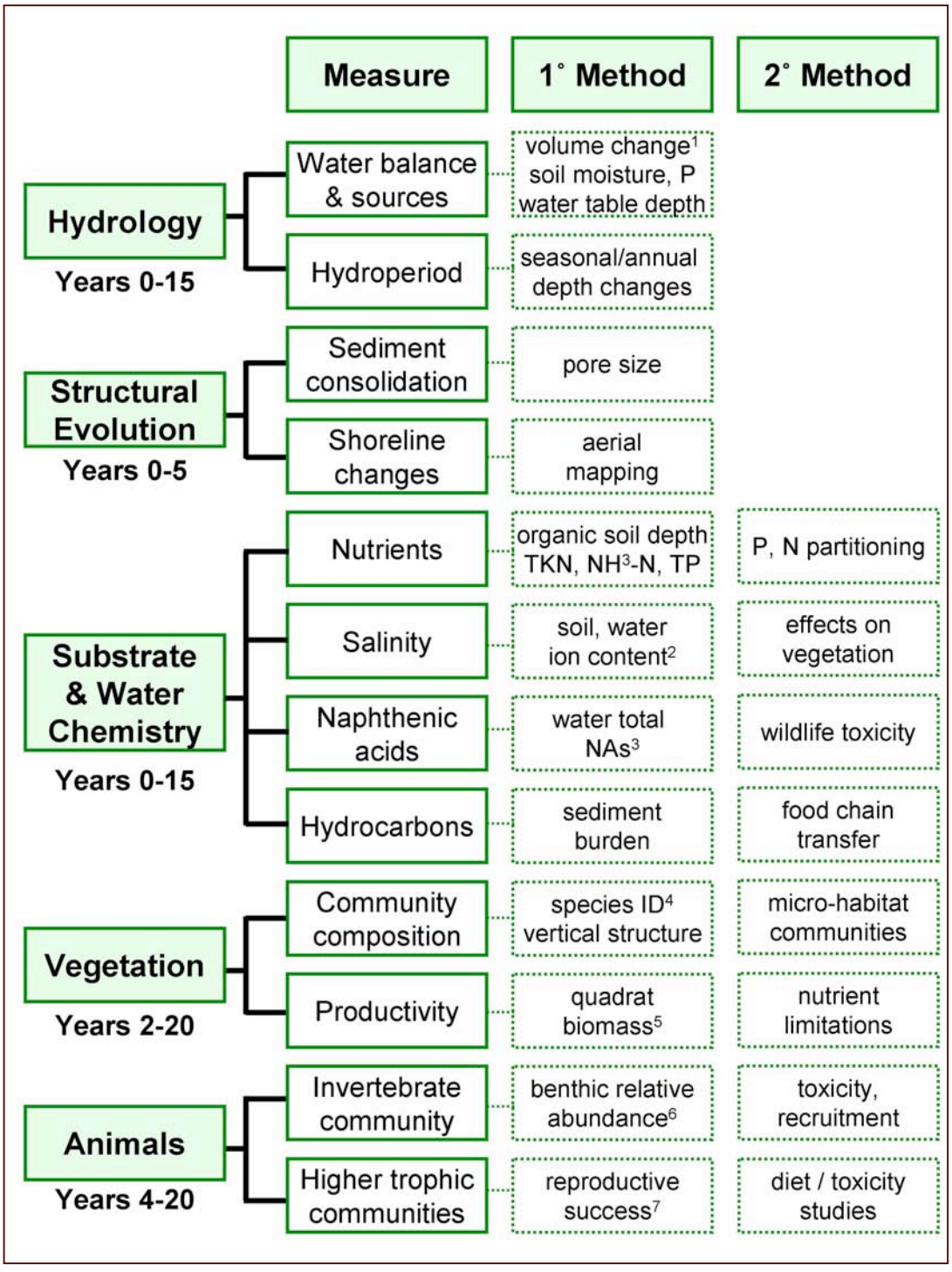

Figure 4.4 Some key physical, chemical and biological monitoring methods for reclaimed wetlands. Superscript numbers refer to methodology guidance references[215].

[215] 1 – Ferone and Devito 2004; 2 – Purdy et al. 2005; 3 – Yen et al. 2004; 4 – Whitehouse and Bayley 2005; 5 – Whitehouse and Bayley 2005; 6 – Gould 2000, Leonhardt 2003; 7 – Gentes et al. 2006

4.3.2 Adaptive management: maintenance and modification

There will always be a need to undertake adaptive management as reclaimed landscapes progress toward closure. It is difficult to anticipate all of the issues that might arise in complex natural systems, but Table 4.6 lists some that have already arisen or that are predicted to arise as environmental conditions change in the region.

Table 4.6 Potential problems encountered with constructed wetlands and applicable adaptive management techniques.

Problem	Adaptive Management
Unsustainable water loss / drying up	▪ Reduce AET (windbreaks, shading, shift in vegetation dominance from vascular plants to mosses) ▪ Reduce recharge (incorporate fine-grained substrate) ▪ Reduce outflow (berms, dams, weirs) ▪ Increase upland runoff (convert from forests to grasslands) ▪ Allow to dry out some seasons ▪ Connect to groundwater discharge by excavating site
Inadequate flood control	▪ Increase wetland size or redesign basin shape ▪ Add fringes of other wetland classes (swamps, marshes) ▪ Add other wetlands downstream or upstream in complex ▪ If a consequence of beaver engineering, then re-assess uses of affected upland fringe and either do nothing, remove riparian tree fringe (aspen, willow) or allow trapping
High rate of infilling with sediments	▪ Dredge and reclaim ▪ Stabilize upland soils with fast-growing vegetation ▪ Add sediment trap upland / upstream from wetland ▪ Let it go terrestrial and reconsider uses
Subsidence/compression of wetland bottom	▪ Add to the sediment cap (infill back to original depth) ▪ Allow to stabilize and adapt target functions of wetland / lake
Shoreline erosion	▪ Accelerate vegetation establishment by planting live facines, cuttings ▪ Shelter from prevailing winds (breakwaters, upland vegetation belts) ▪ Install rip-rap or coarse aggregate
Elevated salinity	▪ Increase flushing / dilution ▪ Control / reduce surface input sources ▪ Increase / change cap on bottom substrates ▪ Establish saline-tolerant communities
Toxicity	▪ Increase microbial community ▪ Increase HRT (size, depth) ▪ Change organic content, nutrients (fertilizers, peat)
Lack of vegetation	▪ Plant propagules, rhizomes, seed plugs / bank

Problem	Adaptive Management
	▪ Change hydroperiod ▪ Change water quality or adapt vegetation plantings to suit ▪ Fertilize ▪ If a consequence of herbivory (muskrat grazing), then assess sustainability and either allow wet-dry marsh cycle to proceed unimpeded or allow trapping
Low plant diversity	▪ Weed out invasive species ▪ Change water quality or adapt vegetation plantings to suit ▪ Plant species which have low rates of natural dispersal
Low benthic invertebrate diversity	▪ Increase broad-leaved macrophyte cover (secondary substrate, other than milfoils) ▪ Inoculate or stock with poor dispersing species ▪ Eliminate / reduce predatory fish populations
Low habitat use	▪ Eliminate barriers to colonization ▪ Transplant vegetation and invertebrates ▪ Increase connectivity with other wetlands ▪ Increase habitat complexity (islands, depths, vegetation) ▪ Introduce artificial nesting / spawning habitat

A shoreline marsh – open water wetland complex along the edge of a small lake south of Albian Sands lease (Credit: Albian Sands 2006)

4.3.3 Monitoring wetlands on oil sands leases: lessons learned so far

Small marshes and ponds have been constructed on reclaimed landscapes, and others have appeared during slope failures or due to dyke **seepage**. They often begin as open water wetlands; however, as wetland vegetation establishes, and provided substrate **consolidation** is not significant (thereby increasing depth), several wetlands have become more marsh-like in form within five years. A general finding of these field-scale trials is that robust wetland plant species will establish opportunistically in marsh and shallow water systems constructed with overburden, peat, soft tailings and process-affected water. These compositional elements may be varied in placement and proportion to suit the target uses and functions of each wetland. Table 4.7 describes some existing examples of marshes on reclaimed landscapes, and provides some possible strategies to optimize their functional efficacy through diversification of flora and fauna. In cases where unpublished monitoring reports are cited in this table, the reader should be aware that the lessons learned are classed as tentative, because the data has not yet been subject to rigorous analysis, interpretation and/or peer-review. CONRAD is currently undertaking a technical transfer process, the intent of which is to provide such an assessment.

Suncor CT Wetland marsh at year five on 4 m of uncapped consolidated tailings (Credit: Wayne Tedder 2005)

Table 4.7 Tentative lessons learned from some demonstration-scale constructed and opportunistic wetlands present on Suncor's lease 86 and Syncrude's Mildred Lake lease[216]. Other adaptive management strategies are listed in Table 4.6.

Design element	Lesson learned	Demonstration system	Possible adaptive management strategies
Hydrology	▪ perched systems may not be sustainable where upland succession reduces interflow to site[217]	Bill's Pond (*c* 1997)	▪ reduce AET by sheltering & shading site ▪ reduce recharge by increasing proportion of fine-grain substrate ▪ establish peat to increase wetland water storage capacity
	▪ watershed: wetlands ratio may not reflect altered/new function	Peat Pond (*c* 2000) (flood control function)	▪ add other wetlands to watershed (Golden Pond)
	▪ shallow water systems with large open areas exhibit significant water losses to evaporation	Demonstration Pond (*c* 1993) CT Wetland (*c* 1999) (AET>P by ~20%)	▪ contour shoreline to provide shorter fetches & more shading by shrubs with vertical element
	▪ drawdown to lower water depths in early spring can inhibit cattail growth by frost damage to roots[218]	CT Wetland	▪ optimal water depth for cattail is 6-10 cm ▪ establish frost-tolerant plant species in drawdown zone
Water chemistry	▪ NaCl or $CaSO_4$ salt crusts form along the edges of wetlands in summer due to water losses from evapo-transpiration	Peat Pond CT Wetland–capped section	▪ reduce AET by sheltering & shading site ▪ plant salt tolerant vegetation in affected zone of shoreline ▪ plan for higher banks in areas with salt-sensitive riparian species
	▪ ammonia levels in tailings water drop to nominal levels within a few days in open water wetlands	CT Wetland – capped section	▪ submit tailings water to open water pond for ammonia removal before input to marsh or other wetlands
	▪ the most labile naphthenic acids require several months to be biodegraded[219]	CT Wetland Demonstration Pond Experimental pits (*c* 1989-1993)	▪ increase HRT to several months in water treatment wetlands

[216] these are preliminary interpretations, based on the early assessments of collected data; there is a need to further verify these interpretations through a more rigorous peer-review process

[217] Appendix C1 (Devito & Mendoza); vegetation controls canopy evaporation & transpiration rates, as well as shallow organic soil depth & storage capacity

[218] Golder Associates 2005a

[219] Scott et al. 2005; after 16 years, 20 – 30% of NAs remain (M. Mackinnon, pers. comm.)

Design element	Lesson learned	Demonstration system	Possible adaptive management strategies
Water chemistry (cont.)	▪ some forms of NAs apparently do not degrade[219]	As above	▪ these forms appear to have negligible toxicity; examine long-term effects on biota
	▪ aging of water-capped fine tailings reduces toxicity; older systems have plankton and benthic communities more similar to natural analogues[220]	CT Wetland Demonstration Pond Experimental pits	▪ allow time (15-20 y) for habitat wetlands to establish
	▪ P, Mb, Zn and Ni appear to adsorb to sediments[221]	CT Wetland	▪ Limit resuspension with basin morphology
	▪ Soluble salts ($CaSO_4$, NaCl) do not decrease in wetlands with HRT<30 d	CT Wetland	▪ flush salts occasionally ▪ establish saline marsh
	▪ Total suspended solids (TSS) above 40 mg_L^{-1} may kill established submergent & emergent vegetation[221]	CT Wetland	▪ Pre-filter process-affected water containing TSS>300 mg_L^{-1} or dilute with other water sources
Substrates	▪ peat in zone affected by ET may exacerbate salt crust problems by wicking water further up shore prior to ET[222]	Peat Pond	▪ amend substrate in affected zone with mineral topsoils or other forms of hydric soil
	▪ high proportions of fine grains in substrate of wetland with long fetches may lead to turbidity-associated faunal mortality[223]	Demonstration Pond	▪ mix fine-grained organic soils with coarse-grained mineral soils high in nutrient value
	▪ uncapped overburden, soft tailings or dyke seepage can result in higher salinity in wetland water	Golden Pond (*c* 2000) CT Wetland – uncapped portion Settling Basin Seepage Pond (*c* 1995)	▪ cap sediments with relatively deep layer of organic : mineral mix substrate

[220] McCormick 2000; Leung et al. 2001; Leonhardt 2003

[221] Golder Associates 2005a; P-phosphorus, Mb-molybdenum, Zn-zinc, Ni-nickel; high TSS levels & increased water depth may have cumulatively led to the disappearance of several plant species from the 1 m CT area in 2003, in particular *Potamogeton filiformis* (pondweed) which only survived where a thick sedge barrier filtered out the TSS

[222] ET = evapotranspiration; Marie Keys, pers. comm.

[223] Harris 2000; episodes of murkiness in summer 1997 were attributed to re-suspension of pink clay, and linked to declines in zooplankton numbers

Design element	Lesson learned	Demonstration system	Possible adaptive management strategies
Substrates (cont.)	▪ substrates composed of uncapped soft tailings result in longer vegetation establishment times than soft tailings capped with peat[224]	CT Wetland	▪ cap soft tailings with mineral : organic topsoil to depth of root penetration
	▪ mineral topsoils contain no wetland seed banks & their use as substrate tends to result in a low diversity of robust wetland plant seeds & aquatic invertebrates[225]	Demonstration Pond Experimental pits Natural – Hummocky Wetland (*c* 1984)	▪ amend mineral topsoils with hydric soils ▪ plant / inoculate with poor dispersers
	▪ fine tailings capped with water consolidate over time making the wetland deeper	Demonstration Pond Experimental pits	▪ create conditions that promote inputs of sediment or organic detritus ▪ plan for changes in use / functions over time
	▪ wetlands with high organic content in sediment (peat) may emit less CO_2 and CH_4 than those with low organic content[226]	Several oil sands process-affected wetlands and reference analogues of varying ages	▪ use peat / organic substrates to limit formation of the photosynthetic biofilm that drives methanogenesis in these systems
	▪ benthic midge larvae have detectable body burdens of PAHs but do not bioaccumulate them, so export in emergent insects is not an effective means of removal of PAHs from wetlands[227]	Several oil sands process-affected wetlands and reference analogues	▪ investigate treatment by microbial degradation and photodegradation where PAHs are prevalent in sediment
	▪ coke used as a substrate without prior pre-rinsing / leaching may be acutely toxic to midge larvae[228]	Laboratory bioassay	▪ monitor the fate of metals released from coke to the water

[224] Golder Associates 2005a
[225] Bendell-Young et al. 2000; Gould 2000; Crowe et al. 2002; robust plant species include common cattail (*T. latifolia*), water sedge (*C. aquatilis*) & soft-stem bulrush (*S. validus*), while robust invertebrates include midge larvae (Chironomidae)
[226] Daly and Ciborowski 2004; results are preliminary & there are complex interactions between wetland age and presence of oil sands process-affected materials
[227] Ganshorn 2002
[228] Squires 2005

Design element	Lesson learned	Demonstration system	Possible adaptive management strategies
Substrates (cont.)	▪ initial colonization of fresh coke by *Chara* and zoobenthos is slower than on reference substrate[229]	Deep Wetland South Ditch CT Wetland Experimental pits	▪ allow weathering / leaching to occur before using as a wetland substrate
Vegetation	▪ natural dispersal / unaided establishment may lead to monocultures or low species diversity[225]	CT Wetland Demonstration Pond Experimental pits	▪ plant propagules, seedlings or use seed banks when low diversity does not suit intended functions of site
	▪ emergent marsh communities can be created on peat-mineral capped CT using transplants to supplement natural colonization	CT Wetland	▪ supplement natural colonization with zone planting where water quality may be sub-optimal
	▪ unaided establishment of salt tolerant plant communities may not occur at suitable sites because of isolation from seed sources[230]	Bill's Pond	▪ establish saline-tolerant communities by planting propagules or seedlings
	▪ temporally extended flooding of planted soil plugs limits species diversity of emerging seedlings, including several saline-tolerant local species[231]	CT Wetland	▪ manipulate water drawdown during the season of planting or until the target species produce seeds ▪ vary placement of plugs along the wet-dry gradient
	▪ transplants from saline wetlands tend to establish in process-affected wetlands faster than those from other sources[231]	CT Wetland	▪ plant seedlings or seed plugs sourced from genetically tolerant local stock where salinity is an issue
	▪ common bulrush is so successful at colonizing process-affected wetlands, it may exclude other species[231]	CT Wetland	▪ provide appropriate water depths for other species
	▪ natural colonization is enhanced in areas adjacent to planted plots[231]	CT Wetland	▪ design planting spacing to maximize opportunities for adjacent areas

[229] Baker and Ciborowski 2006; Chara is a stonewort (calcified algae)
[230] Purdy et al. 2005; see table 2 in paper for common vascular plants in natural saline wetlands in north-eastern Alberta
[231] Cooper 2004; Golder Associates 2005b; species that produce few seeds are least able to migrate with fluctuating water depths (Nuttal's alkali grass - *P. nuttalliana*, common river grass - *S. festucacea*)

Design element	Lesson learned	Demonstration system	Possible adaptive management strategies
Vegetation (cont.)	▪ vegetation established from soil plugs may be diverse, but slow to expand out into process-affected substrates[231]	CT Wetland	▪ use a small spacing between soil plugs or apply other seeding methods in concert with plugs
	▪ phytoplankton may be used to indicate community impacts of NAs, SO_4 or conductivity[232]	Several oil sands process-affected wetlands and natural analogues	▪ NA indicator species = *Glenodinium* & *Gymnodinium* spp., *Peridinium cinctum* ▪ SO_4 indicator species = *Rhodomonas minuata*, *Scenedesmus quadriculata* ▪ Conductivity indicators = *Botryococcus braunii*, *Chrysococcus rufescens*, *Cryptomonas* spp.
Habitat	▪ systems impacted by saline/sodic overburden may produce deformities in exposed fish[233]	South Bison Pond (now Bison Lake, *c* 1988) Experimental pits	▪ ensure adequate flushing in wetlands containing fish
	▪ systems impacted by soft tailings may be acutely toxic to fish[234]	Natural – Hummocky Wetland	▪ cap systems with organic:mineral soil mix ▪ delay introduction of fish ▪ investigate optimal dilution to accommodate CT flux releases
	▪ diversity of epibenthic and epiphytic invertebrate communities is reduced where there is exposure to oil sands process-affected material[235]	Several oil sands process-affected wetlands and reference analogues	▪ inoculate vegetated habitat wetlands with benthic invertebrates as a forage base for waterfowl & fish
	▪ systems impacted by soft tailings may not provide the same energy flow to higher trophic levels, thereby affecting growth and productivity[236]	CT Wetland Natural – Hummocky Wetland Demonstration Pond	▪ inoculate vegetated habitat wetlands with invertebrates to increase diversity and abundance

[232] Leung et al. 2001, 2003; Hayes 2005

[233] van den Heuvel et al. 2000; Nero et al. 2006a; young perch & goldfish showed fin and gill lesions as well as skeletal deformities

[234] Bendell-Young et al. 2000; further laboratory investigations by Nero et al. (2006b) found that NAs extracted from oil sands process-affected water and salts altered gill structure of young perch, reducing their capacity for respiratory exchange of gases and potentially inducing acute hypoxia

[235] Wytrykush et al. 2004; waterfowl in the boreal consume an abundance of large predaceous macroinvertebrates (Hornung and Foote 2006)

[236] Gurney et al. 2005; Gentes et al. 2006; under low stress conditions, mallard duckling and tree swallow nestling growth was reduced, while under high stress conditions (harsh weather events) tree swallow nestling mortality rates were elevated relative to local reference rates

5.0 Restoration of Altered Wetlands

Altered wetlands are wetlands situated on- or off-lease that are not removed during active mining, but which are potentially affected by the mining process. Effects will most often relate to hydrological or geochemical changes in and around the site. The initial Environmental Impact Assessment (EIA) conducted as part of the mine application process examines the potential for alteration of such wetlands and proposes a plan for mitigation. This section does not discuss that EIA process, as it is beyond the scope of the guideline; however, it does provide guidance on how to evaluate alterations and restore the wetland once mining has ceased. Figure 5.1 shows a decision sequence that summarizes the planning steps necessary to progress to restoration. Many of the methods for monitoring are the same as those described in section 4 for reclamation on closure landscapes. The key differences in this restoration process relate to the sequencing of the steps and the magnitude of the changes required to restore wetland function. Monitoring in particular must figure more prominently throughout the process, rather than occurring predominantly after construction is complete.

5.1 Characterization of Altered Wetlands by Monitoring Trends

Unlike constructed wetlands on closure landscapes, altered wetlands remain on the landscape throughout the mining process. It is appropriate to characterize their pre-disturbance structure and function, so restoration can best approximate what existed initially. That characterization should include many of the key landscape-scale and wetland-scale elements identified in section 4:

- hydrology
- geology of upland soils
- topographic setting
- geochemistry of substrates and water
- structural properties of substrates
- vegetation
- aquatic animals

It is also important to identify what class and form of wetland exists pre-disturbance. Based on relative abundance in the oil sands region, most altered wetlands will be peat-forming fens (poor and moderate-rich) or bogs, marshes or a wetland complex encompassing transitions to several distinct classes.

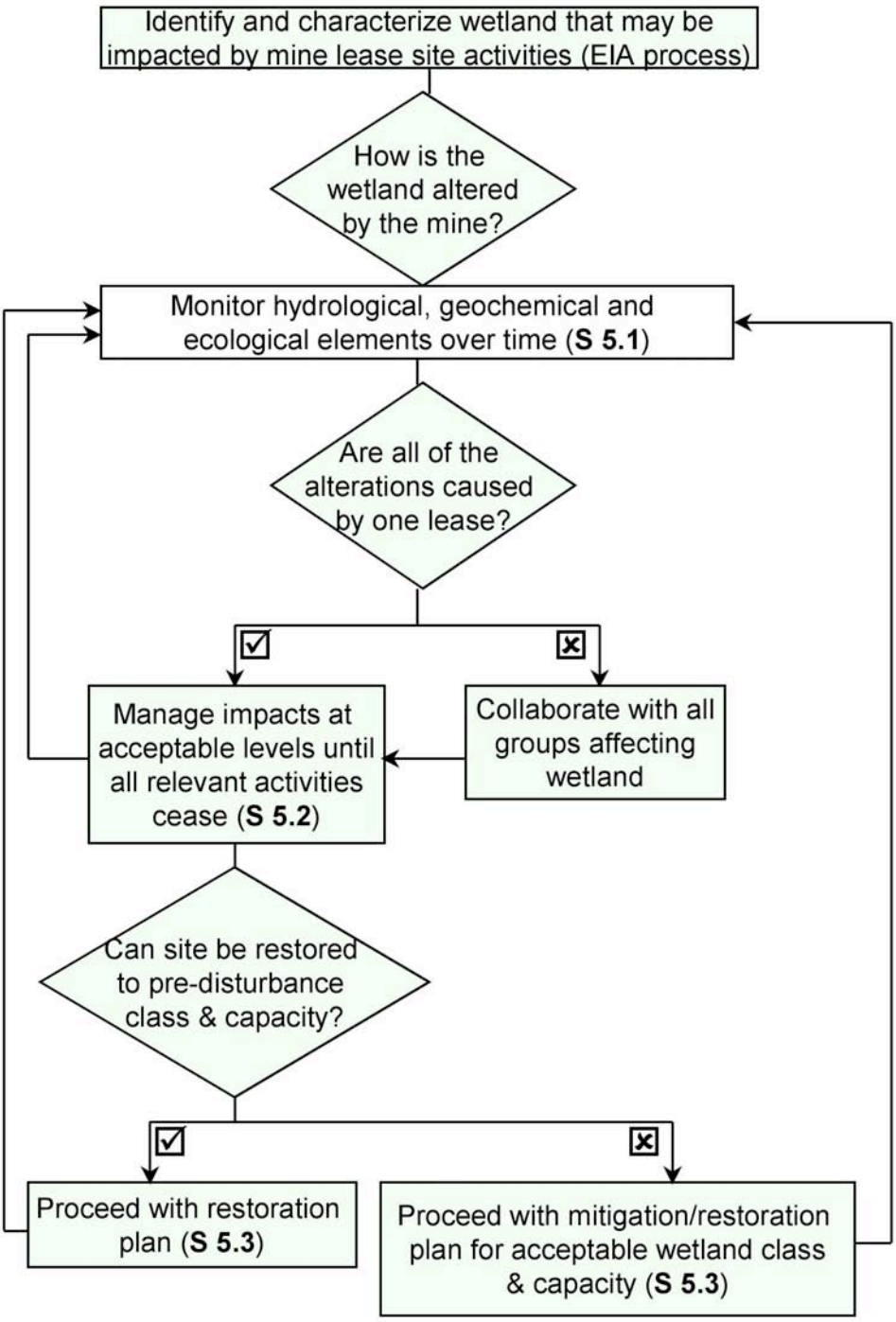

Figure 5.1 Decision sequence for the planning of restoration for wetlands altered by mining activities in the oil sands region. Bracketed numbers refer to the relevant sections in this guideline that describe the subject in that box.

Hydrology

Due to the nature of oil sands mining and its effects on regional groundwater flow, many altered wetlands will show changes to their hydrological cycle. These may be related to drainage, diversion, drawdown of the water table, dewatering, seepage or surface runoff patterns within the catchment. Where impacts are experienced at a larger (catchment) scale, it may be appropriate to monitor other reference wetlands in the catchment (in addition to the altered wetland itself), to establish whether pre-disturbance conditions are attainable.

Key monitoring variables at the landscape-scale should include depth to the water table, the surface runoff coefficient, and rates of precipitation and AET. Key monitoring variables at the wetland-scale should include wetland water balance and hydroperiod[237].

Geology of upland soils

Upland soils may be affected by changes in hydrological patterns, such that leaching of salts or other minerals is modified. The key monitoring variables would relate to **hydraulic conductivity**, permeability and/or porosity.

Topographic setting

Mining in the oil sands region tends to produce steeper gradients and higher relief than the surrounding natural landscapes. The reclaimed landforms within a catchment may also alter hydrological patterns. The key monitoring variables to assess the effects of such changes would be the surface runoff coefficient and rate of erosion.

Geochemistry of substrates and water

Changes to geology, topography and hydrology as related above will inevitably lead to altered geochemistry within the wetland. It is most likely that the predominant changes will be to salinity concentrations, nutrient inputs and sedimentation rates.

Key monitoring variables should include pH, salinity (EC), alkalinity, ionic content (Na^+, Cl^-, K^+, Ca^+, Mg^{2+}, SO_4^{2-}), phosphorus (total and soluble reactive), nitrogen (total, nitrates, nitrites and ammonia), organic carbon, suspended solids and turbidity[238].

Structural properties of substrates

Peat-forming wetlands that lose significant amounts of water compress, which leads to changes in nutrient exchange and hydraulic conductivity[239]. Key monitoring variables should include compressibility, bulk density, state of decomposition (von Post number) and depth of anaerobic layer (catotelm)[239].

The microtopography of undisturbed marshes, swamps and open water wetlands often encompasses a mosaic of substrate patches, differing in

[237] Ferone and Devito 2004; Appendix C1 (Devito & Mendoza)
[238] Bayley and Mewhort 2004
[239] Price et al. 2005a

morphology, hydrology and chemistry[240]. Although it is unlikely that altered wetlands will experience direct microtopographic changes, it may still be prudent to map the system of hummocks, flats and hollows periodically and verify that they remain intact. Such variability is important for microbial activity and nutrient fluxes[240].

Vegetation

Extreme alterations of the hydroperiod or geochemistry of a wetland will create shifts in composition and **abundance** of the emergent and submergent vegetation communities. Riparian vegetation may also be affected if alterations continue up into their rooting zone. Key monitoring variables should include species composition transects, total percent vegetative cover, and productivity and decomposition rates[241].

Aquatic animals

Although many terrestrial animals may use altered wetlands before and during mine disturbance, monitoring them will likely give no clear indication of how alterations to those wetlands have affected them. Their use of other habitats in addition to wetlands makes it difficult to establish cause and effect with trend monitoring. Systems that have a prevalence of aquatic animals (benthic invertebrates, plankton, fish, muskrats) such as marshes and open water wetlands are better suited to monitoring of animal assemblages. Aquatic animal communities may be impacted by changes to hydrology, geochemistry and vegetation. Key monitoring variables should include species composition of benthic and planktonic communities, and abundance of indicator species of fish or muskrat.

Trend monitoring requires strict adherence to a consistent monitoring routine. Section 4.3.1 describes means of designing a statistically robust monitoring program and these apply equally to monitoring of altered wetlands. Trends may take years to identify and it is critical that as much pre-disturbance data as possible is gathered. Data should encompass both annual and seasonal ranges in normality.

5.2 Managing Impacts During the Period of Disturbance

The decision to manage documented impacts while mining continues and prior to undertaking full restoration will be one based on cost-effectiveness, functional value of the altered wetland, and severity of disturbance. Management may take place on highly disturbed sites, where there is a risk of permanent functional losses or where the cost of delaying restorative measures would be significantly greater than the cost of immediate management.

The severity of impacts in altered wetlands will range greatly, but the general nature of the impact will likely follow a few common patterns. It is unlikely that the surface of the wetland itself will often be directly affected, as in peat harvesting or other invasive earthworks. It is more likely that the impact will result from hydrological alterations, erosional forces, or chemical influxes.

[240] Bruland and Richardson 2005
[241] Vitt et al. 2003a; Bayley and Mewhort 2004; Whitehouse and Bayley 2005

In peat-forming fens, prolonged water table declines in the range of two standard deviations (20 cm for poor fens and 14 cm for moderate-rich fens) will be moderate and incur functional changes within the wetland[242]; water table declines of 70 cm will produce severe impacts in fens[243]. Dewatering of peat-forming wetlands can release metals, carbon dioxide and methane. Where monitoring suggests that the water table is dropping by more than 20 cm in a fen for extended periods of time, mid-disturbance management is warranted. That may involve temporarily increasing the input (diverting in) or reducing the output (blocking drains) of surface waters.

Similarly, where marshes or open water wetlands experience extreme changes in hydroperiod, temporary trouble-shooting measures may be worthwhile. For instance, systems used heavily by waterfowl and normally showing routine periods of natural drawdown may experience significant impacts where changes to the hydrological cycle result in a consistently flooded state[244]. Water losses that result in several years with no surface standing water will also affect the anaerobic state of wetland substrates and limit germination and root health of wetland plant species. Temporary control mechanisms for water level (weirs, dams, stop-gates) may be cost-effective solutions in the short term, although they are subject to regulation and require consent.

Severe sediment deposition, greater than 0.3 cm_yr^{-1} will limit wetland plant germination rates and accelerate infilling of the site. Upland erosion may be managed by seeding with grasses and shrubs and by reducing wind erosion with windbreaks.

Increased salinity of wetland water and substrates beyond the tolerance thresholds for the established native species will alter the plant community composition and likely favour the expansion of a few tolerant, 'weedy' species[245]. The cost of weed control at a later date, when full restoration is undertaken, may be substantial and the results not optimal; thus, if water availability is not limited, it would likely be less work to flush the system with more water periodically (diluting the salts), thereby preventing the shifts in plant community structure.

Other management techniques may be adapted from the guidance provided for full restoration in the next section.

5.3 Creating a Restoration Plan

Table 5.1 provides some limited guidance on restoring altered wetlands in the oil sands region. It is important to remember when planning restoration to pre-disturbance conditions that these techniques remain largely untested in this part of the northern boreal ecosystem. Many of the procedures used to restore peat-forming wetlands have proven

[242] Gignac et al. 1991
[243] Zoltai et al. 1999
[244] Butterworth 2003
[245] see Appendix D (Cooper et al.) for further information on species salinity thresholds

successful in eastern North America and western mountainous regions. There will be a period of trial and error in this region, and further research is certainly required, particularly with regard to fens and marshes.

Table 5.1 Design guidance for restoring wetlands altered by oil sands mining activities to pre-disturbance conditions. Further details on some of the guidance recommendations may be found in the reclamation section (4.0), particularly tables 4.3 to 4.6[a]

Potential alteration	Affected wetland class	Restoration guidance
Drop in water table & change in zone of groundwater discharge	F, M, Sw, Sh	▪ re-establishment of original level of water table (landscape-scale change) ▪ excavation to new level of water table, grading, substrate placement, vegetation[246]
Loss of surface runoff & drying of perched system	B, F, M, Sw, Sh	▪ input of alternative water sources to re-establish original water balance (not suitable for bogs) ▪ recontouring of bog surface to retain precipitation, combined with straw mulching[247]
Change in hydroperiod & loss of ecological function	M, Sh	▪ modification of water inputs to approximate original water levels, microclimatic control of AET rates (wind passage, wave energy, surface water temperature, shading), restriction or widening of outlets as appropriate
Infilling of wetland due to increased rates of soil erosion	M, Sh	▪ dredge sediments, stabilize upland soils by revegetation
Smothering of wetland vegetation by sediments	F, Sw, M	▪ stabilize upland soils, increase water level temporarily to flush some sediment out of vegetation then drawdown again and replant
Loss of nutrient inputs to wetland soils and water (associated with groundwater changes)	F, M, Sw, Sh	▪ fertilize with P to encourage growth of vascular plants, which may in turn act as nurse plants for mosses[248] ▪ increase groundwater flow by excavation or diversion
Increase in salinity of wetland soils and water (associated with groundwater changes)	F, M, Sw, Sh	▪ flush by reducing HRT ▪ dilute by increasing hydraulic loading rates ▪ plant salt tolerant vegetation in most affected zone
Drying out of peat and death of the living moss layer	B, F	▪ re-wet by retaining water (straw mulch, excavating shallow basins, restricting outlets)

[246] Cooper and MacDonald 2000
[247] Rochefort et al. 2003; Campeau et al. 2004
[248] Rochefort et al. 2003

Potential alteration	Affected wetland class	Restoration guidance
		▪ plant nurse crops (*Polytrichum* sp)[249]
Loss of original vascular plant diversity & establishment of weed-infested community	M, Sh	▪ control weeds (manual, chemical) ▪ replant sedges, mosses[250]
Loss of connections to other aquatic systems & establishment of barriers to fish	M, Sh	▪ reconnect wetland to other aquatic systems, eliminate barriers
Invasion of fish & loss of benthic invertebrate abundance /diversity	M, Sh	▪ eliminate fish ▪ inoculate with benthic invertebrates, replant key species of macrophytes
Loss of benthic invertebrate diversity (associated with inputs of terrestrial sediments)	M, Sh	▪ dredge or increase hydric substrates ▪ inoculate with poor dispersers

[a] Class abbreviations are as follows: B-bog, F-fen, M-marsh, Sw-swamp, Sh-shallow open water wetland

Shoreline wetland on Albian Sands lease (Credit: Carol Jones 2003)

[249] Groeneveld and Rochefort 2005
[250] Budelsky and Galatowitsch 2000

6.0 Reclamation Certification

The Environmental Protection and Enhancement Act requires that oil sands mine operators conserve and reclaim disturbed land to an equivalent land capability and then obtain a reclamation certificate upon closure. Activities involving the creation of wetlands are also subject to review and approval under the Water Act. Thus, wetland reclamation certification will consider legislated responsibilities and capacity requirements under both Acts (refer section 3.4).

Equivalent land capability means that the ability of the land to support various land uses after reclamation is similar to the ability that existed prior to mining, although individual land uses will not be identical.

The general information requirements for a reclamation certificate application are outlined in the EPEA Conservation and Reclamation Regulation, section 14. They include documentation of conservation and reclamation procedures; with respect to reclaimed wetlands, that will likely entail a physical, chemical and biological characterization of each wetland with an analysis of trends over time. There is also a requirement to describe substances present as a result of mining, and the methods used to remediate any adverse effects they have caused. In the case of reclaimed wetlands, that requisite would apply to salts, sodium, heavy metals, and organic compounds, like naphthenic acids and hydrocarbons.

Criteria that may be used to evaluate reclamation success are not yet defined for wetlands. It is probable that wetlands will be evaluated using a tiered approach, firstly determining the structural and functional integrity and values of each individual wetland, then considering them within the context of larger landscapes, perhaps as wetlands complexes, landform complexes or as whole watersheds.

Criteria are conditions that must be met in order to provide an acceptable result – in this case, a reclaimed wetland.

In the absence of regulatory criteria, this guideline poses three questions that could form the basis for a detailed development of reclamation evaluations. In point form after each question is a check-list of the elements required to achieve a positive response to the question posed.

1. Is the wetland viable / sustainable in the long-term as a wetland ecosystem?
    - Positive water balance (long term water inputs ≥ outputs)
    - Saturated soils
    - Established wetland vegetation
    - Established wetland processes (recharge / discharge, nutrient / mineral sequestration, production / decomposition)

2. Does the wetland have structural and functional integrity?
    - Structural stability with negligible erosion / sedimentation rates
    - Contiguous with surrounding boreal landscape
    - Acceptable water quality (based on generic or specific criteria)[251]
    - Bottom sediments capable of supporting wetland life

[251] Alberta Environment 1999b; Canadian Council of Ministers of the Environment 1999

- Diverse and productive wetland vegetation similar to that found in natural analogues from the region
- Diverse wetland faunal assemblages similar to those found in natural analogues from the region

3. Does the wetland have the capacity to support the intended functions and uses?
    - Functional capacity in watershed management (storage, flood control, groundwater recharge, storm runoff generation)
    - Habitat use by priority species or other species, capability to support required number of individuals
    - Use for indigenous cultural practices
    - Recreation potential
    - Phase-out design and projections for water treatment

Clearly, these check-lists reflect the design and monitoring recommendations set out in section 4 of this guideline. A high standard of monitoring and pre-closure management are currently the best means of preparation for eventual certification (refer section 4.3).

7.0 Addressing Uncertainty with Targeted Research

7.1 Hitting a Moving Target: Challenges for Reclamation

Wetlands reclamation in the oil sands region continues to move forward, albeit in an atmosphere of uncertainty. There are significant local-scale and regional-scale variables that exert unmeasured influences on reclamation efforts. This section identifies some factors that may profoundly alter reclamation conditions and suggests some limited means of incorporating that uncertainty into wetlands reclamation design.

Regional-scale variability affects wetlands reclamation in ways that mine closure teams have little or no control over. Nonetheless, it is important to identify their possible impacts, monitor their influence where possible, and develop strategies for minimizing the risks to wetlands reclamation. The dominant regional-scale uncertainties are:

- Climate change
- **Cumulative** groundwater flow changes within the surface mining zone

Climate change is a global uncertainty, where the predicted impacts vary across continents and latitudes. In the oil sands region, the changes that convey the greatest risks for wetlands reclamation are increased temperatures, reduced precipitation, an increased rate of evapotranspiration, and more extreme modulation in seasonal weather patterns. By 2040, the average air temperature in the region is predicted to increase by 2-3˚C relative to long-term trends (1975-1995)[252]. Currently, the ratio of precipitation to potential evapotranspiration (P÷PET) in the region is ~0.880[253]; by 2040, that ratio is predicted to drop within the range 0.650 – 0.775[254]. For a region where wetlands already persist in a water deficit, that represents a significant loss of water to the landscape.

Water treatment wetlands may undergo changes in efficacy if climate change manifests as changes to winter ice caps or summer rates of evaporation[255]. When ice forms on wetlands, salts are expelled from the freezing water into the remaining water (salt rejection). The thickness of ice caps, date of formation and duration of the ice period influences the peak concentrations of salts, which in turn affects exposure for over-wintering animals (frogs, fish, benthic invertebrates). Shallow wetlands with relatively large surface areas will be most susceptible to increased evaporation rates with warmer summer temperatures. Higher rates will concentrate salts and naphthenic acids in the remaining water. Further, there is some indication that young aquatic systems may respond differently than mature systems[256].

It is unclear whether natural fens and bogs will persist in the oil sands region, and if so whether they will continue to accrue peat (production > decomposition) and how the composition of moss communities will change[257]. Current studies of recent organic matter accumulation in regional wetlands will help address this uncertainty[258].

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[252] Canadian Model, cited in Bayley 2003
[253] Appendix C1 (Devito & Mendoza)
[254] Prairie Adaptation Research Collaborative, cited in Bayley 2003
[255] Golder Associates 2006a
[256] Baulch et al. 2005
[257] Gignac and Vitt 1994; Gignac et al. 1998; Winter 2000; Conly and van der Kamp 2001
[258] see section 7.2, project title ‘Effects of salinity on vegetation and organic matter accumulation in natural and oil sands wetlands’

Mine closure teams are clearly challenged in employing effective response mechanisms, when the source of uncertainty is manifest at such a level; however, it is possible to reflect that uncertainty in some aspects of wetland design:

- Monitor natural analogues for annual changes associated with regional warming and drying trends, and thereby account for the contribution of those effects in reclaimed systems
- Be conservative when estimating water budgets (notably inputs) for wetlands during the design and construction phases
- Look for mechanisms to reduce evapotranspiration losses and contribute to groundwater recharge.

A related, but more regionally impacted variable is that of potential changes to groundwater flow. Climate-induced reductions to groundwater recharge may be exacerbated in the surface mineable oil sands zone by mining-induced alterations in groundwater flow patterns. Particularly where wetlands reclamation efforts are bounded by new mining development, it will be difficult to trace the cumulative impacts and predict the magnitude and direction of groundwater flow on the reclaimed landscape. The best approach to addressing this source of uncertainty is a coordinated and intensive groundwater monitoring program; regional models of groundwater are currently being developed, but their predictive power as always is limited by the quantity of empirical data they incorporate.

Local-scale sources of uncertainty predominantly relate to:

- The variable chemical properties of reclamation materials
- The introduction of new materials created by evolving tailings consolidation techniques
- The poor understanding of nutrient and chemical fluxes in groundwater from reclaimed landscapes, and the potential loadings and concentrations of chemicals in wetlands
- The nature of long-term soil consolidation and permeability
- The unpredictable interactions of wildlife with reclaimed habitats.

Although reclamation materials are reasonably well-defined, there is considerable site-to-site variability in chemical composition. Most significant from a wetlands reclamation perspective is the combined presence of saline and sodic overburden in upland and wetland soils. Some research has addressed the movement of salts laterally and vertically through reclaimed soils, but a considerable level of uncertainty remains.

Similarly, significant research effort has been devoted to understanding the effects of consolidated tailings in experimental marshes (refer to section 4.3.3). That was a priority identified by the first edition of this guideline. However, reclamation engineers and soil scientists are continually experimenting with new methods to produce a stable, trafficable soil from tailings, and changes in consolidation techniques will necessitate a continued analysis of CT effects in wetlands settings.

Reclamation of wetlands on oil sands leases is still in its infancy, even though small-scale research projects have been underway for about twenty years. Where mined terrain has been reclaimed, the soils and sub-soils are still establishing an equilibrated density. The final nature of soil permeability in a variety of soil placement scenarios is unknown. Some monitoring shows permeability increasing with time[259]. Temporal changes in soil permeability will impact on interflow and groundwater recharge, and subsequently affect water inputs to wetlands.

[259] Devito and Mendoza 2003

Release of water from reclaimed materials will also occur for an undetermined period of time and influence the water quality of wetlands in unpredictable ways. There is still a poor understanding of nutrient and chemical loadings to wetlands from uplands composed of varying reclamation materials. The issue of nitrogen and phosphorus limitations to vegetation establishment in reclaimed wetlands are not well known, and thus there is no clear understanding of the role for fertilization as a strategy for improving initial establishment rates.

As wildlife colonize and use reclaimed wetlands, they will affect the dynamics of the ecosystem as well. Grazers and predators interact in a complex and often unpredictable myriad of ways. For the most part, these interactions have consequences for the composition of plant and animal communities in each wetland. However, beaver have the ability to alter the landscape in a much more far-reaching way; they are indeed nature's engineers. Through dam construction, flooding of uplands vegetation and eventual dam failure, beavers redistribute the nutrients and mineral elements from forest vegetation to wetland sediments and re-established upland organic soils. This redistribution increases the availability of nutrients and minerals to vegetation. Beavers can affect the most basic environmental characteristics of boreal forest **drainage** systems for decades[260].

These local-scale sources of uncertainty may contribute significantly to the environmental variability expected on reclaimed landscapes. There is prudence in acknowledging their influence and incorporating them into ongoing research and development programs. In addition, their existence provides further rationale for designing and implementing a robust monitoring and adaptive management program, as outlined in section 4.3.

Immature treed fen with upland forest in background (Credit: Suzanne Bayley 2006)

[260] Naiman et al. 1994; Devito and Dillon 1993

7.2 Research Directions and Projected Knowledge Gains

The Wetlands and Aquatics Subgroup (WASG) of the Reclamation Working Group of CEMA developed the following mission statement to:

> "Support the creation of a range of sustainable wetlands for oil sands reclamation and restoration of disturbed wetlands in the Athabasca Oil Sands Region, by advancing the development of guidelines".

In advancing guidelines, there must be acknowledgement of the remaining knowledge gaps and recognition of the research needs to address those gaps. Thus, WASG has developed a set of research priorities, based on extensive consultation with academics, Aboriginal people, government agencies and industry. Six key research priorities were identified:

- reclamation of peat-forming wetlands, including fens
- incorporation of societal values into wetlands reclamation
- hydrological mechanisms in wetlands reclamation
- biological processes driving wetlands establishment
- water treatment capacity of reclaimed wetlands
- methods for monitoring efficacy of wetland ecosystem establishment.

Reclamation of peat-forming wetlands

Peat-forming wetlands are important in terms of their significant representation in the unmodified boreal ecosystem (~50%), their value to Aboriginal cultural integrity, and their moderating influence in regional water budgets. Despite several examples of successful restoration elsewhere in the world, the potential for reclamation of bogs and fens remains untested. The reclamation of fens and possibly bogs in the oil sands region is a major challenge and a high priority for research. The following WASG projects are investigating the feasibility of establishing sustainable groundwater flow to constructed fens using soils and sediments available in the reclaimed landscape, and the potential for local fen species to accumulate organic matter as peat under the salinity and climatic conditions predicted for the oil sands region.

WASG Projects:
☑ *Creating a fen peatland on a post-mined oil sands landscape: a feasibility modelling study (phase 2)*[261]
Initiation date = Apr 2006 Completion date = Dec 2006
☑ *Effects of salinity on vegetation and organic matter accumulation in natural and oil sands wetlands*[262]
Initiation date = May 2005 Completion date = Jun 2007

Incorporation of societal values into wetlands reclamation

As a 'how-to' focused document, this guideline has not emphasized the values placed on wetlands. However, wetlands in the oil sands region have traditionally been highly valued for indigenous cultural and spiritual growth, and for economic prosperity as habitat for fur-bearers. There has been limited investigation of how reclaimed wetlands may be used to contribute to these community needs.

[261] Phase 1 of this study was CONRAD-funded (Price et al. 2005b)
[262] building on a previous study in preparation by S. Bayley and M Trites, UAlberta

Traditional ecological knowledge could assist greatly to this guideline and to the reestablishment of a range of functioning wetlands, but there is difficulty in the communication of information due to the different methods used by western science and traditional knowledge transfer for naming and categorizing the types of wetlands, and understanding the values and uses of wetlands in the region. A common understanding of the taxonomy of wetlands utilized by both western science and that of the traditional knowledge holders would provide a stepping stone to effectively capture and implement traditional knowledge of the wetlands and to accurately determine their values and uses. That is the objective of the following project.

WASG Project:
☑ *Traditional wetland classifications and use in the Athabasca Oil Sands region*
Initiation date = 2007 Completion date = undetermined

Hydrological mechanisms in wetlands reclamation

The importance of hydrology to wetland persistence and its complexity when applied to wetlands of the boreal forest have been emphasized throughout this guideline. Although there is good information on natural analogues in the region, there is still considerable uncertainty about how to create similar conditions on reclaimed landscapes. Appendix C1-2 of this guideline summarizes the most relevant information gained from studies in northern Alberta in the Boreal Plains system. This may now be extended to find appropriate hydrological designs for reclaimed systems.

WASG Project:
☑ *Applying knowledge of hydrology from natural analogues in the oil sands region to wetlands design on reclaimed landscapes*[263]
Initiation date = May 2004 Completion date = Dec 2005

Biological processes driving wetlands establishment

Connections among biological components in complex systems like wetlands are difficult to trace and predict when designing for their reclamation. Questions remain regarding vegetation tolerances to salinity, peat accrual, and succession processes. The following projects, which relate to collating and interpreting existing information on vegetation establishment, will lead into future studies of field and greenhouse vegetation / propagation trials.

WASG Projects:
☑ *Compiling information on vegetation restoration techniques for application to wetland reclamation in the oil sands region* [264]
Initiation date = Jun 2005 Completion date = Apr 2006
☑ *Identification of reference wetland sites (natural analogues) in the oil sands region*[265]
Initiation date = Jun 2005 Completion date = Apr 2006
☑ *An analysis of existing information on wetland vegetation in the oil sands region - marshes*
Initiation date = Sep 2006 Completion date = Mar 2007
☑ *An analysis of existing information on wetland vegetation in the oil sands region - peatlands*
Initiation date = Nov 2006 Completion date = Dec 2007

[263] the results of this project form Appendix C1-2 (Devito & Mendoza, Devito et al.) of this guideline
[264] the results of this project form Appendix D(Cooper et al.) of this guideline
[265] the results of this project are presented in Golder Associates 2006b

Water treatment capacities of reclaimed wetlands

Although wetlands have been used to treat water on grand scales around the world, the treatment of saline freshwater contaminated with hydrocarbons and naphthenic acids is unique to the oil sands. It remains untested. There are still questions about how much water can be treated using wetlands, whether they need to be used in combination with end pit lakes, how long treatment will need to continue after closure, and at what point wetlands may be used for other purposes like cultural plant gathering. The following projects are a combination of laboratory research and modelling approaches to investigating the existing knowledge gaps.

WASG Projects:
☑ *The role and effectiveness of wetlands for mitigation of oil sands impacted waters*
Initiation date = Jun 2005 Completion date = Sep 2007
☑ *Predicted water quality of oil sands reclamation wetlands: impact of physical design and hydrology*[266]
Initiation date = Jul 2005 Completion date = Mar 2006

Methods for monitoring wetland ecosystem establishment

Considerable hypothesis-driven research has been conducted on pilot-scale reclaimed wetlands, but long-term monitoring of establishing ecosystems requires a different investigative approach (see section 4.3). There is a need to identify the most appropriate and cost-effective methods for monitoring in the unique setting of reclaimed boreal wetlands in the oil sands region. The following projects initiate a larger research plan aimed at identifying monitoring endpoints.

WASG Projects:
☑ *Amphibians as indicators of performance of wetlands in oil sands reclamation areas*
Initiation date = May 2005 Completion date = Dec 2007
☑ *Bird assemblages as integrators and indicators of reclamation effectiveness in oil sands operational areas*
Initiation date = Jan 2006 Completion date = Dec 2007

In addition to the research being advanced through the CEMA Wetlands and Aquatics subgroup, there are a number of ongoing studies coordinated by other multi-stakeholder groups that are contributing to knowledge on wetlands reclamation. These groups include the Canadian Oil Sands Network for Research and Development (CONRAD), the Canadian Water Network (CWN), and the Alberta Society of Professional Biologists (ASPB). A collation of the findings of published studies and unpublished reports and graduate theses is beyond the scope of this edition of the guideline. However, it should be pursued as a priority for inclusion in the next edition.

[266] the results of this project are presented in Golder Associates 2006a

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Glossary

This glossary is not an exhaustive list of wetland reclamation terminology; it defines only those terms used in the body of the guideline and its appendices. For a more complete listing, refer to the Alberta Environment Glossary of Reclamation and Remediation Terms[267]. The following definitions are sourced from that government document unless another source citation is specifically footnoted.

A

Aboriginal people – the descendents of the original inhabitants of North America; includes First Nations and other Native American Indians, Métis and Inuit[268]

Abundance – the number of organisms per unit area or volume

Acid – having a pH less than 7.0; *ant* alkaline

Acrotelm – the upper oxygenated (aerobic) zone of peat in peat-forming wetlands; where the living plants grow and there is hydrological activity; *ant* catotelm[269]

Actual evapotranspiration (AET) – the maximum evapotranspiration that occurs in a given unit area, measured by field observations; *see* Potential evapotranspiration

Acute – with reference to toxicity, having a sudden onset, lasting a short time (usually within hours or days for fish); with reference to a stimulus, severe enough to rapidly induce a response; it can be used to define either the exposure (time) or the response to an exposure (effect). The duration of an acute aquatic toxicity test is generally hours to a few days and mortality is the response measured; *ant* chronic

Adaptive management – a management approach that involves the monitoring and evaluation of wetland structure and function followed by any necessary actions to achieve the intended functional and use objectives; it also allows information to be fed back into the planning and design process so that future wetlands will meet the intended objectives; a tenet of ecological management, in which human resource users can change the way they interact with the environment, based upon need and the availability of new information

Aerobic – living or active in the presence of oxygen; *ant* anaerobic

Algae – a group of aquatic plants, variously one-celled, colonial or filamentous, containing chlorophyll and/or other pigments and having no vascular system

Alkali – having a pH greater than 8.5 or an exchangeable sodium percentage greater than 15 or both; with reference to soil, contains enough sodium to interfere with the growth of most plants

[267] Powter 2002; available online at: http://environment.gov.ab.ca/info/home.asp (search "glossary of reclamation")
[268] Indian and Northern Affairs Canada 19??
[269] Vitt 2003

Alkaline – having a pH greater than 7.0; high in calcium and bicarbonate ions; *see* Saline; *ant* acid

Altered – with reference to a wetland, one that is situated on- or off-lease and is not removed during active mining, but is potentially affected by the mining process

Amendment – with reference to soil, an alteration of the properties of a soil by the addition of substances such as lime, gypsum, manure and sawdust to make the soil more suitable for the growth of plants; technically a fertilizer is also an amendment, but the term is most commonly applied to other types of added substances

Amorphous peat – the structureless portion of an organic peat deposit in which the plant remains are decomposed beyond recognition

Anaerobic – living or active in the absence of oxygen; *ant* aerobic

Aquatic – growing, living in or frequenting water; occurring or situated in or on water

Aquatic environment (regulatory definition) – the components of the earth related to, living in or located in or on water or the beds and shores of a water-body; includes but is not limited to all organic and inorganic matter, living organisms and their habitats; *ant* terrestrial

Aquifer – stratum or zone of subsurface soil, sediment or rock which stores and conveys significant quantities of groundwater and is capable of producing water as from a well; all of the spaces between soil particles are filled with water

Aspect – compass orientation of a slope as an inclined element of the ground surface

B

Bedrock – the solid rock that underlies soil and the regolith or that is exposed at the surface

Bedrock spoil – bedrock material that has been mined and dumped; it may consist of hard fragments or may be soil-sized particles

Benthic – living at, in or in association with the bottom substrate of aquatic environments, including wetlands

Bioaccumulation – where an organism has within its body a higher concentration of a substance than is found in its environment; includes uptake of substances from water (= bioconcentration) and from food (this phenomenon is not necessarily harmful; for example, freshwater fish must bioaccumulate common salt if they are to live because the water in which they swim dissolves the salts out of their bodies)

Biodegradable – with reference to a chemical or organic material, able to be structurally broken down through the action of micro-organisms such as bacteria; materials are considered to be biodegradable if they decompose relatively quickly

Biodiversity – the variety of living components in an ecosystem; it is most often expressed in terms of species diversity but can be assessed on the basis of genetic diversity or landscape diversity (e.g., variety of vegetation types across the landscape); it can also incorporate structural and functional elements

Biological treatment – with reference to wastewater treatment, a process that utilizes the heavy growth of micro-organisms to break down materials (organic and inorganic) through oxidation, absorption and adsorption mechanisms

Biomass – the weight of all living material in a unit area or volume at a given instant in time; it can be expressed at different biological levels (e.g., population, community)

Biomagnification – an extension of the process of bioaccumulation, where tissue concentrations of accumulated chemical compounds are passed up through the food chain so that tissue residues become increasingly concentrated

Bioremediation – the use of micro-organisms to remediate (clean) contaminated soil or water

Bitumen – the heavy viscous hydrocarbon associated with the Athabasca Oil Sands deposit; contains some mineral and sulphur contamination

Bog – a class of peat-accumulating wetland that is described as having the following characteristics: has no significant outflows or inflows; kept wet by direct precipitation with a water table at or near the soil surface; supports acidophilic mosses (particularly *Sphagnum*); virtually unaffected by the nutrient-rich groundwater from surrounding mineral soils, making it generally very acidic and low in nutrients; may be treed or treeless and dominated by mosses and ericaceous shrubs[270]

Brown moss – peat composed of various proportions of mosses from the taxonomic families Amblystegiaceae (*Scorpidium*, *Drepanocladus*, *Calliergon*, *Campylium*), Hypnum, and Tomenthypnum

C

Carbon sequestration – where carbon is removed from the atmosphere and stored in an area such as a forest or wetland, which naturally absorbs carbon dioxide from the air[271]

Carbon storage – *see* Carbon sequestration

Catotelm – the lower un-oxygenated (anaerobic) zone of peat in peat-forming wetlands; where the dead plants accumulate and slowly decompose; *ant* acrotelm[272]

Chronic – with reference to toxicity, having a gradual onset, lasting a long time (often several weeks to years); with reference to a stimulus, severe enough to measurably affect a species; it can be used to define either the exposure (time) or the response to an exposure (effect). The duration of a chronic aquatic toxicity test is generally a few

[270] National Wetlands Working Group 1997
[271] Ducks Unlimited 2006
[272] Vitt 2003

weeks; measures may include but are not limited to early development, growth, reproduction, immune function or behaviour; effects are ultimately reflected by changes in the productivity and population structure of the community; often signifies effects occurring over periods of at least one tenth of the life span of the organism; *ant* acute

Clay – with reference to soils, a fine-grained textural class, made up largely of clay minerals, but commonly also having amorphous free oxides and primary minerals; with reference to particle-size, having a grain less than 0.002 mm equivalent diameter.

Coarse-grained – with reference to soil, the texture exhibited by sands, loamy sands, and sandy loams but not including very fine sandy loam; a soil containing large quantities of these textural classes.

Coastal – *see* Shoreline

Community – an assemblage of organisms characterized by a distinctive combination of species occupying a common environment and interacting with one another

Compaction – the moving of soil particles closer together by external forces; in the compaction process, individual soil particles are packed closer together and soil aggregates are crushed, thus greatly reducing porosity; major causes are natural consolidation during soil forming processes (e.g., the weight of glaciers during the ice ages), trampling by animals and humans, natural shrinkage of soil upon drying, and use of heavy equipment (as in the process of levelling the overburden material of strip mine banks).

Compression – a system of forces or stresses that tends to decrease the volume or compact a substance; the change in volume produced by such a system of forces; compression of a saturated soil is consolidation and compression of an unsaturated soil is compaction

Concentration – a measure of the amount of a substance present per unit volume or per unit weight of material

Conductivity – a measure of the resistance of a solution to electrical flow; conductivity increases with increasing ion content; a numerical expression of the ability of an aqueous solution to carry an electric current; this ability depends on the concentrations of ions in solution, their valence and mobility, and on the solution's temperature. Conductivity is normally reported in the SI unit of millisiemens/metre, or as micromhos/cm (1 mS/m = 10 umhos/cm); *syn* electrical conductivity

Connectivity – the extent to which late seral ecosystems are linked to one another to form an interconnected network

Consolidated tailings (CT) – *see* Soft tailings

Consolidation – the gradual reduction in volume of a soil mass resulting from an increase in compressive stress; the adjustment of a saturated soil in response to increasing load involves the squeezing of water from pores and a decrease in the void ratio

Contaminant – referring to any chemical compound added to a receiving environment in excess of natural conditions; the term includes chemicals or effects not generally regarded as "toxic", such as nutrients, salts and colour

Coversoil – refers to unconsolidated materials, including salvaged surface soils, salvaged Regolith and some bedrock spoil, that are used to top-dress spoils and build a better quality mine soil.

Criteria – a basis for judging adequacy; environmental criteria are usually compilations or digests of scientific data that are used for establishing environmental quality standards on which a judgement may be based; conditions that must be met in order to provide an acceptable result such as a reclaimed wetland

Criteria (water quality) – an estimate of the concentration of a chemical or other constituent in water which, if not exceeded, will protect an organism, a community of organisms, or a prescribed water use or quality with an adequate degree of safety

Cumulative – brought about, or increased in strength, by successive additions at different times or in different ways

D

Decomposition – breakdown of dead organic matter through fragmentation, chemical alteration and leaching[273]

Depression – an area that is lower than the surrounding landscape, and usually less well drained

Detritus – non-living particles of disintegrating biological material (inorganic and dead and decaying organic material) that can be suspended in the water column or deposited at the bottom of aquatic environments

Discharge – with reference to groundwater, the primary process in the hydrologic cycle for the movement of water from the subsurface to the surface[274]; *ant* recharge

Dispersal – the spreading of reproductive plant parts or juvenile animals from one place or area to another

Drainage (soil) – the frequency and duration of periods when the soil is not saturated; terms used are excessively, well, moderately, imperfectly, and poorly drained soil

Drainage Basin – area tributary to or draining to a lake, stream, reservoir or other body of water; *syn* watershed, catchment

[273] Chapin et al. 2002
[274] Smith and Pizalloto 2000

E

Ecological integrity – quality of a natural, unmanaged or managed ecosystem, in which the natural ecological processes are sustained, with genetic, species and ecosystem diversity assured for the future

Ecosite – in Alberta, defined as an area with a unique recurring combination of vegetation, soil, landform, and other environmental components; a Canadian ecological land classification (ELC) system mapping unit, usually mapped at a scale of 1:50,000 to 1:10,000

Ecosystem – a complex of living organisms interacting with each other and their non-living environment, linked together by energy flows and material cycling

Electrical conductivity (EC) – the reciprocal of electrical resistivity; expressed in deci-Siemens per metre (dS/m); provides a measure of water-soluble salt content; *see* Conductivity

Elevation head – elevation of wetland water surface relative to water table[274]

Emergent vegetation – plant species that have a part extending below the normal water level; plants adapted to periodic flooding, including genera such as *Carex* (sedges), *Scirpus* (reeds), and *Typha* (cattails)

End land use – with reference to oil sands mining, the allowable use/s of disturbed land following reclamation; municipal zoning/approval may be required for specific land uses

Ephemeral – a phenomenon or feature that lasts only a short time, such as where a marsh contains standing water for only part of each year

Equivalent land capability (regulatory definition) – where the ability of the land to support various land uses after reclamation is similar to the ability that existed prior to any activity being conducted on the land, but the ability to support individual land uses will not necessarily be equal after reclamation

Ericaceous shrubs – flowering shrubs of the heath family Ericaceae, which are acid-loving or acid-tolerant plants that often dominate bogs and other sites with acidic substrates[275]; includes bog cranberry (*Vaccinium vitis-idaea*), huckleberry (*Vaccinium* sp.), dwarf cranberry (*Oxycoccus microcarpus*), Labrador tea (*Ledum groenlandicum*)

Erosion – the wearing away and transportation of soils, rocks and dissolved minerals from the land surface, shorelines and river bottoms by running water, wind, ice, other geological agents, activities of man or animals, and including such processes as gravitational creep

Eutrophic – nutrient-rich; generally used in lake classification, but may also be applied to marshes, peatlands and shallow water wetlands[275]; *ant* oligotrophic[275]

[275] Mitsch and Gosselink 2000

Evaporation – the conversion of water from liquid form in soils and aquatic environments to vapour form and release to the atmosphere

Evapotranspiration (ET) – a collective term for the processes of evaporation of water from the soil surface and plant transpiration by which water is returned to the atmosphere from the land; *see* Potential evapotranspiration vs Actual evapotranspiration

Exotic species – species which are not native to the province and/or to the natural region

F

Fen – a class of peat-accumulating wetland that is described as having the following characteristics: a high water table that is usually at or above the surface; waters are mainly nutrient-rich and minerotrophic from mineral soils, but nutrients can be highly variable across the class; dominant materials are sedge and/or brown moss peat of variable thickness; associated soils are Mesisols, Humisols, and Organic Cryosols; vegetation consists dominantly of sedges, grasses, reeds, and brown mosses, with some shrub cover and, at times, a sparse tree layer[276]

Fertility (soil) – the status of a soil in relation to the amount and availability to plants of elements necessary for growth

Fetch – the length of open water available for wind-induced waves

Fine tailings – a term used in the oil sands industry to refer to the material accumulating at the bottom of oil sands tailings ponds; a matrix of dispersed clays, fine minerals, residual hydrocarbons, and various contaminants; whole tailings (plant tailings) includes tailings sand which settles rapidly and is used to form tailings dykes

Fine-grained – with reference to soil, the texture exhibited by silt and clay; a soil containing large quantities of the fine fractions; *ant* coarse-textured, medium-textured

Flood duration – the amount of time that a wetland is in standing water[275]

Flood frequency – the average number of times that a wetland is flooded during a given period[275]

Flow – a volume of water passing through a body of water (usually a river reach) per unit time

Food chain – the process by which organisms in higher trophic levels gain energy by consuming organisms at lower trophic levels; the dependence for food of organisms upon others in a series beginning with plants and ending with the largest carnivores

[276] National Wetlands Working Group 1997

G

Generalist – with reference to wildlife, *see* Habitat generalist

Groundwater – underground water supplies, also called aquifers; *see* Aquifer; water that is stored in the pores of subsurface geological deposits (strata) and flows in the direction of decreasing pressure[277]

Guideline – an indication or outline of policy or conduct; a basis for determining a course of action; with reference to a document, generally less prescriptive and more general than a manual or handbook

Gytjja – a flocculent, mineral-rich soil with organic components (decomposed macrofossils of vascular plants like sedges and pondweeds, accumulated algae); found at the bottom of lakes and wetlands, colloquially described as loon sh*t.[278]

H

Habitat – the specific area or environment in which a particular type of plant or animal lives

Habitat generalist – wildlife species that can survive and reproduce in a variety of habitat types (e.g., moose)

Habitat specialist – wildlife species that is dependent on a few habitat types for survival and reproduction (e.g., Cape May warbler)

Handbook – a concise reference book; prescriptive outline of a course of action; *see* Guideline

Heavy metals – a group of metallic elements with atomic weights greater than 40 and with similar electronic distribution in their external shell; includes but is not limited to mercury, lead, arsenic, selenium, molybdenum, cadmium, chromium, manganese and copper

Herb – any flowering plant except those developing persistent woody bases and stems above ground

Hydraulic conductivity – the measure of the ability of fluid to move through earth material; a function of both the soil medium and the fluid; is sometimes used interchangeably with permeability; see Permeability[279]

Hydraulic loading rate – amount of water added to a wetland, generally described as the depth of water per unit of time; often used with relation to treatment wetlands[280]

Hydraulic retention time (HRT) – the average amount of time that a parcel of water stays within the wetland before exiting[281]

[277] Roig 2000
[278] Mitsch and Gosselink 2000
[279] Smith and Pizalotto 2000
[280] Mitsch and Gosselink 2000
[281] Downer and Smith 2000

Hydric – with reference to soil, one that formed under conditions of saturation, flooding or ponding long enough during the growing season to develop anaerobic conditions in the upper part[282]

Hydrocarbon – an organic compound containing only carbon and hydrogen; *see* Polycyclic aromatic hydrocarbons (PAHs)

Hydrology – a broad term that encompasses all hydrologic and hydraulic processes related to wetlands; the water balance and all water components[281]

Hydroperiod – the duration and timing of flooding in a wetland; the seasonal pattern of water level[281]

Hydrophyte – a plant that grows in water, or in wet or saturated soils; water-loving; any plant growing in water or on a substrate that is periodically deficient in oxygen as a result of excessive water content[283]

Hypothesis-driven research – experiments / studies designed to objectively answer a specific pre-conceived question

I

Infiltration – downward water movement into the soil; normally treated as a vertical process

Inland – with reference to wetlands, those which are palustrine or where the functional processes within are driven by groundwater, surface runoff or direct precipitation sources of water; *ant* shoreline

Inorganic – not pertaining to or derived from plant or animal origins; a chemical of mineral origin which does not contain (with few exceptions) carbon or compounds of carbon

Interflow – water moving more or less laterally through the soil above the water table (and aquifer) in the unsaturated vadose zone; can be considered a type of groundwater flow

Intermittent – with reference to aquatic environments, where the presence of water ceases for a time due to climatic conditions, including snow melt/spring runoff, seasonal storms and drought conditions; these water bodies can remain dry for many years and may be fully restored after prolonged precipitation; *see* Ephemeral

Invasive plant – a plant that has moved into a habitat and reproduced so aggressively that it has displaced the original structure of the vegetation community

Invertebrate – an animal lacking a dorsal column of vertebrae or a notochord

[282] Spigolon and Hayes 2000
[283] Cowardin et al. 1979

K

Keystone species (ecological) – a species whose importance in the maintenance of community integrity is disproportionate to its abundance, and without which significant changes to the community would occur[284]

Keystone species (cultural) – a culturally salient species that shapes in a major way the cultural identity of a people, and without which significant changes to the culture would occur[284]

L

Lacustrine – pertaining to lakes or lake shores; describes physical and chemical processes characteristic of lakes[285]

Landscape – all the natural features such as fields, hills, forests, water, etc., which distinguish one part of the earth's surface from another part; usually that portion of land or territory which the eye can see in a single view

Littogenous – minerogenous wetland forms that are connected to riverine or lacustrine sources of water; also referred to as shoreline; *ant* terrigenous[286]

Littoral zone – productive shallow-water zone of lakes, rivers or seas where light can penetrate to the bottom; often occupied by rooted aquatic plants; the biogeographic zone between the high- and low-water marks

Loading rate – see Hydraulic loading rate

M

Macrophyte – refers to the macroscopic forms (i.e., larger than algae) of aquatic vegetation; includes mosses and vascular plants

Marsh – a class of wetland that is described as having the following characteristics: periodically inundated by standing or slowly moving water; surface water levels may fluctuate seasonally, with declining levels exposing drawdown zones of matted vegetation or mud flats; waters are often eutrophic; substratum usually consists dominantly of mineral material, although some marshes are associated with peat or gyttja deposits; associated soils are dominantly Gleysols with some Humisols and Mesisols; characteristically show a zonal or mosaic surface pattern of pools or channels interspersed with clumps of emergent sedges, grasses, rushes and reeds; where open water areas occur, a variety of submerged and floating aquatic plants flourish[286]

[284] Garibaldi and Turner 2004
[285] Mitsch and Gosselink 2000
[286] National Wetlands Working Group 1997

Medium-grained – with reference to soil, the texture intermediate between fine- and coarse-textured; includes very fine sandy loam, loam, silt loam and silt; ***ant*** coarse-textured, fine-textured

Mesotrophic – with reference to peatlands, poor fens (transitional between minerogenous and ombrogenous forms); with reference to water, intermediate in nutrient content between eutrophic and oligotrophic states

Micro-climate – local conditions near the ground resulting from modification of the regional climate by local differences in elevation, exposure or cover

Mineral – with reference to soils, those having ≤ 20-30% organic matter content by weight, depending on clay content[287]; a soil having < 17% organic carbon except for an organic surface layer that may be up to 40 cm thick if formed of mixed peat (bulk density 0.1 or more) or 60 cm if formed of fibric moss peat (bulk density less than 0.1)

Minerogenous – wetlands that receive water and mineral elements from groundwater or littoral sources in addition to directly from the atmosphere; ***ant*** ombrogenous[286]

Monitoring – measurements taken over space or time for the purpose of characterizing and assessing environmental conditions

Mosses – a group of bryophytes (plants that are not vascular plants) common in peatlands; includes brown mosses and *Sphagnum* species

Moult – with reference to birds, the process where flight feathers are shed at a certain stage in the life-cycle or seasonally and a new set produced from the old skin papillae; the process renders the bird temporarily flightless, thus vulnerable and many species retreat to safe places such as large water bodies[288]

Mulch – any material such as straw, sawdust, woodchips, leaves or loose soil that is spread on the soil surface to protect the soil and plant roots from the effects of raindrops, wind erosion, soil crusting, freezing and evaporation

Muskeg – large expanse of peatlands or bogs; a term commonly used in Canada and Alaska[289]; the word is of Algonquin Indian origin and is applied in ordinary speech to natural and undisturbed areas covered more or less with Sphagnum mosses, tussocky sedges, and an open growth of scrubby trees

N

Naphthenic acids – a diverse family of saturated, polycyclic and acyclic carboxylic acids that naturally occur in petroleum deposits; the processing of bitumen in oil sands mining releases this family of chemicals to the soluble fraction of processed waste materials, and they may become concentrated in process-affected water found on reclaimed landscapes; prior to microbial break-down, some types of naphthenic acids are highly toxic to aquatic organisms

[287] Gilbert 2000
[288] Young 1981
[289] Mitsch and Gosselink 2000

Natural analogue – with reference to reclaimed wetlands, natural wetlands in the same region which are considered to be similar in classification, hydrology, geology and biology to the intended reclaimed wetland form; *see* Reference site

Net primary production (NPP) – quantity of new plant material produced annually (gross primary production minus reproduction)[290]

Nitrogen: phosphorus (N:P) ratio – the ratio of the weight of nitrogen to the weight of phosphorus in a medium such as soil or water; N and P are two of the most important nutrients in freshwater systems because inadequate supplies of either nutrient will limit plant (algal) growth and reduce food supplies for the other organisms in the system

Non-segregated tailings (NST) – see Soft tailings

Nutrient – a chemical that is an essential raw material for the growth and development of organisms

Nutrient-limiting – refers to the limitation of an organism or population growth or productivity, due to a limited supply of an essential nutrient; productivity does not increase until the limiting nutrient is supplied

O

Oil sands –a subterranean sand deposit containing between four and eighteen percent bitumen (heavy, crude petroleum); less accurate term is tar sands

Oligotrophic – nutrient poor; most often used with reference to lakes, but may also be used to describe peatlands that are poor to extremely poor in nutrients and with low biological activity; *ant* eutrophic

Ombrogenous – wetlands that receive water only from direct precipitation (rain-fed), where precipitation normally exceeds evaporation during the growing season; the only class like this in Alberta is bog; *ant* minerogenous[286]

Open water wetland – *see* Shallow water wetland

Organic – with reference to soils, those having ≥ 20-30 % organic matter content by weight, depending on clay content[287]; the majority are saturated for most of the year, unless artificially drained; contain 17% or more organic carbon, and the surface layer must extend to a depth of at least 10-60 cm, depending on the bulk density properties; includes peat and gytjja

Organic matter – the organic fraction of the soil that includes plant and animal residues at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population[287]

Overburden – materials of any nature, consolidated or unconsolidated, that overlie a deposit of useful materials; the layers of material (typically sand, gravel and shale) which

[290] Chapin et al. 2002

overlie the oil sands; a general term describing the upper part of a sedimentary deposit, whose weight causes compaction of the lower part

Overwintering habitat – used during the winter as a refuge and/or for feeding

P

Paludification – the blanketing of terrestrial ecosystems by overgrowth of peatland vegetation (typically Sphagnum mosses)[291]

Palustrine – non-tidal vegetated wetlands; often used to describe the grouping of marshes, swamps, bogs, fens[292]

Pan – horizons or layers in the near-surface soil profile that are dense, strongly compacted, indurated or very high in clay content; slowly permeable or impermeable[293]

Peat – fibric organic soil material with virtually all of the organic matter allowing for easy identification of plant forms; bulk density generally <0.1 g_cm^{-3}; material constituting peatlands, exclusive of the live plant cover, consisting largely of organic residues (>80%) accumulated as a result of incomplete decomposition of dead plant constituents under conditions of excessive moisture (submergence in water and/or waterlogging)

Peat-forming – with reference to a wetland, where rate of production exceeds rate of decomposition, resulting in an accumulation of material

Perched – with reference to a wetland, one situated above a virtually impermeable soil lens, and not connected by discharge to the groundwater water table; may also refer to water within a landform that does not connect with the water table

Percolation – the downward flow of water in saturated or nearly saturated soil; movement of water under hydrostatic pressure or gravity through the interstices of rock, soil, or wastes; typically a deep movement into subsurface aquifers; see Recharge

Permeability – the capacity of some structures (e.g., a porous rock, soil, or sediment) for allowing water to be transmitted without damage to the structure; the ease with which gases, liquids, or plant roots penetrate or pass through a bulk mass of soil or a layer of soil

Plankton – *see* Phytoplankton, Zooplankton

Polycyclic aromatic hydrocarbons (PAHs) – a group of over 100 different organic compounds that are present in crude oil and which may be formed during combustion processes (burning of coal, oil and gas, wood, etc); a select number of these chemicals are highly toxic to aquatic organisms

[291] Mitsch and Gosselink 2000
[292] Cowardin et al. 1979; National Wetlands Working Group 1997
[293] Smith and Pizalotto 2000

Pond – *see* Shallow water wetland

Potential evapotranspiration (PET) – the maximum evapotranspiration that can occur in a given region considering the climate, with a low-growing crop that is not short of water and does not completely shade the ground

Prairie potholes – a wetland form common on the Canadian prairies in glaciated depressions; may be temporary or permanent, usually a form of marsh

Presence-absence – manner of completing a vegetation survey or analysis based on the presence or absence of a species instead of abundance-dominance

Pressure head – mass and pressure of a wetland water body relative to the surrounding groundwater system[294]

Primary productivity – the rate at which solar energy is stored by photosynthetic and chemosynthetic activity of producer organisms (chiefly green plants) in the form or organic substances

Process-affected water – water that has been altered in chemical composition by activities associated with oil sands mining; includes raw tailings water, dyke seepage and water released from fine tailings

Progressive reclamation – any interim or concurrent reclamation of land undertaken during, following or in connection with construction/ development and ongoing operations associated with an active disposition

Propagule – a piece of a plant from which a new individual can grow

Phytoplankton – plants that are buoyant and live in the water column; they sink very slowly and most are microscopic

Phytoremediation – the use of living plants (and their associated micro-organisms) for treatment of soil or water through contaminant removal, degradation or containment[295]

R

Recharge – with reference to groundwater, the primary process in the hydrologic cycle for the movement of water from the surface to the subsurface[294]; process by which water is absorbed and added to the zone of saturation; *ant* discharge

Reclamation (regulatory definition) – the process of reconverting disturbed land to its former or other productive uses; all practicable and reasonable methods of designing and conducting an activity to ensure: (1) stable, non-hazardous, non-erodible, favourably drained soil conditions, and (2) equivalent land capability; the removal of equipment or buildings or other structures and appurtenances, the decontamination of buildings or other structures or other appurtenances, or land or water, the stabilization, contouring,

[294] Smith and Pizalloto 2000
[295] Cronk and Rennessy 2001

maintenance, conditioning or reconstruction of the surface of land, and any other procedure, operation or requirement specified in the regulations

Reclamation (wetlands) – creation of wetlands on disturbed land where they did not formerly exist or where their previous form has been entirely lost[296]; *see* Restoration

Reference site – with reference to wetlands reclamation, an area which is undisturbed or unaffected by an activity, but which is otherwise similar to a reclaimed wetland and therefore can serve as a comparison to assess its functional state; *see* Natural analogue

Restoration – the process of restoring site conditions as they were before a land disturbance

Restoration (wetlands) – restoration of a wetland that still exists in some rudimentary form to a condition similar to what it was before disturbance/ alteration[296]; *see* Reclamation

Riparian margin – refers to terrain, vegetation or simply a position adjacent to or associated with a stream, flood plain, lake or wetland

Riparian regime – a classification used in the Canadian Wetlands Classification System to refer to wetlands influenced by lacustrine or riverine processes[297]; *see* Shoreline

Riverine – pertaining to streams, rivers or their banks; describes physical and chemical processes characteristic of rivers

Runoff – the portion of the total precipitation on an area that flows away through stream channels; **Surface runoff** does not enter the soil; **Groundwater runoff** or **seepage flow** from groundwater enters the soil before reaching the stream; **storm runoff** is overland sheet flow generated during peak rainfall events[298]

S

Saline – salty; an aqueous environment containing dissolved salts; high in sodium and sulphate ions rather than calcium and bicarbonate ions; *see* Alkaline

Saline (soil) – a non-alkali soil containing soluble salts (ions such as Na, Ca, K, Mg, Cl, SO_4) in such quantities that they interfere with the growth of most crop plants; the conductivity of the saturation extract is > 4 dS_m^{-1}, the exchangeable-sodium percentage is <15, and the pH is usually < 8.5.

Salt rejection – the process where salts are expelled from freezing water into remaining water at depth in wetlands undergoing ice formation[299]

[296] this definition is based on the Alberta Environment regulatory definition and the intent of the original wetlands reclamation guideline; it may differ from published definitions, which vary slightly by region and discipline
[297] National Wetlands Working Group 1997
[298] see Appendix C1 (Devito & Mendoza)
[299] Golder Associates 2006a

Sand – with reference to particle-size, having a grain between 0.05 and 2.00 mm in diameter

Sediment – solid material, both mineral and organic, that is in suspension, is being transported, or has been moved from its surface of origin by air, water, gravity, or ice and has come to rest on the earth's surface either above or below sea level; with reference to wetlands, the uppermost layer of submerged soils

Sedimentation – the process of accumulating sediment at the bottom of a water body over time from the sinking debris in the water; process may be accelerated by high rates of erosion of upland soils

Seed bank – seeds stored in soils, often for many years; changing the hydroperiod in wetlands can often lead to germination of seeds in a seed bank[300]

Seepage – the slow flow of water into or from a soil; usually involves the lateral flow of water; the emergence of water from the soil over an extensive area in contrast to a spring where it emerges from a local spot; *see* Runoff

Seral – referring to a stage in succession of vegetation communities

Shallow water wetland – a class of wetland that is described as having the following characteristics: having mid-summer water depths <2 m and open water zones occupying 75% or more of the total surface area; may have submerged and floating aquatic vegetation in the open water zone; within a complex of different wetland types, distinguished as a distinct form when >8 ha of open water is present; may be variously called ponds, pools, shallow lakes, oxbows, reaches, channels, impoundments[301]; this guideline refers to these as **open water wetland** or **pond** to avoid confusion with the term 'shallow' (this is, in reality, the wetland type with the greatest water depths)

Shrub – a woody perennial plant differing from a tree by its low stature and by generally producing several basal shoots instead of a single trunk

Shoreline – with reference to wetlands, those where the functional processes within are dominated by lake or ocean sources of water; in particular, water levels or hydroperiod are controlled by fluctuations in the lake or by tides; *ant* inland

Shoreline stabilization – the binding of sediment at or near a shoreline and the physical dissipation of erosive energy caused by waves, currents, ice, etc.[302]

Silt – a soil separate consisting of particles between 0.05 and 0.002 mm in diameter

Slope – the degree of deviation of a surface from horizontal, measured in a numerical ratio, percent, or degrees; expressed as a ratio or percentage, the first number is the vertical distance (rise) and the second is the horizontal distance (run), as 2:1 or 200 %; expressed in degrees, it is the angle of the slope from the horizontal plane with a 90˚ slope being vertical (maximum) and 45˚ being a 1:1 slope

[300] Mitsch and Gosselink 2000
[301] National Wetlands Working Group 1997
[302] Smith and Pizalotto 2000

Slough – a North American term for a shallow prairie pond that largely disappears in late summer; often with a muddy bottom

Sodic – with reference to a soil, one containing sufficient exchangeable sodium to interfere with the growth of most crop plants; SAR of the saturation paste extract is >15

Sodicity – a measure of the amount of sodium on the exchange complex (often expressed as sodium adsorption ratio - SAR)

Soft tailings – formed by injecting mature fine tailings from the tailings ponds into the regular (whole) tailings sand stream, with a flocculent such as gypsum; this mixture is sent to the tailings ponds to form a non-segregating soil mixture which will result in a trafficable surface in the reclaimed landscape; *syn* consolidated tailings, composite tailings, non-segregated tailings

Specialist – with reference to wildlife, *see* Habitat specialist

Staging – with reference to migratory birds, the practice of stopping to rest and eat at sites along the migratory pathway

Storm runoff – *see* Runoff

Strata – layered sedimentary units, as in the layered soils of the oil sands region (laid down by different marine and freshwater sedimentation events)[303]

Stratigraphy – the geologic study of the physical and temporal attributes of strata[303]

Subsoil – the soil material found beneath the topsoil but above the bedrock; technically, the B horizon; broadly, the part of the profile below plough depth

Substrate – any solid surface which forms the place of attachment or place of dwelling of an organism; may be rocks, sand, mud, or the surface of a plant; most often refers to that part of the surface of the wetland soil profile that provides biological and chemical support for the growth of hydrophytic plants; defined by function rather than by a specific soil type[304]

Submergent vegetation – plant species that have no part extending above the normal water level, but which are rooted in a substrate (not floating)

Succession – the natural sequence or evolution of plant communities, each stage dependent on the preceding one, and on environmental and management factors; primary succession occurs on newly created surfaces, while secondary succession involves the development or replacement of one stable successional species by another on a site having a developed soil; secondary succession occurs on a site after a disturbance (fire, cutting, etc.) in existing communities

Surface mineable oil sands area – the geographical area where surface mining is economical in the Athabasca oil sands deposit

[303] Smith and Pizalotto 2000
[304] Spigolon and Hayes 2000

Surface runoff – *see* Runoff

Suspended solids – organic or inorganic particles that are suspended in and carried by the water; includes sand, silt, and clay particles as well as solids in wastewater; measured as the oven dry weight of the solids, in parts per million (ppm), after filtration through a standard filter paper; <25 ppm would be considered clean water, while an extremely muddy river might have ~200 ppm

Sustainable landscape – landscape that can survive extreme events and natural cycles of change without being subjected to accelerated erosion or environmental impacts more severe than those of the natural environment

Swamp – a class of wetland that is described as having the following characteristics: a mineral wetland or a peatland with standing or gently flowing waters occurring in pools and channels; water table is usually at or near the surface; strong water movement from margin or other sources, hence the waters are nutrient-rich; if peat is present, it is mainly well decomposed forest peat underlain at times by fen peat; the associated soils are Mesisols, Humisols, and Gleysols; the vegetation is characterized by a dense cover of coniferous or deciduous trees, tall shrubs, herbs, and some mosses[301]

T

Terrace – a nearly level, somewhat narrow plain, existing naturally along rivers, lakes or seas or created artificially to reduce erosion by overland runoff

Terrigenous – minerogenous wetland forms that are hydrologically connected to local or regional groundwater/ aquifers or to surface runoff systems; *ant* littogenous[305]

Topography – the shape of the ground surface, such as hills, mountains, or plains

Topsoil (soil science definition) – the layer of soil moved in cultivation; the A horizon; fertile soil used to top-dress landscapes[304]

Topsoil (engineering definition) – the surface soil, usually containing organic matter[304]; the uppermost part of the soil, ordinarily moved in tillage, or its equivalent in uncultivated soils, and normally ranging in depth from 5 to 45 cm

Toxicity – the inherent potential or capacity of a material to cause adverse effects in a living organism

Transect – a sampling system that involves the measurement or recording of data along a line; the line intercept method involves measurements of objects that occur beneath the line, while in other cases, small sampling plots are located along the line at specified distances

Transpiration – the process by which plants release water through their leaves to the atmosphere[306]; see Evapotranspiration, Evaporation

[305] National Wetlands Working Group 1997
[306] Roig 2000

Treatment – chemical, biological, or mechanical procedures applied to an industrial or municipal discharge or to other sources of contamination to remove, reduce, or neutralize contaminants

Trophic levels – refers to a functional classification of organisms in a community according to their feeding relationships; the first trophic level includes green plants, the second includes herbivores/ grazers (plant-eaters) and so on up to the top predators (meat-eaters); position in the food chain determined by the number of energy transfer steps to that level

Trophic status – availability of nutrients to plants; classified as eutrophic, mesotrophic or oligotrophic

Turbidity – level of cloudiness of a suspension, such as the murkiness of marsh or pond water

V

Vadose zone – the unsaturated soil zone above the water table of an aquifer; see Aquifer, Groundwater, Water table

W

Water storage capacity – the potential for water storage in a wetland, considering both the surface water volume and the soil moisture content[307]

Water table – elevation at which the pressure in the water is zero with respect to the atmospheric pressure; the upper limit of the soil or underlying rock material that is wholly saturated with water; marks the upper boundary of an aquifer

Watershed – all lands enclosed by a continuous hydrologic-surface drainage divide and lying upslope from a specified point on a stream

Weathering – with reference to contaminants, their change in composition and bioavailability with time as related to natural processes including wind, sun, rain, volatilization, differential mobility, biodegradation and stabilization with reference to soils, the physical and chemical disintegration, alteration, and decomposition of rocks and minerals at or near the earth's surface by atmospheric agents

Wetland – land having the water table at, near, or above the land surface or which is saturated for long enough periods to promote wetland or aquatic processes as indicated by hydric soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to the wet environment; the Canadian Wetlands Classification System identifies 5 classes of wetlands, namely bogs, fens, marshes, shallow waters and swamps[308]

[307] Downer and Smith 2000
[308] National Wetlands Working Group 1997

Z

Zooplankton – animal life, usually microscopic, found floating or drifting in the water column of oceans or bodies of fresh-water; form the link between primary producers (phytoplankton) and the higher trophic levels (e.g., fish, humans)

APPENDICES

to the Guideline for Wetland Establishment on Reclaimed Oil Sands Leases

Revised (2007) Edition

List of Appendices

Title Page Photographs: *Upper right photo*: Tower Road natural wetland, Fort McMurray, AB. Courtesy of Kristina Norstrom (Albian Sands) 2005. *Lower left photo*: Peat Pond, Syncrude Mildred Lake lease (on saline, sodic overburden landform) – the first reclaimed wetland to use the Guidelines for Wetland Establishment on Reclaimed Oil Sands Leases (2000 [first] edition) during the planning and design phases of construction. Courtesy of Clara Qualizza (Syncrude Canada) 2006.

Appendix A

Wetlands and Aquatics Subgroup of the Reclamation Working Group (CEMA) Members List

A Wetlands & Aquatics Subgroup (WASG) Members List

This is a list of 2006 members and may not be a comprehensive list of all members contributing to the revision of the wetlands guideline.

Organization	Representative
Alberta Energy & Utilities Board	Carmalee Farn-Baker
Alberta Environment	Théo Charette (Co-Chair)
Alberta Sustainable Resource Development	Gerry Haekel
Albian Sands Energy	Fred Kuzmic Kristina Norstrom
Canadian Natural Resources Ltd	Jon Gareau Sarah Aho
Fort McKay IRC	Carol Jones (Co-Chair) Ann Garibaldi
Imperial Oil Resources	Sandy Campbell
Suncor Energy Inc	Wayne Tedder
Syncrude Canada Ltd	Mike MacKinnon Neil Rutley Terry Van Meer

Appendix B

Natural Wetlands in the Oil Sands Region

By Linda Halsey
University of Alberta, Department of Biological Sciences, Edmonton, AB

This appendix was written for the first edition of the Wetlands Guideline and has not been altered except to format the layout to match other appendices.

B Natural Wetlands in the Oil Sands Region

TABLE OF CONTENTS

B.1 Classification and Ecology

A wetland is any land saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation, and various kinds of biological activity that are adapted to a wet environment (National Wetlands Working Group 1988). The environmental processes that control wetland development form hydrologic, chemical, and biotic gradients and commonly have strong cross-correlations. These interrelated gradients are represented by five wetland classes, of which three are non-peat forming wetlands generally having < 40 cm of accumulated organics and two are peatlands with > 40 cm of accumulated organics. Non-peat forming wetlands are subdivided into: 1) shallow open water, 2) marsh, and 3) swamp; peatlands can be subdivided into 1) fen and 2) bog (Figure B1). This primary wetland subdivision forms the foundation for defining Alberta's wetlands (Alberta Environmental Protection 1997) and Alberta's wetland policy (Alberta Water Resources Commission 1993).

Shallow Open Waters are non-peat forming wetlands that are characterized by aquatic processes confined to less than 2 m depth at midsummer. These wetlands have submergent to floating vegetation and form a transition to truly aquatic ecosystems. The chemistry of this wetland class is variable and does not distinguish it from the remaining four wetland classes. Floristic composition is dependent on chemical conditions.

Marshes are open, non-peat forming wetlands that are dominated by sedges (Cyperaceae) and other monocots. Marshes are characterized by seasonal water level fluctuations, relatively high amounts of water flow, and are influenced by ground and surface waters. As a result, concentrations of nitrogen and phosphorus are high, leading to abundant vascular plant production; however, peat accumulation is limited by high decomposition rates. Mosses are generally lacking or not abundant as they do not compete well with rapid vascular plant growth and do not tolerate large fluctuations in seasonal water levels. As with shallow open waters, chemical differences in marshes strongly influence their floristic composition. Alkaline marshes (dominated by calcium and bicarbonate) are dominated by *Carex*, *Scirpus*, and *Typha*, whereas saline marshes (dominated by sodium and sulfate) are largely occupied by *Salicornia* and *Scirpus*.

Swamps are forested, wooded or shrubby non-peaty wetlands. Swamps and marshes have a poorly developed bryophyte layer that results from strong seasonal water level fluctuations and high vascular plant production. Peat accumulation is limited in swamps as decomposition rates are high. Swamps are quite diverse in vegetation and in Alberta may be composed of some combination of *Larix laricina*, *Picea mariana*, *Betula*, and *Salix*.

Peatlands, often termed muskeg, differ from non-peat forming wetlands by a combination of interrelated hydrologic, chemical, and biotic factors that results in a decrease in decomposition relative to plant production allowing for the accumulation of peat. Peatlands represent an important terrestrial carbon sink, with an estimated 455 Pg currently stored (Gorham 1991; 1 Pg = 1015 g) or 25% or the world's terrestrial carbon (Woodwell and Houghton 1991). The amount of carbon stored in peatlands is roughly equivalent to 75% of the total amount of global atmospheric carbon.

The initiation of peat accumulation is related to stabilization of seasonal water levels and restriction of water flow through a wetland which, in conjunction with leaching of salts from the mineral substrate, allows for the establishment and development of a moss layer. The stabilization of regional water tables appears to have been an important component in the

successional change from prairie marshes to boreal fens in the western interior of Canada over the past 10,000 years (Zoltai and Vitt 1990).

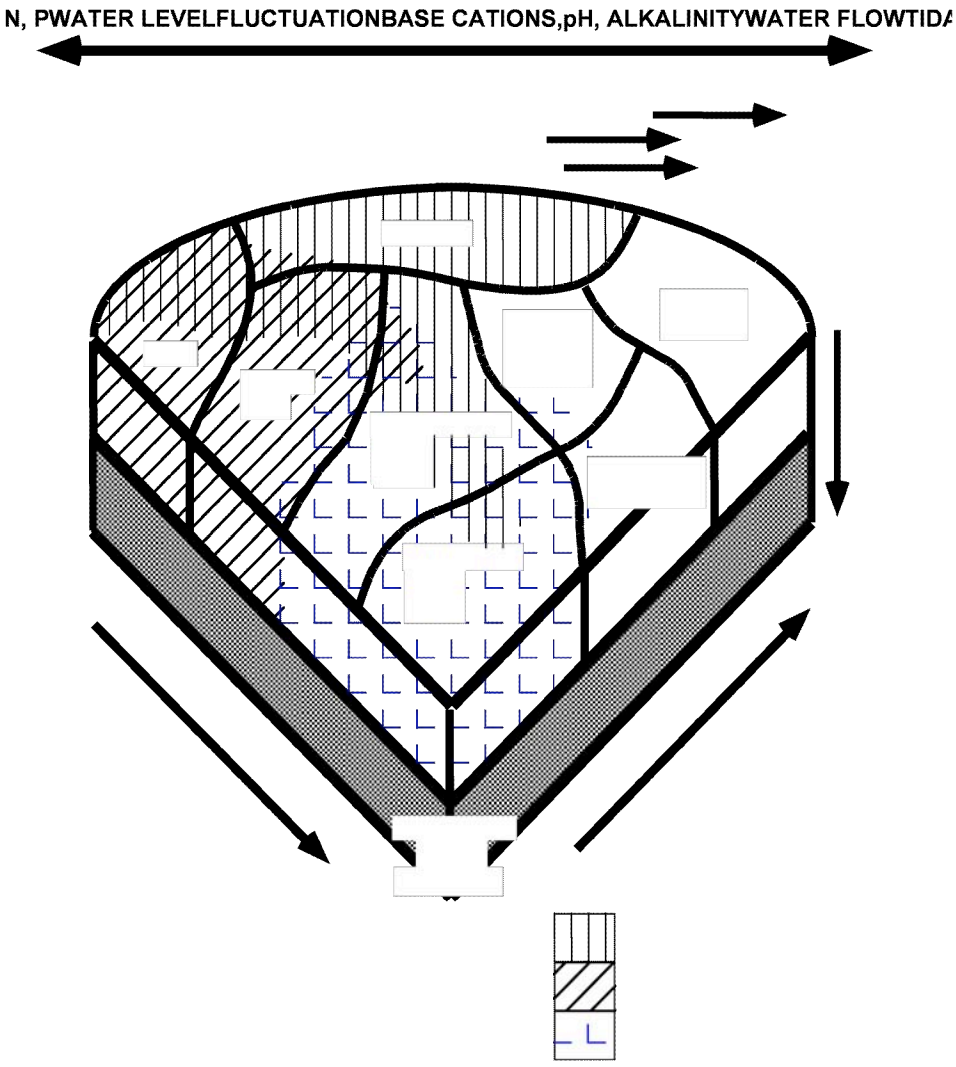
The establishment of a moss layer results in the accumulation and maintenance of nutrients in a non-available form, reducing vascular plant production. Stabilized water levels, anaerobic conditions, and decreased nutrient availability lead to a substantial decrease in decomposition rates. This results in the development of peat accumulating ecosystems (Vitt and Kuhry 1992). Alberta peatlands are classified into geogenous ***fens*** and ombrogenous ***bogs***, each with distinctive indicator species, acidity, alkalinity, and base cation content (Figure B1).

Fens are geogenous ecosystems that are affected by mineral soil waters (ground and/or surface) that may be relatively rich in mineral elements. Fens can be subdivided on the basis of hydrology into: soligenous and largely influenced by flowing surface water; topogenous and largely influenced by stagnant ground water; or limnogeneous and largely influenced by associated lakes and ponds. All three fen types have water levels at or near the peat surface. Soligenous fens commonly have discrete patterns of open pools (flarks) alternating with elongate, shrubby to wooded ridges (strings) oriented perpendicular to the direction of surface water flow. These patterned fens may be either acidic or basic. Topogenous, limnogenous, and some soligenous fens are non-patterned. Fens can be open and dominated by *Carex*, *Scirpus*, and *Eriophorum*; shrubby and dominated by *Betula* and *Salix*; or wooded to forested and dominated by some combination of *Picea mariana*, *Larix laricina*, *Betula*, and *Salix*.

In the past, fens were subdivided on the basis of the number of indicator species: low for poor fens, high for rich fens. This gradient of indicator species correlates with a chemical gradient (Sjörs 1952). Poor fens are acidic (pH 4.5 to 5.5), poor in base cations and have no or little alkalinity. They are dominated by oligotrophic and mesotrophic species of *Sphagnum*. Moderate-rich fens have slightly acid to neutral pH (pH 5.5 to 7.0), low to moderate alkalinity, a ground layer of brown mosses (namely, *Drepanocladus*, *Brachythecium*, *Calliergonella*), and low abundances of mesotrophic species of *Sphagnum*. Extreme-rich fens have basic pH (above 7.0), high concentrations of base cations, and high alkalinity. They are characterized by species of *Drepanocladus*, *Scorpidium*, and *Campylium* and may contain marl deposits.

Bogs are ombrogenous peatlands that receive their surface water only from precipitation and have low water flow. The water table is generally 40 to 60 cm below the peat surface. For these reasons bogs are acidic ecosystems with pH below 4.5; they are poor in base cations and have no alkalinity. Bogs are dominated by oligotrophic species of *Sphagnum*, feather mosses *Pleurozium schreberi* and *Hylocomium splendens*, and lichens of *Cladonia* and *Cladina*. They may be open, wooded or forested with trees limited to *Picea mariana*. As a result of the low thermal conductivity of dry *Sphagnum*, bogs have lower surface water temperatures than other surrounding organic and inorganic soils. Permafrost is consequently restricted to bogs at its southern limit, where it forms peat plateaus and palsas (Vitt et al. 1994).

Figure B1 Ternary diagram of wetland classes and their relationship to chemical and biotic gradients (modified from Vitt 1994)



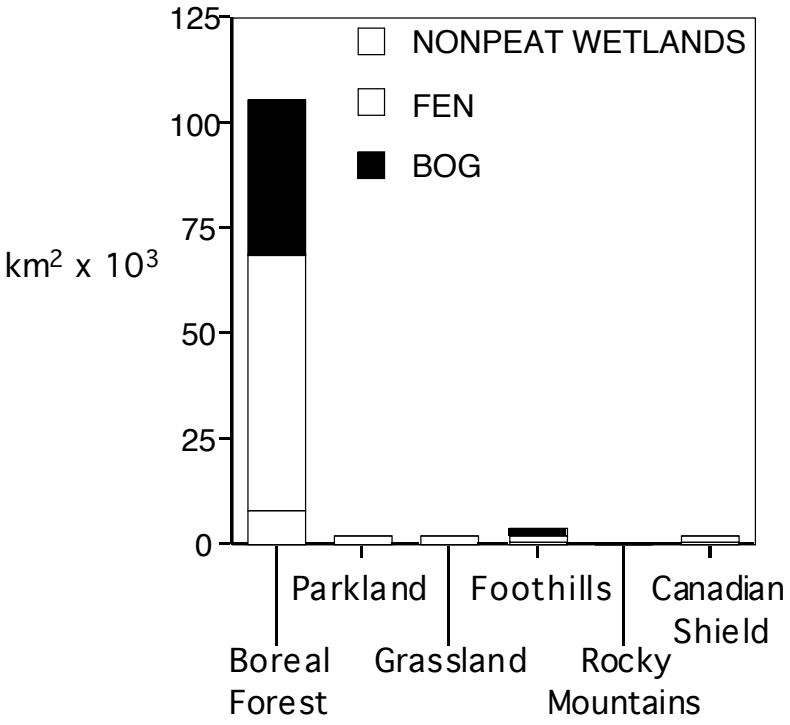
Peatlands form through the lateral expansion of peat over upland areas (paludification) or through infilling of lakes (terrestrialization) (NWWG 1988). Paludification occurs as a result of a rise in the regional water table induced by climatic change or mediated by local peat build-up. Terrestrialization results from sediment and peat infilling a water-filled depression, with aquatic habitats gradually becoming drier. Eventually, the original lake or waterbody can be completely covered with peat. In both scenarios (paludification and terrestrialization), large vegetation changes are evident (NWWG 1988). At the same time, chemical changes occur in the peatland due to peat build-up, isolating the surface from the underlying substrate, as well as through the processes of oligotrophication and acidification (Vitt 1994). Acidification produces complete changes in species, with nutrient stress also causing many species to be replaced by others more tolerant to oligotrophy or nutrient poor conditions (Vitt 1994). Typical successions begin with moderate-rich fens that become progressively poorer as *Sphagnum* invades (Vitt and Kuhry 1992). Bogs represent the “climax” of the succession,

with permafrost developing in climatically conducive areas (Vitt et al. 1994). Depending on allogenic factors, succession may begin or end at any phase of this sequence (Vitt and Kuhry 1992). Secondary internal developmental processes in both paludified and terrestrialized peatlands result in patterning, pool development, and the differentiation of hummocks and hollows (Vitt and Kuhry 1992).

B.2 Natural Wetlands: Types and Distributions

Approximately 114,000 km^2 of wetlands occur in Alberta, representing 18 % of the province's land-base (AEP 1996, Vitt et al. 1996). Most of these wetlands are peatlands (90.4%) found mainly within the Boreal Forest Natural Region (Figure B2), representing 11.3 Gtonnes of stored carbon (Halsey and Vitt, unpublished data). Non-peat accumulating wetlands dominate the Parkland and Grassland Natural Regions (Figure B2). The distribution and type of wetlands found within the province is controlled mainly by climate, specifically mean annual temperature and thermal seasonal aridity index (TSAI - total annual precipitation/ mean growing season temperature) (Vitt et al. 1996). TSAI has also been identified as the primary factor controlling the southern limit of peatlands (Halsey et al. 1998).

Figure B2 Wetlands in Alberta by natural region (data from Vitt et al. 1996, AEP 1996)



The presence or absence of salts within the substrate is also a significant variable explaining wetland variation across the province. Areas of equivalent climates have much higher amounts of non-peat accumulating wetlands when associated with solonetzic soils (Vitt et al. 1996). This can be related to the inability of mosses to establish viable communities in areas associated with salinity (Vitt et al. 1993).

Substrate texture and topography as well as bedrock geology have also been identified as important controls on wetland type and distribution (Halsey et al. 1997). Substrates with high hydraulic conductivity support patterned fens in climatically conducive areas, while non-patterned fens and bogs are associated with substrates of relatively low hydraulic conductivity. Wetlands are extensive in areas with minimal topography and poorly integrated drainage, particularly along major drainage divides such as Alberta's northern uplands. Cover values are low in areas of steep slopes found along Alberta's foothills (Vitt et al. 1996). With respect to geology, acidic bedrock supports higher bog cover than calcareous bedrock where fens dominate (Halsey et al. 1997).

Since factors of climate and geology control wetland type and distribution, changes in these parameters lead to corresponding changes in wetland type and distribution. For example, climatic change during the Holocene led to climatic shifts in wetland distribution (Halsey et al. 1995; 1998), while climatic change predicted by greenhouse gas induced warming could have equally significant impacts on wetland distribution (Gorham 1991). Similarly, development of oil sands leases will significantly alter landscape structure with wetland reclamation goals constrained by this new landscape. Wetland types in the reclaimed landscape may be significantly different than those present prior to mining as the geologic factors controlling wetland distribution are changed.

B.3 Natural Wetlands: Classification and Properties

Table B1 provides information on wetland classification according to the Alberta Wetlands Inventory and ecosites of northern Alberta. Table B2 describes properties of the various types of wetlands.

Table B1 Comparison of Alberta Wetlands Inventory (AWI) forest classification and the Field Guide to Ecosites of Northern Alberta

ALBERTA WETLANDS INVENTORY[a]			FIELD GUIDE ECOSITES[b]
CLASS	**SUBCLASS**		
Shallow open water (W)	n/a	n/a	n/a
Marsh (M)	n/a	n/a	Marsh (l1)
Swamp (S)		Coniferous swamp (Stnn and Sfnn)	Wetter end of horsetail (f)
		Deciduous Swamps (Sons)	any upland ecosites phases
Fen (F)	Open fen (≤10% tree cover)	Patterned fen (Fop)	
		Non-patterned shrubby fen (Fons)	Shrubby poor fen (j2) and shrubby rich fen (k2)
		Non-patterned graminoid fen (Fong)	Graminoid rich fen (k3)
	Wooded fen (>10% - ≤70% tree cover)	No internal lawns (Ftnn)	Treed poor fen (j1) and treed rich fen (k1)
Bog (B)	Wooded bog (>10%, ≤70% tree cover)	No internal lawns (Btnn)	Treed bog (i1) and shrubby bog (i2)

(a) Halsey and Vitt 1996; (b) Beckingham and Archibald 1996. n/a = not applicable.

Table B2 Summary of general wetland types and their properties

Properties	Bogs	Fens	Marshes	Swamps	Shallow Open Water
Peat-forming	yes (*Sphagnum*)	yes (sedges, brown moss)	no	no	no
pH	strongly acidic	acidic to neutral	neutral to slightly alkaline	neutral to moderately acidic	variable
Water Level	near surface	at or near surface	fluctuates seasonally	at or near surface	intermittent or permanently flooded
Flowing Water	no	yes	yes	yes	yes
Nutrients	variable	variable	high	high	variable
Minerals	low	low to high	medium	medium	high
Dominant Vegetation	*Sphagnum*, ericaceous shrubs	sedges, brown moss or *Sphagnum* moss	emergent sedges, grasses, rushes, reeds, submerged and floating aquatics	deciduous or coniferous trees or shrubs, herbs	emergent or submerged vegetation

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Appendix C

Hydrology in the Oil Sands Region

C 1 – Maintenance and Dynamics of Natural Wetlands in Western Boreal Forests: Synthesis of Current Understanding from the Utikuma Research Study Area

by Kevin Devito[1] and Carl Mendoza[2]
[1] University of Alberta, Department of Biological Sciences, Edmonton, AB
[2] University of Alberta, Department of Earth & Atmospheric Sciences, Edmonton, AB

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C.1 Introduction

This appendix is intended to be a supplement to the Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (revised 2007 edition). It provides, first, a general synthesis of the literature on hydrologic processes controlling wetland development and maintenance from a Canadian perspective (Section 2) followed by, second, an overview of controls on type, function and maintenance of Boreal Plain wetlands of Alberta (Section 3). These are used as "natural analogs" and are related to some of the anticipated reconstructed landscapes from oil sands mining to facilitate optimal landform construction for wetland maintenance. This appendix makes use of, and incorporates the philosophy of, the hierarchical approach for defining dominant components of the water cycle and water resources as outlined in the companion Appendix C2 "A framework for classifying and assessing potential water resources: Comparison with Ft. McMurray," and Devito et al. (2005b). The background information on wetland hydrologic processes, natural wetland analogs, together with the accompanying Appendix C2, will aid the reader in conceptualizing the general requirements for wetland maintenance and in assessing the applicability of research findings from other regions in Canada, and elsewhere, to the Ft. McMurray area. For more detailed information on hydrologic processes the reader is further directed to several comprehensive reviews on wetland hydrology by Winter and Woo (1990), Mitsch and Gosselink (2000), and recent reviews by Burt and Haycock (1996), Deford (1999), Winter (2001), Price et al. (2000, 2005), and Buttle et al. (2000, 2005).

C.1.1 Objectives and Questions

The overall goal of the CEMA Wetlands and Aquatics Subgroup is to determine how best to create sustainable wetlands, and the accompanying viable ecosystems, on reconstructed landscapes in the mined oil-sands region. To achieve this, it is necessary to determine what the development trajectory will be (i.e., how long wetlands will take to become established) and how they will be, or can be, maintained. This primary goal leads to accompanying design questions: What types of wetlands can be constructed? Where can these wetlands be constructed? What spatial relationships between geological material(s), landforms and vegetation are required?

One way of addressing these issues is to examine the hydrologic processes operative within natural systems. We refer to these systems as natural analogues. However, interpretation and generalization of studies on natural analogues will be facilitated by a better understanding of general principles and concepts that determine or influence wetland type, function and maintenance. Through a literature review summarizing our understanding of wetland hydrologic processes in a Canadian context, together with observation and measurement of hydrologic properties and responses within appropriate natural analogues, we can determine which processes and factors currently dominate within particular climatic, geologic, vegetative, and topographic regimes, and we can quantify how they might change over time. At present, we are at the stage of quantifying how existing systems perform, and how they respond to climatic forces and anthropogenic effects over the short term (i.e., seasonal, to annual, to decadal timeframes). This aids in understanding the importance of underlying processes and current development of comprehensive models to predict how wetlands will evolve over the long term (i.e., many decades to centuries).

Knowledge of how natural analogues function can provide insight into how best to create or encourage the natural development of wetland features in the reconstructed landscape. The temporal trajectory for the evolution of these wetlands is not known yet. However, by

determining the important, existing, features and characteristics of natural wetlands, in a number of different scenarios, we can be reasonably assured that designed wetlands that have these same characteristics will show promise of developing along similar lines. That is, if a wetland is designed to be analogous to natural systems, they should evolve into similar features. The time required for such an evolution is not presently known; however, choosing the optimal configurations should enhance the rapid development of some wetlands.

C.1.2 Outcomes

The next section, "Wetland Hydrologic Processes", illustrates how wetland hydroperiod (i.e., water level fluctuations) are influenced by interaction of the water balance, water storage potential, and geologic setting in determining the variety of wetland functions and forms. With an understanding of the material in Section 2, the reader will be able to make an informed decision on:

- **what types of wetlands can be constructed on reconstructed landscapes;**
- **what types of wetlands can form spontaneously;**
- **where wetlands can be constructed, and what spatial relationships with landforms (in interaction with climate) are required; and,**
- **what substrate materials are required and how they should be arranged**.

The following section, "Natural Analogues", provides an overview of recent research in the requirements for maintenance and long term sustainability of boreal plains wetlands over a range of hydrogeological conditions. For more specific details the reader is directed to several recently published papers on boreal plains wetlands (e.g., Smerdon et al., 2005; Ferone and Devito, 2004; Devito et al., 2005a,b).

With an understanding of the hydrology of natural analogue wetlands on the Boreal Plain and adjacent forests the reader will be able to make informed decisions to:

- **determine the requirements for wetland development and permanence, and their function;**
- **relate similarities and differences of reconstructed to natural landscapes to:**
- **further estimate needs for creation and maintenance;**
- **assess the influence of vegetation and landform succession on permanence of wetland function; and,**
- **assess future scenarios or trajectories of constructed wetlands, and determine potential time periods for wetland development**.

This appendix is not provided to list wetland types that can or cannot be constructed, nor to determine required wetland functions, as these are numerous and vary with user groups (see Kennedy and Mayer, 2002). Rather, the overall objective is to provide the reader with a basic understanding of wetland hydrologic requirements. This will allow the reader, or planner, to assess potential wetland functions, and to determine the trajectory of constructed wetlands necessary to ascertain if the wetlands and adjacent forests can be maintained. Where necessary, knowledge gaps and areas for future research are highlighted.

C.2 Wetland Hydrological Processes

Wetlands are ecosystems that are transitional between truly upland and truly aquatic environments. Therefore, hydrology is a key determinant for establishing and maintaining a range of wetland types. Furthermore, hydrology creates the living physiochemical conditions that make wetland ecosystems different from well-drained terrestrial systems and deep water

aquatic systems. In fact, wetland hydrology determines wetland processes and functions (Mitsch and Gosselink, 2000).

The range of types of wetlands occurring throughout Alberta and in the Ft. McMurray area is provided in Figure 1 (Vitt, 1994). As described in other appendices, wetland vegetation type and potential succession of wetlands are controlled by water source, rate of water flow, and water table fluctuations (hydroperiods) which influence nutrient and alkalinity availability, as well as substrate decomposition and accumulation (Figure 1). Water and nutrient availability are further affected by the geologic setting, which influences the wetland interaction with the surrounding environment. This section introduces the basic hydrological processes and controls of wetland type and function, the hydroperiod, and illustrates how it is influenced by water balance and water storage capacity. The role of geologic setting on maintaining an ample and persistent supply of water at the ground surface is demonstrated through examples in Section 3.

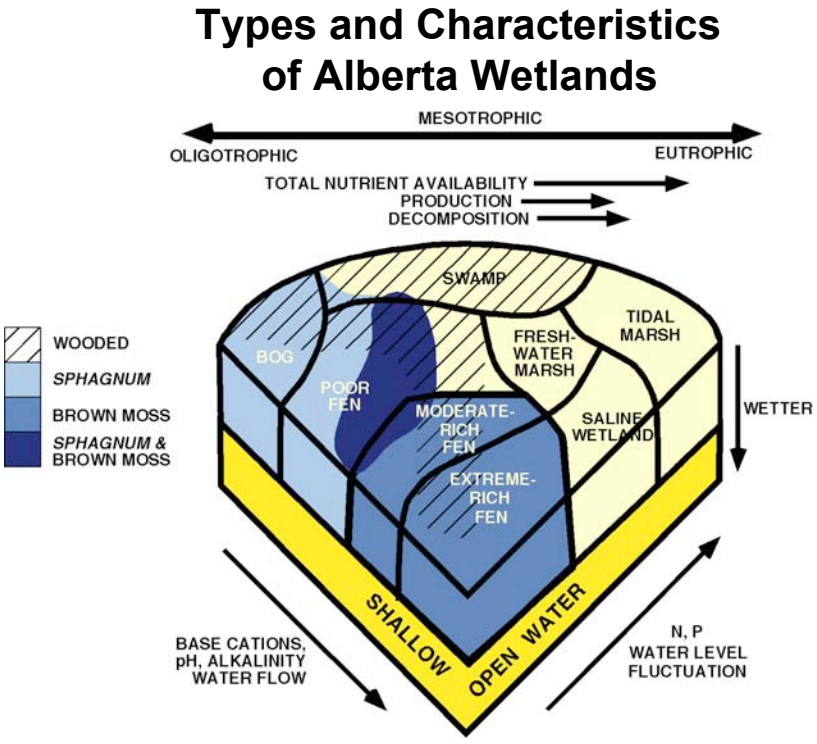


Figure 1 Ternary diagram of wetland classes and their relationship to chemical and biotic gradients (modified from Vitt et al. 1996).

C.2.1 Wetland Hydroperiod

Wetlands are defined as land areas where soils are water saturated long enough to support water loving vegetation (NWWG, 1988). Thus, the seasonal pattern of flooding duration and frequency, and water depth are fundamental for wetland development and maintenance. This pattern, described as the hydroperiod (_WL), is the hydrologic signature of a wetland, and varies among and within wetland types (Figures 1 and 2). The hydroperiod influences the route or pathway of water and the frequency of flooding (Figure 3), the transport of energy and nutrients, the soil biogeochemistry (redox in sediments) and chemical cycling, and ultimately, the establishment and succession of vegetation and other biota within a wetland (Devito and Dillon, 1993; Hill, 1996).

The hydroperiod is defined by Mitsch and Gosselink (2000) as:

$$\mathbf{\_WL = \_Vol \div [A(WL)\_SY]} \qquad \mathbf{(1)}$$

water budget ÷ [water storage potential _ sediment properties]
("Dynamic") ("Static")

Where:

_ = delta, change	**A** = wetland area
WL = water level	**A(WL)** = area function of WL & basin morphology
Vol = water budget (inputs & output)	**SY** = soil specific yield or water holding capacity

The **water balance** (_Vol) represents the balance of water inflows and outflows in the wetland. Water balance is described as temporally dynamic (i.e., it has daily, seasonal, or longer variations). It influences the direction and duration of water table responses.

The size or amplitude of the water table response is influenced by the **water storage potential** of the wetland. This is relatively non-dynamic and varies with area (A) and depth of the surface contour of the wetland basin or depression (morphometry), the hydraulic properties of the sediments within the basin, and the current water levels (antecedent moisture) in the wetland (Mitsch and Gosselink, 2000; Price et al., 2005).

The **geologic setting**, is non-dynamic, and influences development of wetland basin morphometry, properties of substrates within the basin, and storage potential, or groundwater inputs. Geologic setting also interacts with climate to influence the dominance of water balance components, such as surface water versus groundwater interactions (Winter, 2001).

The hydroperiod of a given wetland is a complex interaction of the three factors described above. Thus, wetlands with similar vegetation and classification may actually have different water balance (or climate) interacting with different basin morphometry and geologic setting to produce similar hydroperiods. In the case of reconstructed oil sands landscapes, it is therefore possible to manipulate basin morphometry and geologic setting (which are largely static) for a given climate (which is dynamic) to generate sites with a range of hydroperiods necessary to support a variety of wetland types (Figure 1).

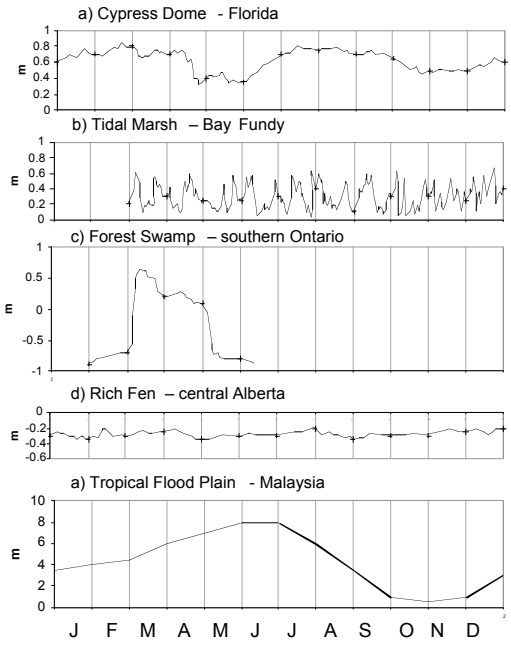


Figure 2 Hydroperiod of several wetlands (modified from Mitsch and Gosselink 2000). Vertical axis denotes water level depth relative to ground surface. Differences in the amplitude and period of water table fluctuations reflect differences in climate control on water budget and geologic setting.

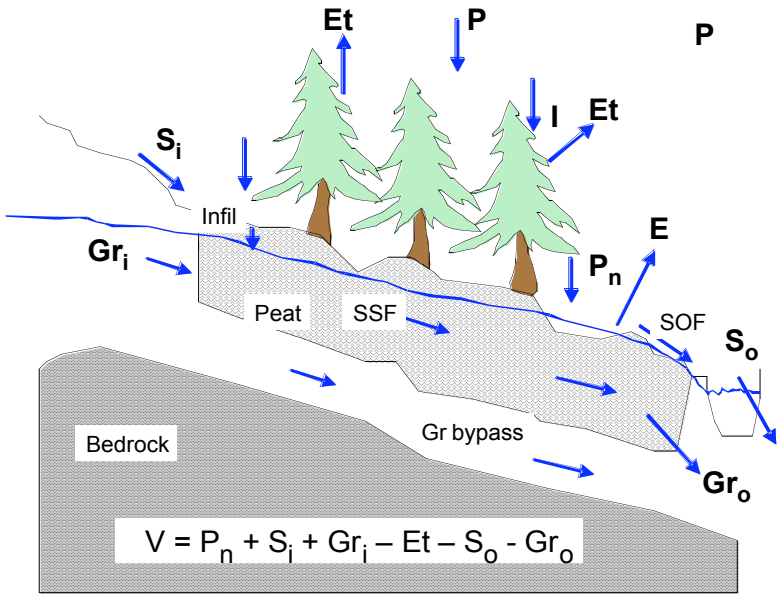


Figure 3 The dominant components of a representative wetland water balance. _V = change in water volume, P = gross precipitation, P_n = net precipitation, I = interception, S_i = surface water inflows, Gr_i = groundwater inputs, E=evaporation, Et = evapotranspiration, S_o = surface outflows, Gr_o = groundwater outputs. Internal pathways of infiltration, saturation overland flow (SOF), and subsurface flow (SSF) are shown.

C.2.2 Wetland Water Budgets

The change in water volume in a wetland is a balance between inputs from net precipitation (P_n), surface water (S_i) and groundwater (G_i), and outputs via evaporation and transpiration (ET), surface water (S_o) and groundwater (G_o) (Figure 3, Equation 2). In fresh or saltwater coastal systems, the ebb and flow of lake sieches or ocean tides (T) also influence the water balance.

$$\Delta Vol = P_n + S_i + G_i - ET - S_o - G_o \pm T \qquad (2)$$

Where: +i are inputs and -o are outputs.

The water balance (or change in water volume) provides a summary of all major hydrologic components over a given time period. It influences the persistence of water necessary for wetland maintenance, and is a major vector for nutrient transport to and from wetlands (Mitsch and Gosselink, 2000; Winter and Woo, 1990; Price et al., 2005). The water balance will affect the dynamics of wetland water levels. The importance of each component can vary seasonally and between different wetland types (Figure 1). Therefore, an understanding of the important characteristics of each water balance component is essential to be able to assess wetland function.

C.2.2.1 Precipitation

Precipitation (**P**) is a component of all wetland water balances and varies spatially and temporally throughout Canada (Figure 4). Precipitation depths range from less than 300 mm to approximately 2000 mm throughout Alberta (Hydrologic Atlas of Canada, 1977).

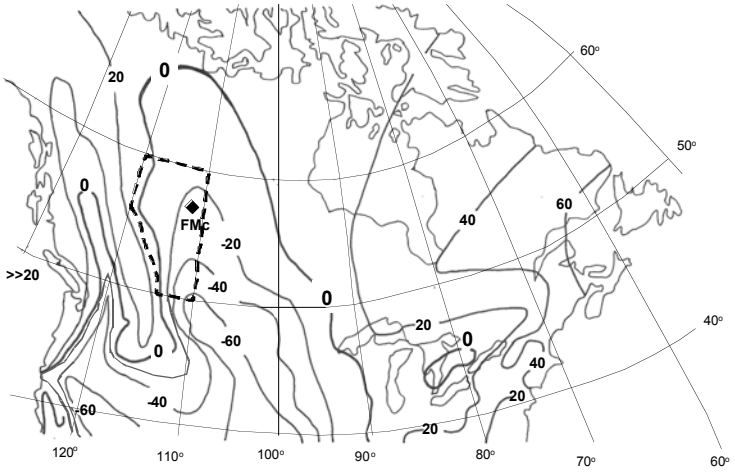


Figure 4 Annual precipitation (P) less open water evaporation (PET) in millimetres in North America. After Winter and Woo (1990), and Woo and Winter (1993).

The form of precipitation (solid snow, sleet, hail and liquid rain, fog) greatly influences temporal dynamics of hydrology (Woo and Winter, 1993). Accumulation of precipitation as snow acts to initially store precipitation and reduce inputs to wetland surfaces during the winter. However, subsequent melt effectively redistributes several months' precipitation into a small number of hydrologic events and increases flooding. Up to 50% of annual precipitation may accumulate in snow in Eastern and Montane regions of Canada, and snow melt is often a major component of wetland inputs (Price et al., 2000; Buttle et al., 2005). However, in the Boreal Plain region, where Ft. McMurray is located, snow accumulation typically accounts for less than 30% of annual precipitation, with accumulations of less than 100 mm. Thus, the influence of snow melt on wetland water balances on the Boreal Plain is reduced as compared to other Boreal and Montane regions.

During winter, drifting can redistribute snow from large areas into wetland depressions, effectively increasing annual snow inputs by an order of magnitude (Hayashi et al., 1998). Indeed, drifting snow can represent a major source of water to Prairie and Arctic depression wetlands, and may provide a major water source to newly constructed wetlands on oil sands leases (Winter and Woo, 1990; Woo and Winter, 1993). Modest upland vegetation growth, however, eliminates drifting snow as a source of water (van der Kamp et al., 2003), and thus drifting of snow may not be a viable source of water on oil sands leases following upland re-vegetation.

Net precipitation (**P_n**) reaching the wetland surface is a function of total precipitation measured in an open area (P), less rainfall intercepted (**I**) by vegetation (Figures 3 and 5). Intercepted P evaporates, with no contribution to wetland water balances. Interception can be as high as 5-10% of P (Buttle et al., 2000). Total I will vary among wetlands with different adjacent or *in-situ* woody vegetation densities and types. Temporal variations in I can be found in areas with predominantly deciduous vegetation (Buttle et al., 2000). The amount of I is also a function of season (snow vs. rain), or storm size and intensity as a greater percentage of rainfall will be intercepted with relatively low rainfall intensities, and intense rainfall events will result in more flow through. In wetlands where vegetation is developing over time, such as in newly constructed systems at Ft. McMurray, P_n inputs to the wetland surface may decrease by as much as 30-50 mm per year as a result of increased I due to re-vegetation.

C.2.2.2 Evapotranspiration

Atmospheric losses can occur by free water evaporation (**E**) and transpiration through vegetation, collectively called ***evapotranspiration*** (**ET**) (Figure 3). ET occurs in all wetlands, with maximum rates of 3-4 mm per day, and totals of 300-700 mm per annum in Canada. Rates in Canada are highly seasonal, with peaks in mid-summer, and low to no ET in late fall to early spring (Roulet, 1990; Winter and Woo, 1990). In continental western Canada, ET can be the dominant output of wetland water balances (Devito et al., 2005a,b).

ET losses from wetlands depend on meteorological, physical and vegetation conditions. ET rates are a function of gradients in vapour pressure at the water or leaf surface and that of the surrounding air. The vapour pressure at the water and air surface is influenced by solar radiation and surface temperature. Vapour pressure of the air is influenced by relative humidity and wind speed. Thus, increases in solar radiation and temperature, together with low humidity and low protection from wind can maximize ET losses. Wetlands sheltered by large trees or hills may experience up to 30% less ET than those which are more exposed. This may have a significant influence on annual water balances and water levels, particularly

in sub-humid to arid climates (Petrone et al., 2005). A sub-humid climate is representative of the Athabasca oil sands region.

ET rates are often reported as potential evapotranspiration (**PET**). PET refers to the rate of water removal that could occur based on temperature and humidity with ample availability of free water (Roulet, 1990; Eaton and Rouse, 2001). Actual evapotranspiration (**AET**) is the amount of water actually removed, and may be much less than PET if water availability is restricted (e.g., below the rooting zone of trees). Conversely, AET can be more than PET as a result of surface heating or wind turbulence (Roulet, 1990; Petrone et al., 2005). The ratio of AET/PET (often called the alpha "_") is a useful measure in managing wetland systems, and understanding how AET varies spatially and temporally is a key area of research in wetland hydrology.

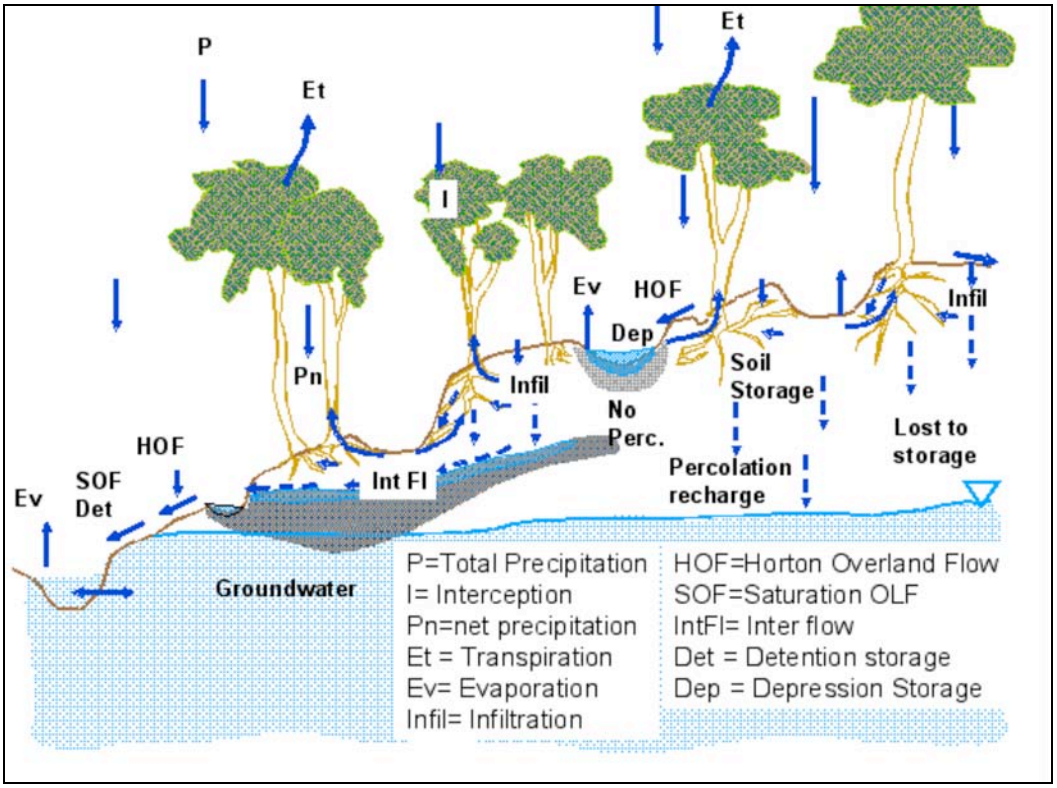


Figure 5 Possible routes for precipitation flow through a forested uplands. See legend for explanations.

The type of vegetation and its stage of development can have a large influence on AET/PET ratios (i.e., _), and subsequently, on the wetland water budget (Roulet, 1990). Growth of emergent vegetation in open water can shade the water surface, and stomata in leafs and stems can restrict water flow, reducing AET. In depression wetlands, willow and aspen vegetation in the riparian area can "pull" water from an open pond into the adjacent hill slope (Hayashi et al., 1998; Meyboom, 1966). This does not directly affect AET of the surface water, but increases losses from the wetland pond via lateral groundwater movement. When water percolates below the surface, the depth of the rooting zone becomes important. In mineral soils or drained upland areas, vegetation uptake through roots can increase AET and

water losses compared to free surface conditions. Thus, encroaching vegetation with roots extending below the water table of dry surface sediments can increase atmospheric water losses; however, in many saturated soils and peatland systems, root depths are restricted to the top 30-50 cm of the wetland soils and do not extend below the water table. AET/PET ratios can shift from 1:1 when the sediments are saturated to much less than 0.6:1 when the water table falls below the rooting zone (Petrone et al., 2005). Reduction in AET by selecting vegetation with restricted root depth can thus conserve water in wetlands during dry periods.

In Boreal and Prairie forest and wetland systems, snow interception and subsequent sublimation during cold and dry winter conditions can represent water losses of up to 30% of accumulated snow depths (Buttle et al., 2000, 2005). Because snow can readily be held on the branches of conifers, snow sublimation is much greater in conifer forested wetlands compared to deciduous forested wetlands. Sublimation losses in the Boreal Plain can exceed 30–40 mm annually. Given the already limited runoff from snow melt and general sub-humid climate, these losses can be significant as compared to wetlands in more humid climates.

C.2.2.3 P-ET, Ultimate Source of Water

It is not P depths (or amount) alone, but rather the difference between P and ET that is probably the most important measure to determine the influence of climate (Figure 4). This difference represents the ultimate source of water directly available to wetlands, as well as recharge for surface and groundwater inputs. Since bogs receive only rainfall (ombrotrophic), the P = PET line is crucial in determining bog formation and distribution.

An examination of the distribution of P-PET (Figure 4), illustrates that although the western Montane regions of Canada may receive high annual P, ET is also high, and there is moderate excess water for wetland maintenance. The largest distribution of wetlands occurs in eastern Canada because, although annual P is moderate, ET rates are relatively low and there is sufficient excess water for wetland maintenance. This contrasts with west central Canada, where annual PET exceeds P and, in most years, soil moisture is in water deficit. In these sub-humid to arid climates, external water sources such as surface and groundwater inputs become critical to wetland maintenance.

One further important consideration in wetland formation and maintenance is the seasonal synchronization of precipitation with vegetation growth and potential evaporation and transpiration. In western and eastern Canada, snow melt occurs in the spring and rainfall peaks in the fall when ET rates are low (Buttle et al., 2005). As a result, seasonal excesses in water occur in wetlands from direct precipitation as well as from surface runoff. In contrast, continental Boreal Plains and Prairie eco-regions receive most of their annual precipitation as rainfall during mid-summer, when ET rates are greatest. The synchronization of rainfall with peak vegetation water demand and evaporation limits direct P inputs and runoff inputs (Carey and Woo, 2001; Devito et al., 2005a). In these climates, consideration of long term wet and dry cycles along with vegetation cycles is required in addition to seasonal cycles (Mitsch and Gosselink, 2000).

C.2.2.4 Surface and Stream Flow

Surface water inputs can potentially occur in all wetlands, with the exception of bogs, and may dominate if a wetland is part of a river or stream network (Figure 3). Flow is often seasonally variable as controlled by patterns of precipitation and spring snow melt.

Detailed flow path of water on hill slopes to streams or ponds is illustrated in Figure 5. Two types of flow are most frequently recognized: ***overland flow*** (**OF**) and ***channel flow*** (Mitsch and Gosselink, 2000). Overland flow refers to non-channelled sheet flow occurring over ground. It may occur as ***Hortonian OF*** (HOF) when rainfall or snow melt intensities exceed soil infiltration rates. This occurs during large storms in arid environments, in poorly vegetated regions, or in areas with compacted soils or frozen soils (Woo and Winter, 1990). Generally, it is not a dominant flow path in forested areas (Buttle et al., 2005). ***Saturation excess OF*** (SOF) is common where the water table intersects the surface, reducing infiltration and resulting in increased surface flow (Hammer and Kadlec, 1986). Wetlands, ephemeral draws, and riparian areas are often saturated and support SOF during rain storms or snow melt (Buttle et al., 2005; Price et al., 2005). The flood storage capacity of wetlands is often overstated, and in certain geologic settings, wetlands function as storm runoff generating areas (Hill, 1996; Price et al., 2005; Waddington et al., 1993).

Channel flow into wetlands is a combination of surface and groundwater inputs to the stream. As seen in Figure 5, movement of precipitation from the hill slope to a stream or pond is a complex interaction of flow paths related to vegetation water demand, soil storage, soil texture, and surface depressions. Since the intensity of most precipitation events is not greater than ***soil infiltration*** (**Infil**) rates, hill slope runoff is controlled by soil water storage and soil texture. Infiltrating water may be initially stored in the soils, and be subsequently taken up by plants. If intercepted in this way, it will not contribute to runoff (Far right, Figure 5). Infiltrating water may percolate directly to the groundwater table and either enter groundwater storage, or move slowly to the stream or wetland. Alternately, water may infiltrate past the roots, exceed soil water holding capacity, and flow along layers of lower permeability towards the stream as ***interflow*** (**Int Fl**). In humid regions, soils are often wet and near maximum holding capacity (i.e., have high antecedent moisture). In these regions runoff occurs during most precipitation events (Buttle et al., 2005; see Appendix C2). In sub-humid regions, soil moisture can be reduced between precipitation events and soil storage can take up precipitation and limit contribution to runoff (Devito et al., 2005a,b). In these areas, surface runoff is often unrelated to annual or seasonal rainfall depths.

General empirical relationships of catchment size, soil texture, runoff amount and timing can be found in the literature. These are important for controlling wetland water level fluctuations, vegetation growth, and tolerance to flooding (Mitsch and Gosselink, 2000). The larger the catchments, the greater the potential for deeper, subsurface storage and release, and thus in large catchment areas, surface flow tends to occur year round. In regions of impervious rock or high clay content, soil and groundwater storage is reduced, and variable flow regimes occur. Higher peak flows are observed during storms, and extended periods of no flow may occur during dry periods. In areas with permeable (i.e., sand) and deeper substrates, soil and groundwater storage moderate upland runoff, resulting in lower peak storm flows and more sustained stream flow during dry periods.

Interaction between climate and hill slope runoff results in rather predictable variability in seasonal flow across North America (Mitsch and Gosselink, 2000). For example, peak stream flows tend to occur during the winter in west coastal Canada, and during early spring in eastern Canada. In contrast, peak flows occur during late spring or early summer in continental boreal plains regions (Devito et al., 2005a). Such differences in flow regimes illustrate that care is required when extrapolating interaction of flood events with vegetation growth and timing of flood tolerance in wetlands from one part of Canada to another.

C.2.2.5 Groundwater

Groundwater interactions are potentially important in all wetlands, and more common than the ecological literature suggests (Reeves et al., 2000; Hayashi and Rosenberry, 2001). Groundwater inputs and outputs are less seasonal than surface water, and dominance of groundwater inputs tends to moderate water table fluctuations in wetlands (Winter and Woo, 1990; Winter, 2001). However, wetlands can have several groundwater functions (Figure 6). The ***recharge*** (water moves down away from the water table surface) or ***discharge*** (water moves up towards the water table surface) function of a wetland can influence water table fluctuations and susceptibility to drying, water chemistry and ultimately vegetation dynamics. It is difficult to generalize without an understanding of the geologic setting (see Section C.3). Often when the water table in the adjacent hill slope is below that in the wetland, the wetland is in a groundwater recharge region, and loses wetland water to the groundwater (Figure 6). When the water table in the adjacent hill slope is above that in the wetland, the wetland is in a groundwater discharge region, and gains water from the groundwater. In many cases, flow through conditions occur where groundwater discharges at one end and recharges at another (Figure 6). Recent studies have further shown that groundwater flow direction can be extremely dynamic, reversing from recharge to discharge (or vice versa) at one location 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).

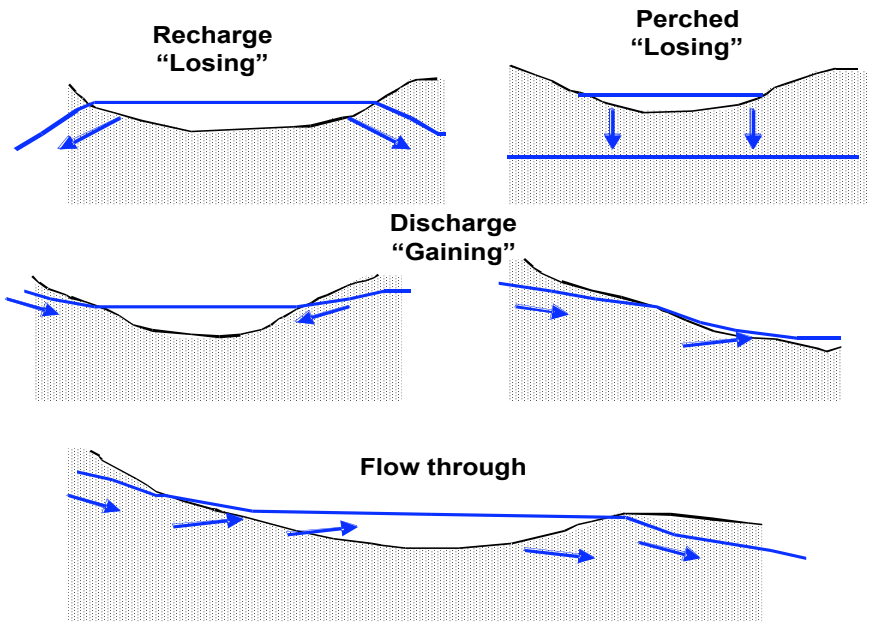


Figure 6 Possible recharge, discharge or flow through groundwater functions of wetlands. After Mitsch and Gosselink (2000).

The importance of area on groundwater movement is best illustrated in an example using the generalized Darcy equation (after Mitsch and Gosselink, 2000),

G = K _ Ax _ s
(3)

Where:
G = groundwater flow (volume/time)
K = hydraulic conductivity (length/time)
Ax = cross-section area, perpendicular to flow
s = water table slope or hydraulic gradient

Although groundwater movement may be slow (e.g., cm per year), it is important to understand that the area of interaction with groundwater can be very large, resulting in large volumes of water entering or leaving a wetland system (Toth, 1999). For silt substrates, a reasonable K is 1_10^{-5} cm/s (Freeze and Cherry, 1979). With a water table gradient (s) of 0.1, groundwater would travel at approximately 0.5 mm per day or approximately 170 mm per year. This may appear to be of little significance, but the face of many ground water seep zones can represent half of the wetland area. If this is the case, groundwater from relatively low permeable silt can contribute almost 100 mm of water to the wetland per year. In continental Canada, this volume can be double the deficit of P-ET and can therefore be the source of water that maintains the wetland. For a sand area with a K of 1_10^{-2} cm/s and an s of 0.01, water will flow at almost 2 m per day or 700 m per year. This is still relatively slow movement compared to surface water velocities, but if the discharge zone occurs over as little as 1% of the wetland, G_i can be as much as 700 mm and can easily dominate the water balance of a wetland relative to precipitation. Thus, when conceptualizing the influence of groundwater movement on water balances, the area of interaction with groundwater must be considered. A small movement of groundwater from an entire hillside or out of a wetland (Figure 6) can translate into large volumes of water flow to or from the wetland or stream.

The scale of groundwater interaction between uplands and wetlands can vary due to topography and geology (Freeze and Cherry, 1979; Winter and Woo, 1990; see also Section C.3) which can further influence the hydroperiod, ephemeral nature, and chemistry of wetlands (Toth, 1999; Winter, 2001). ***Local flow*** systems recharge from the adjacent hill slope and discharge into a bordering depression (Figure 7). Due to the relatively short flow path, local groundwater flows have faster response to precipitation events, more seasonal regimes, and dilute chemistry compared to longer flow paths.

In ***intermediate flow*** systems, recharge from uplands flows beyond the adjacent depression, and in ***regional flow***, recharge from regional topographic highs flows and discharges into regional lowlands (Figure 7). Due to longer flow paths in regional groundwater systems, flow regimes are moderated and often respond to longer term (months to years) climate (P-E) cycles rather than short term weather events. Additionally, intermediate and regional groundwater flow chemistry often has higher salt content than local flow systems (Toth, 1999).

In summary, the dominant hydrologic component of each type of wetland may differ and this will, in part, explain differences in hydroperiod (water table fluctuations) and ultimately in wetland vegetation and type (Figure 1). Although precipitation (P) and evapotranspiration (ET) (Figure 3) occur in all wetlands, differences in stream inflow (S), groundwater (G), and also tides (T) result in the different influence of P and ET on wetland maintenance (Burt and

Haycock, 1996). It is important to understand the differences in dominant hydrological components between wetland types, and to understand differences in amount and seasonal cycling of each component in different climatic regions of Canada. However, when moving across regions with different climates, differences in the combinations of hydrologic components can result in similar seasonal changes in water volume in a wetland. Thus, wetlands with similar vegetation may have differing proportions of water balance components. The water balance further interacts with wetland morphometry and sediment soil storage properties (Equation 1), which are discussed next.

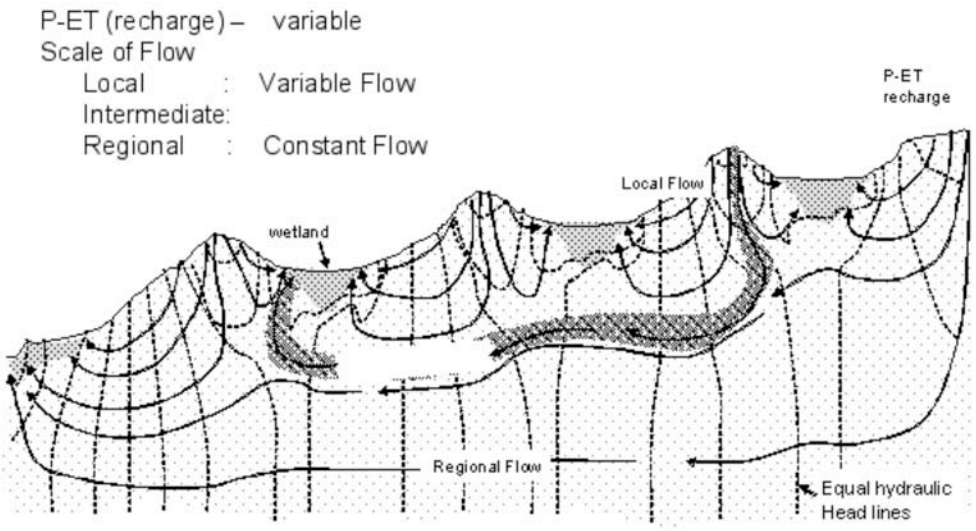


Figure 7 Representative cross section of aquifer illustrating local, intermediate and region scales of groundwater flow to basin wetlands. Modified from Winter and Woo (1990).

C.2.3 Water Storage Potential

The aerial extent and shape of a wetland basin is largely determined by geomorphological processes that influence the geologic setting. Basin morphometry and hydraulic properties of the sediments influence the rate of water level rise for a given change in water volume (water balance).

C.2.3.1 Surface Storage

In general, wetland hydrologists recognize two scales of surface storage: macro–scale storage represents the entire wetland basin, whereas micro-scale storage may occur in

smaller depressions that are poorly connected by a drainage network within the wetland. At the micro-scale, excavation by animals, such as beaver or muskrat, or an abundance of mineral sediments can increase storage of input waters (Mitsch and Gosselink, 2000). The hummock and hollow micro-topography that commonly forms in peatland wetlands also increases storage potential. While micro-scale storage may play an important role in maintaining saturated conditions or standing water through dry periods, micro-scale storage rapidly fills during storm events (Price et al., 2005). Micro-scale storage is often small and rapidly exceeded. Wetland development and maintenance therefore requires an understanding of water storage at the macro-scale.

Figure 8 illustrates differences in rate of area flooded and change in water tables with 3 different basin morphometries. The rate of water level rise depends on the current water level and the shape of the basin. The volume of storage potential is a function of the water level (WL) and the area (A) at that water level.

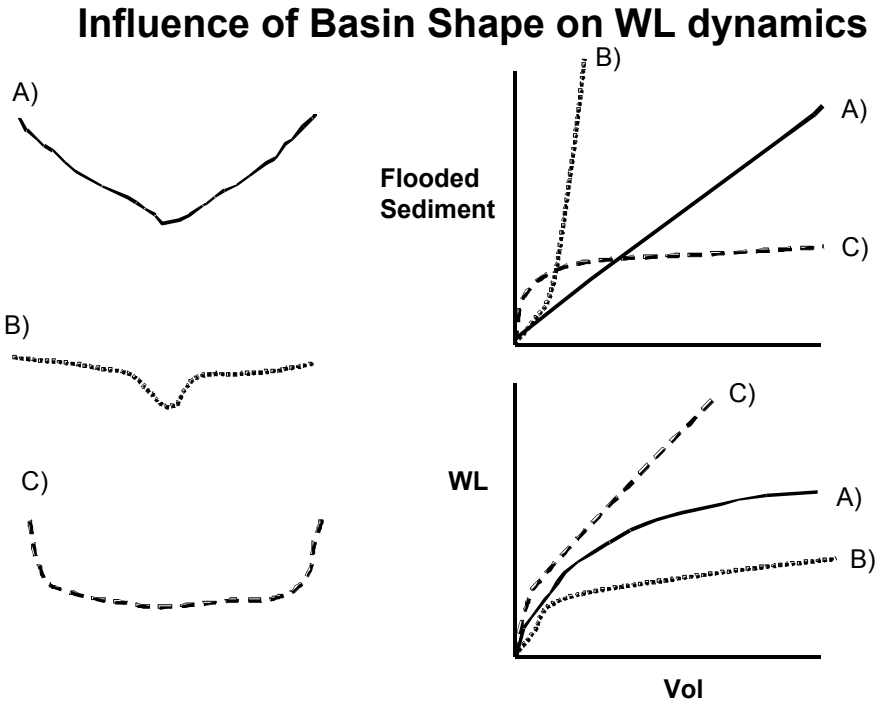


Figure 8 The conceptual influence of basin shape on changes in water level (_WL) or flooded sediment with a given net water balance input or removal (_Vol).

C.2.3.2 Sub-surface Storage

The ***specific yield*** (**SY**) of the sediments filling a wetland basin influences water holding capacity and accelerates water table fluctuations with _Vol. The storage potential is affected by the position of the groundwater table. Below the water table is the ***saturated zone***, where all soil pore spaces are filled with water and no storage is possible. The extent of the ***capillary fringe***, saturated soils above the water table held by capillary pressure, greatly influences storage potential. The height of the capillary fringe above the water table is largely controlled by pore size distribution. Table 1 illustrates the hydraulic properties of mineral and organic soils. In clay rich materials or compacted peat, small pore size can result in a capillary fringe extending 20 to 100 cm above the water table. There is little storage capacity in this zone, so additions of small amounts of water can result in rapid water table rises (Price et al., 2005).

Water storage is largely restricted to the ***unsaturated zone***, where some pores contain air and will allow water entry. Water storage capacity and rise in water level will largely be determined by the SY of the wetland sediments such that:

WT rise = 1 ÷ SY _ water input **(4)**

For example, substrates with SY of 0.1 (10% holding capacity), such as mesic peat or silty till (Table 1), will produce a water table rise 10 times that of the depth of water added. That is, a 10 mm rain event can result in a100 mm water table rise. The larger the specific yield, the smaller the water table rise per unit volume of water added. Furthermore, SY tends to decrease with depth. Thus, the response of the water table to a change in volume input will vary with the depth of the water table in relation to the depth profile of substrate hydraulic properties (Table 1).

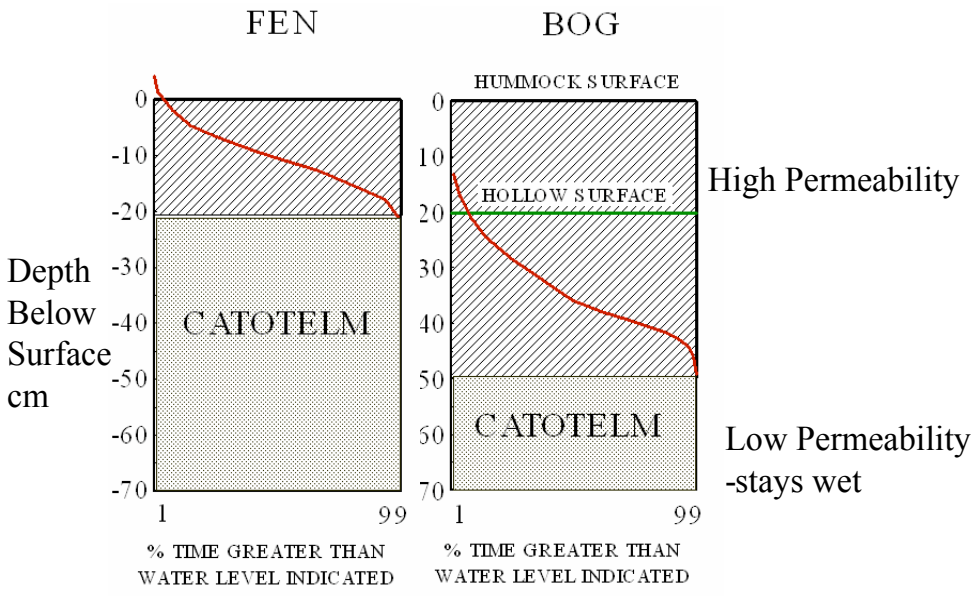
Sediments with small pore spaces and very low specific yield, such as many marsh sediments, can maintain saturated conditions near the surface due to an extended capillary fringe and large water table rises relative to water inputs.

Accumulation of ***organic soils*** (peat) and the resultant rapid changes in hydraulic properties with depth and compressibility of sediments influence water storage potential (Ingram, 1983; Price et al., 2005). Many peatlands have a diplotelmic structure, with a hydrologically active (i.e., experiences temporal changes in hydrologic conditions) surface layer, called the ***acrotelm***, overlaying relatively hydrologically inactive deeper layers called the ***catotelm*** (Figure 9) (Ingram, 1983). The diplotelmic structure maintains the water table near the surface, but limits overland flow erosion of surface materials. Thus, it is important in sustaining peatland development (Figure 1).

The acrotelm is composed of fibric peat with large pores, high K and high SY. As such, the acrotelm moderates water table rises within this zone, facilitates lateral flow, and prevents surface flooding. However, when the water table drops into the lower, compacted, humified layers, small pore size and low permeability detains water by greatly restricting lateral flow and water losses from the peatland. In addition, the very low SY of this layer results in large water table rises with small inputs. Thus, the water table rarely extends below the acrotelm (Figure 9), preventing drying of the peatland.

Table 1 Representative wetland and upland sediment and soil properties. After Mitsch and Gosselink (2000), Winter and Woo (1990), and Redding and Devito (2006).

	Hydraulic Conductivity (K) ($cm\_s^{-1} \times 10^{-5}$)	Specific Yield (%)	Porosity (%)
Marsh			
0 – 10 cm	310	50	90 – 95
10 – 50 cm	1	10	40 – 70
Peatlands (general)			
Fibric – surface / acrotelm	>150	>45	95 – 97
Mesic (or hemic)	1.2 – 150	10 – 45	78 – 94
Humic (sapric) / catotelm	<1.2	<10	
Mineral			
Clay	0.05	<<10	40 – 70
Till	0.5 – 1,000	10	40
Sand	5,000	>50	25 – 50
Gravel	1,000,000		25 - 40



Modified from Dr. J. Price, pers. comm

Figure 9 Differences between fen and bog peat in the location of water table relative to ground surface with the hydrologically active acrotelm layer, relative to catotelm (compacted deeper peat).

Dilation of pore structure in surface fibric and mesic peats further conserves wet conditions near the surface in diplotelmic wetlands (Price, 2003). The peat surface shrinks during water table draw down, and as water re-enters the wetland, surface peat swells. These changes in surface storage potential and hydraulic conductivity conserve water losses and maintain a constant water level relative to the peat surface. Conservation of the diplotelmic structure is important in maintaining and developing peatland wetlands (Ingram, 1983).

It is important to distinguish between detention and depression storage in order to understand long term water level controls. ***Depression storage*** confines water within an effectively impermeable basin and so, vertical groundwater losses are minimal. Water table draw down is controlled primarily by evapotranspiration (vertical fluxes). The basin must be filled for water to spill over and run off. Depression storage is prevalent in clay-lined, Prairie pothole wetlands.

Detention storage maintains water depth by resistance to outflow such that water cannot drain away faster than inputs. In contrast to depression storage, if inputs stop, the stored water will drain and the WT drops at a rate controlled by the surface roughness and/or the subsurface hydraulic conductivity of the outflow. An example of detention storage is water detained within the acrotelm of a large, gently sloping peatland.

In reality, the distinction between detention and depression storage is blurred because of heterogeneity in substrate hydraulic properties. Also, the substrate's ability to confine water movement for depression storage varies with depth.

In summary, interactions between wetland surface and subsurface storage, and wetland water balance in controlling wetland hydroperiod are apparent. Wetlands with a similar water balance, but different basin storage properties may experience different hydroperiods and develop different wetland vegetation and type. Furthermore, wetlands interact with their surrounding environment, and so, the geologic setting of wetlands influences both wetland water balance components and storage properties.

C.2.4 Wetland Geologic Setting

Wetlands are transitional ecosystems that are often positioned between upland and aquatic areas, resulting in a wide variety of hydrologic, biogeochemical and biological roles or functions (Brinson, 1993; Hill, 1996; Bradford, 1999). Wetland hydrology creates living physiochemical conditions that make wetland ecosystems different from well-drained terrestrial and deep water aquatic systems (Mitsch and Gosselink, 2000). The hydrologic role is driven by the interaction of a wetland with its surrounding environments as controlled by its position in the landscape, or the ***geologic setting*** (Winter and Woo, 1990).

A key question to consider when understanding the occurrence and function of wetlands is, "Why does a wetland exist in this location?" To address this question, the wetland needs to be examined in the context of its geologic setting. This provides information on landscape linkages in order to understand the processes that maintain the wetland, and ultimately to perceive the wetland's functional role (Winter, 2001). Knowledge of the geologic settings of a variety of wetland types provides a framework to determine how and where to construct wetlands, and to assess their future role.

As discussed previously, wetlands require a specific ***hydrology*** to provide excess water and to maintain water levels near the ground surface. These are the dynamic conditions that influence the timing and duration of the wetland hydroperiod. Of equal importance for

wetland existence is the specific ***geologic setting*** that favours ponding of water (water storage), or brings water to the surface to provide the physio-chemical environment for wetland biota. These are relatively constant conditions that vary between wetlands, and require the planner to adopt a catchment landscape approach to assess wetland functions (Winter and Woo, 1990; Winter, 2001).

When constructing wetlands on oil sands leases at Ft. McMurray, the planner must work with the existing climate, which will put limits on the hydrology of the wetlands. Since climate cannot be manipulated, the planner is restricted to contouring the landscape and controlling the placement of materials with different hydraulic properties in order to create the specific hydro-geologic settings required for a range of wetland types and functions. Following is a review of a range of geologic settings in which wetlands are found in order to assist oil sands planners in constructing landscape units for wetland construction.

In assessing wetland forms and function, it is useful to distinguish between two main geologic settings—***inland***, or ***palustrine***, and ***coastal***, or ***shoreline*** – as vastly different geologic processes act on each. The reader is directed to reviews by Winter and Woo (1990), Winter (2001), Price et al. (2005), and Ontario Wetlands Evaluation System (1993) for further detail on concepts and nomenclature.

C.2.4.1 Inland Settings

Much of Canada, including Alberta, has been shaped by recent Pleistocene glaciations. Glacial-fluvial processes and the landforms they create represent a range of geologic settings that can provide a framework for assessing wetland forms and functions (see Devito et al., 2005b; Appendix C2).

Depressions are commonly associated with wetland locations. Although some depressions have an underlying layer of fine textured material to impede and "trap" water as depression storage, this is not true for all depression wetlands. Depressions can be formed in many ways, and have different linkages to the surrounding landscape (Figure 10).

Confined Depression, surface drainage

Glacial scour regions, such as the Canadian Shield, have produced millions of small to large depressions within relatively impervious bedrock, forming expansive wetlands of a wide range of types (NWWG, 1998). Water supply originates largely from precipitation and surface runoff generated from uplands with shallow soils. Water is held by depression storage. In these depressions, groundwater interactions are generally minimal as wetlands are often perched above regional groundwater tables (Winter and Woo, 1990). In glacial deposition zones, irregularities in moraines composed of fine grained silts and sands (often ice melt moraines), create analogous situations. Surface depression pothole marshes, and peatland wetlands confined by clay bottoms and fed by precipitation and surface runoff, occur throughout the Boreal Plain and Prairie regions of continental Canada (van der Kamp and Hayashi, 1998; Ferone and Devito, 2004).

Subsidence Holes

In these locations, the ground surface drops below the groundwater table, resulting in water "ponding". There is potential for large groundwater interactions, especially in coarse grained substrates, and many systems have no visible surface inflow or outflow. Water storage is usually not seen as depression storage, but rather as detention of water within a groundwater flow system. As a result, an understanding of recharge and flow path within the groundwater flow system, and the depth profile and grain size of the substrate is required to predict water table fluctuations in these locales. Subsidence holes occur in karst landforms,

such as dissolution depressions in the Wood Buffalo region of Alberta. Kettle and kame landforms commonly occur in glacial deposition regions throughout Canada. For example, small kettle depression wetlands occur throughout sandy glacial outwash areas in Ontario and Alberta (Winter and Woo, 1990). In drier climates, such as the Boreal Plain, groundwater interactions can provide a constant water supply to these subsidence holes to maintain a wide variety of wetland types from marshes to bog peatlands.

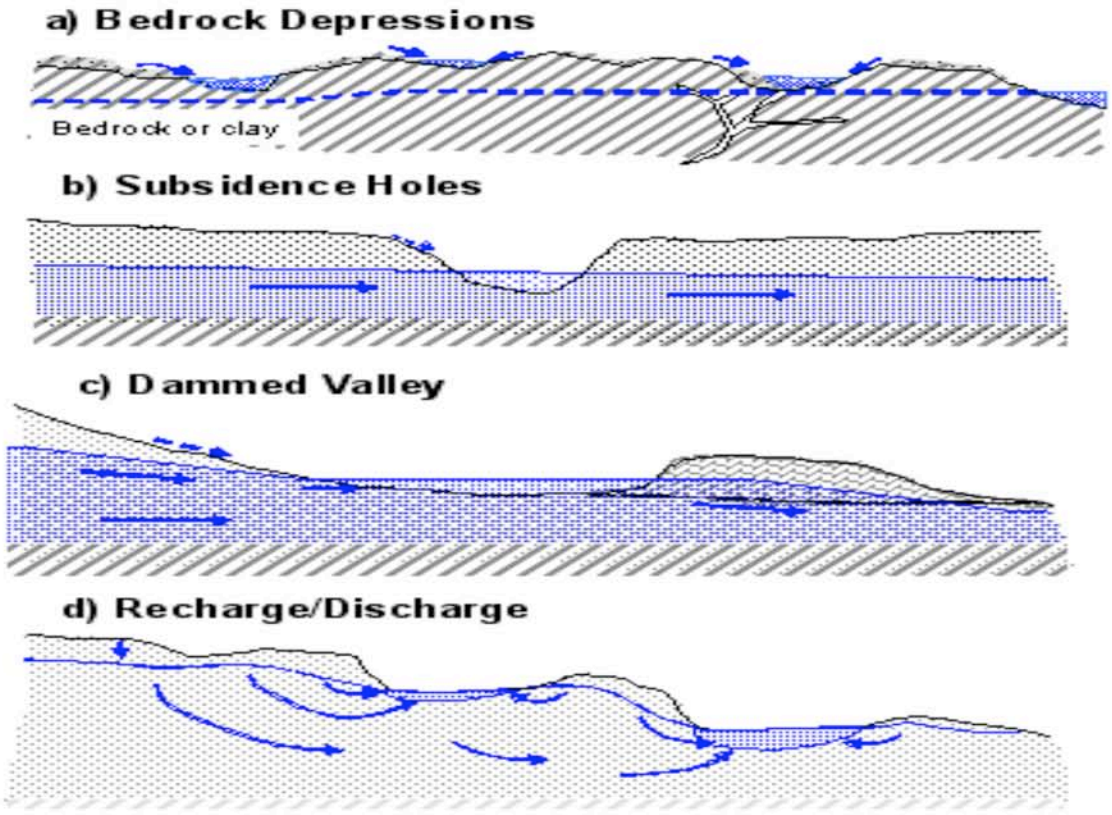


Figure 10 Four geologic settings of surface wetland depressions.

Dammed Valley

Wetlands may form behind dams that block water traveling down confined valleys. There are numerous processes that create dams including glacial-fluvial damming by lateral moraines or levees, geologic mass wasting, and tectonic activities (Winter and Woo, 1990; Mitsch and Gosselink, 2000). Beaver dam construction and human activities with road and reservoir construction also occur throughout Alberta and Canada (Woo and Waddington, 1990). Behind a dam, inflow usually occurs as surface channel flow, however, in some locations groundwater flow may be blocked, forcing water to the surface and creating wetlands. Water storage can be a combination of depression and detention, depending on the hydraulic conductivity of the damming material. For example, when a beaver constructs a dam, the

impeding clay layer often does not reach the top of the dam. If the pond has a clay bottom, following a flood, detention storage maintains the water level to a height at or just above that of the dam (Woo and Waddington, 1990). However, during a dry period, the water level will drain to the height to which the clay layer can hold water by depression storage.

Hummocky Terrain

In landscapes with rolling hills, defined as hummocky terrain (Fenton et al., 2004), local to regional scale groundwater flow systems may develop (Figure 10; see Section C.3; Toth 1999). Groundwater recharge on hummocks discharges into hollows (or depressions) creating saturated conditions for wetland development. It is important to note that, in these landscape positions, depression storage is not required to maintain saturated conditions. Rather, discharging groundwater can maintain saturated conditions which restrict the degree to which infiltration of rain or snow melt enhances ponding of water. Recharge/discharge systems support a wide range of wetland types and typically occur in hummocky moraine landforms, drumlin fields and in aeolian sand dune regions (Winter and Woo, 1990).

In areas with ***Slope Discontinuities***, no depressions are necessary since groundwater discharging to the surface provides excess water for wetland development (Figure 11). Water is held by detention, and rapidly flows off the seepage areas or discharge zones. Due to association with streams and drainage networks, these saturated sites can be important areas for storm runoff generation within a catchment (Roulet, 1990; Hill, 1996; Buttle et al., 2005). Determining the aerial extent and hydroperiod of such wetlands requires an understanding of the area's groundwater flow system and discharge regions. Such "seepage" wetlands commonly occur along steeply sloping banks of rivers or streams, or in locations with abrupt changes in slope.

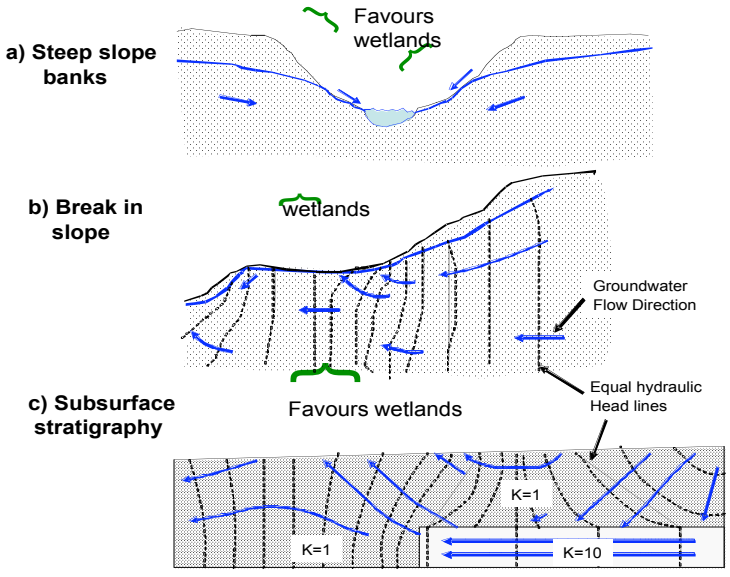


Figure 11 The relationship of water table location, groundwater flow and ground surface with various slope discontinuities and subsurface stratigraphy (modified from Winter and Woo 1990).

Steep Banks
"Seep" zones commonly occur along steep banks of streams or rivers, where the groundwater table intersects the surface prior to entering the stream (Figure 11). Such areas are often associated with the riparian wetland vegetation of larger river valleys, such as on the steep slopes of the North Saskatchewan or Athabasca Rivers.

Breaks in Slope
"Seep" wetlands may also occur away from streams or river valleys. With abrupt changes in slope, groundwater tends to move upward and discharges at the base of the slope (Winter and Woo, 1990; Winter, 1999). Depending on the discharge volume and local climate, surface water outflow may or may not develop. Such wetlands have been observed at the sloping end of moraines protruding onto a flat plain or at river terraces.

Heterogeneity in bedrock and surface substrates (***Subsurface Stratigraphy***) can produce discharge zones capable of maintaining wetlands in locations that are not related to ground surface topography (Freeze and Cherry, 1979; Winter, 1999; Toth, 1999). Figure 11c, illustrates conditions where permeable bedrock located at depth pinches out, and creates complex groundwater flow systems. In this case, groundwater discharges to the surface, creating a wetland in an area with no fine grained deposits to impede drainage. Here again, the hydroperiod of the wetland is controlled by a larger scale groundwater flow system. The source of the water (recharge zone) is also controlled by the location, depth, and contrast in permeability of the lower rock that pinches out. Thus, an understanding of the geologic history and lithology of a region is required to assess the linkages in such settings. Such wetlands can be found in areas with tectonic activity, where faulting results in the shifting of strata. They are also common in Glacial-fluvial river areas where old point bars are buried with finer grained material as a result of glacial advancement (Fetter, 1994). Such landforms are common in association with many larger river systems in Alberta.

Peat Formations
The formation of peatlands throughout Canada is often related to surficial and bedrock geology. Peat tends to form in water saturated areas. Since peat often has hydraulic properties that impede flow, peat accumulation can dam water, creating additional wet areas in which more peat can form. This positive feedback mechanism influences hydrology and can create a "new landscape". For example, the formation of a domed bog can influence local and regional topography such that the groundwater systems associated with the bog can be independent of the underlying mineral terrain.

C.2.4.2 Lacustrine Coastal (Shoreline) Settings

Large lakes or water bodies will be produced during oil sands mining and tailings management. Construction of coastal, or shoreline, wetlands will represent a significant portion of wetlands constructed in this landscape. Coastal processes form lagoons as embayments, inlets or estuaries where shallow water levels predominate to facilitate emergent vegetation growth. Coastal processes isolate areas from long shore currents transporting water and sediments, and result in sediment depositions and wetland maintenance.

Coastal wetlands and processes are dominated by lake or ocean sources of water, and thus the water levels or hydroperiod of the wetland are largely controlled by the adjacent lake or ocean. With ocean shoreline wetlands, tidal fluctuations must also be considered. This section limits the discussion to freshwater coastal wetlands even though the dominant

processes and maintenance of oceanic or freshwater coastal wetlands are comparable (see Mitsch and Gosselink, 2000).

In lakeshore wetlands, consideration of the lake geologic setting, shoreline structure and water budget, and thus lake hydroperiod, is required to assess coastal wetland function, construction and maintenance. If the lake is large enough, internal seiches or rise and fall of lake levels may result in periodic (or alternating) and significant flooding and drying conditions, particularly following storms (see Wetzel, 1983; Kalff, 2002).

Processes that promote gentle slopes or submerged banks (vs. steep bathymetry) in the littoral zone adjacent to open water with water depths that are shallow enough to promote emergent vegetation are important to consider. Not all shorelines support wetlands naturally, and it is important to recognize that not all constructed shorelines will support extensive wetlands. Beach erosion can occur on most shorelines (Wetzel, 1983), thus the shallow depths result from dynamic interaction between sedimentation and erosion. The shallow depths required for lakeshore wetland development can only be maintained in areas where sedimentation rates are equal to or greater than erosion rates by wave action or fluvial forces. Thus the direction of dominant weather patterns, relative fetch on a lake and its influence on shoreline wave erosion areas, and long shore sediment transport should be considered. Although emergent vegetation will increase sedimentation rates, the erosion control of shoreline wetlands is often over-stated. Fresh- and salt-water wetlands are located in regions protected from wave and storm energy (Figure 12; Mitsch and Gosselink, 2000).

The addition of sediments is crucial to long term maintenance of coastal wetlands and may occur via a number of processes (Mitsch and Gosselink, 2000). With land use changes, care should be taken to ensure that sediment sources are not interfered with, as degradation of shoreline wetlands may occur. Sediments may be transported by fluvial processes and deposited in deltas, such as the Fraser River and Peace – Athabasca River deltas. Deltaic wetlands can form at mouths of smaller rivers and wetland maintenance or water depth will be a function of dynamic deposits of sediments from upstream and potential shoreline erosion. Significant amounts of sediments may be transported by long shore currents, particularly in larger water bodies, with finer material deposited on the leeward side of points and jetties. Upon establishment of submergent and emergent vegetation, physical entrapment may increase sedimentation rates, resulting in infilling of deeper littoral zones. In regions were water levels are rising (i.e. long term wet periods, additions of water) increased sedimentation by physical entrapment may off-set water level rises and be required for wetland maintenance. In areas were water levels are not rising, long term entrapment may initiate isolation of wetlands from lakes and terrestrialization. Accumulation of organic material (peat) can also occur, but infilling by such processes occurs at exceptionally slow rates (1000's of years) (Mitsch and Gosselink, 2000).

Consideration of setting of coastal wetlands in nature will facilitate effective construction of, and opportunistic establishment of, lakeshore wetlands. Mitsch and Gosselink (2000) distinguish four natural settings where they occur (Figure 12). Coastal wetlands often occur in protected bays where erosion and sedimentation rates are low (Figure 12 a). Coastal wetlands also occur on the leeward side of sheltered spits, offshore bars and islands which trap sediments transported by prevailing currents or wind (Figure 12b). Shore terraces with low gradients can be created by sediment deposition at river mouths or estuaries at protected bays, or deltas where deposited sediments create protected spits (Figure 12c). Coastal wetlands may also occur inshore of shingle beaches or berms, where dropping water levels or land uplifting or ice push ridges (e.g., Hudson Bay) isolate back shore marshes from shoreline erosion (National Wetlands Working Group 1998). Along developed shorelines with breakwaters, wetlands have developed in leeward bays where sediments carried by

shoreline currents are deposited and result in shallow water conditions conducive to marshes (Mitsch and Gosselink, 2000; Bradford, 1999). However, breakwater development does interfere with coastal movement of sediments and may reduce sediment depositions and impact wetlands located further down the shore.

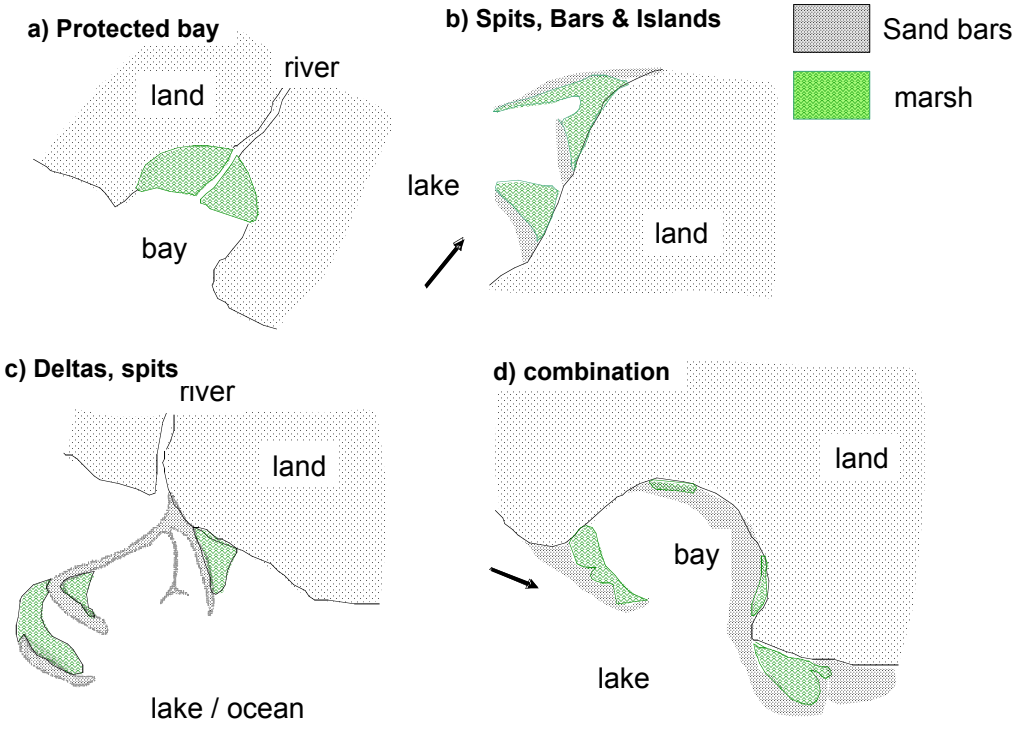


Figure 12 Geologic setting of representative coastal (shoreline) wetland systems showing coastal features that influence wetland development (modified from Mitsch and Gosselink 2000).

C.3 Natural Analogues

The purpose of this section of the manual is to provide an overview of natural analogues on the Boreal Plain of Alberta, and to relate them to some of the anticipated reconstructed landscapes from oil sands mining. We do this by outlining our current understanding of the relevant processes on different natural landscapes and by comparing them to the anticipated characteristics of reconstructed sites. We also outline why results from different climatic zones and geologic regions may not be applicable to this ecoregion.

C.3.1 Framework

The framework for evaluating and comparing the hydrologic responses within and between landscapes follows the hierarchical classification criteria for hydrologic systems outlined in Appendix C2 and by Devito et al. (2005b). Furthermore, the water balance concepts are used to evaluate the role of different processes.

First, we provide a basic summary of the hydrologic classification criteria, as applied to wetlands and surrounding uplands in the Fort McMurray area and at our natural analogue sites. This method of evaluation requires that the important characteristics of an area be considered in a hierarchical order, basically from large-scale to small-scale. Thus, the hydrology of a system should be considered based on (a) climate, (b) bedrock geology, (c) surficial geology, including depth to bedrock, (d) soils and vegetation, and (e) topography. Soils and vegetation classification was largely confined to differences in organic content versus mineral soil, but it could be expanded to consider differences in vegetation type (e.g., aspen vs. tamarack vs. pine vs. grasses vs. shrubs vs. peat). Differences in vegetation type were not considered as part of this review. Essentially, this framework postulates that if the climate is different, for example, hydrologic generalizations based on geology or topography may not be applicable. We demonstrate, in the next section, that climate is one of the overriding factors.

Second, hydrologic processes must be described and quantified within the framework of hydrologic budgets (i.e., conservation of mass). From Section C.2.2, a reasonably general hydrologic budget, for a particular area over a particular timeframe, may be expressed as follows:

$$\mathbf{P + G_{in} - ET - G_{out} - R = \Delta S}$$

where
P = precipitation
G = groundwater flow
ET = evapotranspiration
R = surface runoff
Δ**S** = change in soil/groundwater/peat storage

In many areas/reports (including the previous version of the Wetlands Manual) it is common to assume that ΔS is zero on an annual basis. In general, we find that this is not applicable for the climate of the Boreal Plain and ΔS can be highly variable. In this context, ET is "actual" evapotranspiration (AET); however, "potential" evapotranspiration (PET) is often discussed, and AET is sometimes taken as a fraction of PET, because PET is easier to measure or estimate.

Our natural analogues primarily fall into two geographic, but similar climatic, locations (Figure 13): Lac La Biche (55.1˚N, 113.8˚W) and the Utikuma Research Study Area (URSA) (56.1˚N, 116.5˚W). The reconstructed landscapes, of course, are all located just north of

Fort McMurray (56.8˚N, 111.5˚W). The Lac La Biche site is a 50 ha headwater catchment less than 200 km SSW of Fort McMurray (Devito et al., 2005a). URSA is a large study area, with highly diverse, yet representative, landscapes, located 250-300 km WSW of Fort McMurray. URSA has been studied at a variety of different scales, from regional hydrology (Figure 14), to site-specific/pond-level scales (discussed later). As will be demonstrated in the next section, the climate at URSA is very similar to Fort McMurray. All sites are on the Boreal Plain of northern Alberta. Similarly, the geologic and topographic characteristics of URSA mimic those that either are or could be expected of many reconstructed landscapes (Figure 15).

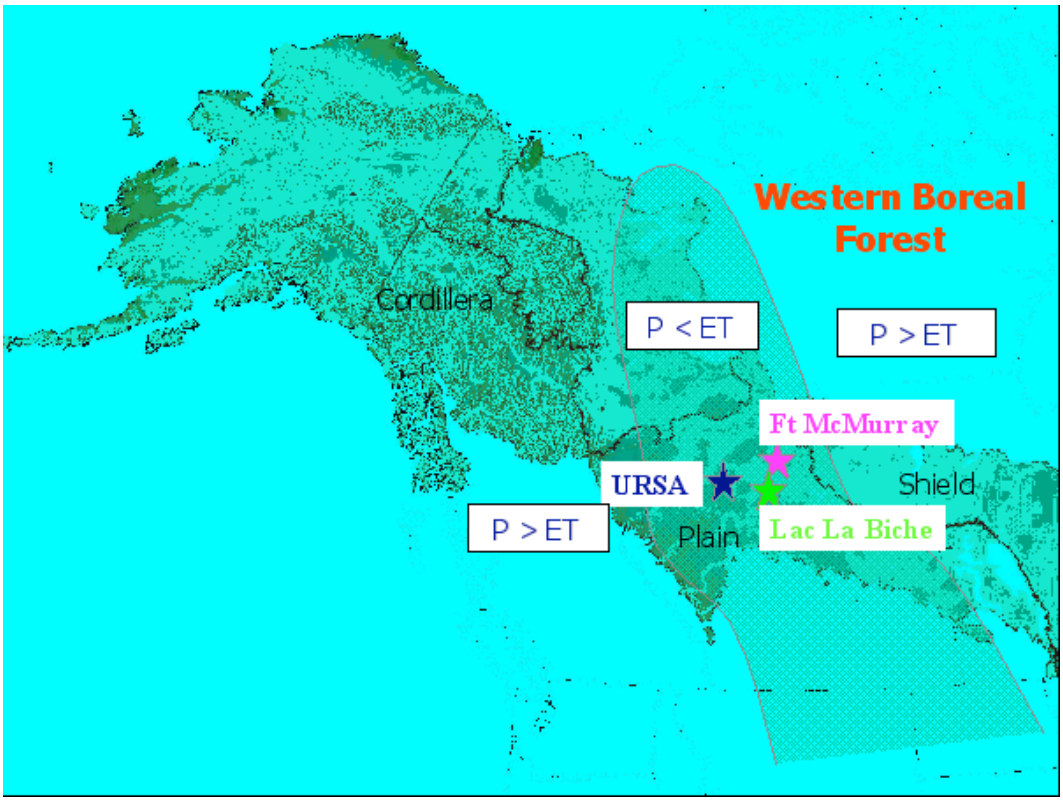


Figure 13 Map of western Canada, showing the Boreal Shield, Plain and Cordillera regions. The shaded area illustrates the general division between sub-humid (P < PET) and humid (P > PET) areas, and the approximate location of the study sites. Climate boundaries are adapted from Winter and Woo (1993). Base map courtesy of Ducks Unlimited Canada

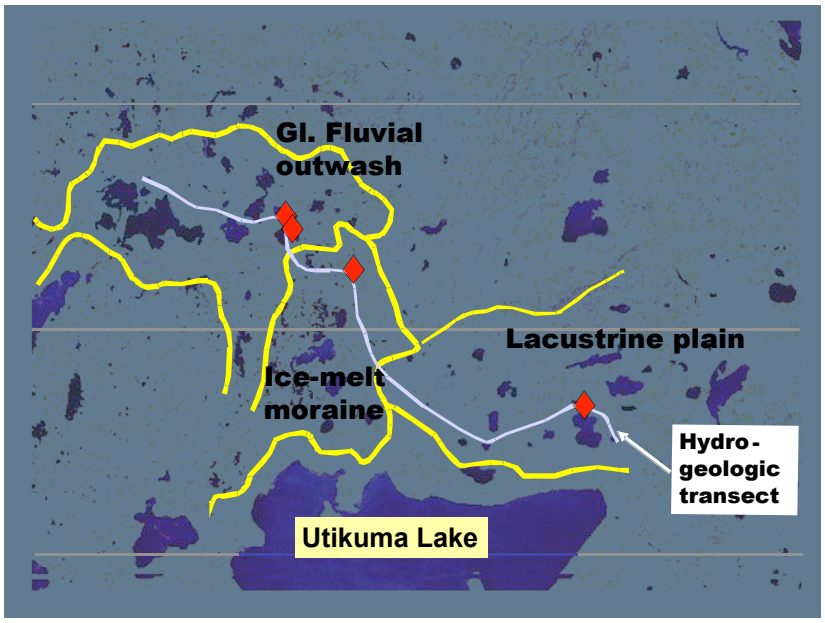


Figure 14 Enhanced satellite imagery of the Utikuma Research Study Area (URSA), showing generalized distributions of the primary geological features. The horizontal distance represented by the figure is about 70 km. The hydrogeologic transect is shown in Figure 15. Imagery is courtesy of Duck Unlimited Canada. Geology is from field observations, deep borehole data and the Alberta Geological Survey surficial geology map (Fenton et al., 2003). Diamonds indicate Case Study locations (ponds 16, 19, 43 and 171, from NW to SE).

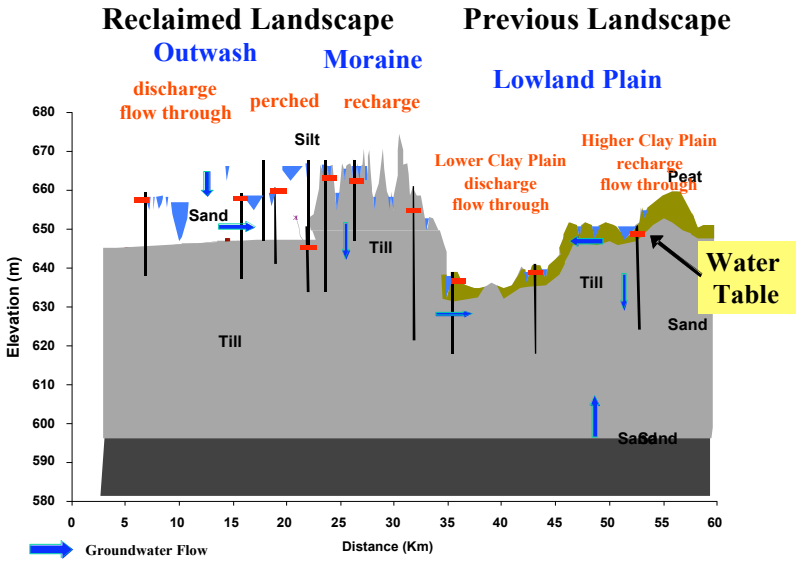


Figure 15 Hydrogeologic cross-section, NW to SE, from Figure 14. Vertical bars indicate boreholes with measured water levels. Arrows indicate general groundwater flow directions. The lowland plain is similar to the previous, and surrounding, landscape of the oil-sands area, while the outwash and moraine are analogues for many of the reclaimed landscapes. Note the large vertical exaggeration.

C.3.2 General Boreal Plain Characteristics

The Boreal Plain of Alberta has the following hydrologic, geologic and physiographic characteristics: the climate is sub-humid (i.e., P ≤ PET, on average) (Figure 13), the bedrock is sedimentary (with significant amounts of carbonate minerals), the surficial materials are thick (20-200 m) and of (variable) glacial origin, there are extensive wetlands, including peatlands, and the upland forested areas are primarily populated with aspen or pine. The topography is subdued, but may be locally variable. Largely because of the climate, but also because of the geologic materials and the subdued topography, the runoff coefficient (= R/P) also tends to be low, yet variable, in this region. Winter and Woo (1993) show runoff coefficients of about 30% near the margins of the P = ET line on Figure 13; these coefficients decrease to less than 20% in the URSA and Fort McMurray regions.

C.3.3 Climate

Climate is the overarching controlling factor for hydrology on the Boreal Plains (Appendix C2; Devito et al., 2005b). It controls precipitation and evapotranspiration, and the difference between the two. Although studies from other areas often use stream flow runoff (R) as the primary, obvious, manifestation of climate influences, in the sub-humid climate of the Boreal Plain stream flow is often low, yet highly variable. As shown, below, this is likely due to water storage effects. Thus, annual stream flow may not be an appropriate index for hydrologic or wetland sustainability on the Boreal Plain.

Figure 16 shows (average) monthly P and PET depths for URSA (Ecodistricts 612 and 613) and for the oil-sands region north of Fort McMurray (Ecodistricts 579, 580, 608, 609 and 632). The seasonal trends are very similar, with dry fall and winter periods, and wet summers. Annual P for URSA and the oil-sands region are 481 mm and 457 mm, respectively (Agriculture and AgriFood Canada, 1997). The corresponding PET values are 518 mm and 519 mm, resulting in potential (average) water deficits of 38 mm at URSA and 61 mm north of Fort McMurray (Bothe and Abraham, 1993). These relationships demonstrate that the climates of these areas are very similar, which provides the fundamental foundation (Appendix C2; Devito et al., 2005b) for being able to use the URSA sites as natural analogues for reconstructed landscapes in the oil-sands region. It is worth noting that the oil-sands region is, on average, somewhat drier than URSA, so any effects due to water deficits may be slightly accentuated in the oil-sands area, compared to our natural analogues.

Furthermore, these functions (Figure 16) show that major precipitation periods are synchronized with evapotranspiration and that the amount of water stored as snow tends to be small. Thus, on average, there tends to be a high demand for water at the same time that it becomes available. Consequently, there may be limited opportunity for overland flow and runoff (Devito et al., 2005a). This is unlike some other climatic zones or areas (e.g., the Boreal Shield, Wisconsin, Minnesota, Oregon) where a significant fraction of the annual water budget is released (as snowmelt) or delivered (as rain) in the spring, before the growing season begins (Winter and Woo, 1990).

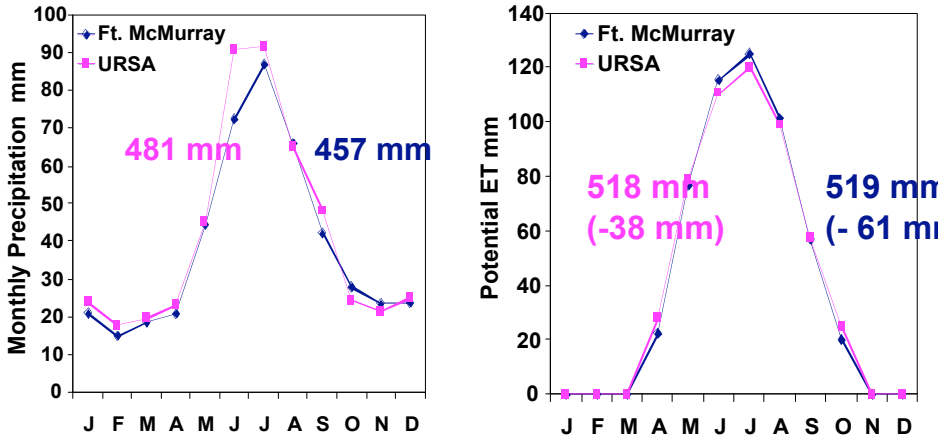


Figure 16 Average monthly P and PET, plus yearly totals and water deficits, for URSA and the oil-sands region (see text for details). Based on data from Agriculture and AgriFood Canada, 1997.

In sub-humid climatic regions, the fine balance between (average) P and ET means that small temporal variations in either P or AET may lead to anomalously wet, or perhaps very dry, years. In general, PET is fairly constant from one year to the next (Bothe and Abraham, 1993); however, P can vary significantly from one year to the next. For example, between 1944 and 2004, annual P recorded at the Fort McMurray airport ranged from 242 mm (1998) to 675 mm (1973), with a standard deviation of 91 mm (Environment Canada Climate Data). Average annual P for this 60 year timeframe was 442 mm.

Figure 17 illustrates the cumulative departure from the normal precipitation (CDNP) from 1970 to 2002 for Lac La Biche. An upward limb on this curve indicates wetter conditions; a downward limb indicates drier conditions. This function illustrates (a) the variability in P over time, (b) that P was relatively high during the 1970s, yet relatively low (i.e., a deficit) near the end of the millennium, and (c) that there appear to be cycles in P. Our preliminary (unpublished) work indicates that the dominant frequencies in P variations correspond to about 5, 10 and 30 year climate cycles. These cycles can probably be related to global-scale phenomena (e.g., the Pacific Decadal Oscillation, el Nino, la Nina, etc.). The variability in hydrologic response to such cycles must be planned for in landscape design. However, there is a need to better quantify these cycles and to evaluate their impact on wetland sustainability. There is also a need to predict how these cycles might change in the future, perhaps in response to global warming.

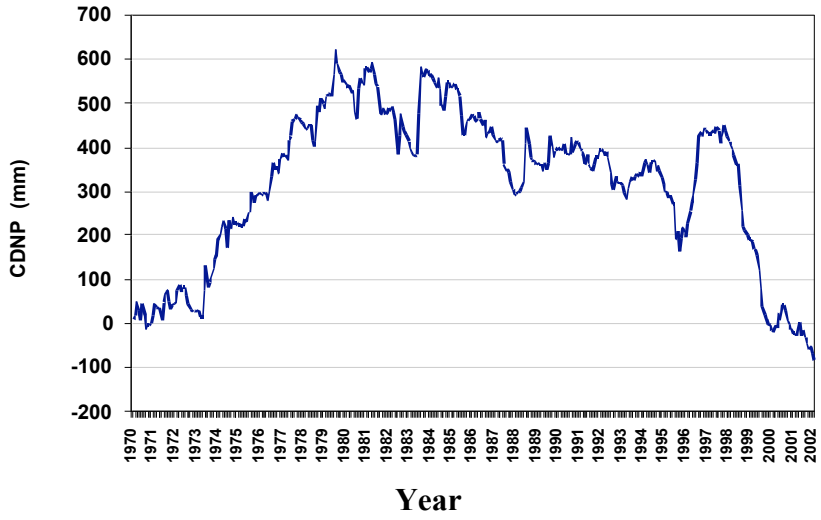


Figure 17 Cumulative Departure from the monthly Normal Precipitation (CDNP) from 1970 to 2002 for Lac La Biche. Rising limbs indicate wetting conditions (excess water); falling limbs indicate drying conditions (water deficit). Data from Environment Canada.

One consequence of this variability in P is that, at the local (i.e., pond or hill slope) scale, water levels may vary appreciably from one year to the next. However, our observations indicate that this is not a general consequence – some ponds may have large changes in water levels (e.g., some URSA ponds essentially dried out during the drought of 2001 and 2002), while others may show very little change (e.g., some URSA ponds did not dry out during the same timeframe). Each of these specific circumstances is discussed later in the section on URSA case studies. Air-photos also show some dry ponds in the late 1940s, another period of low P. These differences in behaviour can be explained by the other factors in our hierarchical approach to studying the hydrologic cycle (e.g., geology, landscape position, pond morphology and connection to groundwater flow systems). This is discussed below.

Furthermore, at the regional scale, where processes acting on multiple slopes and ponds are integrated, one might expect that years with higher than average precipitation would result in higher stream flow runoff because of the excess of water delivered to the system. We find that this is, in general, not true – R and P are not necessarily directly correlated because of the (transient) soil storage component of the water budget (Devito et al., 2005a). This effect is manifest in the low runoff numbers (< 30%) reported by Winter and Woo (1993) for regional-scale watersheds and should be planned for in reclamation.

For example, a multi-year water budget for the Lac La Biche study catchment and Figure 18 shows the P, ET and R for the surrounding basin (Devito et al., 2005a). In Figure 18, peak

runoff (1997) in the Logan River is seen to lag the peak rainfall (1996) by a year. In addition, Devito et al. (2005a) show that during, and following, a single wet year (2000) that followed two dry years, the runoff coefficient for the basin was less than 1%. The “excess” rainfall was taken up by soil storage, so it did not immediately contribute to regional runoff and stream flow.

Rainfall events on the Boreal Plain tend to be numerous, yet small and isolated. We have analyzed 1971-2000 Climate Normals (Environment Canada, 2005) for our study areas. Again using Fort McMurray airport data as an example, during the months of June, July and August, there is about an 8% chance that daily rainfall will exceed 10 mm; however, the probability that daily rainfall will exceed 25 mm is only about 1.5%. Given that two thirds of Fort McMurray’s rainfall (i.e., 230 mm, which is more than 50% of P) falls during these three months, it is obvious that most precipitation events are spread out over the summer, as a series of small events, and that large precipitation events are rare. Measured precipitation distributions at URSA, and nearby Environment Canada monitoring stations (e.g., Red Earth Creek), show similar probabilities.

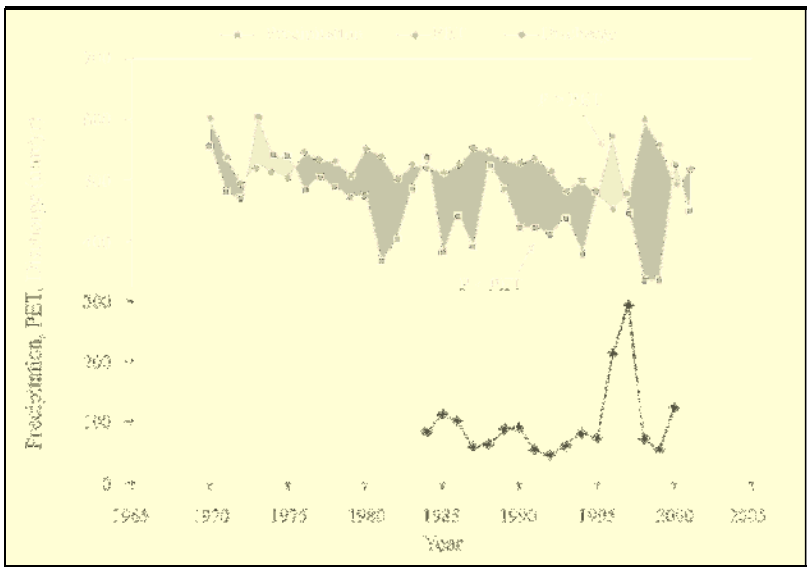


Figure 18 Water balance for the regional catchment surrounding the Lac La Biche study area (modified from Devito et al. 2005a).

The above summary of climate on the Boreal Plain demonstrates that the wetlands in the region continue to exist in a (climatic) water deficit. There are several mechanisms that could lead to maintenance of these wetlands: (a) an external source of water; (b) water storage mechanisms; or (c) decreased actual, compared to potential, evapotranspiration.

a. External sources of water could be from surface water; however, we observe little overland flow at our study sites. Alternatively, external water could be supplied by either shallow or deep groundwater flow systems, which may originate beyond a watershed defined by topography. This appears to be a significant process in coarse-grained materials, but only if the wetlands are topographically low in the flow system (Smerdon et al., 2005). Also, Devito et al. (2000) demonstrated that it is common for peatlands (i.e., fens) to be located in groundwater discharge zones – water slowly infiltrates over a large area, but is focused into a narrow discharge zone, which supplies enough water, and the constant water levels, necessary for peatland formation.
b. Enhanced water storage capability may exist because of the nature of the geologic materials (see below, Section C.3.4, and Section C.2.3), the morphology of pond/wetland basins (Section C.2.3), or the presence of ice (work in progress).
c. Finally, decreased AET may occur in wetlands containing peat and emergent vegetation because they may transpire less than surrounding upland trees and shrubs or open water (Petrone et al., 2006). The determination, and quantification, of the processes responsible for the maintenance of wetlands in a sub-humid climate is an urgent research need. We are working towards this goal; however, both geological and vegetation effects need to be quantified.

C.3.4 Geology

On much of the Boreal Plain the sedimentary bedrock is encountered at a significant depth (e.g., often greater than 50 m). Although very long term (i.e., regional) groundwater flow paths and geochemistry may be influenced by the presence of this bedrock, most hydrologic processes of significance are constrained to the thick, overlying glacial deposits. These glacial deposits are highly varied (i.e., heterogeneous), ranging from sand-rich outwash deposits, to various moraine deposits, to lacustrine clay deposits (Figures 14 and 15).

For our purposes, we classify these (natural) unconsolidated deposits as being either “coarse-grained” (e.g., sand and gravel) or “fine-grained” (e.g., stiff silt or clay). In general, coarse-grained materials will have a high hydraulic conductivity and a high specific yield, while fine-grained materials will have the opposite characteristics. With respect to geologic materials commonly encountered or created during oil-sands mining and processing, sand tailings would be coarse-grained, while most other materials (e.g., till or shale overburden, mature fine tailings (MFT)) would be classified as fine-grained. Composite tailings (CT) are likely to fall within the transition zone between these two broad classifications; however, overall, they are likely to exhibit properties that are closer to fine-grained materials, rather than coarse-grained materials.

Heterogeneity, with materials having several orders of magnitude variation in hydraulic conductivity and large differences in storage capacity (e.g., specific yield), is the norm in our natural analogue landscapes. This is even true within areas of “similar” materials. Our preliminary results show that this geologic heterogeneity may play a significant role in controlling how wetlands form and are maintained within this sub-humid climate. Traditional practice by oil-sands companies is to segregate coarse and fine grained materials. When considering the application of knowledge gained from the natural analogues for designing

wetlands, it may be prudent to reconsider or modify this practice of segregation. That is, there may be significant benefit to incorporating layers or lenses of materials with contrasting hydraulic properties. These features of the natural landscape are explored in the case studies below.

The combination of general geology and climate of the Boreal Plain, compared to that of the Boreal Shield (and elsewhere), yield significant differences in the hydrologic behaviour and the dominance of processes. Figure 19 summarizes these differences using conceptual models. The sub-humid Plain is shown to be characterized by thick surficial deposits with a significant ET component. This leads to soil storage and groundwater flow playing significant roles in the water budget, with minimal runoff and perched wetlands. To a large extent, vertical movement of water dominates, except in the regional groundwater flow systems. The humid Shield is characterized by a thin veneer of unconsolidated material overlying relatively impermeable bedrock. P is a dominant process, which leads to significant, lateral, surface runoff. Soil storage does not play a significant role in the hydrologic budget. The manifestation of these differences is illustrated in Figure 20. For both the Boreal Shield and the Boreal Plain, ET is seen to be relatively constant over time (about 500 mm). On the Shield, where P varies around a value of about 1500 mm, runoff is seen to be highly correlated to P. This is indicative of changes in soil storage being fairly small. However, on the Boreal Plain, P varies around a value that is close to ET, but is most often less than ET. This results in very low runoff values, and R is neither directly nor immediately correlated to P. Because of these differences, care must be taken when extrapolating research results and observations from other areas, such as the Boreal Shield and elsewhere. That is, the dominant conditions and processes should be similar when trying to transfer results from one region to another.

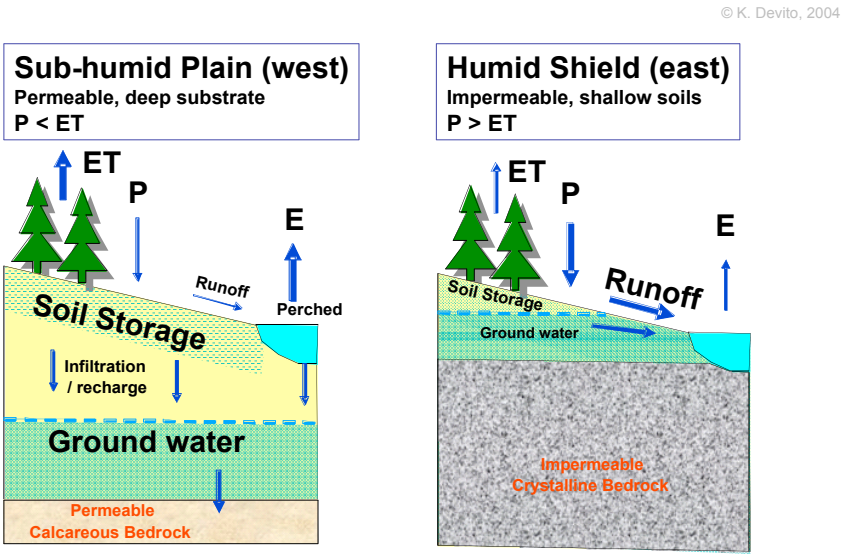


Figure 19 Conceptual diagrams of hydrologic processes on (a) the Boreal Plain and (b) the Boreal Shield. Dominant processes or mechanisms are shown in a bold font and with accentuated arrows. Adapted from Devito et al. (2005a,b), Buttle et al. (2005) and Winter (2001).

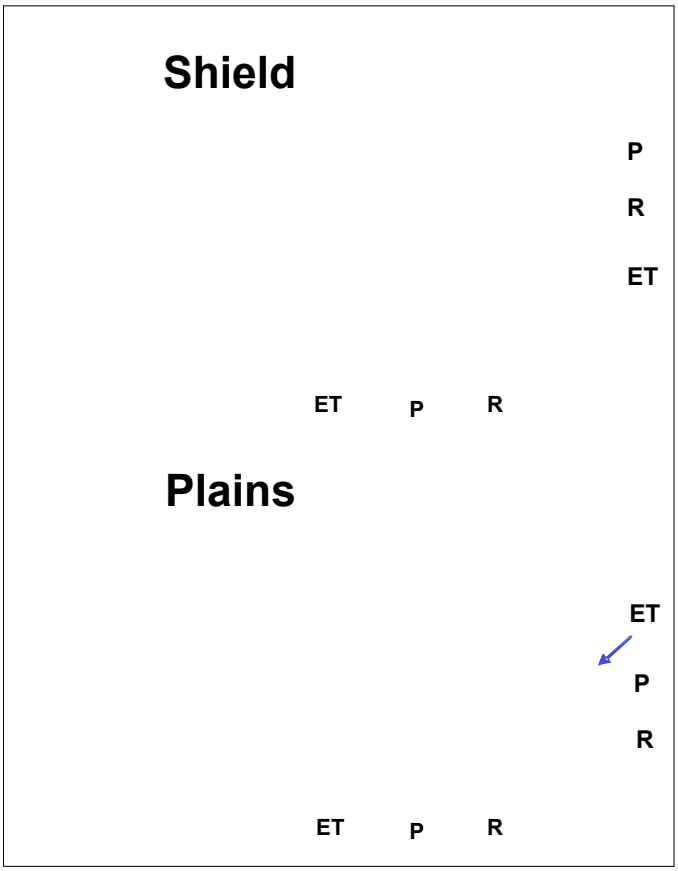


Figure 20 Long-term, regional water balances for the Boreal Shield and the Boreal Plain. Adapted from Buttle et al. (2000, 2005).

C.3.5 Vegetation

Vegetation plays an important role in the hydrologic budget. Water evaporates from open bodies of water and exposed, saturated, soil surfaces; however, it is vegetation that controls (a) interception by the forest canopy, which directly leads to evaporation, and (b) transpiration. Although it depends upon the type, density and maturity of vegetation and antecedent conditions, it is likely that interception in forests can remove, on average, the first 5-10 mm of many precipitation events (Buttle et al., 2005). Furthermore, water that does make it to the ground will first have to pass through the forest floor. Our preliminary results (Redding, unpublished) indicate that the storage capacity of the forest floor is likely about 1.5 mm for every cm of organic forest floor (i.e., LFH) material. That is, given an average forest floor depth of 10 cm, 15 mm of a precipitation event will be held in the very shallow subsurface, where it will be readily accessible for uptake by trees. Thus, by considering only interception and shallow soil storage effects, only rainfall events greater than about 20-25 mm in forested areas will lead to movement of water to depth (e.g., recharge of regional

groundwater systems) or, perhaps, lateral flow. As mentioned above, the probability of such events is quite small.

On the reconstructed landscapes, primary succession of vegetation needs to be considered. A given landscape will be initially established with essentially nothing, but will progress to having full forests or riparian areas, based on one of the targeted land uses being forest production. This will lead to temporal changes in ET – we would expect ET to increase, and so water tables and soil storage to decrease, over time, as forests become established. Alternatively, if peat can become established in wetland areas, we might expect the peat to play a moderating role in (a) increasing water storage and (b) reducing ET, leading to a stabilization of the water budget for a pond or wetland. There is a need to conduct research into the impact that primary vegetation succession has on water budgets. However, it is to be expected that increased vegetation will generally lead to increased ET rates on uplands, and so less water delivery to ponds. For example, several studies have measured little (<5 mm) to no runoff from aspen forest uplands on the Boreal Plain and montane regions during most years (Carey and Woo, 2001; Ferone and Devito, 2004; Devito et al., 2005a).

C.3.6 Topography

Figure 15 shows that the variation in topography of URSA is fairly subdued, with a range in elevation of only about 40 m. The outwash plain is, largely, topographically low; however, it does rise to the SE, towards the elevated moraine deposits (Figure 15). These deposits are similar to overburden waste and tailings sand storage deposits in the oil-sands area, although initial slopes in the oil-sands area tend to be steeper, more abrupt and more uniform. Over time these reconstructed slopes can be expected to develop hummocky topography due to settling, erosion and localized slope failures. The lowland clay plain area is flat, similar to much of the existing topography in the oil-sands region.

Related to topography is the concept of the area of catchment to area of wetland ratio. Mitsch and Gosselink (2000) provide a simple equation to estimate the surface catchment area required based on long term moisture deficit and rainfall runoff ratios. For the moisture deficits (~50 mm) and large scale runoff values (< 20%) for Fort McMurray, a catchment:wetland area ratio of 2:1 is predicted. Our current understanding of soil and groundwater storage on the Boreal Plain indicates that, in many cases, this is an underestimation of catchment area required. Thus considerable caution should be used when predicting appropriate upland areas. This is due to the non-linear and time variant behaviour of runoff coefficients (i.e., variations from less than 1% to over 50%) which in turn vary tremendously with particle size of substrate (Devito et al., 2005a,b). Reclamation planners will need to consider that the required moisture for wetland development will depend on interaction of differing geologic setting, water balance and storage, as noted in Appendix C2 and Section C.2. For example, natural wetlands (ponds, marshes and peatlands) in the URSA have upland:wetland area ratios ranging from <1 to greater than 10 in response to differences in interaction of fine- and coarse-grained material configurations, scales of surface and groundwater flow, and soil and wetland basin storage properties (Devito and Mendoza, unpublished data). In some cases, the water catchment area extends beyond the topographical watershed boundary.

C.3.7 URSA Case Studies

In this section we summarize the published results of field studies at URSA, and relate our observations to possible reconstructed landscapes in the oil-sands region.

C.3.7.1 Outwash

Smerdon et al. (2005) report on the hydrology of a pond (Lake 16) near the SE margin of the outwash deposits at URSA (Figure 14, Figure 15). The geologic material consists of thick (> 20 m) sand and gravel deposits overlying clay till. Lake 16 is located in the middle of a staircase of lakes: Lake 17 to the SE is about 1.5 m higher; Lake 5 to the W is about 1 m lower in elevation. Outside of precipitation that falls directly on Lake 16 and riparian areas, this pond receives water from the regional groundwater flow system (Figure 21). Water is lost through evaporation, groundwater flow to Lake 5 and through a small stream at the W end of the lake. Thus, this lake is a flow through system that exhibits a high degree of connectivity to the regional hydrologic environment. From analyses of water balances, we find that the lake acts as a significant evaporation window for the regional groundwater system. Although water levels do fluctuate in response to yearly changes in precipitation, these fluctuations are far smaller than those exhibited by other, more isolated ponds in the study area (e.g., on the transition zone and the moraine, discussed below).

The hydrologic behaviour observed in this setting is typical of what one would expect for topographically low areas in coarse-grained materials (e.g., near the base of sand tailings structures). These locations essentially act as drains for the very large up-gradient areas receiving recharge.

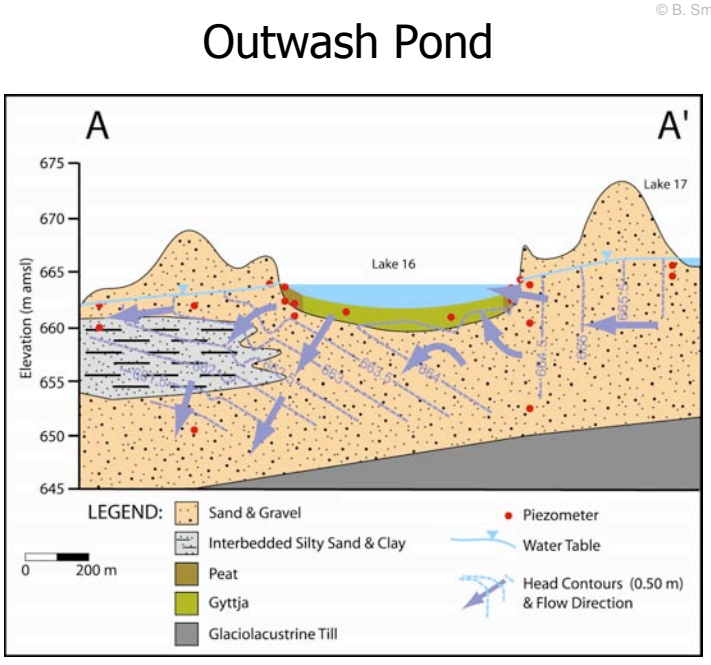


Figure 21 Hydrogeologic cross section through the centre of Lake 16, showing measurement locations, geological features and interpreted flow paths (based on Smerdon et al. 2005).

C.3.7.2 Transition Zone

Topographically up-gradient from Lake 16 we are currently studying an area at the margin of the outwash and moraine deposits (Figure 14, Figure 15). A thin (2 to 5 m) veneer of fine-grained deposits can locally be found on top of the thick outwash deposits. The regional water table is found at a significant (~20 m) depth, with an intervening unsaturated zone (Figure 15). In this area, we only find ponds (e.g., Pond 19) and peatlands in depressions that are lined with low conductivity material (e.g., stiff silt or clay). Depressions, shallow or deep, without such a lining are dry. Thus, these wetlands are perched and may be largely isolated from the regional groundwater system.

Work is ongoing to quantify the water balance and the dominant hydrologic processes in this geologic zone. However, our preliminary observations indicate that some form of confining basin is required to maintain wetlands in topographically high areas on permeable deposits. Considerable lateral flow of water to wetlands has been observed from areas with 1 to 2 m of permeable substrate over fine grained confining layers that are connected to the wetland.

C.3.7.3 Moraine

The moraine deposits at URSA support a large number of small ponds and wetlands, with essentially most depressions showing an indication of holding water. Overall, drainage is poorly integrated, reflecting the irregular topography associated with ice-melt moraine deposits and their predominantly fine-grained materials. We have intensely investigated the area in and around Pond 43 for a number of years, including a couple of years that exhibited lower (1999) and higher (2000) than average P (see Ferone and Devito, 2004). Pond 43 receives much of its water from direct precipitation to the pond and its riparian peatland area, and from a large up-gradient peatland. We have not observed overland flow nor significant interflow from the adjacent hill slopes. Water leaves the pond through a beaver-cut channel to a down-gradient pond. ET represents the dominant loss of water from the pond.

Water levels in a series of piezometers from the hill slope, through the peatlands and into the pond are shown in Figure 22. The water levels are shown for two different times, low flow conditions (Figure 22a) and high flow conditions (Figure 22b). In all cases, the water table beneath the hill slope is lower than the pond, indicating that water should be recharging the groundwater system. This is contrary to most traditional models of water table configurations, where it would be assumed that groundwater beneath the hill slope would be discharging to the pond. Also, deep boreholes in the vicinity indicate that the pond is likely perched, signifying a poor hydraulic connection to regional groundwater systems. The primary difference between the two scenarios in Figure 22 is that during high flow conditions (i.e., following precipitation events) the water level in the extensive peat deposits is higher than the pond. This indicates that the peatlands are crucial for supplying water to the pond. The high water levels in the peat arise from the small specific yield of peat. Furthermore, Petrone et al. (2006) have shown that microclimates reduce AET in riparian peatlands to less than summer precipitation inputs. The peatland regions represent water source areas for adjacent uplands and ponds.

Changes in water storage, manifest by changes in pond water levels, tend to be large in Pond 43: during two sequential dry years (2001 and 2002), the pond essentially dried out. Subsequently the pond level recovered, partially from the release of water from adjacent peat deposits and from increased P, but also because the morphology of the basin changed through compaction of the underlying organic sediments. The down-gradient pond also dried out during these two years of drought; however, because of its shallow basin morphology it

dried out more quickly. Grasses, and now willows, have encroached on this (unmonitored) pond, so it has not been able to recover to its pre-drought conditions.

The implications of our observations on natural analogue sites are somewhat uncertain. However, it would appear that within most natural ponds on fine-grained materials with local-scale topographic variations, local peat deposits and peatlands tend to flourish, but are limited in extent or size. Given large climate cycles and extended dry periods, pond basin storage must be large enough to withstand several years of water deficit (i.e., in general, the basin must be over 1 m depth, but contributing area and adjacent vegetation may be important modifiers).

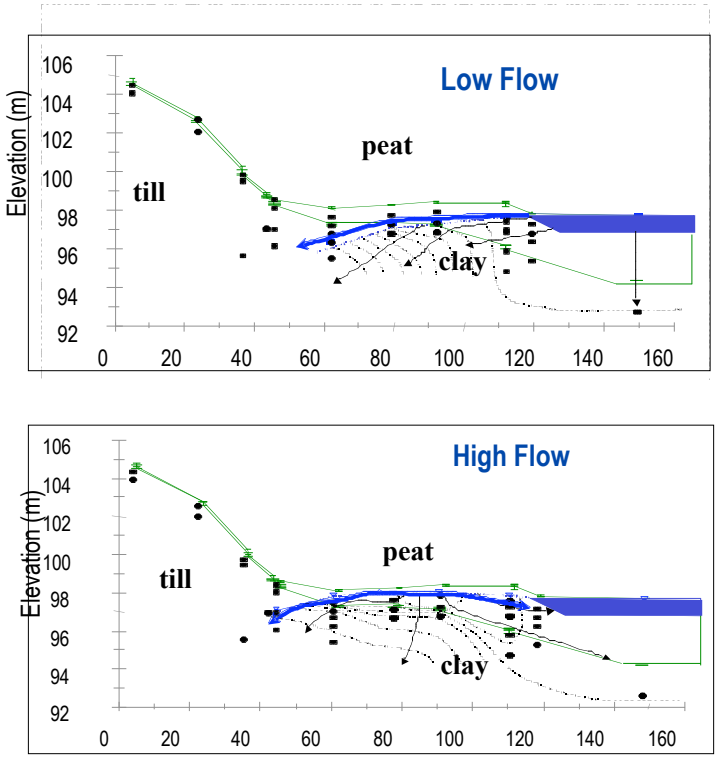


Figure 22 Hillslope to pond cross sections for Pond 43 on the ice-melt moraine with low flow conditions and high flow conditions. Adapted from Ferone and Devito (2004).

C.3.7.4 Lacustrine Plain

The lacustrine plain area of URSA (Figure 14, Figure 15) best represents the existing (i.e., relatively flat) landscape in the oil-sands region. This portion of the landscape (e.g., Pond 171) is dominated by peatland deposits, interspersed with shallow till hummocks (i.e., 1-3 m elevation above the peat) forested with aspen. Surface flow networks along peatland tracks have developed in gently sloping terrain overlying low conductivity fine-grained glacio-lacustrine clay or till (Figures 14 and 15). Due to the unique properties of peat (Section C.2.3), the water table remains near the surface (< 1 m depth) throughout wet and dry cycles, and the peatlands may be considered runoff generating areas (Devito et al., 2000;

Devito et al., 2005a; Price et al., 2005). The water table gradients in adjacent mineral aspen upland hummocks trend below the peat, similar to our moraine sites, and so little or no runoff is generated from uplands (Ferone and Devito, 2004).

Water levels in wells and piezometers around pond 171 are illustrated in Figure 23. Deep boreholes in the vicinity indicate that water recharges to depth, but the low permeability of the clay substrate results in limited interaction with regional groundwater systems. The pond is a flow-through system that collects water from a peatland that extends for approximately 1 km up a gentle (< 1%) slope. Nonetheless, shallow groundwater enters the pond during both dry and wet periods. This groundwater flows through the surrounding peat: however, the flow rate is considerably reduced when the water table drops into the less permeable peat at depth (see Section C.2.3). During dry periods the standing water is maintained because outflow is restricted through the lower permeability of the peat on the pond bottom and because compaction of loose sediments in the basin releases stored water.

Our observations of the hydrology of the low-lying lacustrine plain imply that extensive wetlands can exist on flat plateau areas; however, it is also clear that peat plays a key role in the permanence of these deposits. That is, the physical and hydraulic properties of peat help retain water on the landscape during dry periods. It is, however, uncertain whether such peat deposits could develop in the existing climate.

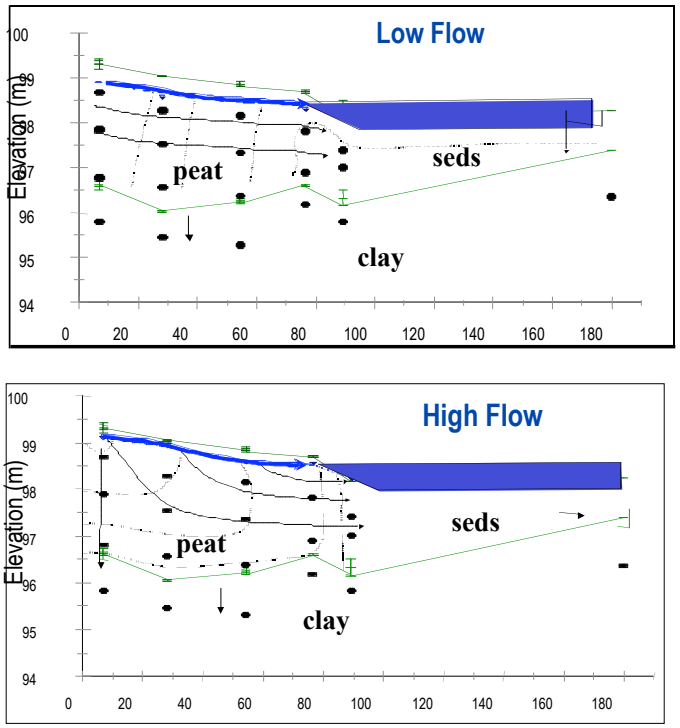


Figure 23 Peatland to pond cross sections for Pond 171 on the low lying clay-till plain with low flow conditions and high flow conditions. Adapted from Ferone and Devito (2004).

C.4 Summary

In considering wetland function or construction of new wetlands, a good understanding of the influence of interactions between the (dynamic) water budget, the basin storage properties, and the geologic setting is required to assess wetland hydroperiod, and thus form and function of the wetland (Kennedy and Mayer, 2002). Planners may manipulate combinations of the above three properties to produce required hydroperiod and a specific wetland type. In natural systems, two wetlands may have similar water budgets, but be located in different geologic settings. This could result in different local hydroperiod, and thus different wetland type and function. Similarly, two wetlands may be located in different geologic settings that interact with different water balances to produce similar hydroperiods and water sources, and thus similar vegetation types and wetland classification. However, these similar wetland types may have different connections to landscape and thus different overall functions and susceptibility to upland succession (Bedford, 1999).

C.4.1 Conceptual Models

With the above background on our current understanding of the hydrologic processes operative within our different natural analogue sites, we can develop three basic conceptual models for the hydrologic behaviour, and the existence and maintenance of wetlands, in the sub-humid climate of the Boreal Plains of northern Alberta. These simplified models should form the basis for the design of wetlands on reclaimed landscapes at oil-sands mines.

1. ***Fine-grained deposits*** (Figure 24a). Most depressions with fine-grained material have the potential to saturate and create wetland areas; however, regional connectivity will be limited. Wetlands on fine-grained deposits will tend to be isolated (e.g., at topographic highs) or have only local-scale flow systems (e.g., if hill slopes are present). They will largely be perched, and may act as recharge areas for adjacent hill slopes for much of the time. Providing adequate basin storage or peatland storage will be crucial to wetland resilience to periods of drought. Wetlands on very flat terrain require peat to retain water on the landscape.
2. ***Coarse-grained deposits*** (Figure 24b). Topographically low areas will tend to be connected to larger-scale, regional flow systems. These wetlands will function as discharge areas, with relatively constant water levels, because of the uniform supply of groundwater. The effective catchment area of these wetlands may be very large, depending upon the lateral scale of the deposits. In upland areas, wetlands will only exist where a fine-grained confining layer is present. Such wetlands will be perched above the regional groundwater system, and so will be somewhat isolated from the regional hydrologic system.
3. ***Coarse-grained veneer on fine-grained deposits*** (Figure 24c). In the presence of a permeable veneer, groundwater flow systems will be shallow, which implies that responses to climate will be accentuated and that there will be enhanced connection between wetlands, relative to more homogeneous landscapes.

The permanence of perched wetlands will be governed by the local geology, morphology and vegetation, and perhaps the ability to establish peat deposits. Fluxes of water will tend to be vertical, dominated by precipitation (P) and evapotranspiration (ET). Because of the large variation in P from one year to the next, it is to be expected that the change in storage (ΔS) will be large. Thus, the basin morphology of such wetlands must be sufficient to accommodate substantial variations in climatic inputs, or there must be a mechanism to

deliver excess water (e.g., there must be fine-grained material in ephemeral draws) to the wetland or to store water (e.g., established and growing peat) within the wetland. Most hill slopes can only be counted on to supply water following several years of excess precipitation.

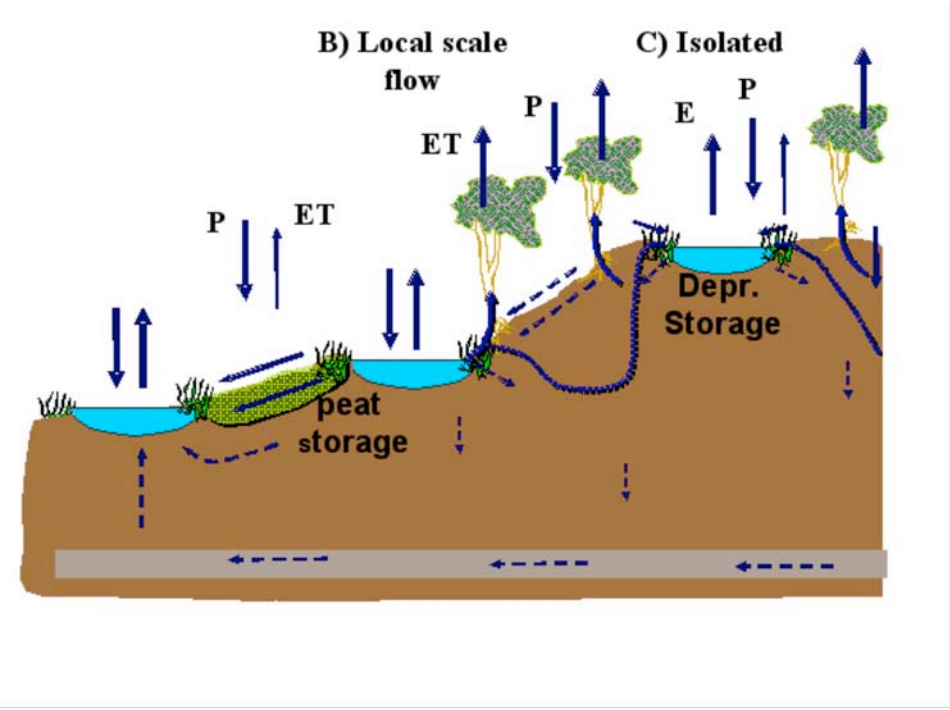


Figure 24a Conceptual model of dominant storage and water flow path for fine-grained moraine and low lying plain (overburden and MFT analogy) within the sub-humid climate of the Western Boreal Plain.

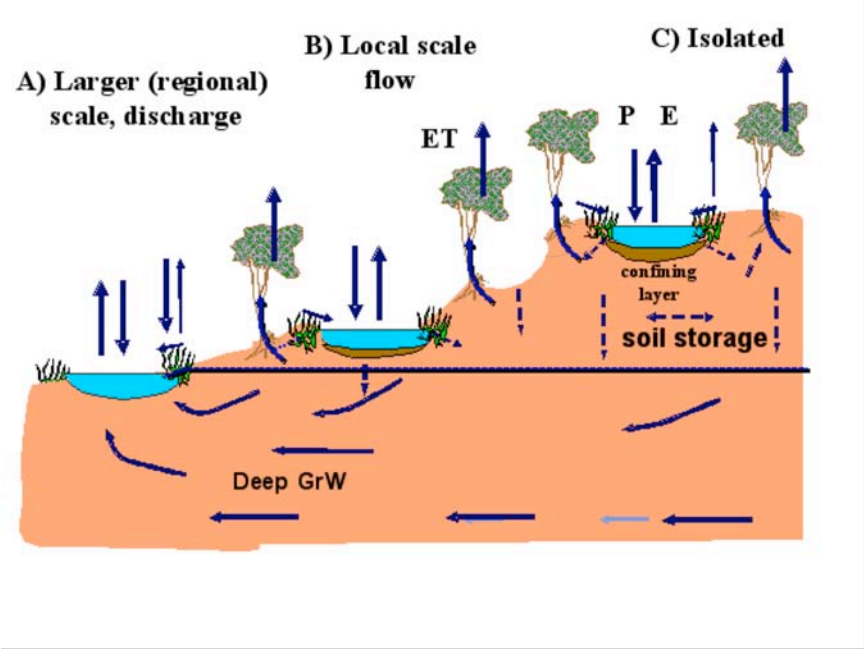


Figure 24b Conceptual model of dominant storage and water flow path for coarse-grained outwash (sand tailings analogy) within the sub-humid climate of the Western Boreal Plain.

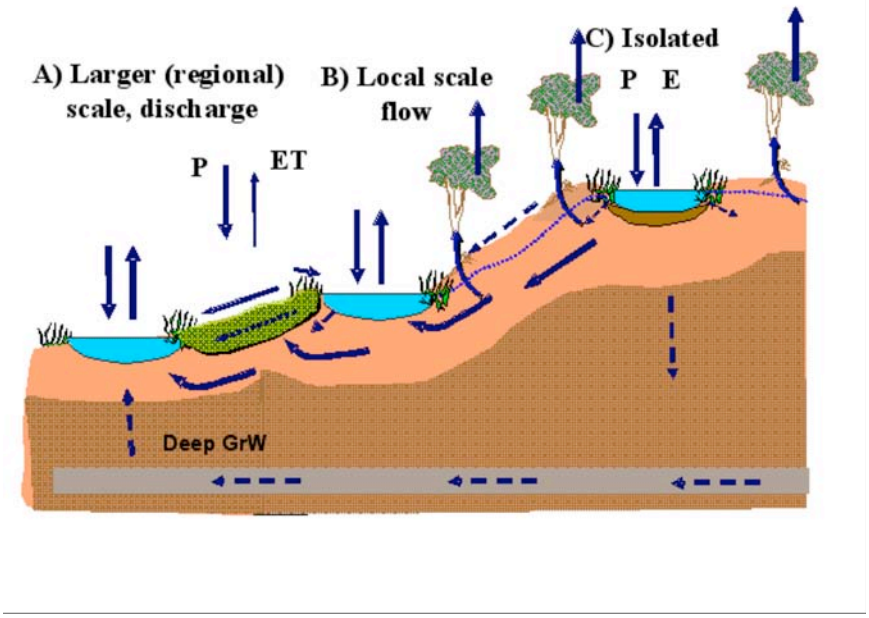


Figure 24c Conceptual model of dominant storage and water flow path for layered systems transition to outwash and moraines (potentially CT analogy) within the sub-humid climate of the Western Boreal Plain.

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C 2 – A Framework for Classifying and Assessing Potential Water Resources: Comparison with Ft. McMurray

By Kevin Devito[1], Carl Mendoza[2], U Silins[3], Rich Petrone[4], Thian Gan[5] and Irena Creed[6]

[1] University of Alberta, Department of Biological Sciences, Edmonton, AB
[2] University of Alberta, Department of Earth & Atmospheric Sciences
[3] University of Alberta, Department of Renewable Resources
[4] Wilfrid Laurier University, Department of Geography, Waterloo, ON
[5] University of Alberta, Department of Civil & Environmental Engineering
[6] University of Western Ontario, Department of Biology, London, ON

This appendix is adapted from:

Devito K, Creed I, Gan T, Mendoza C, Petrone R, Silins U, Smerdon B. 2005. A framework for broad-scale classification of hydrologic response units on the Boreal Plain: is topography the last thing to consider? Hydrological Processes 19: 1705-1714.

C.6 Summary

Presented is an adaptation of a framework published in Devito et al. (2005a) for defining effective hydrologic response units in landscapes at both local and regional scales. This framework may be applied to conceptualize water cycling and wetland function on oil sands developments, Ft. McMurray, Alberta, Canada. Further, it may be used by practitioners to best assess how to extrapolate existing hydrologic studies from other climates and geologies to the climate, and the range of landform materials being created at the oil sands region, Ft. McMurray. This framework summarizes research conducted at the Utikuma Research Study Area (URSA), Alberta, Canada, and reviews other research typical of the Ft. McMurray area. The Ft. McMurray area and URSA are both characterized by sub-humid climate ($P \leq PET$), where low relief and deep glaciated substrates result in the dominance of soil storage, evapotranspiration and vertical, rather than lateral, water exchange in hill slope water balances (Devito et al 2005a). Furthermore, heterogeneity in the scale of surface-water and groundwater interactions is associated with heterogeneity of glacial landforms (e.g., sand outwash, clay-silt moraines, and low-lying peatlands) that preclude the use of topographic watershed boundaries to define water sources. We present a comparative analysis of hydrologic cycling in different regions of the boreal forest that forms the basis for a hierarchy of factors to classify hydrological systems. The hierarchy moves in the direction of decreasing spatial scale when considering the relative importance of controlling factors in water cycling. This analysis shows that regional sampling and mapping to select representative landscape units that reflect climate, bedrock and surficial geology, and soil type and depth controls on hydrological systems, prior to topography, are imperative for effective generalizations of water and energy cycles in the Western Boreal Forest. This framework is designed to aid in the regionalization of catchment hydrology, direct the effective use of instrumentation, monitoring and modeling approaches, and direct adaptive management of water resources in both simple and complex landscapes.

C.7 Introduction

Clearly defined hydrologic response units (HRUs) that incorporate unifying concepts in hydrology - the complete hydrologic cycle and conservation of mass (Doodge, 1986) - are required to direct and integrate local, regional and continental scales of hydrologic research and management (Figure 1). The topographically-defined watershed or catchment has been championed as the basic HRU (Doodge, 1968) and the concept is used routinely for the creation and management of oil sands waste rock piles and tailings impoundments. However, topographically defined catchment units often focus on runoff, and assume little or no soil storage or groundwater interactions – which can be dominant components of the hydrologic cycle (Figure 1) in some areas. Recent reviews argue that using topographically defined catchments alone will not be sufficient, particularity in sub-humid regions as Ft. McMurray (Devito et al. 2005a). Broad scale classifications of climate, geology and wetland distribution are required for generalizing dominant hydrological processes and thoroughly integrate surface water and groundwater processes (Winter, 2001a,b; Sophocleous, 2002, Sivapalan, 2003; McDonnell and Wood, 2004, Buttle et al., 2005). This is also required to assess soil moisture distribution important in assessing re-vegetation of landscapes (Rodriguez-Irtube, 2000; Grayson and Western, 2001). We provide a summary of work presented by Devito et al. (2005a) which outlines protocols for defining representative hydrologic response units (HRU) for characterizing water resources, directing field methodologies, and applying hydrologic model structures.

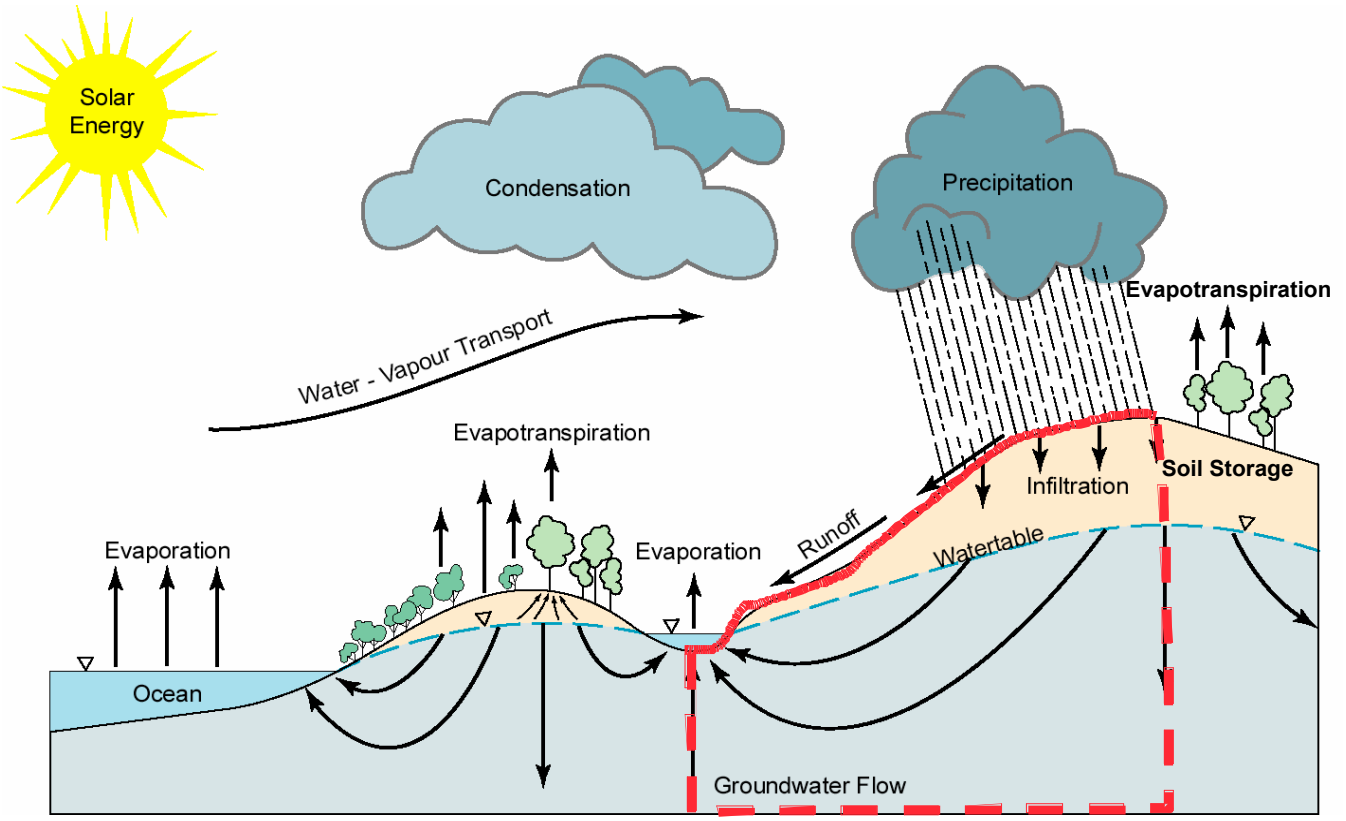


Figure 1 The hydrologic cycle, showing all components that need to be considered in understanding water flow. The red line denotes a Hydrologic Response Unit (HRU) that incorporates atmospheric fluxes, surface water as well as groundwater fluxes. Note the inclusion of "soil storage"

C.8 Hierarchy of Factors for Defining HRUs

Herein, we present a hierarchy of factors (Table 2) that expands on work from URSA and other landscapes to define: (a) regions of dominant hydrologic processes (i.e., HRUs); and (b) boundaries that incorporate the complete hydrologic cycle and mass balance of water for a specific region (Winter and Woo, 1990; Rodriquez-Iturbe, 2000; Winter, 2001a; McDonnell and Wood, 2004; Buttle et al., 2005). In Table 2 we argue that, for broad scale classification of a HRU, the order in which factors are considered is important and the factors should be considered in sequence of decreasing spatial scale to determine the relative influence on controlling hydrologic processes and budgets.

Table 2 Hierarchical classification to generalize the dominant controls on water cycling and indices to define effective catchment units. The specified order (i.e., A to E) should be followed to develop a conceptual framework to determine the dominance of specific components of the hydrological cycle and to determine the scale of interaction (e.g., local to regional) that should be considered (after Devito et al., 2005a)

Factor		*Range of Factor*		*Scale*
A	**Climate**	**Dry, arid to sub-humid (P<PET)** ▪ R poorly correlated with P ▪ Storage or uptake dominates ▪ Tendency for vertical flow	**Wet, humid (P>PET)** ▪ R closely correlated with P ▪ Runoff dominates ▪ Tendency for lateral flow	**Continental to local**
B	**Bedrock geology**	**Permeable bedrock** ▪ Intermediate to regional flow systems ▪ Lack of topographic control on direction of local flow ▪ Vertical flow dominates in surface substrate **Bedrock slope perpendicular to land surface** ▪ Complex watershed boundaries ▪ Regional aquifer definition needed to determine flow direction	**Impermeable bedrock** ▪ Local to intermediate flow systems ▪ Topographic control on direction of local flow ▪ Lateral flow dominates in surface substrate **Bedrock slope parallel to land surface** ▪ Simple watershed boundaries	**Continental to regional**
C	**Surficial geology**	**Deep substrates** ▪ Intermediate to regional flow **Coarse texture** ▪ Vertical flow ▪ Deeper subsurface flow **Spatially heterogeneous deposits** ▪ Complex groundwater flow systems ▪ Groundwater flow modeling important	**Shallow substrates** ▪ Local flow most probable (but see bedrock geology) **Fine texture** ▪ Lateral flow ▪ Depression storage and/or surface and shallow subsurface flow **Spatially homogeneous deposits** ▪ Simple groundwater flow systems ▪ Surface flow modeling important	**Regional to local**
D	**Soil type & soil depth**	**Upland mineral soils** ▪ Subsurface flow dominates ▪ Slow flow generation (matrix flow) **Storage** ▪ Deeper soils with large water storage potential **Transpiration** ▪ Deep roots access stored water ▪ P=AET during dry periods	**Lowland organic soils** ▪ Return flow and surface overland flow pathways dominate ▪ Quick flow generations (return flow, saturation overland flow) **Storage** ▪ Shallower soils with small water storage potential ▪ Lower specific yield of organic soils and compression leads to surface saturation **Transpiration** ▪ Shallower roots limit access to stored water ▪ AET<PET during dry periods	**Local to regional**
E	**Topography & drainage network**	**Gentle slopes** ▪ Disorganized inefficient drainage network ▪ Large groundwater recharge ▪ Small variable runoff yield	**Steep slopes** ▪ Organized efficient drainage network ▪ Small groundwater recharge ▪ Large uniform runoff yield	**Local to regional**

C.8.1 Climate Controls

Hydrologists should first consider broad scale differences in climate because it varies regionally with latitude and altitude, and locally with aspect (Table 1) (Burtsaert 1982; McDonnell and Wood, 2004). Climate governs the difference and seasonal synchronization between precipitation (P) and evapotranspiration (ET) and defines broad limits, or constraints, on the relative roles of vadose zone storage and frost, vegetation water demand, and the dominant direction of fluid flow (e.g., vertical vs. lateral) (Woo and Winter, 1993; Rodriquez-Iturbe, 2000; Winter, 2001a; Grayson and Western 2001). Broad scale frameworks based on indicators of dryness, such as the ratio of potential ET (PET) to P have been developed to generalize basic water balances of lakes, wetlands, and forests (Winter and Woo, 1990; Buttle et al., 2000; Rodriquez-Iturbe, 2000) (Table 1).

The distribution of humid (P > PET) and sub-humid to semi-arid climates (P ≤ PET) in Canada are provided in Figure 2. In humid (i.e., P > PET) eastern Boreal Canada, annual changes in soil storage are small, so annual P vs. runoff (R) relationships and assumptions of unit area runoff models tend to hold, especially over longer periods (Buttle et al., 2000, 2005). In contrast, in sub-humid climates (P ≤ PET), such as the oil sands region and URSA, ET and changes in soil storage dominate water balances, which produces low runoff and poor relations to annual P (e.g., Everson, 2001). This has been observed in a wide range of topographic and geologic settings, such as continental Boreal Canada (Devito et al., 2005b), Cordillera (Carey and Woo, 2001), and northern Precambrian Shield (Spence and Woo, 2003). Thus, care should be taken when generalizing hydrologic research results, of either natural or constructed systems, from humid climates to the Ft. McMurray area.

C.8.2 Hydrogeologic Architecture (Bedrock Geology)

Following climate, the bedrock geology (permeability and lithology) of each region establishes the regional hydrogeologic architecture upon which water table configuration and groundwater flow systems (local, intermediate, regional) are manifested (Table 2; Figure 2) (Tóth 1963, 1999; Freeze and Witherspoon, 1967; Winter, 1999, 2001a). Recognition of differences in the configuration of bedrock geology across the Boreal forest, and continentally (Back et al., 1998), is required to determine the scale of interaction and defining effective HRUs that incorporate all water sources (Winter, 2001a). For example, watershed boundaries for streams on the Shield are generally easy to define as recharge areas, and infiltrating water is restricted largely to localized, lateral flow due to thin or lack of surficial deposits on relatively impervious crystalline bedrock (Farvolden et al., 1988), with the exception of fractures (Winter, 2001a) or thicker surficial deposits (Hinton et al., 1993) (Table 2). Recharge areas for streams on the Cordillera are defined by the slope and extent of bedrock faults in anticline or syncline valleys, or thrust faces, which can slope in the opposite direction of local topography, and headwater streams may feed or receive water from within or beyond the topographic divide (Foxworthy et al., 1998; Stein et al., 2004). Defining recharge areas for streams in the oil sands area, as with other areas on the Boreal Plains, is complex. Infiltrating water is dominated by vertical flow (Figure 3), and can develop into local, intermediate, and/or regional scales of groundwater flow due to thick surficial deposits on permeable and heterogeneous bedrock (see Figure 4) (Lennox et al., 1988; Winter, 2001a).

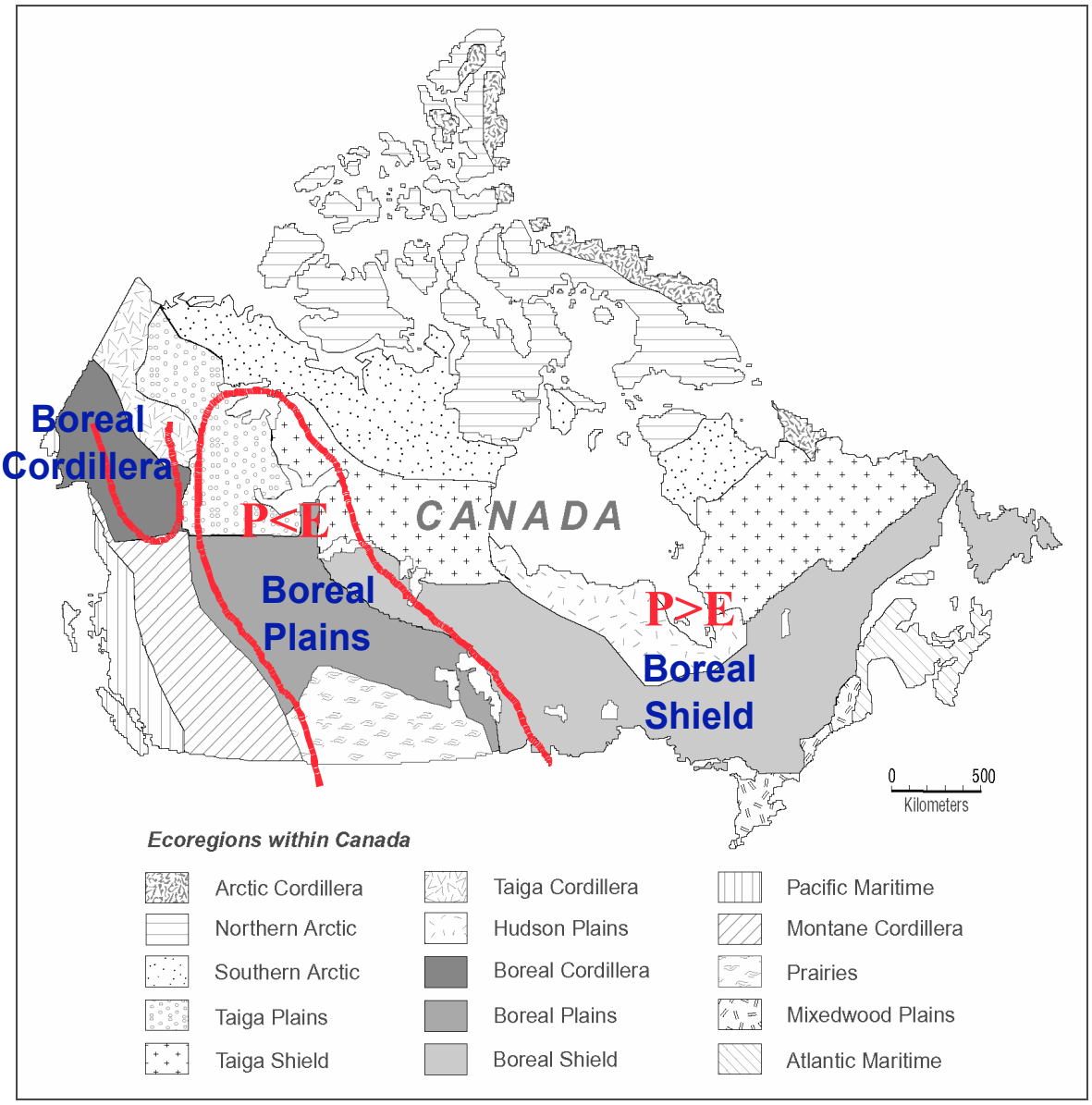


Figure 2 Eco-regions within Canada, showing regions of distinct climate, geology and vegetation with similar, and often unique, hydrologic properties. The line shows location where precipitation (P) equals potential evapotranspiration (PET). Sub-humid to arid areas of Canada located within south west (After Winter and Woo, 1993; Buttle et al., 2005).

C.8.3 Surficial Geology

Within regions of similar bedrock geology, the depth, texture, lithology and heterogeneity of surficial geologic deposits vary from local to regional scales in definable units associated with coarse- to fine-grained glacial-fluvial and glacial-lacustrine surficial deposits (Table 2) (e.g., Klassen, 1989; Halsey et al., 1997; Winter, 2001a) (see also Figure 1). Each of these distinct landforms has characteristic vadose zone moisture storage, infiltration, and recharge capacities, with generally higher rates in coarser sediments (Figure 5a-c) (Hendry, 1983; Saxton et al., 1986; Haldersen and Kruger, 1990). The potential for lateral redirection of

vertical water fluxes and modification of groundwater flow systems, or development of perched wetland and lake systems, will increase in surficial deposits with layering of fine and coarse textures (Freeze and Witherspoon, 1967; Stein et al., 2004). The depth and texture of surficial deposits influence the extent, ephemeral nature and type of flow path connecting slopes to streams, wetlands and lakes in a wide range of geologic settings (Devito et al., 1996, 2005b; Buttle et al., 2000; Halsey and Devito, in press). Further, the depth and texture of distinct landforms have been shown to influence the scale of groundwater interactions and influence the water table configuration and the distribution of losing and gaining functions for streams, wetlands or lake edges (LaBaugh et al., 1997; van der Kamp and Hayashi, 1998; Tóth, 1999; Winter, 1999).

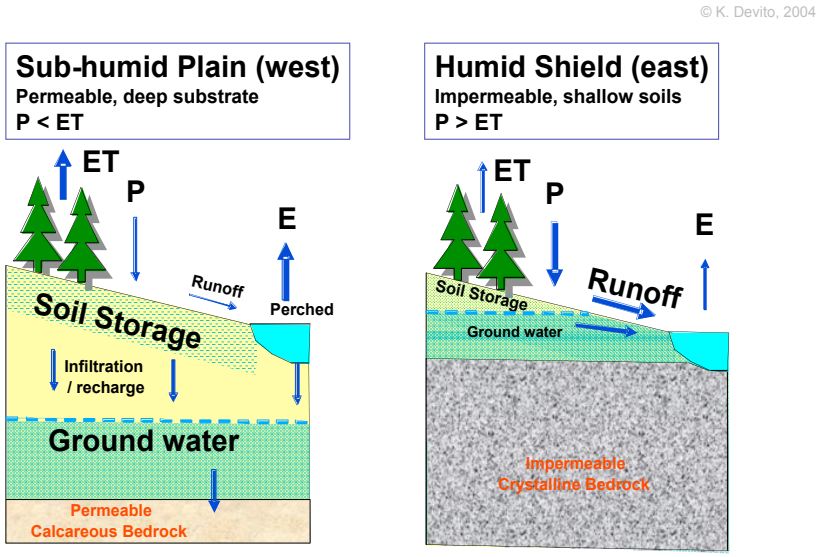


Figure 3 Comparison of sub-humid Boreal Plains and humid Boreal Shield hydrology illustrating the influence of climate and geology on dominant water storage and flow paths in catchments. The size of labels and arrows signifies their relative magnitude. In the sub-humid climate, characteristic of the Boreal plain, soil storage dominates and water flow is predominantly vertical, resulting in limited near surface flow and lower susceptibility to surface disturbance.

C.8.4 Soils and Vegetation (Peatland/Wetlands)

At a finer scale, distinction between wetlands, particularly peatlands, and mineral uplands reflect differences in soil organic content and depth (Table 2). This governs compressibility, hydrologic and thermal properties, which influence frost regimes, water storage and transmissivity (Woo and Winter, 1993; Comer et al., 2000; Grayson and Western, 2001; Price 2003). Such a distinction represents fine scale changes in the ratio of actual evapotranspiration (AET) to PET as the availability of water, depth of roots and influence of vegetation vary with soil and vegetation type (Rodriguez-Iturbe, 2000, Price et al., 2005). Furthermore, near surface moisture in organic soils is conserved relative to mineral uplands during years of extended dry periods, due to adaptation of peat transmissivity, ice storage and reduction in AET, and low vertical unsaturated moisture transport (Ingram, 1983; Silins

and Rothwell, 1998; Petrone et al., 2004). In regions where P < PET, fine scale spatial changes in AET can have a large influence on water storage thresholds and water table gradients. (Mills and Zwarch, 1986; Hayashi et al., 1998; Petrone et al., submitted).

Due to the contrast in antecedent conditions and storage capacity, the flow path and runoff response of peatlands and riparian wetlands can vary greatly, and often behave independently of adjacent hillslopes. Thus, these must be considered key runoff generating areas (HRUs) that dominate regional water balances in a wide range of climates and can occur at spatial scales finer than HRUs defined only by geology (Gibson et al., 2002; McDonnell, 2003; Price et al., 2005; Devito et al., 2005b).

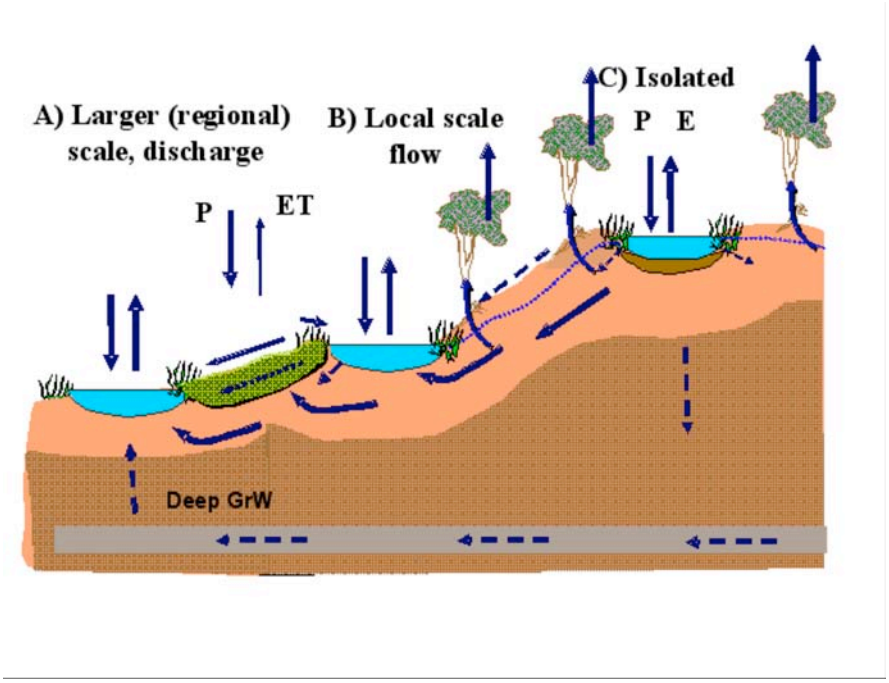
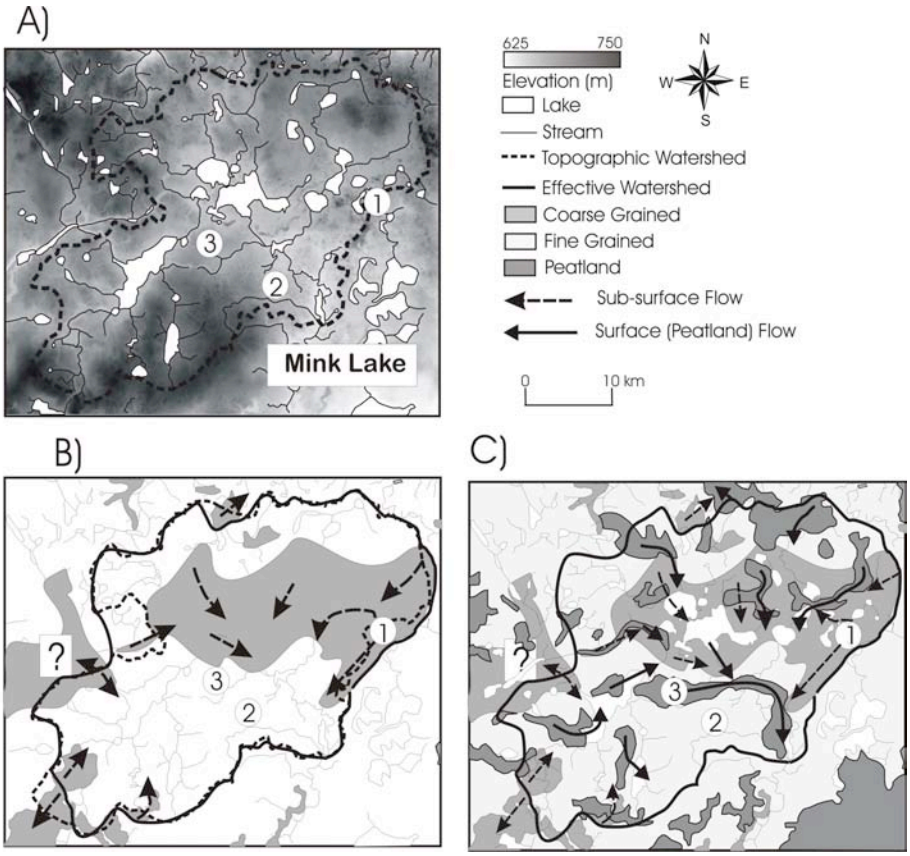


Figure 4 Variation in dominant hydrologic components and linkages to the surrounding environment of aquatic systems in isolated, local and intermediate groundwater flow systems. The water table responses to climate change and susceptibility of aquatic systems to disturbance in adjacent uplands will vary with the position of aquatic systems in the landscape.

C.8.5 Topographic Control of Drainage Networks

Clearly, topography will influence recharge and discharge areas (Tóth, 1963), detention and depression storage (Buttle et al., 2005), and flow rate and direction across spatial scales in many landscapes (Sivapalan, 2003; Wood, 2004) (Figures 4 and 5). In general, increasing surface water flows are expected with an increase in relief and efficiency or connectivity of drainage networks (Table 2). However, the assumptions underlying the use of a topographic or channel framework for modeling water cycling should be carefully examined and limited to landscape units of similar climate, bedrock and surficial geology, and peatland distribution (Table 1). There is growing evidence, particularly in the climatic and geologic setting of the Boreal Plain, that elevation differences among geologic surface features at coarse scales, or riparian wetlands and upland features at fine scales, do not provide adequate information on the hydraulic gradient and the flow of water, nor the scale of interaction between units (see

Figure 3) (Meyboom, 1966; Rodriguez-Iturbe, 2000; Grayson and Western, 2001; McDonnell 2004; Ferone and Devito, 2004; Smerdon et al., in press).



digital terrain analyses (Hutchinson, 1989; Hutchinson and Gallant, 2000). Three numbered sites illustrate hydrologic boundaries and scales of groundwater interaction and potential flow paths from contributing areas to Mink Lake: assuming topographic control and humid climate, Site 1 is outside the topographic divide and does not contribute flow; Site 2 is adjacent to a stream directly feeding Mink Lake; and, Site 3 is near a tributary of a stream that feeds Mink Lake. Panel (b) shows the distribution of: 1) coarse grained sediments (depth 10-20 m) from aeolian and glacial-fluvial processes, and 2) fine grained sediments from stagnant ice moraines (Fenton et al., 2003; Paulen et al., 2004). In contrast to Panel (a), hydrologic boundaries differ in Panel (b), and arrows on dashed lines show possible groundwater flow in permeable surficial aquifers. At Site 1 surface water systems are perched and groundwater flows beneath topographic divides. Areas with question marks (eastern edge) indicate unknown groundwater divides. In this sub-humid climate minimal runoff occurs from fine grained materials (Ferone and Devito, 2004; Devito et al., 2005b). Thus Site 2 is not a major water source to Mink Lake. Panel (c) incorporates distribution of

peatlands, and arrows on solid lines indicate regions where surface runoff through peat dominates (Gibson et al., 2002; Devito et al., 2005b). Consequently, there are larger surface water contributions from Site 3, compared to Site 2 (After Devito et al., 2005a).

C.9 Effective Delineation of a Catchment Using Dominant HRUs: A Boreal Plain Example

Ongoing research at our Utikuma Research Study Area (URSA), Alberta, Canada, reveals that glaciated regions, such as the Boreal Plain, represent a region with deep glaciated substrates resulting, arguably, in some of the most complex surface and groundwater interactions (e.g., Winter, 1999, 2001a). In addition, wetlands and peatlands are widely distributed across the landscape (NWWG, 1988) and often the water table does not mirror local topography (Meyboom, 1966; Ferone and Devito, 2004; Smerdon et al., in press).

The difference in a hydrologist's perception of the effective catchment area by first utilizing topography, rather than considering climate and geology, is illustrated in an example presented in Figure 5. From the data provided and the scale of the example, similar runoff contribution per unit area would often be assumed, and the hydrologic response time of rainfall at Site 2 would be considerably less than at Site 3. Catchment delineation and tracking of water flow described on Figure 1a may hold for some eco-climate regions, but this approach assumes a lack of influence by, or homogeneity in, climate, geology and wetland peat distributions. Research in areas with a sub-humid climate and low relief shows that unsaturated zone storage, vegetation water demand or evapotranspiration, and vertical flow dominate over lateral flow in hill slope water balances (Rodriquez-Itrube, 2000; Winter, 2001a; Smerdon et al., in press). This results in dynamic thresholds in surface water regimes and hill slope water balances with low runoff ratio's (< 20%), especially when summer precipitation dominates annual water budgets (Carey and Woo, 1999; Devito et al., 2005b).

The spatial heterogeneity of surficial glacial deposits (e.g., sand outwash, clay-silt moraines, and peat covered low-lying lacustrine clay) in the URSA (Figure 5b) (Fenton et al., 2003; Paulen et al., 2004) are associated with variations in vadose zone storage, runoff, and the scale of surface water and groundwater interactions. Hydrogeologic studies indicate minimal regional groundwater interaction with Mink Lake, due to 50 m of low permeability till deposits overlaying shale bedrock of low permeability (Vogwill, 1977; Ceroici, 1979). In the fine grained moraine till landform, (Site 2; Figure 5b) groundwater is largely restricted to local flow that conforms to topographic divides (van der Kamp et al., 2003; Ferone and Devito, 2004). The sub-humid climate and fine grained deposits restrict infiltration of precipitation to the shallow soil zone (i.e., vadose storage), which is subsequently taken up by high vegetation water demands (Rodriquez-Iturbe, 2000; Devito et al., 2005b). Although Site 2 is geographically the closest site to Mink Lake, in most years the water table elevation in the uplands is below adjacent valley or wetland depressions; therefore, runoff contributions are very small to non-existent (Ferone and Devito, 2004; Devito et al., 2005b).

In contrast, coarse grained deposits (Figure 5b) enhance both infiltration and sub-surface flow, and in sub-humid climates the water table mirrors the underlying confining layer rather than surface topography (Halsey and Devito, in press; Smerdon et al., in press). Regional surveys indicate that the coarse grained deposits are 20 m thick and that the underlying confining layer slopes downward from east to west, towards Mink Lake (Ceroici, 1979, Mendoza and Devito, unpublished data). Increased baseflow contribution to Mink Lake can be expected, compared to other fine grained surficial geologic units (Winter, 2001a), from subsurface flow paths originating beyond local topographic divides (Winter et al., 2003) at

several areas of the Mink Lake catchment (Site 1; Figure 5b) . In fact, some surface water systems are perched 15 to 20 m above the regional water table at Site 1 (Mendoza and Devito, unpublished data). In this catchment the actual groundwater divide and the direction of flow within the coarse deposits results in an effective catchment area that is considerably different relative to topographically defined regions (Figure 5b).

Major wetland peat deposits (Figure 5c), represent distinct hydrologic units within the defined HRU (McDonnell, 2003; Price et al, 2005). As noted earlier, runoff contributions to adjacent wetlands are small in a sub-humid climate, although infrequent large runoff contributions via surface pathways can occur during extended wet periods (Devito et al., 2005b). Higher antecedent moisture conditions are maintained in wetlands vs. forested uplands, as a result of contrasts in vadose zone storage capacity, thermal properties, and vegetation cover (Price, 2003; Price et al., 2005). Furthermore, near surface moisture in organic soils is conserved during years of extended dry periods due to rapid reduction in transmissivity of peat with depth, ice storage, reduction in actual to potential ET ratios due to shallow rooting zones, and low vertical unsaturated moisture transport (Silins and Rothwell, 1998; Petrone et al., submitted). Counter intuitively, water table gradients often slope against topography (i.e., from peatlands to adjacent mineral uplands) in the Boreal Plains, and water may move into the hill slope to recharge groundwater or be transpired by upland vegetation (Mills and Zwarch, 1986; Hayashi et al., 1998; Ferone and Devito, 2004). In peatland and riparian wetland areas (Site 3; Figure 5c), the wetter surfaces generate little surface water fluxes towards Mink Lake (Gibson et al., 2002; Devito et al., 2005b). Thus in the Boreal Plain, peatlands (which comprise 25 to 50% of the land area; NWWG, 1988) and low relief complicate traditional (i.e., topographic) definitions of HRUs. Therefore, the distribution and hydraulic connectivity of wetland areas provide more practical insights into effective drainage networks and surface runoff contributing areas, than topography within surficial geologic units (Devito et al., 2000; Wolniewicz, 2002).

Finally, precipitation falling on large lake systems will feed depression storage and can be evaporated during the growing season or recharge local coarse grained surface aquifers. In coarse grained areas, large lakes can act as evaporation windows to groundwater, exposing regional aquifers to significant water losses (Winter, 1999; Smerdon et al., in press).

C.10 Conclusions

The framework provided allows the practitioner to determine which major features or indices can be generalized to collectively explain the greatest variation in dominant hydrological processes, and the appropriate scale at which they interact (Sivapalan, 2003). With respect to oil sands planning, an understanding of the range of waste, tailings and composite materials, and their hydraulic properties, will allow the practitioner to either use such material as building blocks to create specific hydrologic conditions or to predict what the hydrologic cycling will be in current landscape construction. The practitioner should be aware of when and when not to assume topographic control of hydrologic systems. That is, in some landforms, constructed with some materials, the scale of each hydrologic component may not be confined to the scale of topographic control. The practitioner should consider geology and climate before topography to determine the potential for transfer of water across initially defined topographic divides, or to predict whether a hill slope will contribute little or no runoff. Each factor in the hierarchy acts at different scales; we consider the climate and landscape features that interact at larger scales first (Table 1). The framework provides the first step in qualitative “integrated, holistic description of heterogeneity” and a hierarchy of factors nested within each other to progressively define the relative importance of different scales and types

of hydrologic interactions or processes to effectively define hydrologic boundaries (Sivapalan, 2003).

The actual scale of dominant hydrologic processes in water cycling may be much finer (e.g., E and ET vary from open water to peatlands to hill slopes) or coarser (e.g., regional groundwater flow) than the "ideal" size for most topographically defined catchment studies (Winter 2001a; McDonnell, 2003; Wood, 2004; Buttle et al. 2005). An appreciation of the differences in the scale at which dominant hydrologic processes act is required to direct appropriate methodological and modeling strategies for any given region or landscape (see Sivapalan, 2003; McDonnell and Wood, 2004).

The heuristic, conceptual framework that we have provided should allow both hydrologists and non-hydrologists (e.g., managers) to identify appropriate indices and to make qualitative predictions of the dominant hydrologic processes influencing water resources at the local (i.e., within climatic and geologic zones) and regional scales for the complex glaciated Western Boreal Forest of Canada, and the reconstructed landscapes of the oil-sands region (see Sivapalan, 2003). Besides leading to an understanding of natural systems, these evaluations will facilitate assessments of the potential susceptibility of aquatic systems to impacts from anthropogenic and natural environmental changes. Furthermore, our approach encourages the explicit determination of the scale at which water resources interact with the surrounding environment without any *a priori* assumptions about the "catchment" area. This will be necessary to assess cumulative environmental effects of multiple land use impacts and to formulate appropriate adaptive management strategies. For example, managers could use indices of climate and surficial geology to determine if a particular hillslope is likely to generate runoff, and thus to assess the susceptibility of associated aquatic systems to disturbance (e.g., logging). Indices of bedrock and surficial geology could also provide information on the likelihood that subsurface flow may dominate, and at what scale. That is, they could determine whether the hill slope above a stream defines the source area for the stream, or not, and subsequently assess the degree of susceptibility to a particular disturbance, either inside or outside the "topographic catchment". Similarly, these indices could be used to design reconstructed landscapes that will provide the hydrologic functionality (e.g., wetlands of various forms) that is desired for a particular reclamation project.

C.11 Acknowledgements

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Appendix D

Plant Establishment for Wetland Reclamation: A Review of Plant Establishment Techniques and Species Tolerances for Water Level and Salinity

by David Cooper, Evan Wolf, and Edward Gage
Department of Forest, Rangeland and Watershed Stewardship
Colorado State University, Fort Collins, CO

Plant Establishment for Wetland Reclamation: A Review of Plant Establishment Techniques and Species Tolerances for Water Level and Salinity

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D.1 Introduction

A number of approaches have been used to establish a desirable cover of vascular plant species on wetland restoration and reclamation sites. Several of these approaches are reviewed in section D.2 of this document to highlight the opportunities that each approach offers, and to identify the drawbacks of each approach. In addition, a number of physical, chemical, and ecological variables can influence the success of these plant establishment approaches, and a number of critical variables are also reviewed.

Section D.3 of this document reviews the hydrologic and geochemical tolerances of 40 vascular plant species that could potentially be used in wetland restoration or reclamation projects in the Alberta Oil Sands region. In addition, we provide a review of published information on the establishment requirements for each species.

In section D.4 we provide a summary and synthesis table identifying suites of vascular plant species that could be used in wetland restoration and reclamation in different hydrologic and geochemical environments. In this chapter we also provide suggestions for creating different types of wetlands in the Oil Sands region.

Wetland restoration and reclamation projects should have specific goals. Project goals should be determined during the planning process, and the project designed and implemented to achieve those goals. However, because reclaiming wetlands is complex, in some instances it may be desirable to first build the wetland, and then monitor its hydrologic regime, geochemistry and soil environments so that appropriate species can then be chosen for introduction. Then one or more plant establishment techniques could be implemented so the biotic target can more easily be determined and reached (Pfadenhauer and Grootjans 1999).

D.2 Approaches for Establishing Vascular Plants

D.2.1 Overview of Plant Establishment Techniques

D.2.1.1 Direct Placement of Soils – Soil Seed Bank

The direct placement of peat or other soils from mining areas to restoration or reclamation areas could potentially be used for establishing a plant cover. However, several factors could make this approach more or less suitable to the goal of establishing a desirable plant cover. First, the natural composition of the soil seed bank for wetland communities in the study area is unknown. If the soil seed bank contains desired species, and if these species can germinate in the hydrologic and geochemical environments created by the wetland reclamation project, then the use of transplanted soils may be a useful restoration technique (Salonen 1987). The use of transplanted soil may also increase plant species diversity and cover as reported by Stauffer and Brooks (1997).

However, seed bank assays should be conducted to ensure that the correct species are present in the soil. In addition, generally only the upper soil horizons contain a viable seed bank (Salonen 1987); therefore, the thickness of soil containing a viable seed bank must be determined by analysis. Seed banks can be depleted if a site is drained prior to

soil collection, or during the storage process. It would be useful to determine the effects of storage on the soil seed bank. Analyses should be conducted for soils from different wetland communities and using different storage methods. We suggest that three different approaches for soil collection, storage and use should be tested for their influence on seed bank longevity: (1) blocks of sod cut intact from natural vegetation and stored intact, but each in dry and wet environments, (2) the top 40 cm of soil cut and mixed, and stored in dry and wet environments, and (3) the entire soil or peat body stored in dry and wet environments. For each of these soil storage methods the most suitable conditions for seed germination should then be determined.

In addition to soil seed banks, collected soils will contain roots and rhizomes of desirable species. However, it is unknown how long these propagules can remain alive in a stockpiled soil. Since these are potentially important propagules for restoration, it would be valuable to analyze their longevity under different soil collection and storage schemes.

An additional need is to determine the effects of soil storage on organic matter mineralization rates, and the resulting nitrogen and phosphorus concentrations in soils applied to different types of reclamation sites. The seedlings of many plants may be sensitive to high nutrient levels, and high nutrient levels could facilitate the invasion and establishment of undesirable plant species, such as *Phalaris arundinacea*, that have high nitrogen requirements, or high biomass production.

D.2.1.2 Seeding

Existing studies of directly seeding wetland plant species into reclamation or restoration sites have generally produced poor results. However, because direct seeding is inexpensive relative to more intensive approaches such as planting plugs, seedlings or bare root stock, it continues to be used for wetland reclamation projects. Little seedling establishment occurred from seeds sown for fen species in Europe (Mass 1988) and in the US (Cooper and MacDonald 2000). In tests of seedling trials for a rich fen in Colorado, the only species to germinate and form seedlings was *Triglochin maritima* (Cooper and MacDonald 2000), and no *Carex* or *Kobresia* seedlings were established.

A number of researchers have analyzed germination of seeds for different species and have found the requirements for germination are species-specific. Germination was highest for 5 European *Carex* species in non-flooded stands, compared to flooded stands, and growth was best in sites with bare soil, and without existing vegetation (Isselstein et al. 2002, Tallowin and Smith 2001, Bakker 1989). Irrigation may facilitate germination and seedling establishment, while shading inhibits germination. Higher soil temperatures may improve germination rates.

Several factors could improve the use of seeding as a re-vegetation technique for wetlands in northern Alberta. Seeds should be collected from the area where re-vegetation would occur, to ensure that appropriate genotypes of each species are used. This would provide genotypes that are adapted to the local environment. While field collection of seeds for use in reclamation and restoration projects ensures that plantings are adapted to local environmental conditions, it may be impractical for very large-scale projects. In such cases, locally collected seeds can be collected and plants grown in a commercial nursery until they produce seed, and these seed populations then used for reclamation. All seed should be cleaned/threshed/screened to remove the fruiting bracts,

scales, floral parts, awns, perigynia, and other non-seed debris to the maximum degree possible (Dunne et al. 1998).

Seeds should be stratified for 4 weeks under wet, cold (4°C) conditions (Roth et al. 1999) or temperature fluctuations of the diurnal rhythm (Mass 1988) to break dormancy. This could be done in the lab, or by dispersing seeds in the fall and allowing them to over-winter in the field. There are benefits and drawbacks of fall vs. spring seed dispersal. Winter storage in a laboratory necessitates cold stratification prior to seed dispersal. However, field dispersal in the fall, allows seeds to be eaten by herbivores during the winter, or to be moved by snowmelt water in spring. The appropriate dispersal time may be site dependant.

Another way to introduce seeds into wetland restoration sites is by cutting hay in wetlands in late summer when plant seeds are ripe. This hay can then be spread onto reclamation sites (Pfadenhauer and Grootjans 1999). Hydro-seeding is an inappropriate technique for wetlands, as the mulch, binder, and seed/seedlings may be washed away should water levels rise above the seeded area prior to germination and seedling establishment (CNAP 1998). Drill seeding may be appropriate, although if sites are inaccessible to large equipment, broadcast seeding is preferable (CNAP 1998). The appropriate soil depth of incorporation of the seed varies by species, but general guidelines are to plant to a minimum depth of 0.7 cm and a maximum depth of 1.3 cm for most small seed mixes. With mixes containing larger seeds, a minimum depth of 1.5 cm and a maximum depth of 2.6 cm may be more appropriate (Dunne et al. 1998).

Seeding rates are species-specific, and where known are presented in the species reports.

D.2.1.3 Seed Rain

Many characteristic peatland species are not capable of seed dispersal over large distances, particularly where surface water flow is interrupted (Bakker et al. 1996). Water is the best dispersal agent for all species, other than those with wind disseminated propagules, such as species of *Typha* or *Eriophorum* (Poschlod et al. 1998). Aerial invasion and establishment of species such as *Eriophorum vaginatum* accelerated the later establishment of typical bog plant species, especially species of *Sphagnum* on mined sites in eastern Canada (Lavoi et al. 2003). Thus, establishment of *Eriophorum vaginatum*, or other wind-dispersed plants onto fen restoration sites could facilitate later establishment of mosses.

Natural seed rain from species of *Salix* has been used to populate restoration sites with appropriate water table depths (Cooper and Van Haveren 1994). This approach could work for riparian areas that would be dominated by woody plants. However, it does not appear that natural seed rain can be counted on to provide propagules for large wetland reclamation sites, especially for fens or bogs.

A few researchers have identified the use of remnant islands as a potentially important source of propagules for wetland restoration (Money and Wheeler 1999). Islands could be left during the mining process, or created with blocks of sod transplanted intact into reclamation areas. However, in some mined bogs, the vegetation of remnant islands was different than the vegetation of natural bogs due to effects on drainage (Poulin et al. 1999).

D.2.1.4 Plugs and Bare Root Stock

A number of species have been successfully used for restoring the vegetation of wetlands from field collected roots, rhizomes, and plugs. However, this approach is time consuming, and is suggested only for relatively small restoration areas. *Carex rostrata*, when planted as rhizome segments, formed open vegetation within two years at a wetland in the Netherlands (Pfadenhauer and Grootjans 1999). At this site, *Sphagnum* spp. invaded around the *Carex* shoots, allowing the moss to grow up the *Carex* shoots and escape water level fluctuations. *Kobresia simpliciuscula*, *Carex utriculata* and other species were successfully established at a peat mined fen in Colorado from rhizomes collected from a natural area (Cooper and MacDonald 2000).

When planting roots and rhizomes, the species to be used should first be analyzed in field trials. For example, Yetka and Galatowisch (1999) found that rhizome planting was not successful for *Carex stricta*, but was for *C. lacustris*. In addition, the time of year when planting occurred might be important. For these two species of *Carex*, planting was most successful when implemented in spring, not in fall when new shoots are initiated. In addition, the best success occurred at the water's edge, thus water level was also key to plant survival.

Transplanting of soil plugs onto consolidated tailings (CT) deposits near Fort McMurray, Alberta (Golder Associates 2005) allowed the establishment of several species. The salt tolerant species *Scirpus validus*, *Puccinellia nuttalliana*, *Scirpus pungens*, *Triglochin maritima*, *Juncus balticus*, and *Scolochloa festucacea* were transplanted, and the first three had good survival; however, overall survival was limited by water levels rising too high. In addition, plug transplants of *Carex aquatilis*, *C. atherodes*, *C. praegracilis*, *C. bebbii*, *C. utriculata*, *Typha latifolia* and other species were used to increase biodiversity. Many species have survived, although again, increases in water level have negatively affected many species. Plugs from a saline seep area dominated by *Dodecatheon pauciflorum* were also implemented. A large number of other species from the seep area were also transplanted with the plugs, and many species have survived for several years (Golder Associates 2005).

The use of bare root *Typha latifolia*, *Scirpus validus* and other species was also tested on several different thicknesses of CT deposits with and without surface soil application at Fort McMurray, Alberta by Golder (Golder Associates 2005). Good survival was noted in several of the experimental environments, but growth and survival were also highly influenced by water levels.

D.2.1.5 Containerized Stock and Stocking Rates

Field collected seed, stratified in a greenhouse, germinated and grown into seedlings in small plastic tubes (4-10 cm3) has been used in many restoration projects (Cooper unpublished data). Success with *Carex aquatilis*, *C. utriculata*, *Calamagrostis canadensis*, *Carex vesicaria*, *Scirpus pungens* and several other species of grasses, sedges, and herbaceous dicots has been obtained. In addition, large numbers of such seedlings have been grown and planted, up to 500,000 plants for individual projects, at a cost (including planting) of $0.77 to $1.25/plant. While there is a considerable cost associated with this approach, plant survival is very high, disturbance to sites for collection of rhizomes is avoided, seed is easily collected, stored and processed, and

seedlings take up little space in a greenhouse. In addition, the desired species can be placed directly into the physical environments where they will perform best. Once established, plants provide localized centers of seeds for future plant establishment, as well as vigorously growing rhizomes that can spread over large areas. Planting densities of 2 to 4 plants/m^2 have been used, and for rhizomatous species, a planting density of even 1 plant per m^2, or lower densities, could be used to introduce the desired species over large areas, or to supplement other plant propagation approaches, such as direct seeding (Cooper unpublished data).

D.2.2 Environmental Factors Influencing Plant Establishment

D.2.2.1 Seed Bed Preparation

Several factors may influence the success of seeding, seed rain, and planting onto prepared soil surfaces. Micro-topography can be used to create site heterogeneity, and influence habitat for species establishment. For example, different plant species and patterns of species richness occur on hummocks, flats and hollows in a restored wetland in North Carolina (Bruland and Richardson 2005). Topography in the form of wind breaks, or patches created by straw, as well as depressions have been shown to increase moss and vascular plant establishment (Quinty and Rochefort 1996). Microtopographic patterns can be produced by earth moving equipment during site grading, or by natural or controlled fires (Barry et al. 1996, Cantelmo and Ehrenfeld 1999, Benscoter et al. 2005). In wetland restoration grading plans Cooper et al. (unpublished data) have created in the US, microtopography up to 40 cm high was used to increase hydrologic diversity, allowing wind blown seeds to be captured and seedlings of different species to be planted at different heights above the water table. Straw mulch can also be applied to stabilize restoration sites and create soil heterogeneity. Straw is most effective as a seed bed if spread thin, not scant or thick (Quinty and Rochefort 1996).

Large wetland restoration project sites are typically open to the wind and its desiccating effects. Nurse plants have been used to create site heterogeneity and protection for establishing seedlings and other plantings. Establishing carpets of the moss *Polytrichum strictum*, from fragments, and the application of straw mulch have been used to reduce frost heaving by reducing the number of freeze-thaw cycles. The mulches slowed the rate of ground thaw in the spring, and reduced the unfrozen water content of the peat during the spring thaw (Groeneveld and Rochefort 2005). If herbaceous species are to be planted at the end of the growing season in sites where the water may rise above the ground surface during freezing temperatures, plants should be cut within 5 cm of the ground surface so that rising ice will not pull the plants out of the ground (CNAP 1998).

D.2.2.2 Water Table Depth Influence on Plant Establishment

Water table depth is the most commonly cited factor controlling vegetation establishment in wetlands, although edpahic factors such as soil salinity may also be important (Purdy et al. 2005). Water levels control seed germination and plant establishment in almost all wetlands. In a study of a restoration site in New York, little plant establishment occurred where the water table was more than 45 cm below the soil surface during the summer (Brown and Bedford 1997). Where trenches or ditches are found in wetlands, the

hydrologic control on water tables by the ditches was the main factor related to re-vegetation patterns (Lavoie et al. 2003).

Reclaimed wetlands should be designed for a minimum amount of human maintenance of water level (Mitsch and Gosselink 2000). The hydrologic regime of the reclaimed wetlands should be allowed to reach equilibrium across the landscape with little to no reliance on ditches, levees, dams, or other water control structures that require upkeep. The most straight-forward approach to achieving this is to restore the ground level to its pre-mining elevation in all locations, and to ensure that any drainage structures built during the mining process are removed or filled in. Hydrogeomorphic features, such as rivers or lakes, which were removed or altered during mining need to be restored to their original configuration.

Water tables in the restored area must match the ecological amplitude of the species proposed for restoration. This should occur through a combination of site grading and analysis of water table dynamics. Once hydrologic zones are understood, then a planting plan can be developed to match each hydrologic zone. This approach is simpler and more effective than making a vegetation map first and attempting to manipulate the hydrologic regime to match that planting scheme (Mitsch and Gosselink 2000).

D.2.2.3 Soil and Water Chemistry Influences on Plant Establishment

Hydrologic regime is typically regarded as the principal abiotic factor driving wetland vegetation patterns; however, soil and water chemistry gradients can also be important factors influencing vegetation. For example, wetland fertility, specifically nitrogen and phosphorus availability, in part define the poor to rich gradient (Bragazza and Gerdol 2002). The concentrations of mineral ions such as calcium (Ca^{2+}) and pH are generally thought to co-vary with nutrient-availability gradients, and are often used to characterize peatland habitats. Also of importance in the oil sands region is soil and water salinity. For example, in a study of natural and reclaimed landscapes in Alberta, Purdy et al. (2005) attributed differences in plant communities within saline landscapes to gradients in soil salinity. They found a high degree of similarity among plant communities established at similar levels of soil salinity, suggesting a strong role for salinity in determining plant community composition. In non-saline habitats, they observed a graded series of plant communities, which they attributed to hydrologic gradients.

High levels of the salts sodium chloride and sodium sulphate, elevated chromium concentrations, as well as the presence of naphthenic acids in the Athabasca Oil Sands region produce saline and potentially toxic conditions that may be limiting to plant establishment. These pollutants are derived mainly from the oil-bearing marine sands that underlie surficial organic soils. In the natural state, these pollutants are in low concentrations at the surface due to leaching and vertical accumulation of peat. During the mining process the peat layer is removed, the underlying sands are processed to remove oil, and the resulting consolidated tailings (CT) are replaced back on site. Thus the soil stratification is rearranged, bringing the saline sands to the surface. In an experimental re-vegetation of CT placed back into mined areas, plant success depended on whether peat was mixed into the surface layer of CT (Golder Associates 2005).

In areas where CT was mixed with peat, wetland reclamation was considered successful. *Typha* colonization and expansion was high, transplanted shoreline areas retained as many as 13 original species, and greater than 98% average plot cover was

achieved. In addition, transplants of saline adapted species (dominated by *Dodecatheon pauciflorum*, shooting star) survived well on the mixed CT/peat substrate. Wetland restoration was less successful at sites with only CT. *Typha* expansion was lower, natural colonization retained fewer original species and plot cover was lower, less than 45%. Although the saline and potentially toxic conditions of reclaimed oil sands present challenges to wetland restoration, incorporation of peat into the top 1 m of CT fill significantly increased plant establishment success (Golder Associates 2005).

D.2.2.4 Mycorrhizae

Several decades ago it was thought that wetland plants lacked mycorrhizae. However, recent research has demonstrated that many wetlands plant species can host mycorrhizae. For example, Turner and Friese (1998) found significant levels of arbuscular mycorrhizal fungal infection in many fen plants. Cooke and LeFor (1998) found that most wetland species had mycorrhizae, including species of *Scirpus*, *Carex*, *Eleocharis*, *Juncus*, *Kalmia*, *Populus* and *Salix*. Cooke and LeFor (1998) suggested several important concepts for using wetland soils in restoration projects to protect and enhance mycorrhizal fungi. First, the original topsoil containing microorganisms must be saved and used in re-establishing vegetation. Second, if re-vegetation is delayed, the stored topsoil piles should be planted with clover or alfalfa to increase the survival of N-fixing bacteria and fungi. Third, the topsoil should not be mixed with subsoil because most living fungi are in the upper portion of the soil. Fourth, where plants are grown for transplanting, either as seedlings, or as containerised stock, the plants should have some natural soil used in their growth containers so that they can be colonized by mycorrhizal fungi.

An analysis of the effects of CT release water in the oil sands of northern Alberta on mycorrhizae indicated that CT release water inhibits many species of fungi (Kernaghan et al. 2002). CaCl salts were the most toxic salts to fungi. This suggests that while mycorrhizae can help seedlings get established, mycorrhizae may not survive in the more saline environments present in the oil sands reclamation sites.

D.2.2.5 Plant Competition

Competition from plants that are rapid invaders of reclamation sites, or produce high above ground biomass, can influence the establishment of the desired plant species. For example, the above ground production of *Phalaris arundinacea* can influence the species richness and presence of characteristic fen species in restoration sites (Gusewell and Edwards 1999). Many fens with low primary production rates have complex spatial fertility gradients that are reflected in their vegetation composition (Verhoeven and Schmitz 1991). Nutrient enrichment can result in a shift to a single common and highly productive species.

Natural succession in restored wetlands, including fens, can lead to the development of near monocultures of *Typha latifolia* and *Phalaris arundinacea*. This can occur because the target species of *Carex* were present in low quantities in the soil seed bank, or had low seed dispersal, while *Typha* and *Phalaris* had high seed dispersal rates (Roth et al. 1999). In either case, the presence of tall and highly productive plants can limit the potential to establish the desired plant species. Consequently, purposeful introduction of aggressive competitors such as *Typha latifolia* and *Phalaris arundinacea* should be

avoided, as once these species become established, they may make the establishment of more desirable species difficult.

In all restored peatland areas, establishment of peat forming vegetation must be the initial goal for vegetation restoration. These species form a dense rhizome network that holds the existing peat together and the die-off of their belowground production generates new peat. An appropriate water regime that maintains saturated soil conditions in concert with properly established peat forming vegetation should exclude non-peatland invasives and allow other peatland plants to thrive.

D.2.3 Additional Design Considerations: Water Level Management

Water control structures, if used, may be valuable tools during the initial planting and vegetation establishment (Weller 1990, Hammer 1997). Complete dewatering of sites may make planting much faster and easier than planting in standing water. Additionally, water control structures could be used to offset the effects of a very dry or wet year that happens to coincide with the timing of planting. However, caution must be exercised to ensure that the control structures do not modify the hydrologic regime so much that, upon removal of the structures, a plant community has become established that is unsustainable in relation to the final hydrologic regime.

A variety of control structure designs have been developed for water level management in wetlands. Examples include stoplog culverts, valves, swiveling and flashboard pipe structures (Hammer 1997). Each type of structure has advantages and disadvantages in terms of cost of installation, maintenance requirements, and flexibility in controlling water levels. Ideally, water control structures should allow for relatively precise control of water elevations, allow for the complete dewatering of the wetland as well as the raising of water levels to the maximum safely allowed by the design, require little maintenance, and inhibit blockage by vegetation or the activities of beaver (Hammer 1997).

Where water control structures have been installed, water levels can be managed for specific habitat goals. For example, the seasonality of drawdowns can influence the production of seeds from wetland plants, providing an important food source for waterfowl. The seasonality of drawdowns can be important, with early and midseason drawdowns typically resulting in the greatest seed production (Fredrickson 1991). By allowing for the periodic release of surface water across wetlands as sheet flow, water control structures can also be used to help flush salts accumulated in wetland soils that inhibit plant growth or limit species composition (Fredrickson 1991). In another example, Merendino and Smith (1991) detail recruitment and survival of emergents under different drawdown dates and re-flooding depths in Manitoba. They found that maximum vegetative cover, maximum seed production, and the highest biomass production by *Scirpus* spp. was achieved under a mid-May drawdown, while *Typha* and *Lythrum* reached the highest cover under a mid-June drawdown.

Development of desirable plant communities in reclaimed wetlands requires stable substrates for plant growth. The inclusion of design features aimed at stabilizing substrates in low energy systems like fens is not generally required; however, in high energy systems such as riparian areas and the margins of large lakes, erosion control is

often needed. For example, while alluvial rivers and streams naturally migrate in response to changing water and sediment inputs, newly created or modified channels can be particularly unstable. Instability in riverine systems is caused by current-induced forces, and is typically greatest on the downstream portion of meander bends and at intermediate to high stream stages. Tractive forces remove material at the toe of the bank, undermining bank stability and causing failure (Hayes et al. 2000). Waves are often a source of local instability along fringe (shoreline) wetlands in large lakes. Wave erosion is concentrated near the waterline but fluctuating water levels can expand the zone of attack, undercutting banks and leading to mass failure (Hayes et al. 2000).

A variety of approaches can be taken where stability is a concern. Armoring of banks using natural or artificial materials like stone rip-rap, Geoweb, or straw waddles, can stabilize stream banks long enough to allow for the establishment of woody riparian shrubs (Willard et al. 1990). Once established the shrub roots will stabilize soil and their shoots will dissipate high flow energy. Planting density depends on the site characteristics and objectives. For example, the density of grid plantings can vary from <1000 stems/ha, upward to 10,000 stems/ha for critical sites. In sites with few suitable planting spots, planting in suitable microsites is more important than adhering to rigid spacing. Erosive forces such as waves are likely to be amplified if fetch is great. Consequently, the physical design of wetlands should minimize fetch (Marble 1992). In general, deeper water yields larger waves, so for a given wind speed, direction, and fetch length, the wind waves generated on a deep lake will be larger than a small one (Hayes et al. 2000). Therefore, steep banks should be avoided during wetland design. More gentle slopes also provide greater potential habitat for emergent species. Where exposure to erosive waves is expected to be high, the selection of species and planting methods should be modified. In these sites, broadcasting seed or planting plugs is an approach almost guaranteed to fail, while planting woody species such as willows may provide the needed stability. Breakwater structures may be required on shorelines of large bodies of water. Tires have been successfully used in Wisconsin to block wave energy from uprooting newly planted seedlings (Levine and Willard 1990).

D.2.4 Recent Wetland Reclamation Research in the Oil Sands Region

Three recent projects have addressed information needs for wetland reclamation in the Oil Sands Region. These are a masters thesis by Natalie Cooper (2004), a 2005 report by Golder Assoc (Golder 2005), which is a follow up of Natalie's thesis, and a report by Golder Assoc (Golder 2004) which analyzes reclamation trials from the years 2000-2004.

D.2.4.1 Vegetation Community Development on Reclaimed Oil Sands

This thesis (Natalie Cooper, MSc thesis, University of Alberta) analyzed seedling emergence and survival from soils transferred from reference and other wetlands to CT wetlands at the Suncor demonstration wetland facility. Soil transfers to CT wetlands resulted in higher % plant coverage and species richness compared with controls. However, the seed-bank of natural reclaimed and newly constructed wetlands were dissimilar in species composition. In addition, the flora of natural wetlands differed from that of other wetlands, including those on 1 and 4 m thick CT. Sites that were within opportunistic or natural wetlands had higher vegetation cover and species richness than those in large areas of CT material. Colonization of CT soils by *Scirpus validus*, *Typha*

latifolia, *Eleocharis acicularis*, and *Potamogeton pectinatus* indicated that the study soils did not inhibit plant colonization. These habitats were shallowly or deeply flooded for much of the year and most likely the deep water levels controlled which species could germinate and survive. The propagules of most species likely arrived on the CT wetlands by seed rain from adjacent wetlands, not from the wetland soil transfers. Differences in vegetation between treatment plots are likely due to limited dispersal of many wetland plant seeds. CT did affect seedling emergence from soil seed-banks compared with other soil types, such as potting soil, and there was lower seedling emergence. Soil seed-banks of natural wetlands had more species than standing vegetation, thus many species are present in the seed-bank that could not survive in the existing vegetation. The use of natural recovery processes, using soil seed-banks from natural wetlands was advocated because it allows less easily dispersed species to be introduced to reclaimed wetlands. However, because CT produces saline soils and water, it is unlikely that the species composition of CT reclaimed wetlands would be similar to natural non-saline wetlands. In addition, the author suggested that it was unpredictable how vegetation communities on CT tailings might develop on a large scale site. If sites were capped with sand, or soil, or if fresh water was added, the resulting community might be different than if CT was used as the sole soil medium. Most of the trials and analyses were for marsh conditions, with shallow standing water, not for wet meadows or fens that had shallow water tables, and slow flowing groundwater. She concluded that two years was an inadequate time period to determine the success of the soil transfers and the future of the wetland vegetation.

D.2.4.2 Natural Recovery of Consolidated/Composite Tailings Wetlands Using Salvaged Wetlands Soils – 2004 Monitoring Program

Because two years was determined to be inadequate to evaluate the success of the soil seed bank transfers (Natalie Cooper 2004) an additional year of monitoring was performed and presented in this report (Golder Associates 2005). The goals of this report were to clarify whether CT is a hospitable growing medium for wetland plants, determine the effectiveness of soil seed banks from natural wetlands for natural recovery of CT wetlands, and determine whether the vegetation that develops on CT wetlands is similar to natural marshes or wet meadows in the Oil Sands region. Vascular and bryophyte species richness increased over time, but some of this may have been due to a beaver dam failure which changed site hydrologic regime, and created opportunities for species intolerant of deep water to establish. The key result from this work is that CT does not prohibit the germination and establishment of wetland plant species.

D.2.4.3 Consolidated Tailings (CT) Integrated Reclamation Landscape Demonstration Project (technical report #5)

This report included a number of studies conducted during the five year period from 2000-2004 (Golder Associates 2004). These included analysis of *Typha* establishment, natural aquatic plant colonization, saline lake transplants, aquatic shoreline plug establishment, planted and existing *Scirpus validus* monitoring, existing *Carex aquatilis* monitoring, muskeg peninsula monitoring, *Scirpus* cover on 4 m CT plots, and shooting star transplant survival.

Typha latifolia established on all landforms and was a good candidate for wetland reclamation on CT. The colonization of aquatic species was enhanced by the presence of donor species nearby, to enhance seed rain. Without these nearby propagule

sources the processes of colonization would likely be much slower. Several species established from the aquatic shoreline plug establishment trials, some from the root mass in the transplants, and others recruited from the soil seed bank. However, these trials resulted in very high variability, with many species establishing, but others dying. The planted *Scirpus validus* has been highly successful in many of the CT reclaimed wetland plots. However, there has also been die-back of many plants, for unexplained reasons. *Carex aquatilis* transplant cover has also declined sharply during the study period, likely due to the rising water levels, although this was not documented.

Most species transplanted from the saline lake are highly tolerant of high soil salinity, and should be good performers in the reclaimed CT wetland. However, the hydrologic regime of plots where the saline lake soils were transplanted has shallow standing water, as would be found in a marsh, and water levels rose during the course of the study, resulting in poor performance of most species. *Scholochloa festucaeae* and *Puccinnellia nuttalliana* typically grow in saline meadows that lack flooding, or where flooding is of short duration. *Scirpus pungens* is most common in seasonally, but not permanently flooded sites. Therefore, the hydrologic conditions to analyze the tolerance of these taxa to the CT environment were only partially accomplished. Transplants from the shooting star saline site produced mixed results. Several of the key species, *Dodecatheon pauciflorus*, *Lycopus asper*, *Aster puniceus* and *Galeopsis tetrahit* were alive after two years. In addition, these plots had a moderate number of species in them. Thus, this method has promise for introducing salt tolerant species to the CT wetlands.

D.3 Species Profiles

Acorus calamus L. (sweet flag, calamus)

General description

Acorus calamus L., a member of the Acoraceae, is an obligate perennial plant discontinuously distributed throughout circumboreal regions. In North America, it is found from Nova Scotia and Quebec, through the Great Lake region to Alberta and Eastern Washington, south to Florida, Texas and Colorado (Thompson 2004). Common names include flagroot, myrtle-flag, sweet calamus, sweet flag, and sweetroot. The plant produces volatile oils, concentrated in rhizomes, and has long been used for medicinal purposes. Taxonomists have debated whether *Acorus* is native or introduced, as well as the number of taxa found in North America. Currently, evidence supports the existence of two species - *A. calamus*, a sterile triploid introduced from Europe, and *A. americanus*, a native fertile diploid (Packer and Ringius 1983, Thompson 2004). Because of this confusion, references to either name in the literature should be scrutinized. Synonyms include *Acorus americanus* auct. non (Raf.) Raf. and *Acorus calamus* L. var. *americanus* auct. non (Raf.) Raf. In general, *A. calamus* has longer and wider leaves and longer spadices (Thompson 2004).

Water level tolerance

Acorus calamus and *A. americanus* are both obligate wetland species, and are intolerant of droughty soil conditions. In Europe, *Acorus calamus* has been assigned an Ellenberg indicator value of 10 on a scale of 12, which represents species characteristic of shallow-water sites that may lack standing water for extensive periods (e.g. emergent marshes) (Hill et al. 1999). *Acorus calamus* occurs in sites with stable water table elevations, as well as sites with large water-level fluctuations during winter and summer months (van den Brink et al. 1995). Hammer (1992) includes *A. calamus* among a list of species tolerant of seasonally flooded to permanently flooded hydrologic regimes, with maximum water depths ranging from 15-50 cm.

Water quality tolerance

Acorus spp. occur across a relatively wide pH range, from 5.3 to 7.2 (USDA NRCS 2004). In Europe, *A. calamus* was assigned an indicator value for soil reaction of 7 (on a scale of 9), suggesting that the species is typically found under weakly acidic to weakly basic conditions. Cizkova et al. (2001) found *A. calamus* in wetlands with Ca concentrations of 14.5 mg/l, Mg concentrations of 7.8 mg/l, K concentrations of 3.01 mg/l, and Na concentrations of 12.0 mg/l. *Acorus calamus* is associated with nitrogen-rich soils. The species was given a nitrogen index rating (i.e. Ellenberg indicator value) of 7 on a scale of 9, indicating N-rich conditions (Cizkova et al. 2001). *Acorus* appears to be tolerant of heavy metal pollution. In China, it was documented in mine tailing ponds in sediments with extremely high concentrations of Pb (11,161 mg/kg), Zn (4612 mg/kg) and Cu (649 mg/kg) (Deng et al. 2004).

Salinity tolerance

Acorus spp. occur in fresh to brackish water, with salinity up to approximately 10 ppt (Thunhorst 1993). *Acorus calamus* was documented in a marsh in Czech Republic with the following conductivity: 252 ± 18 mS/cm (Cizkova et al. 2001).

Substrate requirements

Neither *A. calamus* nor *A. americanus* are adapted to coarse-textured soils (Bush 2002). Both are typically found in mineral soils, although they may occasionally be found in peat soils as well. *Acorus calamus* is tolerant of prolonged submergence on mineral, moderately reductive sediments and on organic, highly reductive sediments. It occurs in isolated as well as in very dynamic floodplain lakes, although it is less common in isolated lakes. It can be found on mineral to organic reductive sediments (van den Brink et al. 1995).

Reproduction and establishment requirements

Acorus calamus and *A*. *americanus* can be propagated vegetatively by plant or rhizome division. *A*. *americanus* can also be established by seed, although germination rates are generally low (Hagen 1996). Vegetative propagation should be conducted in either the fall or spring using firm, vigorous rhizomes cut into 5-10 cm-long sections. Rhizome sections should be planted 10-15 cm deep and 30 cm apart. Alternatively, individual sprigs from clumped plants can be separated and transplanted 30 cm apart (Bush 2002).

To establish *A. americanus* from seed, scatter seeds on the surface of a shallow tray filled with an organic soil mix during the fall or winter in a greenhouse; do not bury seeds further than 3-4 mm deep. Keep soil moist to saturated. *Acorus* seed does not require stratification and typically germinates in less than 2 weeks. Seedlings should be transplanted to larger pots when they reach 7-10 cm tall. Plants should be placed in shallow water or regularly irrigated to maintain very moist to saturated conditions until ready for transplantation outdoors in the spring (Bush 2002). With adequate moisture seed can also be planted outdoors spring through early summer or in a cold frame late summer through fall. Starter fertilizers may be used indoors to improve early growth but are unnecessary once transplanted outdoors into a rich soil (Bush 2002).

Associated species

Acorus occurs in a variety of habitats, including freshwater and brackish tidal marshes, inland freshwater marshes, wet meadows, and low-energy riparian systems (Thunhorst 1993). Not surprisingly then, it can occur with a variety of species. Cizkova et al. (2001) found *Acorus calamus* along with *Carex gracilis*, *Galium palustre*, *Iris pseudacorus*, *Lysimachia vulgaris*, *Lythrum salicaria*, *Peucedanum palustre*, *Scutelaria galericulata*, *Calamagrostis canescens*, *Cicuta virosa*, *Phalaris arundinacea*, *Solanum dulcamara*, *Urtica dioica*, *Glyceria maxima*, *Phragmites australis* in the Czeck Republic (Cizkova et al. 2001). It was documented from freshwater and brackish tidal marshes in Connecticut, USA dominated by *Typha angustifolia*, *Phragmites australis*, *Zizania aquatica*, *Leersia oryzoides*, *Peltandra virginica*, *Sagittaria latifolia* Willd., and other wetland macrophytes (Farnsworth and Meyerson 2003).

Beckmannia syzigachne (Steud.) Fern. (American sloughgrass)

General description

Beckmannia syzigachne is an annual or short lived rhizomatous perennial grass (Poaceae). Synonyms include *Beckmannia eruciformis* auct. non (L.) Host, *B. eruciformis* (L.) Host ssp. *baicalensis* (Kusnez.) Hultén, *B. eruciformis* (L.) Host var. *uniflora* Scribn. ex Gray, *B. syzigachne* (Steud.) Fern. ssp. *baicalensis* (Kusnez.) Koyama & Kawano, *B. syzigachne* (Steud.) Fern. var. *uniflora* (Scribn. ex Gray) Boivin (ITIS 2004, USDA NRCS 2004). The species and genus are widespread in temperate Eurasia and North America, occurring in marshes, moist meadows and vernal pools, ditches and muddy depressions in irrigated fields, edges of lakes, sloughs, and ponds throughout the northwest and north central United States and all Canadian provinces (Boe and Wynia 1985, NatureServe 2005). *Beckmannia syzigachne* is considered secure globally (G5), nationally in Canada and the United States (N5), and secure in Alberta (S5) (ANHIC 2005, NatureServe 2005). It frequently colonizes denuded wetland soils resulting from mud flat exposure, livestock grazing, or agricultural disturbance.

Water level tolerance

Beckmannia syzigachne is an obligate wetland species *sensu* Reed (Reed 1988). There are relatively few studies directly or indirectly quantifying the hydrologic variables influencing the distribution and abundance of the species. It is referenced in a variety of marsh ecosystem studies; most describe it as occurring in shallow-marsh zones where soils are inundated or saturated through spring and early summer (Sloan 1970, Stewart and Kantrud 1972). Tiner et al. (2002) reported *Beckmannia syzigachne* in marshes with seasonally flooded hydrologic regimes (Tiner et al. 2002). The species is an indicator of seasonally flooded low elevation basins in Colorado (Carsey et al. 2003). Hammer (1992) includes *B. syzigachne* among a list of species tolerant of seasonally or permanently flooded (to a depth of 15 cm) hydrologic regimes.

Water quality tolerance

Beckmannia syzigachne can grow in acidic or slightly basic soils (Payne 1992). Suitable pH values reported for *B. syzigachne* range from 5.5 to 7.5. The species has been reported to have a low $CaCO_3$ tolerance (USDA NRCS 2004).

Salinity tolerance

Beckmannia syzigachne appears moderately tolerant of saline conditions. Although it is most common in fresh water, it may also occur in wetlands with oligosaline and mesosaline systems. For example, mean EC in prairie potholes supporting *Beckmannia syzigachne* was 1.5 mS/cm, although values ranged from <0.5 to 9.5 (Kantrud et al. 1989a). The USDA (2004) suggests medium salinity tolerance for the species.

Substrate requirements

For restoration or reclamation, *Beckmannia syzigachne* appears to be most adapted to fine texture soils, ranging from silty-loams to clays (Goodwin and Sheley 2003). The USDA NRCS suggests adaptation to medium – fine textured soils (USDA NRCS 2004).

Reproduction and establishment requirements

Several attributes suggest that *Beckmannia syzigachne* may be useful for revegetation efforts in the oil sands region. The species is a natural colonizer of disturbed marsh systems (Stewart and Kantrud 1972, Boe and Wynia 1985). *Beckmannia syzigachne* seeds can be efficiently grown and harvested and some genotypes are commercially available (Native Seed Network 2005). Seeds exhibit relatively high germination rates when sown in favorable sites. For example, Boe and Wynia (1985) found high germination rates, ranging from 70-96%, in laboratory trials of *Beckmannia syzigachne* seeds. They observed germination rates of 45% in the field for spikelets that had matured and disarticulated in the summer. These data indicated a lack of complex seed dormancy characteristics for the species (Boe and Wynia 1985).

Its relatively modest germination requirements and prolific seed production capabilities may be important characteristics associated with the species' ability to rapidly colonize exposed mudflats and disturbed wetlands such as found in cropland depressions (Dix and Smeins 1967). Overwintering, either dry or moist, has been reported to enhance germination, and stratification has resulted in much greater seed germination rates (Hoffman et al. 1980).

Anecdotal accounts report strong seedling vigor, rapid establishment, and good plant coverage 60-100 days post seeding (Native Seed Network 2005). Fall planting is preferred to spring planting. Seeding rates of 19 lbs pure live seed/acre were suggested for reclamation use in western Montana (Goodwin and Sheley 2003). Seed weight has been estimated at 523,600 seeds/kg (USDA NRCS 2004). Payne suggests establishing the species from either transplants or seeds, collecting the latter when mature from July to October and storing at 5°C before sowing onto moist ground (Payne 1992).

Associated species

Beckmannia syzigachne was reported as a characteristic species in the shallow-marsh zone of prairie potholes along with species such as *Glyceria grandis* (tall mannagrass), *Sparganium eurycarpum* (giant burreed), *Carex atherodes* (slough sedge), *Scolochloa festucacea* (whitetop), *Eleocharis palustris* (common spikerush), and *Scirpus americanus* (common three-square) (Sloan 1970). In addition to relatively pristine wetlands, *B. syzigachne* occurs in disturbed wetlands. Stewart and Kantrud (1972) included the species along with *Alisma triviale*, *Alopecurus aequalis*, and *Polygonum coccineum*, among the principal pioneering shallow-marsh species found following agricultural disturbances. Tiner et al. (2002) list *B. syzigachne* as an indicator of seasonally flooded hydrologic regimes in prairie pothole wetlands along with species such as *Eleocharis palustris*, *Sparganium eurycarpum*, *Alisma plantago-aquatica*, *Carex atherodes*, *Phalaris arundinacea*, *Glyceria grandis*, and *Scolochloa festucacea*.

Calamagrostis canadensis (Michx.) Beauv. (bluejoint)

General description

Calamagrostis canadensis is a perennial grass (Poaceae) widely distributed throughout the northern portions of the United States and Canada (NatureServe 2005). It is highly variable throughout its range, with one subspecies and eleven varieties described (Tesky 1992). Common names include bluejoint and bluejoint reedgrass (ITIS 2004). *Calamagrostis canadensis* is ranked globally (G5), is considered nationally secure in Canada and the United States (N5), and regionally secure (S5) in Alberta (NatureServe 2005, ANHIC 2005, NatureServe 2005).

Water level tolerance

Kantrud (1989) characterized the hydrologic regime of prairie pothole wetlands supporting *C. canadensis* as temporarily flooded (Kantrud et al. 1989a). Thunhorst (1993) recommended sites seasonally or regularly inundated up to 30 cm or saturated 75% of the growing season.

Water quality tolerance

Recommended pH values for *C. canadensis* range from 4.5-8.0 (USDA NRCS 2004). The species can tolerate acid or neutral pH (Payne 1992) and is reported to have low soil fertility requirements (USDA NRCS 2004).

Salinity tolerance

Calamagrostis canadensis is restricted to freshwater systems with low salinity (<0.5 ppt) (Payne 1992, USDA NRCS 2004). Kantrud reported a mean EC of 1.4 mS/cm, with a range of 0.4 to 3.8 mS/cm in northern Great Plains wetlands (Kantrud et al. 1989a). In Alberta, Purdy et al. (2005) commonly found *Calamagrostis canadensis* in nonsaline, slightly saline, and reclaimed oil sands wet-meadows, but not in strongly saline habitats.

Substrate requirements

Calamagrostis canadensis is found in sites with mineral and organic soils. In mineral soil sites, it occurs on soils of both fine and course texture (Payne 1992, USDA NRCS 2004). On organic soils, *Calamagrostis canadensis* cover was positively correlated with peat thickness (Ashworth 1997).

Reproduction and establishment requirements

Seeds, rhizomes, or plugs can be used for revegetation (Thunhorst 1993). Payne suggested establishing *C. canadensis* from either seeds or sprigs, collecting the former when mature from July to September and storing at 5°C before broadcasting (Payne 1992). He also recommended collecting and separating young individuals for immediate replanting on site or into containers. Rate of spread once established is slow (Thunhorst 1993). Seeds are light, on the order of 1,740,650 seeds/kg (USDA NRCS 2004). In Colorado, time to germination of *C. canadensis* seeds was 11-14 days; seeds were sown in a greenhouse under a tent with misters set for 10 sec/15 min watering intervals at 12 hours intervals (Native Plant Network 2005a).

If established via plugs or rhizomes, plant at 30-90 cm spacing depending on how quickly complete aerial cover is desired (Thunhorst 1993). Vesicles suggesting the presence of VAM fungi were found in *C. canadensis* in a riverine marsh in southern Alberta, suggesting that mycorrhizae may be important (Thormann et al. 1999).

Calamagrostis canadensis exists in temperate forest sites of different successional age and is able to rapidly colonize disturbed sites to form dense swards (MacDonald and Lieffers 1991). It appears to display an `opportunistic guerrilla' strategy of clonal foraging, readily expanding into favorable areas through vegetative spread (Macdonald and Lieffers 1993). Research in prairie potholes found that many species common to natural systems including *C. canadensis* were notably absent or infrequently occurring in created wetlands 12 years after their construction, suggesting that active revegetation is generally needed to establish the species (Mulhouse and Galatowitsch 2003). The species had the highest cover of any species on 1 m CT and Control substrates in reclaimed oil sands wetlands (Golder Associates 2005).

Associated species

Calamagrostis canadensis occurs in a variety of habitats including fresh tidal and nontidal marshes, shrub carrs, and wet meadows (Thunhorst 1993). Specific associates vary geographically and by habitat type, but can include obligate wetland species from peatlands as well as facultative and upland species. For example, *C. canadensis* is a common species in Montana cottongrass (*Eriophorum angustifolium*)-dominated fens along with *E. chamissonis*, *E. viridicarinatum*, *Carex magellanica, Comarum palustre*, *Drosera anglica*, *Menyanthes trifoliate*, *Sphagnum angustifolium*, *S. subsecundum*, and *Aulacomnium palustre* (Cooper & Jones 2004). It also is found in forested and shrub-dominated vegetation types. Examples include the *Abies lasiocarpa* - *Picea engelmannii* /*Calamagrostis canadensis* forest and Salix *drummondiana* / *Calamagrostis canadensis* shrubland vegetation associations from Colorado (Carsey et al. 2003). Purdy et al. (2005) recorded *Calamagrostis canadensis* in a range of community types including wet meadows and both shrub-dominated and forested wetlands.

Calamagrostis inexpansa (=Calamagrostis stricta (Timm) Koel. ssp. inexpansa (Gray) C.W. Greene) (northern reedgrass)

General description

Calamagrostis inexpansa (Poaceae, subfamily Pooideae, tribe Aveneae) is a perennial rhizomatous grass that is widespread in northern latitudes of North America (USDA NRCS 2004). The taxonomy of the species is complex and some authorities now classify the species as a subspecies of *C. stricta*, *C. stricta* (Timm) Koel. ssp. *inexpansa* (Gray) C.W. Greene; this name will be used through the rest of the assessment (Kartesz 1994, NatureServe 2005). Over 20 synonyms, including a variety of sub-specific and varietal designations, exist for *Calamagrostis stricta*, adding to the confusion over classification (ITIS 2004).Common names include northern reedgrass and slimstem reedgrass (USDA NRCS 2004). *Calamagrostis stricta* ssp. *inexpansa* is considered secure at the global (G5), national (N5), and regional level in Alberta (S5) (NatureServe 2005).

Water level tolerance

The wetland indicator status of *C. stricta* var. *inexpansa* is facultative wetland (FACW and FACW+), indicating that it usually occurs in wetlands (estimated probability 67%-99%), but is occasionally found in non-wetlands (Reed 1988, USDA NRCS 2004, Kaul 2005). *Calamagrostis stricta* var. *inexpansa* often occurs in depressions and swales on the margins of springs, lakes, or stream channels where soils are saturated or seasonally flooded (Carsey and others 2003). It occurs throughout the Rocky Mountains and Intermountain region on wetter sites with very low-velocity surface and subsurface flows such as large meadows in montane or subalpine valleys and narrow strips bordering ponds, streams, or toeslope seeps (Christy 2004). It is a relatively common emergent hydrophyte of palustrine wetlands with temporarily flooded moisture regimes in the prairie pothole region (Kantrud et al. 1989a). Purdy et al. (2005) found that *Calamagrostis inexpansa* had an affinity for wet meadows, but not dry meadow, shrub-dominated or forested wetland communities. Hammer (1992) includes *C. stricta* var. *inexpansa* among a list of species tolerant of seasonally to permanently flooded (to a depth of 15 cm) hydrologic regimes.

Water quality tolerance

The USDA NRCS list a pH range of 5.5 to 8.0 for *C. stricta* var. *inexpansa*, as well as rating its tolerance for $CaCO_3$ as low (USDA NRCS 2004).

Salinity tolerance

The USDA characterizes the salinity tolerance of *C. stricta* as medium (USDA NRCS 2004). Kantrud (1989) reported a mean EC of 2.6 mS/cm for water in sites where *C. stricta* var. *inexpansa* occurred, with a range from <0.5 to 17.6 mS/cm (Kantrud et al. 1989a). It is a common dominance type in oligosaline palustrine wetlands in the northern plains (Kantrud et al. 1989b). Purdy et al. (2005) found *Calamagrostis inexpansa* in slightly and strongly saline landscape settings.

Substrate requirements

Calamagrostis stricta var. *inexpansa* has relatively broad affinities, being adapted to fine and medium textured mineral soils (USDA NRCS 2004), as well as organic substrates in peatlands (Christy 2004, USDA NRCS 2004).

Reproduction and establishment requirements

Calamagrostis stricta var*. inexpansa* flowers in late spring and seeds mature from summer through early fall. It produces light seeds easily dispersed by the wind. The USDA suggests that the species could be propagated by seed or sprigs, but not through cuttings, sod, or tubers (USDA NRCS 2004). Cold stratification of seeds is not required and once established, *C. stricta* var*. inexpansa* spreads vegetatively at a moderate rate (USDA NRCS 2004). In *C. stricta* and other *Calamagrostis* species, self-incompatibility, population structure, and infrequent flowering limit seed production; plants persist primarily by rhizomes and often occupy relatively stable, late-successional habitats (Greene 1984).

Associated species

It occurs in a variety of vegetation associations. For example, it has been reported from a community dominated by *J. balticus* in Colorado; associated species reported include *Agrostis gigantea*, *Argentina anserine*, *Poa pratensis*, *Carex praegracilis*, *Carex simulate*, *Deschampsia cespitosa*, *Phleum pretense, Hordeum jubatum* ssp. *jubatum, Plantago eriopoda, Dasiphora floribunda, Iris missouriensis, Taraxacum officinale* (Rocchio 2004). It has also been documented in a vegetation association dominated by *Carex pellita*; other associated species reported included *Deschampsia cespitosa*, *Eleocharis palustris*, and *Phleum pratense* (Carsey et al. 2003). *Calamagrostis stricta* var*. inexpansa* occurs occasionally in *Carex lasiocarpa*-dominated communities in Idaho fens (USDA NRCS 2004). In the eastern Dakotas, it is found in small depressions along with *Carex lanuginosa* and *Juncus balticus* (Sieg and King 1995).

Carex aquatilis Wahlenb. (water sedge)

General description

Carex aquatilis is a perennial obligate wetland graminoid that is widespread throughout Canada and the U.S. It is normally dominant or co-dominant in the wetlands where it occurs. The individual shoots live approximately 5 years, while the roots live 10 to 15 years. In arctic systems, the roots are confined to the top 20-30 cm of soil (Daly et al. 1989). The rhizomes of *C. aquatilis* grow approximately 5 cm below the soil surface and form dense clumps (Dirschl and Coupland 1972, Bernard 1990). The crowded rhizome network results in a density of 1,000-2,000 shoots per square meter. (Bliss and Grulke 1988). This dense sod stabilizes soils and streambanks. The shoots are a minor component of ungulate grazers' diets (moose, deer, elk, caribou) but can be a major part of bison winter forage in northern Canada (Bernard 1990). Approximately 10% of annual foliage overwinters to initiate the following 35 to 40 day leaf-growing season (Daly et al. 1989).

Water level tolerance

The water regime best suited for *Carex aquatilis* is one with the water table above ground level in early June and adequate moisture in the root zone throughout the year (Dirschl and Coupland 1972, Dirschl et al. 1974). *Carex aquatilis* grows best on flat or concave surfaces with a maximum slope of 10 percent (Padgett et al. 1989). The preferred water table depth range reported for *C. aquatilis* in Alberta was 0 to 7 cm (Golder Associates 2005).

Water quality tolerance

Carex aquatilis invaded oil-damaged areas successfully compared with other vascular plants, and it appeared to have some tolerance to the toxic effects of crude oil (Bliss and Wein 1972, Kershaw and Kershaw 1986).

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Carex aquatilis* occurred in wetlands with a mean specific conductivity of 1.6 mS/cm, a minimum of 0.3 mS/cm and a maximum of 3.8 mS/cm (Smeins 1967, Kantrud et al. 1989a). In Alberta, Purdy et al. (2005) commonly found *Carex aquatilis* in nonsaline and reclaimed oil sands wet-meadows, but not in slightly or strongly saline habitats.

Substrate requirements

Carex aquatilis grows best in cold, organic soils with textures ranging from sandy loam to clay (Chapin III and Chapin 1981) with pH ranging from 6.2 to 7.1 (Hansen et al. 1990) and a minimum pH of 4.0 (USDA NRCS 2004). The organic component of *C. aquatilis* substrate is usually a mass of roots and rhizomes, varying in degree of decomposition (Bliss and Grulke 1988). *Carex aquatilis* will also grow on mineral soils. The soil supporting *C. aquatilis* characteristically has a very high moisture-holding capacity with shallow to deep peat and a shallow to moderate active layer (Dirschl and Coupland 1972, Daly et al. 1989) . It appears that phosphorous is the limiting nutrient of *C. aquatilis* in wet tundra, meadows (Chapin III and Chapin 1981), and freshwater marshes (Ngai and Jefferies 2004).

Reproduction and establishment requirements

Carex aquatilis regenerates primarily through the spreading of underground rhizomes. Each year approximately 6 to 9 percent of the shoots flower, and few viable seeds are produced (Bliss and Grulke 1988, van der Valk et al. 1999). *Carex aquatilis* is an opportunistic colonizer of disturbed areas including firelines, vehicle tracks in tundra, and oil spills (Bliss and Wein 1972, Kershaw and Kershaw 1986, Cargill and Chapin III 1987, McKendrick 1987, Bernard 1990). Colonization occurs by seed on drier sites and by rhizomatous spreading in wetter sites (McKendrick 1987). Sexual and vegetative reproduction rates are slow, resulting in limited colonization. The low rate of colonization has been found to correlate with soil temperature and level of phosphorous in the soil (Auclair 1977) and thus *C. aquatilis* responds well to phosphorus fertilizer (McKendrick 1987). Once established, *C. aquatilis* is a strong competitor, forming dense clumps that prevent establishment of other species within stands of the sedge (Bliss and Grulke 1988, Daly et al. 1989, Hansen et al. 1990). Two years after transplanting *C. aquatilis* seedlings in a fen restoration in Colorado, 50% of the plants survived (Cooper and MacDonald 2000). The recommended planting density is between 8525 and 11,860 plants per hectare (USDA NRCS 2004). In reclamation studies in the oil sands region, transplanted plugs of *C. aquatilis* survived on the 1 m CT, 4 m CT, and control substrates (Golder Associates 2005). These same authors also report that the species naturally colonized reclaimed wetland sites.

Associated species

Species often present in plant communities containing *Carex aquatilis* include: willows (*Salix* spp.), other sedges (*Carex atherodes, C. utriculata*), tufted hairgrass (*Deschampsia cespitosa*), Baltic rush (*Juncus balticus*), bog birch (*Betula glandulosa*), leafy aster (*Aster foliaceus*), spike rush (*Eleocharis pauciflora*), narrowleaf cottonsedge (*Eriophorum angustifolium*), entire leaf mountain avens (*Dryas integrifolia*), reedgrass (*Calamagrostis canadensis*)(Kershaw and Kershaw 1986, Daly et al. 1989). Willows and other shrubs are a late-successional component of *Carex aquatilis* dominated communities (Dirschl et al. 1974).

Carex atherodes Spreng. (awned sedge)

Common names

Wheat sedge, slough sedge, awned sedge

Synonyms

C. aristata R. Br. in Richards.
C. trichocarpa var. aristata L. H. Bailey
C. aristata var. *browniana* Asch. (Dibble 2001).

General description

Carex atherodes is a perennial obligate wetland graminoid that is widespread throughout Canada and the northern U.S. Its mature height is 30 cm up to 150 cm. It is often a dominant or co-dominant species of the upper-marsh zone that receives annual, but not permanent flooding.

Water level tolerance

The highest seedling density in Delta Marsh, Manitoba was 10 cm above the shoreline (Welling et al. 1988). *Carex atherodes* was most abundant 15 cm below the high water line of wetlands whose water level fluctuated an average of 39 cm per year (Galatowitsch and van der Valk 1996). *Carex atherodes* is intolerant of inundation. Water depths of 15 cm or greater for 4 years almost completely eliminated *C. atherodes* in a northern Minnesota marsh (Harris and Marshall 1963), and a 1 m rise in water for 2 years totally drowned the sedge in the Delta Marsh of Lake Manitoba (van der Valk 1994). The preferred water table depth range reported for the species in Alberta was 0 to 5 cm (Golder Associates 2005).

Water quality tolerance

Suitable water pH ranges from 4.5 to 7.2 (USDA NRCS 2004).

Salinity tolerance

Delta Marsh where *C. atherodes* is abundant, had an electrical conductivity measuring 1.8 to 3.3 mS/cm (Welling et al. 1988). In wetland communities near Saskatoon, SK it exhibits low tolerance to saline conditions compared to other plants (Walker and Wehrhahn 1971). In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Carex atherodes* occurred in wetlands with a mean specific conductivity of 2.0 mS/cm, ranging from only a trace level of conductivity to a maximum of 8.0 mS/cm (Kantrud et al. 1989a). In the oil sands region of Alberta, Purdy et al. (2005) found *Carex atherodes* in both slightly and strongly saline landscape settings.

Substrate requirements

Carex atherodes grows best in fine and medium textured soils and can tolerate anaerobic soil conditions. This substrate preference is largely related to the plant's high water requirements that demand a near saturated soil with high water holding capacity. The roots of *C. atherodes* require a minimum depth of 20 cm of suitable substrate to succeed in. Golder Associates (2005) found that *C. atherodes* transplants could survive on landforms composed of a variety of substrates, including their 1 m CT, 4 m CT, Control, and Downstream landforms.

Reproduction and establishment requirements

Carex atherodes reproduces primarily through vegetative, rhizomatous spreading. This strategy creates dense stands that exclude most other species. The recommended planting density is between 4200 and 11,860 plants per hectare (USDA NRCS 2004). Reclamation studies in the oil sands region suggest the species can be established from transplanted plugs (Golder Associates 2005). These same authors also report that the species naturally colonized reclaimed wetland sites.

Associated species

Scolochloa festucacea (Welling et al. 1988), *Carex rostrata* (Coupland 1950), *C. utriculata, Lemna minor, Typha latifolia* (Bayley and Mewhort 2004), *Calamagrostis canadensis, Carex aquatilis, Poa spp*. (Timoney 1999).

Carex aurea Nutt. (golden sedge)

Common names

Golden sedge, golden-fruit sedge, elk sedge

General description

Carex aurea is a perennial graminoid that is designated an obligate wetland species in central and southern U.S. and a facultative wetland species in the northern U.S. and Alaska. It grows in clumps and reaches a mature height of about 40 cm (USDA NRCS 2004). It is often an early colonizer of fens, dunes, and sandbars in Alaska (Tande and Lipkin 2003).

Water level tolerance

Carex aurea has high tolerance to flooding and anaerobic soil conditions, but low tolerance to drought (USDA NRCS 2004).

Water quality tolerance

The range of pH tolerance for *Carex aurea* is 5.5 to 7.2 (USDA NRCS 2004).

Salinity tolerance

Often found in calcareous sites (personal observation).

Substrate requirements

Carex aurea prefers medium to coarse textured soil (USDA NRCS 2004)

Reproduction and establishment requirements

The recommended planting density is between 4,200 and 11,860 plants per hectare (USDA NRCS 2004)

Associated species

Eleocharis quinqueflora, *Carex utriculata*, *C. aquatilis*, *C. illota*, *C. rossii*, *C. microptera*, *C. scirpoidea*, *C. aurea*, *Eleocharis pauciflora*, *Caltha leptosepala*, *Pedicularis groenlandica*, *Equisetum arvense*, *Hypericum perforatum*, *Deschampsia cespitosa*, *Triglochin palustris* (Ecological Society of America 2005).

Carex chordorrhiza Ehrh. ex L. f. (rope-root sedge)

Common names

Rope-root sedge, cordroot sedge, creeping sedge, string sedge

General description

Carex chordorrhiza is a perennial obligate wetland plant, with far-creeping rhizomes and solitary shoots arising from the base of the flowering stems (Kennedy and Murphy 2003). It has a circumboreal distribution that includes the northern U.S. and Canada (USDA NRCS 2004). *Carex chordorrhiza* is restricted to peatlands and is considered an indicator of meso- to minero-trophic fen conditions.

Water level tolerance

Carex chordorrhiza is tolerant of inundation in up to 10 cm of water, and is intolerant of desiccation (Kennedy and Murphy 2003).

Water quality tolerance

Carex chordorrhiza is often an indicator of weak minerotrophy (aka, mesotrophy), or poor-fens. In zones of mixing between ombrotrophic (precipitation derived) and minerotrophic (groundwater source) water, it will occupy the mesotrophic area (Sjors 1963, Wheeler et al. 1983). It has a broad range of tolerance for dissolved calcium, ranging from 2.7 to 19.6 mg/L (Wheeler et al. 1983).

Salinity tolerance

In Scotland, *Carex chordorrhiza* occurs in wetlands with specific conductivities between 104 mS/cm and 304 mS/cm (mean of 220 mS/cm). The sodium content in these wetlands ranges from 4.80 mg/L to 7.68 mg/L (mean of 6.67 mg/L)(Kennedy et al. 2003).

Substrate requirements

In a large northern Minnesota wetland *Carex chordorrhiza* was found at sites with pH ranging from 4.4 to 6.9 (Wheeler et al. 1983). In Scotland pH ranges for wetlands supporting *C. chordorrhiza* were from 5.7 to 7.3 (Kennedy and Murphy 2003). In Iowa pH measures were from 4.1 to 5.9 (Faber-Langendoen 2001). Slightly negative redox potentials (reducing conditions), as found in Scottish wetlands supporting *C. chordorrhiza*, might favor the plant by excluding competitors (Kennedy and Murphy 2003). In Alaska, addition of nitrogen and phosphorus increased growth rate much greater than did an elevated temperature treatment (Johnson et al. 2000).

Reproduction and establishment requirements

Carex chordorrhiza has a distinct method of vegetative reproduction. Prostrate culms of the previous year sprout new shoots from the nodes (Wheeler et al. 1983).

Associated species

In the Northwest Territories *Carex chordorrhiza* is associated with *Salix glauca*, *Chamaedaphne calyculata*, *Andromeda polifolia*, *Betula glandulosa*, *Ledum groenlandicum*, *Epilobium angustifolium* and *Scorpidium scorpioides* (Ritchie 1985). In Iowa, U.S. *C. chordorrhiza* is associated with *C. lasiocarpa*, *C. limosa*, *C.oligosperma*, *Rhynchospora alba*, *Trichophorum caespitosum* (= *Scirpus cespitosus*), *Scheuchzeria palustris*, and *Sarracenia purpurea* (Faber-Langendoen 2001). In the oil sands region *C. lasiocarpa*, *C. limosa*, *Menyanthes trifoliata*, *Utricularia intermedia*, *U. minor* and mosses

Campylium spp., *Scorpidium scorpioides*, *Meesia triquetra*, and *Drepanocladus* spp. occur with *C. chordorrhiza* (TrueNorth 2001).

Carex norvegica Retz. (Norway sedge)

Common names

Norway sedge, Scandinavian sedge

General description

Carex norvegica is a perennial facultative wetland plant that is widespread throughout Canada and the western and northern U.S. (USDA NRCS 2004). It grows to a height of 15 to 30 cm (University of York 2005).

Water level tolerance

Water quality tolerance

Carex norvegica is listed as inhabiting “nonbasic” environments in the White Mountains of California, U.S. (Morefield 1992).

Salinity tolerance

Substrate requirements

Reproduction and establishment requirements

Associated species

Carex canescens, *C. disperma*, *C. utriculata*, *Liqusticam porteri*, *Saxifraga odontoloma*, *Caltha leptosepala*, *Calamagrastis canadensis*, *Salix monticola*, *S. drummondiana*, *Chamerion angustifolium*, *Achillea millefolium*, *Mertensia ciliata*, *Agrostis scabra* (Ecological Society of America 2005).

Carex raymondii Calder (Raymond's sedge)

Common names

Raymond's sedge, black sedge, nodding sedge

Synonym

Carex atratiformis Britt. ssp. *raymondii* (Calder) Porsild

General description

Carex raymondii is a facultative wetland perennial graminoid that occurs in Canada (except the Atlantic provinces) and Alaska, U.S. (NatureServe 2005).

Water level tolerance

Water quality tolerance

Salinity tolerance

Substrate requirements

Reproduction and establishment requirements

Associated species

Carex rostrata Stokes (beaked sedge)

Synonyms

Carex rostrata var. *ambigens* Fern.
Carex inflata V.I.Krecz. non Huds.
Carex ampullacea Gooden
Carex ampullacea ssp. *ampullacea* Gooden

General description

Carex rostrata is an obligate wetland graminoid that is widespread throughout Canada and the U.S. It grows up to 120 cm tall and individual shoots live for about 2 years in the northern U.S. (Bernard 1976), and up to 6 years farther north (Bernard and Solsky 1977). It is usually dominant or codominant where it grows, and often occurs in monospecific stands. *Carex rostrata* is eaten by cattle, horses, bison, elk, moose, deer and reindeer (Boggs et al. 1990). It is often mistaken for the more common *C. utriculata* (Cope 1992).

Water level tolerance

Carex rostrata has a high tolerance for saturated, anaerobic soil conditions and a low tolerance to desiccation (Steed et al. 2002). It is also tolerant of large fluctuations in water level (Hultgren 1989).

Water quality tolerance

In Scottish wetlands with *C. rostrata* the average calcium content was 3.8 mg/L, with a range of 1.5 mg/L to 7.5 mg/L (Gorham and Pearsall 1956). *Carex rostrata* is tolerant of concentrations of potassium of 7.3 ppm, sodium of 13.7 ppm, and chloride of 23.9 ppm.

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Carex rostrata* occurred in wetlands with a mean specific conductivity of 1.1 mS/cm, a minimum of 0.2 mS/cm and a maximum of 2.6 mS/cm (Dix and Smeins 1967, Kantrud et al. 1989a). In Scotland *C. rostrata* occurred in very fresh sites, with an average conductance of 0.06 mS/cm, ranging from 0.04 mS/cm to 0.09 mS/cm (Gorham and Pearsall 1956).

Substrate requirements

Carex rostrata grows best in medium to fine grained soil with pH ranging from 4.5 to 7.0 (USDA NRCS 2004), but has been found in soils ranging from 3.0 to 7.9 (Pierce and Johnson 1986).

Reproduction and establishment requirements

Carex rostrata spreads rapidly through clonal, rhizomatous growth, with rhizomes ranging from 1 cm to 2.5 m long. (Bernard and Solsky 1977). The plant can also reproduce by cut shoots re-rooting and by stolon spreading (Hultgren 1989). The recommended planting density is between 6,670 and 11,860 plants per hectare (USDA NRCS 2004). Golder Associates (2005) report that the species naturally colonized reclaimed wetland sites in the oil sands region.

Associated species

Compared with its riparian associates, beaked sedge occurs on some of the wettest sites. There are three phases of beaked sedge habitat; the wettest is indicated by codominance with awned sedge (*Carex atherodes*) and inflated sedge (*Carex vessicaria*). Water sedge and tufted hairgrass (*Deschampsia cespitosa*) are indicators of drier sites where beaked sedge grows. Other associates include willow (*Salix* spp), sphagnum moss (*Sphagnum* spp.), fewflowered spikesedge (*Eleocharis pauciflora*), Kentucky bluegrass (*Poa pratensis*), common willow-herb (*Epilobium ciliatum*), water horsetail (*Equisetum fluvaiatile*), purple cinquefoil (*Potentilla palustrus*), and timothy (*Phleum pratense*) (Cope 1992).

Carex utriculata Boott (beaked sedge)

Common names

Northwest Territory sedge, beaked sedge

Synonyms

Carex inflata Huds. var. *utriculata* (Boott) Druce
Carex rhynchophysa Fisch., C.A. Mey. & Avé-Lall
Carex rostrata Stokes var. *utriculata* (Boott) Bailey

General description

Carex utriculata is an obligate wetland graminoid that is widespread throughout Canada and the U.S. It grows up to 1 m tall. It frequently forms floating mats on lake margins, and is an aggressive colonizer of inundated habitat (Robbins 1918) with little or no shade (Anderson et al. 1996). In Alberta *Carex utriculata* is more abundant in marsh wetlands than fens. Marshes differ from fens by having deeper water, greater water level fluctuations, higher nutrient concentrations, and fewer bryophytes (Bayley and Mewhort 2004).

Water level tolerance

Carex utriculata is tolerant of inundation and some fluctuation in water level. The preferred water table depth range reported for *C. utriculata* in Alberta was 0 to 5 cm (Golder Associates 2005).

Water quality tolerance

Carex utriculata grows in wetlands in Maine, U.S. with a mean calcium concentration of 2.39 mg/L and a standard deviation of 1.35 mg/L (Anderson et al. 1996).

Salinity tolerance

The specific conductivity of a fen with *Carex utriculata* on an island in Maine, U.S. was between 0.066 mS/cm and 0.078 mS/cm (Almquist and Calhoun 2003). In the oil sands region of Alberta, Purdy et al. (2005) found *C. utriculata* in nonsaline wetlands, but in neither slightly nor strongly saline landscape settings.

Substrate requirements

Carex utriculata grows best in medium to fine grained soil with pH ranging from 5.7 to 7.7 (USDA NRCS 2004). In Maine, U.S., *C. utriculata* occurred at sites with a mean pH of 6.44 and standard deviation of 0.64 (Anderson et al. 1996).

Reproduction and establishment requirements

The recommended planting density is between 27,180 and 44,480 plants per hectare (USDA NRCS 2004). Direct seeding is an effective method of propagation for wetland restoration. Widely fluctuating above-freezing temperatures and a moist substrate isolated from disturbance (e.g. flooding) provide the best germination conditions in the field. These conditions are usually achieved in the spring following any surface water peak flows resulting from snowmelt runoff (Cooper and Jones 2004). Two years after transplanting *C. utriculata* rhizomes in a fen restoration in Colorado, 65% of the plants survived (Cooper and MacDonald 2000). In reclamation studies in the oil sands region, transplanted plugs of *C. utriculata* survived on the control and downstream landforms,

but were not reported from the 1 m CT and 4 m CT lanform types (Golder Associates 2005).

Associated species

Carex aquatilis, *C. atherodes*, *C. lasiocarpa*, *C. diandra*, *C. canescens*, *C. chordorrhiza*, *C. paupercula*, *C. bebbii*, *Eriophorum chamissonis*, *Glyceria pulchella*, *G. grandis*, *Sium cicutaefolium*, *Potentilla palustris*, *Triglochin maritima*, *Potamogeton americanus*, *Equisetum fluviatile*, *Acorus calamus*, *Scolochloa festucacea*, *Scirpus validus*, *Typha latifolia*, *Utricularia vulgaris*, *Ranunculus sceleratus*, *Calamagrostis americana*, *C. canadensis*, *Poa palustris*, *Sparganium* sp., *Salix* spp. (Lewis et al. 1928)

Deschampsia cespitosa (L.) Beauv. (tufted hairgrass)

General description

Deschampsia cespitosa is a facultative wetland, cool season, perennial bunchgrass that is widespread throughout the U.S. and Canada (USDA NRCS 2004). It is found in various habitats from sea level to over 4,000 m in elevation, on dry slopes to saturated peatlands, but rarely in areas of deep shade (Walsh 1995). It is both a colonizer of disturbed land, especially post-burns areas, and a component of long-term stable (climax) habitats. Its culms (stems) grow to between 20 and 120 cm in height. The root system is mostly shallow, with 45% of roots occurring in the top 2 cm and lesser proportions in each successively deeper 2 cm increment (Weaver 1982).

Water level tolerance

In the Sierra Nevada of California, U.S., *Deschampsia cespitosa* was found to be an indicator species of meadow habitat with the lowest average water table depth and greatest fluctuation in water level. The mean high water level for sites with *Deschampsia cespitosa* was 12 cm below surface (SE = 3 cm), and the mean low water level was 78 cm below surface (SE = 4 cm) (Allen-Diaz 1991).

Water quality tolerance

Deschampsia cespitosa occurs on sites with pH ranging from 3.3 (mine tailings in Ontario)(Hardy BBT Limited 1989) to 8.4 (in central Idaho)(Rabe et al. 1994). However, a range of 5.2 to 5.4 is optimal for growth (Johnson and Billings 1962).

Salinity tolerance

Deschampsia cespitosa is tolerant of low or infrequent saline conditions (Frenkel and Morlan 1991, Mors and Begin 1993). In Alberta, Purdy et al. (2005) noted *D. cespitosa* in both slightly and strongly saline wet and dry meadow communities.

Substrate requirements

Deschampsia has been used effectively to revegetate acidic mine tailings (Brown et al. 1988) and sites with heavy metal contamination (Hardy BBT Limited 1989). Some tufted hairgrass populations are highly tolerant of lead, zinc, copper, or manganese contaminated tailings (Hardy BBT Limited 1989), and source seed for restoration should be selected from populations with desired tolerances (Walsh 1995). *Deschampsia cespitosa* grows well in a broad range of nitrogen and phosphorus availability (Brown and Chambers 1990). It is also tolerant of a wide variety of soil textures (Walsh 1995). *Deschampsia cespitosa* was one of 4 species noted for high cover by Golder Associates (2005) on their control landform revegetated with plugs. However, the species was not abundant in the 1 m CT or Dyke Uncapped landscape types they examined.

Reproduction and establishment requirements

Deschampsia cespitosa is a good competitor in boreal regions. Natural reproduction is achieved solely through seed dispersal and seedling establishment, not vegetative spreading. Late fall seeding is most successful because establishment is improved if seeds are cold stratified through the winter (Chambers et al. 1987). Near Lake Tahoe, U.S., *D. cespitosa* seedlings were successfully transplanted via removal and replanting of natural wetland plugs (Greytak 1992). A revegetation project at an open-pit gold, copper, and silver mine at 3,000 m elevation in Montana, U.S. achieved 72% survival of

transplanted *D. cespitosa* plugs after one year (Brown and Johnston 1978). *Deschampsia cespitosa* sod was removed and stored for two weeks during a pipeline construction project in Colorado, U.S. The sod was replaced and, after 18 years, is the most successfully reestablished native plant (Buckner and Marr 1990). In west-central Alberta *D. cespitosa* colonized spoils of abandoned coal mines (Russell 1985).

Associated species

Carex utriculata, *C. aquatilis*, *C. microptera*, *C. aurea*, *C. magellanica*, *C. scopulorum*, *C. illota*, *Caltha leptosepala*, *Geum macrophyllum*, *Mentha arvensis*, *Juncus balticus*, *Calamagrostis canadensis*, *Trifolium longipes*, *Taraxacum officinale*, *Dasiphora floribunda*, *Phleum alpinum*, *Salix planifolia*, *S. geyeriana*, *S. brachycarpa*, *S. boothii*, *Allium geyeri*, *Fragaria virginiana*, *Pedicularis groenlandica*, *Prunella vulgaris*, *Eleocharis quinqueflora*, *Mertensia ciliata*, *Poa pratensis*, *Hordeum jubatum* (Ecological Society of America 2005).

Eleocharis acicularis (L.) Roemer and J.A. Schultes (needle spike-rush)

General description

Eleocharis acicularis is an annual obligate wetland graminoid that is widespread throughout the U.S. and Canada. It grows to 20 cm in height and is a poor competitor (Keddy et al. 2000). *Eleocharis acicularis* is classified as an isoetid, a wetland plant whose slow growth rate, small stature (up to 20 cm tall), and evergreen tissues make it well suited to survive in nutrient-poor, high stress habitats (Day et al. 1988).

Water level tolerance

Eleocharis acicularis can withstand complete inundation up to 60 cm in vernal pools of California, U.S. (Ferren et al. 1998). *Eleocharis acicularis* preferred the mean low water level to be higher than 120 cm below ground in the Midwest US (Kadlec and Wentz 1974).

Water quality tolerance

In marshes with *Eleocharis acicularis* near Ottawa pH ranged from 6.1 to 7.0, phosphorus concentration was between 4.4 mg/L and 7.8 mg/L, magnesium was present from 79.1 mg/L to 163.6 mg/L, and potassium concentration was from 35.3 mg/L to 56.0 mg/L (Day et al. 1988).

Salinity tolerance

Near Ottawa *Eleocharis acicularis* occurred in marshes with specific conductivity between 0.0473 mS/cm and 0.1026 mS/cm (Day et al. 1988). In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Eleocharis acicularis* occurred in wetlands with a mean specific conductivity of 1.5 mS/cm, ranging from a minimum of 0.1 mS/cm to a maximum of 5.8 mS/cm (Smeins 1967, Kantrud et al. 1989a).

Substrate requirements

The soil in marshes near Ottawa with *Eleocharis acicularis* had gravel content ranging from 0.2% (by mass) to 20%, sand content from 63.7% to 85%, and silt/clay from 10.3% to 23.8% (Day et al. 1988). In the same study pH ranged from 6.1 to 7.0, phosphorus concentration was between 4.4 mg/L and 7.8 mg/L, magnesium was present from 79.1 mg/L to 163.6 mg/L, and potassium concentration was from 35.3 mg/L to 56.0 mg/L (Day et al. 1988).

Reproduction and establishment requirements

The recommended planting density for *Eleocharis acicularis* is between 4,200 plants per hectare and 11,860 plants per hectare (USDA NRCS 2004). They can be propagated via transplants, root stocks and rhizomes, tubers, or by seed (Kadlec and Wentz 1974).

Associated species

Spartina patens, *Schenoplectus americanus*, *S. pungens*, *Calamagrostis canadensis*, *Glyceria elata*, *G. borealis*, *Eleocharis compressa*, *E. palustris*, *Pascopyrum smithii*, *Carex scopulorum*, *C. aquatilis*, *C. magellanica*, *C. rossii*, *Caltha leptosepala*, *Ranunculus flammula*, *Epilobium watsonii*, *Lactuca serriola*, *Ambrosia tomentosa*, *Oenothera canescens*, *Rorippa sinuata*, *Buchloe dactyloides*, *Echinochloa crus-galli*, *Eragrostis cilianensis*, *Sagitaria latifolia*, *Verbena bracteata*, *Polygonum arenastrum*,

Juncus balticus, *Baccharis halmifolia*, *Phragmites australis* (Ecological Society of America 2005).

Eleocharis palustris (L.) Roemer & J.A. Schultes (creeping spike-rush)

Common names

Common spikerush, creeping spikerush, spikesedge

Synonyms

Eleocharis calva Torr. var. *australis* (Nees) St. John
Eleocharis macrostachya Britt.
Eleocharis mamillata auct. non Lindb. f.
Eleocharis palustris (L.) Roemer & J.A. Schultes var. *australis* Nees
Eleocharis palustris (L.) Roemer & J.A. Schultes var. *major* Sonder
Eleocharis palustris (L.) Roemer & J.A. Schultes var. *vigens* Bailey
Eleocharis perlonga Fern. & Brack.
Eleocharis smallii Britt.
Eleocharis smallii Britt. var. *major* (Sonder) Seymour
Eleocharis xyridiformis Fern. & Brack. (USDA NRCS 2004)

General description

Eleocharis palustris is a perennial, rhizomatous, obligate wetland graminoid that is widespread throughout Canada and the U.S. At maturity it reaches up to 120 cm in height (Snyder 1992a). It is moderately competitive in high nutrient environments (ranked 12 out of 26 Ottawa River shoreline plants after one year, 13 out of 23 after 2 years) and more competitive in low nutrient environments (ranked 7 out of 26 after one year, 10 out of 23 after 2 years) (Keddy et al. 2000).

Water level tolerance

Eleocharis palustris occurs in habitats that are intermittently flooded (Atkinson 1984). It inhabits the riparian zone between 0.5 m above and 0.5 m below the level of the River Wye in England (Merry et al. 1981). The community dominated by *Eleocharis palustris* occupied the majority of plots that were inundated at least 30 % of the time, and occupied all plots inundated > 60 % of the time (up to 99 %, above which was open water with no vegetation) along the Gunnison River in Colorado (Auble et al. 1994). *Eleocharis palustris* dominated the zone ~0 to 15 cm above the late August water line along the Ottawa River (Day et al. 1988). The mean low water level had to be higher than 50 cm below ground for *E. palustris* in the Midwest US (Kadlec and Wentz 1974). During an experimental reclamation project in the Athabasca Oil Sands region *E. palustris* exhibited a preference for saturated conditions with the water table at 0 cm depth, and was tolerant of seasonal flooding (Golder Associates 2005).

Water quality tolerance

Suitable water pH ranges from 4.0 to 8.0 (USDA NRCS 2004).

Salinity tolerance

In a coastal marsh in British Columbia *Eleocharis palustris* inhabited plots with fairly high salinity, up to ~16 mS/cm specific conductivity. However, it (along with all other plants) died in plots with salinity of ~30 mS/cm (Dawe et al. 2000). In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Eleocharis palustris* occurred in wetlands with a mean specific conductivity of 2.7 mS/cm, ranging from a minimum of 0.1 mS/cm to a maximum of 14.5 mS/cm (Smeins 1967, Kantrud et al. 1989a) In a Louisiana coastal

marsh *Eleocharis palustris* was codominant in areas with soil salinity of ~0.15 mS/cm, and not dominant in areas with salinity of ~2.5 mS/cm. When soil water salinity was manipulated through the addition of saline water (15 mS/cm), both duration of exposure (up to 3 months) and depth of inundation (up to 15 cm) negatively impacted *E. palustris* aboveground biomass and stem density. Growth was stunted by salinity levels of 7.5 mS/cm (Howard and Mendelssohn 2000) and the most severe treatment, three-month exposure to 15 cm deep saline water (15 mS/cm), caused total mortality of *E. palustri*s (Howard and Mendelssohn 2000).

Substrate requirements

In a Louisiana marsh on the Gulf of Mexico, the soil that supported *Eleocharis palustris* contained ~70 % organic matter. The inorganic fraction was ~50 % sand, ~5 % silt, and ~45 % clay (Howard and Mendelssohn 2000).

Reproduction and establishment requirements

The recommended planting density is between 27,180 to 46,950 plants per hectare (USDA NRCS 2004). Common spikerush regenerates primarily by rhizomes (Routledge 1987), colonizing areas not conducive to seedling establishment and spreading rapidly (Dawe et al. 2000). Seeds are always present in the seed bank (long-lived propagules) and can germinate in standing water (Smith and Kadlec 1985). In the Netherlands, where *Eleocharis palustris* is very rare, the plant emerged from the seedbank following a removal of the top 5 cm of sod from a wet meadow (Oomes et al. 1996). Golder Associates (2005) report that the species naturally colonized reclaimed wetland sites in the oil sands region.

Associated species

Watercress (*Nasturtium officinale*), monkey face (*Mimulus guttatus*), cattail (*Typha* spp.), sedge (*Carex* spp.), bulrush (*Scirpus* spp.), rush (*Juncus* spp.), horsetail (*Equisetum* spp.), western wheatgrass (*Agropyron smithii*), creeping bentgrass (*Agrostis stolonifera*), tufted hairgrass (*Deschampsia cespitosa*), foxtail barley (*Critesion jubatum*), water groundsel (*Senecio hydrophyllus*), and willow (*Salix* spp.) (Snyder 1992a).

Equisetum arvense L. (field horsetail)

General description

Equisetum arvense, a member of the Equisetaceae, is a perennial pteridophyte with a cosmopolitan distribution (Hauke 2005). Synonyms include *E. arvense* var. *alpestre*, *E. arvense* var. *boreale*, *E. arvense* var. *campestre*, *E. arvense*. var. *riparium*, *E. calderi* (ITIS 2004, USDA NRCS 2004, ITIS 2004). Common names include field horsetail, scouring rush, and western horsetail (ITIS 2004). *Equisetum arvense* is ranked globally (G5) and apparently secure (S5) in Alberta (NatureServe 2005). Field horsetail and water horsetail (*E. fluviatale*) will hybridize where they occur together producing *E. x litorale* , which is sterile but vegetatively vigorous and persistent (Sullivan 1993).

Water level tolerance

The wetland indicator status of *E. arvense* varies regionally from Facultative Upland (FACU) to FAC+, suggesting that it frequently, although not always, occurs in wetlands. It can occur in a diverse range of ecosystem types, from shrub or forest-dominated riparian area, marshes, or fens, and thus is found in various hydrologic regimes. Comer et al (2003) described a vegetation alliance dominated by *E. arvense*, with a semi permanently flooded water regime (Christy 2004). *Equisetum arvense* occurs in poor to extreme rich fens in Montana in sites with standing water from early in the growing season to midsummer and that are perennially saturated to within 10 cm of the surface (Cooper and Jones 2004). Crowe et al. (2004) describe an *E. arvense* vegetation association (CEGL003314) from sites that are flooded during spring runoff, and where the water table remains within 30 cm of the soil surface (Crowe et al. 2004).

Water quality tolerance

The species is reported from sites with both acidic and neutral pH (Payne 1992). The USDA reports a pH range of 4-7 (USDA NRCS 2004). Water chemistry data from poor to extreme rich fens supporting *E. arvense* included pH values ranging from 4.7 to 7.7 (Cooper and Jones 2004). In Britain, the species was assigned an Ellenberg indicator value for nitrogen of 6 on a scale of 9, indicating that it occurs in moderately fertile to rich sites (Hill et al. 1999). Although *Equisetum* spp. are often thought to be of little value to ecosystems, a study of an Alaskan shrub wetland showed that they acquired and cycled phosphorus and other nutrients more efficiently than other plant community members (Marsh et al. 2000). Water chemistry data from *E. arvense*-dominated low riparian terrace communities included 46.8 mg/l for Ca^{2+} and 28.1 mg/l for Mg^{2+} (Cobbaert et al. 2005).

Salinity tolerance

The USDS reports a low salinity tolerance. Kantrud et al. (1989) found *E. arvense* in waters with an EC of 0.4 mS/cm (Kantrud et al. 1989a). The USDA reports that *E. arvense* has a low tolerance for salinity.

Substrate requirements

Equisetum arvense can occur in course, medium, or fine textured soils, as well as on peat (USDA NRCS 2004). Crowe et al (2004) describe an *E. arvense* vegetation association (element #CEGL003314) on cobbly or gravelly alluvial bars or incipient floodplains with highly coarse and fragment rich soils along first, second, and third order

streams (PFF 2005). In Montana, it occurs on peat substrates in poor to extreme rich fens (Cooper and Jones 2004).

Reproduction and establishment requirements

Payne suggested establishing *Equisetum* spp. using transplants, digging up and separating plants for immediate planting on site or into containers (Payne 1992). *Equisetum arvense*, as with many other members of the genus, are effective at early colonization of disturbed sites (Bishop and Chapin 1989, Borgegard 1990, Tsuyuzaki 1997, Tu et al. 1998). Plants produce spores, not seeds, which are easily dispersed by wind. In addition, they can expand through rhizomes. The USDA suggests that *E. arvense* can be propagated by sprigs or by bare root materials. They also describe a moderate vegetative spread rate (USDA NRCS 2004). Golder Associates (2005) report that the species naturally colonized reclaimed wetland sites in the oil sands region.

Associated species

Equisetum arvense occurs in a range of habitat types, including stream banks, meadows, ditches, and moist woods (Snyder 1992b). Auble et al. (1994) describe an *Equisetum* cover type consisting of mesic to xeric herbs and grasses dominated by *Equisetum hyemale*, *Poa compressa*, *Agrostis stolonifera*, *Muhlenbergia racemosa*, and *Euthamia occidentalis*. It is a common component of multiple forest and shrub vegetation associations in Colorado (Carsey et al. 2003). Bottum recorded a number of species with *E. arvense* including *Pinus contorta, P. ponderosa, Pseudotsuga menziesii, Hypericumperforatum, Leucanthemum vulgare, Centaurea biebersteinii, Hieracium caespitosum, Antennaria microphylla, A. rosea, Bromus inermis, Poa pratense, Plantago lanceolata, Larix occidentalis, Spiranthes romanzoffiana, Achillea millefolium, Agrostis stolonifera, Dactylis glomerata, Berberis repens, Carex lenticularis, Veronica americana, Solidago canadensis, Danthonia intermedia, D. california, Veratrum californicum, Betula glandulosa, Juncus* spp.*, Goodyera oblongifolia, Taxus brevifolia,* and *Asarum caudatum* (USDA NRCS 2004). Cooper and Jones (2004) document *E. arvense* in fens dominated by *Carex utriculata* as well as *Carex prairea, Carex aquatilis*, *Maianthemum stellatum*, *Petasites sagittatus*, *Aulacomnium palustre*, *Calliergon giganteum*, *Campylium stellatum*, and *Palustriella falcate* scattered Betula *glandulosa*, *Salix candida* and *Rhamnus alnifolia* shrubs present (Cooper and Jones 2004). They also describe it from *Eriophorum angustifolium*-domintated peatland along with *E. chamissonis, E. viridicarinatum, Calamagrostis canadensis, Carex magellanica, Comarum palustre, Drosera anglica, Menyanthes trifoliata*, *Sphagnum angustifolium, S. subsecundum,* and *Aulacomnium palustre* (Cooper and Jones 2004). It is also common in forested wetlands and riparian areas. For example, Moseley et al. (1991) describe a *Picea glauca/Equisetum arvense* vegetation association, similar to *Picea engelmannii/E. arvense* habitat types elsewhere (Moseley et al. 1991, Carsey et al. 2003). Picking and Veneman report the following associates in a sloping calcareous fen in Massachusetts: *Aster puniceus, Sagittaria latifolia, Agrostis alba, Thelypteris palustris, Viola sp. Lycopus spp., Lysimachia terrestris, Carex stricta, Eleocharis sp.,* and *Alisma subcordatum* (Picking and Veneman 2004).

Eriophorum vaginatum L. (sheathed cottongrass)

Common names

Tussock cottongrass, sheathed cottonsedge, cottonsedge, cottongrass, hare's tail, hare's-tail grass.

Synonyms and subtaxa

There are two recognized North American varieties (USDA NRCS 2004):
Eriophorum vaginatum L. var. *vaginatum*
Eriophorum vaginatum L. var. *spissum* (Fern.) Hult.

General description

Eriophorum vaginatum has a circumboreal distribution with a southern boundary in North America at the northern and northeastern states of the U.S. It is an obligate/facultative wetland perennial graminoid that forms tussocks up to 70 cm high (Howard 1993). Their roots penetrate up to 10 cm deep, or until reaching permafrost (Moorhead et al. 1993). Individual tillers live up to 8 years and the estimated life span of tussocks ranges from 122 to 187 years (Mark et al. 1985). *Eriophorum vaginatum* tussock communities are stable for many decades, but are eventually replaced in the absence of disturbance. Frequent fire and frost action are especially important in maintaining *E. vaginatum* stands in the arctic (Howard 1993).

Water level tolerance

Eriophorum vaginatum thrives in areas where the water table is shallow and surface conditions are near saturation. In southern Quebec *E. vaginatum* quickly colonized a disturbance with a water table < 40 cm below ground and a surface peat with > 70 % water by volume (Lavoie et al. 2005). In England, interception of flow across a bog by ditches reduced flow rate and lowered the water table from between 3 cm and 18 cm above the ditches to between 7 cm and 28 cm downslope of the ditches (water levels are cm below ground). A marked reduction in cover of *Eriophorum vaginatum* accompanied this hydrologic modification (Stewart and Lance 1991).

Water quality tolerance

The upper 40+ cm of soil that supports *Eriophorum vaginatum* is typically peat with pH ranging from 3.0 to 5.1 in the Yukon and NW Territories (Howard 1993) or 2.98 to 4.0 in the British Isles (Wein and MacLean 1973).

Salinity tolerance

In Britain, *Eriophorum vaginatum* occurred in bogs with a range of specific conductivity from 0.038 mS/cm to 0.425 mS/cm (Gorham 1956).

Substrate requirements

Phosphatase activity around the roots of *Eriophorum vaginatum* add phosphorus to the typically nutrient-poor soils where the plant grows (Moorhead et al. 1993). *Eriophorum vaginatum* has high nutrient use efficiency in low-nutrient conditions and high nutrient uptake efficiency in luxuriant nutrient conditions (Sylvan et al. 2005).

Reproduction and establishment requirements

Eriophorum vaginatum is an excellent colonizer of sites denuded by peat mining (Famous and Spencer 1989). It also recovered well following an oil spill (Bliss and Wein 1972). It reproduces both sexually by seed and vegetatively by tillering. *Eriophorum vaginatum* individuals produce seed first at age three, and are prolific thereafter (Salonen et al. 1992). Their seed often dominates northern seedbanks, and buried seeds remain viable for up to 200 years (McGraw et al. 1991). Tillers are produced at a rate of one to three per year with accelerated production following disturbance (Fetcher and Shaver 1982).

Associated species

Carex bigelowii, *C. rupestris*, *Salix* spp., *Distichium inclinatum*, *Hylocomium splendens*, *Ledum decumbens*, *Dryas integrifolia*, *Cassiope tetragona*, Bryophyta (Ecological Society of America 2005).

Glyceria borealis (Nash) Batchelder. (small floating mannagrass)

General description

Glyceria borealis (Poaceae) is a native perennial grass distributed through most of Canada and the northern United States (NatureServe 2005). Synonyms include *Panicularia borealis* Nash (USDA NRCS 2004). Common names include small floating mannagrass and manna grass. *Glyceria borealis* is ranked globally secure (G5) and apparently secure (S4) in Alberta (NatureServe 2005, NatureServe 2005).

Water level tolerance

Glyceria borealis is an obligate wetland species *sensu* Reed 1988 (USDA NRCS 2004). It occurs with other emergent species in Montana marshes just above the aquatic zone occupying positions that are inundated for most of the growing season (Kantrud et al. 1989a). Throughout the prairie pothole region, *G. borealis* is a common emergent hydrophyte in the shallow-marsh zone of palustrine wetlands with seasonally flooded hydrologic regimes (Kantrud et al. 1989a). Moving from deeper to shallower water in ponds and lakes, it occurs adjacent to pond or lake shores above zones dominated by *Nuphar lutea* ssp. *polysepala*, *Potamogeton* spp., *Sparganium* spp., *Schoenoplectus* spp., and *Eleocharis palustris*. *Typha latifolia* may dominate if water along the shoreline is poorly oxygenated (PFF 2005). Comer et al (2003) describe a *G. borealis* vegetation alliance with a semi-permanently flooded hydrologic regime (Christy 2004). *Glyceria* is intolerant of low moisture conditions, unlike plants such as *Eleocharis* spp. (Brooks and Clemants 2005).

Water quality tolerance

Glyceria borealis is found across a gradient of pH from 5.0 to 8.5 and is generally associated with intermediate to high soil fertility levels (USDA NRCS 2004).

Salinity tolerance

The USDA reports low tolerance for salinity by *G. borealis*. Kantrud et al. (1989) found it in waters with an EC of 1.0 mS/cm (Kantrud et al. 1989a).

Substrate requirements

Glyceria borealis is found in a variety of soil types including fine, medium, and coarse textured mineral soils to peat substrates (USDA NRCS 2004).

Reproduction and establishment requirements

Glyceria flowers in June through August (Snyder 1992b), and fruits late summer. Baskin (2003) describes propagation of *Glyceria striata* via seed and containers (plug). Seeds exhibited physiological dormancy, were cold stratified for 150 days before germinating at alerting temperatures of 19/15 °C (Stevens and Hoag 2000). Such an approach may be useful with *G. borealis* as well. Both *G. acutiflora* and *G. fluitans* can be propagated by seeds or division of wild or nursery stock (Payne 1992).

Associated species

Glyceria borealis is a dominant component of many marshes found just above the aquatic zone occupying positions that are inundated for most of the growing season but where water levels draw down at some point in most years. Characteristic plant associates include *Typha latifolia*, *Carex utriculata*, *Carex atherodes*, and

Schoenoplectus acutus (Kantrud et al. 1989a). In Idaho, *Glyceria borealis* is associated with *Carex vesicaria* on sites with long periods of standing water; additional species include *Eleocharis palustris*, *Juncus balticus*, *Sparganium emersum*, *S. eurycarpum*, *Equisetum fluviatile, Zizania aquatica, Carex atherodes, Polygonum* spp., *Phalaris arundinacea*, and *Utricularia* spp.(USDA NRCS 2004). In Colorado, *Glyceria borealis* is found associated with *Carex vesicaria, G. elata*, and *Menyanthes trifoliata* is subalpine kettle holes (Favorite 2002a). Crowe et al. (2004) describe a *Glyceria borealis* vegetation association supporting *Carex utriculata*, *Eleocharis palustris*, *Alopecurus aequalis*, *Utricularia macrorhiza*, *Potamogeton gramineus*.
In the Great Lake region, *Glyceria borealis* is commonly found in an *Equisetum fluviatile* and/or *Eleocharis palustris* dominated association; other prominent species reported include *Isoetes echinospora, Potamogeton gramineus*, and *Utricularia macrorhiza* (Faber-Langendoen 2001). A large number of species were reported associated with *G. borealis* in another Great Lakes marsh including *Alisma triviale*, *Lythrurn salicaria , Brasenia schreberi Mentha spicata , Calamagrostis canadensis, Polygonum arnphibium , Calamagrostis stricta, Pontederia cordata , Carex chordorrhiza Potamogeton grarnineus , Carex lasiocarpa, Proserpinaca palustris , Carex pseudo-cyperus, Rhynchospora rnacrostachya , Carex retrorsa, Sagittaria grarninea , Carex stipata, Salix exigua , Cephalanthus occidentalis, Salix nigra , Cladium mariscoide,s Salix pedicellaris , Dulichium arundinaceum, Spiraea alba, Eleocharis palustris, Typha latifolia , Glyceria striata, Utricularia gibba , Juncus canadensis*, *Utricularia intermedia, Lemna minor*, *Utricularia purpurea , Lysimachia thyrsijlora*, and *Utricularia vulgaris* (Native Plant Working Group 2000).

Glyceria grandis S. Wats (American mannagrass)

General description

Glyceria grandis is a native, perennial, semi-aquatic grass (Poaceae) widely distributed throughout Canada and the northern U.S. (USDA NRCS 2004, NatureServe 2005). Synonyms include *G. grandis* S. Wats., *G. grandis* S. Wats. var. *grandis* , and *G. grandis* S. Wats. var. *komarovii* L. Kelso (USDA NRCS 2004). Common names include American manna grass and tall manna grass. *Glyceria grandis* is ranked secure globally (G5), nationally (N5) in Canada, and regionally (S5) in Alberta (NatureServe 2005).

Water level tolerance

There is little quantitative data in the literature on the specific hydrologic requirements for *G. grandis*. Kantrud (1989) classified *G. grandis* as a species of seasonally flooded, shallow-marsh zones. It is particularly prevalent along small riparian systems, and is adapted to moderate to high fluctuations in water table elevations (Marriott and Faber-Langendoen 2000a, Carsey and others 2003). *Glyceria grandis* is often found in depressional wetlands, including the margins of reservoirs and ponds. Some basins are seasonally, temporarily, or intermittently flooded, but dry out at some point, sometimes for extended periods of time (Carsey and others 2003). In Alberta, *G. grandis* is reported to colonize areas recently flooded by beaver (*Castor canadensis* Kuhl).

Water quality tolerance

Glyceria grandis typically occurs in moderately acid to alkaline systems. Kadlec and Wentz (1974) report a pH range of 5.9-8.8, for the species (Kadlec and Wentz 1974). In Alberta, it was observed in wetlands with a mean pH of 6.8. The concentration of Ca^{2+} was 41 mg/l, and Mg^{2+} 10 mg/l (Nicholson 1995). Alkalinity values ranged from 8.0-245.0 ppm $CaCO_3$ (Kadlec and Wentz 1974).

Salinity tolerance

Glyceria grandis has a generally low tolerance for salinity, although anecdotal accounts exist of it in slightly brackish water (Stewart and Kantrud 1972). Mean EC in wetlands supporting *G. grandis* was 0.7 mS/cm, and values ranged from <0.5 to 4.0 (Kantrud et al. 1989a). Conductivity was 4.78 mS/cm in Alberta wetlands supporting *G. grandis* (Nicholson 1995).

Substrate requirements

Glyceria grandis can grow on fine to coarse soils. It is generally found in communities developed on mineral soils, although it may be found in peat as well (Nicholson 1995, Carsey and others 2003).

Reproduction and establishment requirements

Glyceria grandis is generally an early seral species. It, along with *Eleocharis palustris*, *Alopecurus aequalis*, *Beckmannia syzigachne*, and *Sium suave*, was identified as an indicator of disturbance in Saskatchewan wetlands (Walker and Wehrhahn 1971). There is little information regarding specific propagation techniques for *G. grandis*, however, methods used for related species may be applicable. For example, Baskin (2003) describes propagation of *Glyceria striata* via seed and containers (plug). Seeds exhibited physiological dormancy, were cold stratified for 150 days before germinating at alternating temperatures of 19/15 °C (Stevens and Hoag 2000). Such an approach may

be useful with *G. grandis*. Renartz and Warne (1993) report seed weights of *G. grandis* of 4500 seeds/gram (Reinartz and Warne 1993). Both *G. acutiflora* and *G. fluitans* can be propagated by seeds or division of wild or nursery stock (Payne 1992).

Associated species

Coupland (1950) observed *G. grandis* along with *Calamagrostis inexpansa*, *C. canadensis*, *Agrostis hiemalis*, *Deschampsia cespitosa*, *Persicaria nebraskensis*, *Gaura glabra*, *Ranunculus* spp., *Geum strictum*, *Urtica procera*, *Stellaria* spp., and *Hierochloe odorata* (Coupland 1950). *Glyceria grandis* is the dominant species in Colorado in the *G. grandis* Herbaceous Vegetation association, where it occasionally occurs as monotypic stands. Often a variety of forbs and graminoids, usually with fairly low cover and constancy also occur, including *Bidens cernua*, *Mentha arvensis*, *Solidago* spp., *Persicaria* spp, *Eleocharis palustris*, *Phalaris arundinacea*, *Agrostis gigantean*, *Beckmannia syzigachne* , and *Leersia oryzoides* (Carsey and others 2003). *Glyceria grandis* is a characteristic species in the shallow-marsh zone of prairie potholes along with species such as *Scolochloa festucacea*, *Sparganium eurycarpum*, *Carex atherodes, Beckmannia syzigachne*, *Eleocharis palustris*, and *Scirpus americanus* (Sloan 1970). In Montana, Cooper and Jones (2003) describe nearly monotypic stands of *G. grandis* and *Alopecurus aequalis*, other associates included *Carex atherodes*, *Eleocharis palustris*, *Carex utriculata*, *Eleocharis acicularis*, *Glyceria borealis*, *Schoenoplectus acutus* (Kantrud et al. 1989a). In Alberta, it occurs along wetland margins and shallow peat formations. Common species reported include *Carex aquatilis*, *C. rostrata*, *C. atherodes*. Other species that occur are the grasses *Beckrnannia syzigachne*, *Hordeum jubatum*, *Calamagrostis canadensis*, *Polygonurn amphibium*, *Typha latifolia*, and *Sium suave* (Nicholson 1995). It is also found along perennial streams at higher elevations in the Black Hills region, where it is a part of the *G. grandis* vegetation type. Associated species include *Agrostis stolonifera*, *Poa palustris*, *Scirpus microcarpus*, *S. pallidus*, and *Cicuta douglasii* (Marriott and Faber-Langendoen 2000a).

Glyceria striata (Lam.) A.S. Hitchc . (fowl mannagrass)

General description

Glyceria striata (Poaceae) is a native, perennial grass widely distributed throughout North America. Synonyms include *Glyceria striata* (Lam.) A.S. Hitchc, *Glyceria elata* (Nash ex Rydb.) M.E. Jones, *Glyceria nervata* (Willd.) Trin., *Glyceria striata* (Lam.) A.S. Hitchc. var. *stricta* (Scribn.) Fern., *Glyceria striata* (Lam.) A.S. Hitchc. ssp. *stricta* (Scribn.) Hultén, *Panicularia nervata* (Willd.) Kuntze, and *Panicularia striata* (Lam.) A.S. Hitchc. *Glyceria striata* is considered secure globally (G5) and apparently secure (S4) in Alberta (NatureServe 2005, NatureServe 2005).

Water level tolerance

Glyceria striata is an obligate (OBL) wetland species. It occurs in communities with often quite variable hydrologic regimes and degrees of disturbance from flooding (Carsey and others 2003). In the prairie pothole region, it is a common emergent hydrophyte of palustrine wetlands with saturated moisture regimes (Kantrud et al. 1989a).

Water quality tolerance

The USDA NRCS report a pH range of 4.0-8.0 for *Glyceria striata*. Its fertility requirement is reported to be medium, as is its tolerance to $CaCO_3$ (USDA NRCS 2004).

Salinity tolerance

Glyceria striata is reportedly intolerant of saline conditions (USDA NRCS 2004). Kantrud reports a mean conductivity for G. *striata* of 0.8 mS/cm (Kantrud et al. 1989a).

Substrate requirements

Glyceria striata can occur in mineral or organic sediments. Carsey et al. (2003) describe it as occurring on mud or gravel substrates (Carsey and others 2003). It is reportedly adapted to medium and fine textured soils (USDA NRCS 2004). Moseley (1991) documented it occurring on organic soils, ranging in depth from 0.46 to >1 m (Moseley et al. 1991).

Reproduction and establishment requirements

Glyceria striata can be established via seed or sprigs (USDA NRCS 2004). Seeds are relatively light, numbering approximately 450 seeds/g (Reinartz and Warne 1993). Planting densities between 8600-19000 individuals/ha were suggested by the USDA (2004). Seed vigor and spread rate are reported as medium, while vegetative spread rate is rated as low. The Native Plant Network details an approach to propagation of *Glyceria striata* via seed and containers (plug). Seeds exhibited physiological dormancy, were cold stratified for 150 days before germinating at alerting temperatures of 19/15 °C (Native Plant Network 2005b).

Associated species

Over its broad range, *Glyceria striata* occurs in a variety of habitats including peatlands, forests, prairie, wet meadows, in riparian area and shrub carrs. Carsey et al. (2003) describe a *Glyceria striata - Mimulus guttatus - Epilobium lactiflorum* Herbaceous Vegetation association in Colorado. Associated species include *Mimulus guttatus, Epilobium lactiflorum, Veronica americana, Juncus tracyi,* and *Carex microptera*. It typically occurs in small patches along small creeks and brooks in the montane to

subalpine zones, and although it is an herbaceous community type, it may occupy small openings in spruce-fir forests. In the southern Rocky Mountains, *G. striata* co-occurs with *Calamagrostis canadensis*, *Picea engelmannii*, Abies *lasiocarpa*, *Carex utriculata*, *Equisetum arvense*, *Senecio triangularis*, *Heracleum maximum*, *Alnus incana* ssp. *tenuifolia*, *Ligusticum porteri*, and *Ligusticum tenuifolium* along small order mountain streams (Carsey and others 2003). In Montana, G. *striata* has been documented in fens with the following species: *Equisetum arvense, Equisetum laevigatum, Agrostis stolonifera*, *Glyceria striata, Calamagrostis stricta* ssp. *inexpansa*, *Heracleum maximum* (= *Heracleum lanatum*), *Sanicula marilandica*, *Angelica arguta*, and *Geum macrophyllum* (Cooper and Jones 2003). It was documented with a wide range of species in a Great Lakes marsh including *Alisma triviale*, *Lythrurn salicaria , Brasenia schreberi Mentha spicata , Calamagrostis canadensis, Polygonurn arnphibium , Calamagrostis stricta, Pontederia cordata , Carex chordorrhiza Potamogeton grarnineus , Carex lasiocarpa, Proserpinaca palustris , Carex pseudo-cyperus, Rhynchospora rnacrostachya , Carex retrorsa, Sagittaria grarninea , Carex stipata, Salix exigua , Cephalanthus occidentalis, Salix nigra , Cladium mariscoide,s Salix pedicellaris , Dulichium arundinaceum, Spiraea alba , Eleocharis palustris Triadenurn sp., Typha latifolia , Glyceria borealis, Utricularia gibba , Juncus canadensis*, *Utricularia intermedia , Lemna minor*, *Utricularia purpurea , Lysimachia thyrsijlora*, and *Utricularia vulgaris* (Singer et al. 1996). It is common in wet meadows in Idaho where it co-occurs with a mix of *Agrostis stolonifera*, *Glyceria grandis*, *Carex stipata*, *Carex bebbii*, *Carex lanuginosa*, and *Eleocharis palustris* (Jankovsky-Jones 1997). In the prairie pothole region, *G. striata* is a primary species found in the fen emergent zone along with *Typha latifolia*, *Phragmites communis*, *Scirpus validus*, *Carex aquatilis*, *Salix interior*, *Salix candida*, *Cicuta maculata*, and *Aster junciformis* (Stewart and Kantrud 1972).

Juncus balticus Willd. (Baltic rush)

General description

Juncus balticus is a perennial, rhizomatous herb in the Juncaceae widely distributed throughout North America, Mexico, South America, and Asia (Brooks and Clemants 2005). Its taxonomy is uncertain, with some treatments, including that presented in the Flora of North America reclassifying the species as *Juncus arcticus*; its taxonomy should be considered tentative until molecular investigations are conducted (Brooks and Clemants 2005). Synonyms and sub-specific taxa include *Juncus arcticus* var. *balticus* Willdenow, *J. balticus* var. *littoralis* Engelm., *J. balticus* var. *montanus* Engelm, *J. balticus* var. *vallicola* . Common names include Baltic rush, wire rush, and wiregrass (Snyder 1992b). It is ranked secure globally (G5) and regionally (S4) in Alberta (NatureServe 2005).

Water level tolerance

The wetland indicator status of *J. balticus* varies regionally from Facultative wetland (FACW) to obligate (OBL)(USDA NRCS 2004). Thunhorst (1993) characterized the hydrologic regime of J. *balticus* in non-tidal settings as seasonally, regularly, or permanently inundated up to 15 cm for approximately 13-100% of the growing season (Thunhorst 1993). It is reportedly relatively tolerant of periodic dry soil conditions (Brooks and Clemants 2005). *Juncus balticus* can tolerate flooded, anoxic soil conditions, at least periodically, but it also occurs on drier sites with seasonally fluctuating water tables, and thus can tolerate seasonal drought (Stevens and Hoag 2000). Kantrud et al. (1989) describe it from palustrine wetlands with temporarily flooded moisture regimes (wet meadows) (Kantrud et al. 1989a). Golder Associates (2005) reports a preferred water table depth of 0 cm for the species. While tolerant of flooding, *J. balticus* can also persist in drier meadows.

Water quality tolerance

Juncus balticus can tolerate moderately acidic to alkaline conditions (Stevens and Hoag 2000, Brooks and Clemants 2005). The USDA reported a pH range of 6.0-9.0 for the species (USDA NRCS 2004). *Juncus* species may be planted from bare rootstock or seedlings from container stock or directly seeded into the soil. Fluctuating the water level during the establishment period may speed spread and control weeds in reclamation or restoration projects (Stevens and Hoag 2000).

Salinity tolerance

Juncus balticus occurs in sites with fresh to slightly brackish water (Thunhorst 1993). It can tolerate mild to moderate soil salinities and alkalinities. Mean EC in wetlands supporting *J. balticus* was 3.3 mS/cm, although values ranged from 0.1 to 20.1 mS/cm (Kantrud et al. 1989a). In the oil sands region of Alberta, Purdy et al. (2005) noted that *J. balticus* occurred in slightly saline wet and dry meadows and shrub-dominated wetland communities.

Substrate requirements

Juncus balticus occurs on mineral soils ranging in texture, organic matter, and other properties. It is reported to be an aggressive colonizer on fine-textured soils (Marriott and Faber-Langendoen 2000a).

Reproduction and establishment requirements

Juncus balticus is a useful species for soil stabilization, as it spreads aggressively through rhizomes and once established is resistant to disturbances such as grazing or drought (Payne 1992). Payne provides general guidance for the establishment of *Juncus* spp, suggesting the use of transplants, rootstock, or seeds. For transplants and rootstock, he suggests digging up and separating plants or rootstock for planting on site or into containers (Payne 1992). For seeds, he recommends collecting seed at maturity (July-October), storing it in water at 5°C before eventual broadcast and raking into soil (Payne 1992). Another suggested approach involves sowing seeds in pots in a cold frame in early spring and transferring to larger containers or out-planting into the field once sufficiently large (PFF 2005). Propagation via division should be conducted in spring. Stevens and Hoag (2000) recommend planting plugs, either from the greenhouse or wild transplants, as the surest way to establish a new stand. Plugs spaced 25-30 cm apart when planted will fill in within one growing season (Stevens and Hoag 2000). In reclamation studies in the oil sands region, transplanted plugs of *J. balticus* survived on the 1 m CT landform, but not the others examined (Golder Associates 2005). The same authors also report that the species naturally colonized reclaimed wetland sites.

Associated species

Juncus balticus is found in a variety of habitats, from low to high elevations. It is found in wet depression, swales, moist meadows, sloughs, along streams, and around springs. In Idaho, *J. balticus* is associated with *Carex vesicaria* on sites with long periods of standing water along with *Eleocharis palustris*, *Glyceria borealis*, *Sparganium emersum*, *S. eurycarpum*, *Equisetum fluviatile*, *Zizania* aqua*t*ica, *Carex atherodes*, *Polygonum* species, *Phalaris arundinacea,* and *Utricularia species* (USDA NRCS 2004). A community dominated by *J*. *balticus* var. *montanus* has been described in Colorado; associated species include *Agrostis gigantean*, *Argentina anserine*, Poa *pratensis* , *Carex praegracilis*, *Carex simulate*, *Deschampsia cespitosa*, *Phleum* p*retense, Hordeum jubatum* ssp*. Jubatum, Plantago eriopoda, Dasiphora floribunda, Iris missouriensis, Taraxacum officinale* (Rocchio 2004). A similar association has been described from the Black Hills region of South Dakota (Marriott and Faber-Langendoen 2000a , Marriott and Faber-Langendoen 2000b).

Kobresia simpliciuscula (Wahlenb.) Mackenzie (simple bog sedge)

Common names

Simple bog sedge, simple Kobresia

Synonyms

Carex simpliciuscula Wahlenb.
Kobresia bipartita (All.) Dalla Torra
Kobresia caricina Willd.
Kobresia simpliciuscula (Wahlenb.) Mackenzie var. *americana* Duman

General description

Kobresia simpliciuscula is a perennial facultative/wetland graminoid that grows up to 50 cm tall (USDA NRCS 2004). It has a circumboreal distribution that includes most of Canada and the northwestern U.S. (Williams 1990). It is typically an indicator of extreme-rich fens with high cation concentrations and basic pH. A nitrogen and phosphorus fertilization experiment caused a reduction in cover of *Kobresia simpliciuscula* as other grasses greatly increased and out-competed it (Jeffrey and Pigott 1973).

Water level tolerance

In Colorado, *Kobresia simpliciuscula* rhizome planting survived best in areas where the water table was 0 to 30 cm below ground; mortality was highest in areas with 0 to 20 cm of standing water (Cooper and MacDonald 2000).

Water quality tolerance

In fens in the Rocky Mountains of Colorado *Kobresia simpliciuscula* occurred in fens with an average calcium concentration of 115 mg/L and mean pH of 7.4 (Johnson and Steingraeber 2003). Another study found *K. simpliciuscula* in similar settings, with calcium concentrations > 100 mg/L and pH at or above 7.6 (Cooper and MacDonald 2000).

Salinity tolerance

In fens in the Rocky Mountains of Colorado *Kobresia simpliciuscula* occurred in fens with an average electrical conductivity of 0.58 mS/cm (Johnson and Steingraeber 2003).

Substrate requirements

Reproduction and establishment requirements

Kobresia simpliciuscula rhizomes were planted in mined peatlands in Colorado and after two years, 26% had survived (Cooper and MacDonald 2000).

Associated species

Sedges (*Carex* spp.), common butterwort (*Pinguicula vulgaris*), creeping juniper (*Juniperus horizontalis*), tufted bulrush (S*cirpus cespitosus*), dwarf birch (*Betula pumila* var. *glandulifera*), and sweet gale (*Myrica gale*) (Williams 1990). *Eleocharis quinqueflora, Carex simulate, Kobresia myosuroides, Thalictrum alpinum, Salix brachycarpa, Ptilagrostis porteri, Juncus balticus, Polygonum viviparum, Deschampsia*

cespitosa, Muhlenbergia filiformis, Dasiphora floribunda, Carex aquatilis, C. capillaris (Carsey et al. 2001)Menyanthes trifoliata L. (buckbean)

Common names

Buckbean, Bogbean

Synonym

Menyanthes trifoliata L. var. *minor* Raf.

General description

Menyanthes trifoliata is an obligate wetland herb that grows 10 to 30 cm tall. It is circumboreal in distribution and occurs across Canada and the northern and western U.S (USDA NRCS 2004, NatureServe 2005).

Water level tolerance

Menyanthes trifoliata often grows submerged in water and on floating mats (Haraguchi 1991). It is intolerant of desiccation and only grows on soils that remain moist to saturated (Hewett 1964). Hammer (1992) included *M. trifoliata* among a list of species tolerant of seasonally flooded to permanently flooded hydrologic regimes, with maximum water depths ranging from 15-50 cm.

Water quality tolerance

Menyanthes trifoliata can withstand a range of pH from 2.2 to 7.5, but is typically found in water with pH ranging from 4.63 to 6.51 (University of York 2005). Calcium concentration is typically low in the water that *Menyanthes trifoliata* grows in. In south-east Labrador concentrations were less than 2.0 mg/L (Foster and King 1984) and in northern Britain values ranged from 1.9 mg/L to 12.9 mg/L (Gorham and Pearsall 1956).

Salinity tolerance

Specific conductivity of the water in a Japanese floating mat with *Menyanthes trifoliata* ranged from 0.023 to 0.064 mS/cm (Haraguchi 2004). In south-eastern Labrador, Canada, electrical conductivity in a poor fen with *Menyanthes trifoliata* ranged from 0.0045 mS/cm to 0.011 mS/cm (Foster and King 1984). Across northern Britain conductivity ranged from 0.049 mS/cm to 0.096 mS/cm (Gorham and Pearsall 1956).

Substrate requirements

The soils that *Menyanthes trifoliata* occurs on have high organic content ranging from 13% to 92% and an inorganic fraction of silt and clay (Hewett 1964).

Reproduction and establishment requirements

The primary means of reproduction for *Menyanthes trifoliata* is by rhizomatous spreading (Haraguchi 1996), but viable seeds are also produced. It is often an early colonizer of open flooded substrate and does not compete well against established, closed communities (Hewett 1964).

Associated species

Carex lasiocarpa, *C. utriculata*, *C. limosa*, *C. livida*, *C. microptera*, *C. diandra*, *Deschampsia cespitosa*, *Triglochin maritima*, *Limprichtia revolvens*, *Cladium mariscoides*, *Sphagnum*, *Utricularia intermedia*, *Equisetum*, *Lemna minor*, *Typha latifolia* (Ecological Society of America 2005).

Muhlenbergia glomerata (Willd.) Trin. (bog muhley)

Common names

Bog Muhly, Spiked Muhly, Satin Grass

Synonyms

Muhlenbergia glomerata (Willd.) Trin. var. *cinnoides* (Link) F.J. Herm.
Muhlenbergia racemosa (Michx.) B.S.P. var. *cinnoides* (Link) Boivin

General description

Muhlenbergia glomerata is a facultative wetland perennial grass that grows up to 90 cm tall (USDA NRCS 2004). It widely distributed throughout Canada and the northern U.S (NatureServe 2005). It reaches unusually high latitudes for grasses with the C4 photosynthetic pathway, which are generally more competitive in warmer, drier climates. In the northern extent of its range it prefers unshaded microhabitats, and can be excluded from areas by tall woody vegetation (Kubien and Sage 2003). It is considered an extreme rich fen indicator (Glaser et al. 1990).

Water level tolerance

Muhlenbergia glomerata is found in areas of standing water in Minnesota, U.S. (Glaser et al. 1990).

Water quality tolerance

In Alberta, *Muhlenbergia glomerata* occurs in fens with pH between 7.3 and 8.3, calcium concentrations from 43 mg/L to 85 mg/L and sodium concentrations between 23 mg/L and 33 mg/L (Rochefort and Vitt 1988).

Salinity tolerance

Muhlenbergia glomerata occurs in a rich fen north of Edmonton, Alberta, with specific conductivity between 0.44 mS/cm and 0.62 mS/cm (Rochefort and Vitt 1988).

Substrate requirements

Muhlenbergia glomerata performs best in silty (loam) to sandy/silty soils. It grows poorly in clay rich soils and gravelly soils (Ahlenslager 1988).

Reproduction and establishment requirements

Muhlenbergia glomerata, which is rare near Ottawa, Ontario, was an early colonizer in a burned forest (Catling et al. 2001).

Associated species

Sphagnum, *Myrica gale*, *Carex livida*, *C. eburnea*, *C. sterilis*, *C. leptalea*, *C. stricta, C. pellita*, *Cornus amorum*, *Potentilla fruticosa*, *Alnus* sp., *Juncus canadensis*, *Solidago patula* (Ecological Society of America 2005). *Carex exilis*, *Drosera anglica*, *Typha latifolia*, *Rhynchospora alba* (Glaser et al. 1990).

Phragmites australis (Cav.) Trin. ex Steud. (common reed)

General description

Phragmites australis (Poaceae) is a large (2–6 m height) perennial grass widely distributed throughout North America and Europe. Synonyms include *P. australis* var. *berlandieri* , *P. communis*, *P. communis* ssp. *berlandieri*, *P. communis* var. *berlandieri*, and *P. phragmites (USDA NRCS 2004)*.

Water level tolerance

The wetland indicator status of *Phragmites* varies geographically, ranging from FACW to OBL (Reed 1988). Rhizomes can reach almost 2 meters below ground to reach low lying ground water, allowing the species to exist in hydrologic extremes characterizing many marshes (NatureServe 2005). In nontidal regimes, the species occurs in sites seasonally, regularly, or permanently inundated up to 60 cm or saturated (Thunhorst 1993). The mean low water level preference was between 100 cm below ground to 200 cm of standing water above ground for *P. australis* in the Midwest US (Kadlec and Wentz 1974).

Water quality tolerance

Phragmites can occur across a wide pH gradient, from 3.7 – 9 (Thunhorst 1993). *Typha* spp. and *P. australis* can both accumulate heavy metals in their tissues and have been successfully used for phytoremediation of Pb and Zn mine tailings under waterlogged conditions (Deng et al. 2004). *Phragmites* has been given an Ellenberg indicator value for nitrogen of 7(out of 9), indicating that is generally found in N-rich environments (Cizkova et al. 2001). *Phragmites* is also relatively tolerant of high Cd concentrations, suggesting that it could be useful for bioremediation. However, the simultaneous presence of elevated concentrations of Cd, Cu and Zn may limit the efficiency (Ait Ali et al. 2004). Hammer (1992) included *P australis* among a list of species tolerant of seasonally flooded to permanently flooded hydrologic regimes, with maximum water depths ranging from 15-50 cm.

Salinity tolerance

Salinity is an additional factor controlling the distribution and performance of *Phragmites*. *P. australis* is especially common in alkaline and brackish (slightly saline) environments (Haslam 1971). The maximum salinity tolerance among populations varies, with reported maxima ranging from 12 ppt (1.2%) in Britain to 29 ppt in New York state, and 40 ppt on the Red Sea coast (NatureServe 2005). Thunhorst (1992) provides a salinity range from fresh to brackish water, at 20 ppt. *Phragmites* has a low tolerance for wave and current action, but is capable of thriving in stagnant waters. EC in marshes supporting P. *australis* ranged from 252 to 503 mS/cm (Cizkova et al. 2001).

Substrate requirements

Phragmites can thrive in fine or course textured soils, although it is more frequently found in fine textured sediments. In *P. australis* stands, Haslam (1971) concluded that litter accumulation helps prevent invasion by other species, as the build up of litter from the aerial shoots prevents or discourages other species from germinating and establishing (Haslam 1971).

Reproduction and establishment requirements

Phragmites generally flowers and sets seed between July and September and may produce great amounts of seed. Seeds are dispersed through autumn and winter, although frequently much of the seed produced is not viable (NatureServe 2005). Although there are native genotypes in North America, expansion of more aggressive genotypes is a serious issue in many regions (USDA NRCS 2004), so caution is needed when considering establishing the species. Payne (Payne 1992) suggested establishing *P. australis* using either transplants or rootstock, digging up and separating plants or rootstock for planting on site or into containers. Experimentally, seed germination of *Phragmites* was unaffected by salinities as high as 5000 mg/l of NaCl, whereas seed germination of *Typha* and *Scolochloa* was reduced significantly by 1000 mg/l of NaCl (Ignacio Galinato and Van Der Valk 1986). Its salinity tolerance is likely one of several reasons for its dominance in many wetlands. Through its stout rhizomes, *Phragmites* can spread rapidly, from 1 to over 9 m a year. It can be aggressive, and is considered a weed in many regions, although it is an effective soil stabilizer for extreme erosion problems (Thunhorst 1993).

Associated species

In the Czech Republic, *P. australis* was noted with *Carex canescens*, *Juncus bulbosus*, *Juncus effusus*, *Ranunculus flammula*, *Utricularia australis*, *Carex gracilis*, *Calamagrostis canescens*, *Cicuta virosa*, *Solanum dulcamara* , *Urtica dioica*, *Glyceria maxima*, *Lythrum salicaria*, *Carex elata*, and *Phalaris arundinacea* (Cizkova et al. 2001). In addition to *P. australis*, Farswoth and Meyerson documented *Zizania aquatica*, *Leersia* oryzo*ides, Peltandra virginica, Sagittaria latifolia, Acorus calamus , Typha angustifolia*, and other wetland macrophytes in freshwater and brackish marshes in the Northeast U.S. (Farnsworth and Meyerson 2003).

Poa palustris L. (fowl bluegrass)

General description

Poa palustris (*Poaceae*) is a perennial grass, widely distributed through Eurasia and North America. It is non-rhizomatous, exhibiting a bunch growth form. Common names include fowl bluegrass, fowl meadow grass, and swamp meadow grass (USDA NRCS 2004). Synonyms include *Poa crocata*, *Poa eyerdamii*, and *Poa triflora*. The species' conservation status is considered secure globally (G5) as well as regionally in Alberta (S5) (NatureServe 2005).

Water level tolerance

The wetland indicator status of *Poa palustris* varies regionally from FACU to FACW+ (USDA NRCS 2004). It occurs in sites with a variety of hydrologic regimes including perennially flooded, perennially saturated, and seasonally wet to flooded (Carsey and others 2003, Christy 2004). In the prairie pothole region, *Poa palustris* is a common emergent hydrophyte of palustrine wetlands with temporarily flooded moisture regimes (i.e. wet meadows) (Kantrud et al. 1989b). In wet meadows of the Midwest, stands of *Poa palustris* occur on the floodplains of small streams, in poorly drained depressions, beaver meadows, and lakeshores with water regime varying between temporarily and seasonally flooded (Faber-Langendoen 2001).

Water quality tolerance

Poa palustris occurs across a relatively broad pH gradient, from 4.9-7.5 (USDA NRCS 2004). It has low tolerance for $CaCO_3$ and intermediate fertility requirements. *Poa palustris* was assigned an Ellenberg indicator value of 7 out of 9 for soil reaction, indicating that it is typically found in weakly acid to weakly basic conditions (Hill et al. 1999). In the Czech Republic, *Poa palustris* was found in wetlands with Ca^{2+} concentration of 14.5 mg/l and Mg^{2+} concentrations of 7.8 mg/l (Cizkova et al. 2001).

Salinity tolerance

Poa palustris has a low tolerance to salinity. Hill et al. (1999) assigned an Ellenberg indicator value of 0 on a scale of 9 for salinity tolerance, indicating that it is absent from saline sites (Hill et al. 1999). Its low salinity tolerance is also noted by USDA (USDA NRCS 2004). Kantrud et al (1989) observed a mean conductivity of 1.4 mS/cm, with a range of <0.5 to 3.4 mS/cm in wetlands with *P. palustris* (Kantrud et al. 1989a). In Alberta, Purdy et al. (2005) noted that *P. palustris* occurred in both nonsaline and slightly saline wet and dry meadow communities.

Substrate requirements

Poa palustris can occur in a variety of edaphic settings. It is adapted to fine and medium textured mineral soils, but can be found on peat substrates as well (Faber-Langendoen 2001, Christy 2004, USDA NRCS 2004).

Reproduction and establishment requirements

Poa palustris flowers in the spring and produces seed from late spring through the summer (USDA NRCS 2004). Seeds can be harvested in the wild or are often available for purchase through commercial vendors (Native Plant Working Group 2000). Seeding is the only known effective propagation technique (USDA NRCS 2004). *Poa palustris* seeds are light, on the order of 2000- 2300 seeds/g and can exhibit good emergence,

seedling vigor, and growth (Native Plant Working Group 2000). *Poa palustris* germinates best following dry storage overwinter, although stratification also enhances germination relative to autumn sowing (Hoffman et al. 1980). Golder Associates (2005) found that *P. palustris* had high plot cover (18%, second only to *Calamagrostis canadensis*, which had cover of 29%), on their control landform revegetated with plugs. However, the species was not abundant in the 1 m CT or Dyke Uncapped landform types they examined.

Associated species

Because of its broad circumboreal distribution and diverse habitats, *Poa palustris* can occur with a variety of other species. It can occur as a subdominant species in a variety of wetland types including wet meadows, marshes, fens, and riparian wetlands. In Europe, it has been reported with species such as *Acorus calamus*, *Carex gracilis*, *Galium palustre*, *Iris pseudacorus*, *Lycopus europaeus, Lysimachia vulgaris, Lythrum salicaria, Myosoton aquaticum, Ranunculus flammula, Scutelaria galericulata, Solanum dulcamara, Agropyron repens, Calamagrostis canescens, Galium aparine, Phalaris arundinacea*, *Glyceria maxima, Urtica dioica*, and *Phragmites australis* (Cizkova et al. 2001). Auble et al. (1994) recorded *Poa palustris* as part of an *Eleocharis* cover type dominated by *Agrostis stolonifera, Euthamia occidentalis, Eleocharis palustris, Phalaris arundinacea, Epilobium ciliatum,* and *Poa compressa* (Auble et al. 1994). In Oregon, it occurs in a variety vegetation types in marshes, fens, and riparian shrublands and woodlands (Christy 2004). In the black hills, it occurs as a peripheral species in several wet meadow and riparian vegetation associations and it is a dominant species in a *Glyceria grandis - Poa palustris* – Mixed herbaceous vegetation association, which supports *Glyceria grandis, Agrostis stolonifera, Scirpus microcarpus, S. pallidus, Cicuta douglasii, Catabrosa aquatica, Mimulus guttatus,* as well as *Epiliobium* spp. (Marriott and Faber-Langendoen 2000a).

Puccinellia nuttalliana (J.A. Schultes) A.S. Hitchc. (Nuttal's alkali grass)

Common name

Nuttall's alkaligrass

Synonyms

Puccinellia airoides (Nutt.) S. Wats. & Coult.
Puccinellia cusickii Weatherby

General description

Puccinellia nuttalliana is circumboreal in distribution and is widespread throughout Canada and the western U.S. (NatureServe 2005). It is a perennial facultative/obligate wetland graminoid that grows up to 25 cm tall (USDA NRCS 2004). It is most competitive in saline environments, and is suppressed by competition in fresher conditions (Kenkel et al. 1991).

Water level tolerance

Puccinellia nuttalliana has high tolerance to flooded, anaerobic soil conditions and low tolerance to drought (USDA NRCS 2004). The preferred water table depth reported for the species in Alberta was 0 cm, and it was noted that the species is tolerant of seasonal flooding (Golder Associates 2005).

Water quality tolerance

The range of pH the *Puccinellia nuttalliana* grows in ranges from 6.5 to 8.5 (USDA NRCS 2004).

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Puccinellia nuttalliana* occurred in wetlands with a mean specific conductivity of 20 mS/cm, a minimum of 1.4 mS/cm and a maximum of 76.4 mS/cm (Dix and Smeins 1967, Kantrud et al. 1989a). In west-central Manitoba, Canada, *Puccinellia nuttalliana* occurred in an area of saline seeps with specific conductance of 83 mS/cm (Johnson-Green et al. 2001). Purdy et al. (2005) noted the presence of *Puccinellia nuttalliana* in wet-meadow communities in strongly saline landscapes of Alberta. Golder Associates (2005) reported *P. nuttalliana* as one of only a few species that performed well in the dyke uncapped landform, attributing this to the species' high saline tolerance.

Substrate requirements

Puccinellia nuttalliana performed well on a broad range of soil textures (USDA NRCS 2004).

Reproduction and establishment requirements

Puccinellia nuttalliana primarily reproduces by seed. The recommended planting density is between 12,350 plants per hectare to 27,180 plants per hectare (USDA NRCS 2004). *Puccinellia nuttalliana* was one of 4 species noted for high cover in plots established by plugs on the 1 m CT landform in Alberta; however, the species was not dominant in either the control or Uncapped Dyke plots (Golder Associates 2005). Golder Associates (2005) observed *P. nuttalliana* naturally colonizing reclaimed wetland sites in the oil sands region.

Associated species

Carex nebraskensis, *Schoenoplectus pungens*, *Eleocharis palustris*, *Mentha arvensis*, *Triglochin maritima*, *Typha latifolia*, *Juncus balticus*, *Senecio serra*, *Solidago canadensis*, *Veronica peregrina*, *Argentina anserina* (Ecological Society of America 2005). In saline meadows of Wood Buffalo National Park: *Hordeum jubatum*, *Agropyron trachycaulum*, *Calamagrostis stricta*, *C. inexpansa* (Timoney 1999).

Sarracenia purpurea L. (pitcher plant)

Common names

Pitcher plant, flytrap, sidesaddle plant, huntsman's cap, frog's britches

Subtaxa and hybrids

S. purpurea ssp. *purpurea* Wherry - northern plants
S. purpurea ssp. *purpurea* forma *heterophylla* (Eaton) Fern. - yellow flowers
S. purpurea ssp. *venosa* Raf. - southern plants
S. purpurea X *S. alata* = *S. exornata*
S. purpurea X *S. flava* = *S. catesbaei*
S. purpurea X *S. leucophylla* = *S. mitchelliana*
S. purpurea X *S. minor* = *S. swaniana*
S. purpurea X *S. rubra* = *S. chelsonii*

General description

Sarracenia purpurea is an obligate wetland carnivorous perennial herb that grows to 10 to 20 cm in height. It is known from all Canadian provinces except Nunavut and the Yukon Territories and is found in the eastern and southeastern U.S., California and Washington. *Sarracenia purpurea* is listed as S2, imperiled, in Alberta (NatureServe 2005). The two major threats to the species are habitat loss and over collection by plant poachers.

Water level tolerance

Sarracenia purpurea is tolerant of saturated conditions and often forms floating mats (Walkup 1991a).

Water quality tolerance

Sarracenia often occurs in acidic sites, associated with acid tolerant species, but is occasionally found in alkaline marls around the Great Lakes. In a Vermont, U.S. peatland with *Sarracenia purpurea*, pore water pH ranged from 3.8 to 6.7 (Mouser et al. 2005).

Salinity tolerance

In a Vermont, U.S. peatland with *Sarracenia purpurea*, electrical conductivity ranged from 0.025 mS/cm to 0.2 mS/cm (Mouser et al. 2005). Calcium concentrations in the Vermont bog ranged from 0.6 mg/L to 25 mg/L.

Substrate requirements

Frequent disturbance and creation of bare ground, such as by fire, are essential for seedling establishment. *Sarracenia purpurea* is usually found in nutrient poor soils, e.g. deficient in trace elements such as molybdenum, and obtains missing nutrients from captured animals (Walkup 1991a).

Reproduction and establishment requirements

Reproduction is primarily by seed but can also occur by rhizomatous spreading. Seed germination is dependant on bee pollinators. Seedlings are slow-growing and intolerant of shade and therefore require bare ground for establishment. *Sarracenia purpurea* can be successfully transplanted as "living mats" cut from existing peatlands (Wilcox and Ray 1989). Individuals may live for 20 to 30 years (McDaniel 1971).

Associated species

Sphagnum, Vaccinium oxycoccos, Drosera intermedia, D. rotundifolia, Chamaedaphne calyculata (Wilcox and Ray 1989), *Pinguicula, Eriocaulon, Utriculata, Calopogon, Burmannia* (McDaniel 1971). *Carex stricta, C. exilis, C. lasiocarpa, C. pauciflora, C. chordorrhiza, Menyanthes trifoliata, Kalmia polifolia, Myrica gale, Rhynchospera alba, Oclemena nemoralis, Eriophorum virginicum, Scheuzeria palustris, Pentaphylloides floribunda, Eleocharis smallii* (Ecological Society of America 2005).

Scirpus cespitosus (L.) Hartman. (tufted bulrush)

General description

Scirpus cespitosus is rhizomatous, perennial sedge (Cyperaceae) with tufted stems arising from short rhizomes. Currently, most botanical authorities place the species in the genus *Trichophorum* (USDA NRCS 2004, NatureServe 2005). Synonyms include *Baeothryon caespitosum*, *Baeothryon cespitosum*, *Scirpus caespitosus*, and *Trichophorum cespitosum* (L.) Hartman (ITIS 2004, USDA NRCS 2004). *Scirpus cespitosus* is ranked secure globally (G5) and apparently secure regionally (S4) in Alberta (NatureServe 2005).

Water level tolerance

Scirpus cespitosus is an obligate (OBL) wetland species *sensu* Reed (1988). There are few studies specifically examining its hydrological requirements, but anecdotal accounts of its habitat suggest that it only occurs in sites where the water table is within approximately 50 cm during the growing season (Glaser et al. 1990). Gignac found it occurring in sites with a mean depth to the water table of 17 cm (Gignac et al. 2004).

Water quality tolerance

Scirpus cespitosus occurs in peatlands with varying pH, from somewhat acidic to near circumneutral. The USDA reports a pH range from 4.5-6.5 for the species (USDA NRCS 2004). In a broad-scale study of sedge distribution and ecology in Maine, Anderson et al. (1996) observed *S. cespitosus* most abundant in moderate-rich fens although it was also present in more ombrotrophic settings as well (Anderson et al. 1996)

Salinity tolerance

The USDA suggests that *S. cespitosus* has no tolerance for salinity, although no quantitative salinity guidelines are available (USDA NRCS 2004). However, the lack of salinity tolerance is consistent with the freshwater habitats it has been documented in (Bottum 2004, Gignac et al. 2004).

Substrate requirements

Scirpus cespitosus is most prevalent in peatlands. However, the USDA also reports that it is adapted to fine and medium textured mineral soils, but not coarse textured soils (USDA NRCS 2004).

Reproduction and establishment requirements

There is little information regarding reproductive requirements of *S. cespitosus* or the efficacy of different propagation techniques. The USDA reports that it can be propagated using bare root and container stock, as well as by seed and sprigs. Seedling vigor and the natural rate of spread by seeding once a population is established is considered low (USDA NRCS 2004). The USDA also recommends a minimum planting density of 4200 individuals/ha and a maximum density of 11800 individuals/ha for *S. cespitosus* (USDA NRCS 2004). The rate of vegetatative spread is considered moderate.

Associated species

Scirpus cespitosus occurs in a variety of habitats, but is most abundant in peatlands. Anderson et al. (1996) observed it in various peatland habitats in Maine, including *Sphagnum* lawns, shrub heath, and poor and moderate-rich fens. Particularly common

associates included *Rynchospora alba*, *Carex lasiocarpa* var. *americana*, and *Trichophorum alpinum*. It occurs in both ombrotrophic and minerotrophic systems. For instance, *S. cespitosus* was commonly found in ombrotrophic systems beside species like *Erica tetralix, Molinia caerulea*, *Vaccinium oxycoccos*, and *Gymnocolea inflate*, but also occurred with species of more circumneutral character like *Carex rostrata*, *C. lasiocarpa*, and *Menyanthes trifoliata* (Boeye and Verheyen 1994). In Idaho, it was observed in peatland complexes on broad, banded hummocks with *Eleocharis pauciflora* and *Carex limosa* interspersed in wet swales. Other associations reported include *Carex buxbaumii*, *Drosera anglica*, and *Carex livida* (Bottum 2004).

Scirpus microcarpus J.& K. Presl . (smallfruit bulrush)

General description

Scirpus microcarpus is a native perennial sedge (Cyperaceae) widely distributed in wetlands throughout the north central and northwestern United States and Canada (NatureServe 2005). Synonyms include *Scirpus microcarpus* var. *longispicatus* M.E. Peck, *S. microcarpus* var. *rubrotinctus* (Fern.) M.E. Jones, and *S. rubrotinctus* Fern (USDA NRCS 2004). Common names include panicled bulrush, red-tinge bulrush, and smallfruit bulrush (ITIS 2004). *Scirpus microcarpus* is ranked secure globally (G5) and regionally (S5) in Alberta (NatureServe 2005).

Water level tolerance

Scirpus microcarpus is an obligate wetland species sensu (Reed 1988). RMNP recommend planting the species in sites with saturated soils or seasonal standing water (RMNP 2005).

Water quality tolerance

The USDA NRCS report a pH range of 5.4-7.4 for *S. microcarpus*. It is reported to have low $CaCO_3$ tolerance and fertility requirements (USDA NRCS 2004). Anecdotal accounts indicated a relatively broad tolerance for acid, neutral, and alkaline soils (PFF 2005).

Salinity tolerance

The USDA suggests that S. *microcarpus* has no tolerance for salinity (USDA NRCS 2004).

Substrate requirements

Scirpus microcarpus is reported to be tolerant of fine, intermediate, and coarse textured soils (USDA NRCS 2004, PFF 2005). Christy (2004) describes a *S. microcarpus* association occurring on organic, loam, and sand substrates. It has been described elsewhere from sites with sandy loam and clay loam soils with a high organic matter content in the upper layers (Carsey and others 2003).

Reproduction and establishment requirements

A variety of propagation techniques can be used for *S. microcarpus* including bare root, container, propagation via springs, and seed (USDA NRCS 2004). Seeds are widely available commercially or can be harvested from local plant stock (RMNP 2005). If propagating in a greenhouse, seeds should be sown immediately below the soil surface in a cold frame in pots or trays standing in approximately 3cm of water; plant out in the field in early summer (PFF 2005). Once established, S. *microcarpus* exhibits a rapid rate of vegetative spread (USDA NRCS 2004).

Associated species

Because of its extensive range, *S. microcarpus* has a large number of vegetation associates. For example, in the Black Hills region, S. *microcarpus* occurs as a peripheral species in a *Glyceria grandis - Poa palustris* – Mixed herbaceous vegetation association, which supports *Glyceria grandis, Agrostis stolonifera, S. pallidus, Cicuta douglasii, Catabrosa aquatica, Mimulus guttatus,* and *Epiliobium* spp. (Marriott and Faber-Langendoen 2000a). At low elevations in Colorado, it occurs as an understory species in *Populus deltoides* riparian woodlands along with *Salix amygdaloides*, *Muhlenbergia*

asperifolia, *Distichlis spicata*, *Panicum virgatum*, and *Eleocharis palustris*, while at higher elevations, it occurs in several shrub-dominated communities with associates such as *Salix geyeriana*, *Calamagrostis canadensis*, *Thalictrum fendleri*, *Salix boothii*, *Ribes lacustre*, *Salix planifolia*, *Alnus incana* ssp. *tenuifolia*, *Salix wolfii*, *Fragaria virginiana* ssp. *glauca*, *Carex aquatilis*, *Poa pratensis* (.-%) *Salix monticola*, *Phleum pratense*, *Carex utriculata*, *Carex microptera*, *Ribes inerme*, and *Heracleum maximum* (Carsey and others 2003). A *S. microcarpus* vegetation association has been described in the Northwest U.S. found in marshes, fens, and springs. Stands are usually monotypic although some associated species also occur including *Lysichiton americanus*, *Athyrium filix-femina*, *Oenanthe sarmentosa*, *Stachys ajugoides* var. *rigida*, *Carex aquatilis*, and *Senecio triangularis* (Crowe et al. 2004, Christy 2004).

Scirpus pungens Vahl. (three square bulrush)

General description

Scirpus pungens, now classified by some authorities as *Schoenoplectus pungens* (Vahl) Palla var. *pungens* (Smith 2005a), is a rhizomatous, perennial herb in the Cyperaceae (USDA NRCS 2004). Synonyms include *Scirpus americanus* Pers. var. *polyphyllus* (Boeckl.) Beetle and *Scirpus pungens* Vahl var. *polyphyllus* Boeck (USDA NRCS 2004). It is rated secure globally (G5) and apparently secure (S4) in Alberta (NatureServe 2005).

Water level tolerance

Scirpus pungens is a common emergent macrophyte of palustrine wetlands with seasonally flooded moisture regimes in the prairie pothole region, corresponding to the shallow-marsh zone described in the literature (Kantrud et al. 1989a). Kadlec and Wentz (1974) reported a maximum depth of 60 cm (Kadlec and Wentz 1974).The hydrologic regime for S. *pungens* has been characterized as seasonally, regularly, or permanently inundated up to 15 cm for 13 to 100% of the growing season (Thunhorst 1993). The preferred water table depth range reported for the species in Alberta was 0 to 10 cm (Golder Associates 2005).

Water quality tolerance

Scirpus pungens occurs across a fairly wide pH gradient. The USDA reports a pH range of 3.7-7.5. Kadlec and Wentz report pH values from 6.7-8.9 and alkalinity from 12.7-277.0 ppm $CaCO_3$ (Kadlec and Wentz 1974). It is reported to have medium $CaCO_3$ tolerance and fertility requirement (USDA NRCS 2004).

Salinity tolerance

Scirpus pungens has medium salinity tolerance (USDA NRCS 2004) and occurs in fresh to brackish water (Kadlec and Wentz 1974, Payne 1992). Mean EC in communities supporting S. *pungens* was 4.9 mS/cm, ranging from 0.5 to 70.0 mS/cm (Kantrud et al. 1989a). Thunhorst (1993) reported tolerance of fresh to brackish water; up to 15 ppt., for the species. In Alberta, Purdy et al. (2005) noted *S. pungens* in slightly saline wet meadow communities.

Substrate requirements

Scirpus pungens generally occurs on fine textured substrates (Payne 1992). Soil preferences reported range from sandy, loamy, and clay soils (PFF 2005).

Reproduction and establishment requirements

Payne suggested establishing *S. pungens* using either transplants or tubers, digging up and separating plants or rootstock and ensuring the presence of at least one growth point before planting on site or into containers (Payne 1992). The species can also be established via seed. Seeds are fairly light, and number approximately 575/g of seed (USDA NRCS 2004). Seed production has been estimated at 240 kg/ha. Seeds ripen in late summer or early fall and exhibit dormancy. Payne recommended that collected seed should be stored dry, at room temperature (Payne 1992). One suggested approach to propagation involves sowing seeds in trays placed in shallow standing water in a cold frame or greenhouse and planting seedlings in early summer (PFF 2005). The species

can also be successfully propagated via the use of dormant rhizomes, bare root plants, peat pots, and containers (Thunhorst 1993).

Associated species

Scirpus pungens occurs in a variety of habitats including the margins of streams, ponds and lakes, in sloughs, and roadside ditches, where it can occur with a variety of plant species (Favorite 2002b). In Colorado, it occurs as an understory component in several woodland riparian vegetation associations dominated by species such as *Populus deltoides* and *Salix spp.*, as well as being a component of several herbaceous vegetation associations (Carsey and others 2003). Carsey et al (2003) also describe a *Schoenoplectus pungens* (=*Scirpus pungens*) plant association formed on small, low stature marshes in low-lying swales and abandoned stream channels where soils remain saturated. This association is characterized by pure stands of *Scirpus pungens*, with the occasional occurrence of other graminoid species such as *Agrostis gigantea*, *Eleocharis palustris*, *Juncus balticus* var. *montanus*, *Mentha arvensis*, *Hordeum jubatum* ssp. *jubatum*, and *Polygonum douglasii* (Carsey and others 2003).

Scirpus validus Vahl. (softstem bulrush)

General description

Scirpus validus is a robust, perennial herb in the Cyperaceae broadly distributed across North America and Eurasia. Most new world botanical authorities have reclassified the species as *Schoenoplectus tabernaemontani* (K.C. Gmel.) Palla; this name will be used subsequently in the assessment (USDA NRCS 2004, NatureServe 2005, Smith 2005a). Synonyms include *Schoenoplectus lacustris* (L.) palla ssp. *creber* (Fern.) A.& D. Löve, *Scirpus lacustris* L. ssp. *creber* (Fern.) T. Koyama, *Scirpus lacustris* L. ssp. *glaucus* (Reichenb.) Hartman, *Scirpus lacustris* L. ssp. *tabernaemontani* (K.C. Gmel.) Syme, *Schoenoplectus* lacustris (L.) Palla ssp. *tabernaemontani* (K. C. Gmel.) A.& D. Löve, *Schoenoplectus lacustris* (L.) Palla ssp. *validus* (Vahl) T. Koyama, *Scirpus lacustris* L. ssp. *validus* (Vahl) T. Koyama, *Scirpus tabernaemontani* K.C. Gmel, *Scirpus validus* Vahl, *Schoenoplectus validus* (Vahl) A.& D. Löve, *Scirpus validus* Vahl var. *creber* Fern, *Schoenoplectus validus* (Vahl) A.& D. Löve ssp. *creber* (Fern.) A.& D. Löve, *Schoenoplectus validus* (Vahl) A.& D. Löve ssp. *luxurians* (Miq.) Soják. Common names include great bulrush, soft-stemmed bulrush, common bulrush, giant bulrush, and bull whip (USDA NRCS 2004). It is considered secure globally (G5), and nationally in Canada (N5) (NatureServe 2005).(NatureServe 2005)

Water level tolerance

Schoenoplectus tabernaemontani is an obligate (OBL) wetlands species *sensu* Reed (1988) found in deep or shallow water, or marshy ground around lakes, ponds, streams, and wooded wetlands (Favorite 2003). Hydrologic regimes in prairie pothole wetlands supporting *S. tabernaemontani* were characterized as semipermanently flooded and saturated, corresponding to zones of deep-marsh and fen vegetation, respectively (Kantrud et al. 1989a). The species can survive following periodic draining and flooding but can be impacted by prolonged inundation or drought (Favorite 2003). Kadlec and Wentz (1974) recommend establishing it in sites with water table <120 cm (Kadlec and Wentz 1974). Hammer (1992) included *S. tabernaemontani* among a list of species tolerant of seasonally flooded to permanently flooded hydrologic regimes, with maximum water depths ranging from 15-50 cm. The USDA, Natural Resource Conservation Service reports that S. *tabernaemontani* can tolerate flooding up to a depth of 91 cm (Hoag et al. 2001). The preferred water table range for the species as reported by Golder Associates (2005) was 0 to 49 cm of standing water above the ground surface.

Water quality tolerance

Kadlec and Wentz present a range in pH of 5.3-7.8 and alkalinity 115 ppm $CaCO_3$ for *S. tabernaemontani* (Kadlec and Wentz 1974). Similar numbers are reported by the USDA NRCS, who list a pH range of 5.4-7.5 for *S. tabernaemontani* (USDA NRCS 2004). Thunhorst (1993) lists a pH range of 6.5-8.5. *Schoenoplectus tabernaemontani* is reported to have medium tolerance to $CaCO_3$ (USDA NRCS 2004).

Salinity tolerance

Schoenoplectus tabernaemontani can tolerate fresh to brackish water, up to approximately 5 ppt (Thunhorst 1993). Kantrud et al. (1989) report a mean EC of 1.8 mS/cm and a range of 0.2 to 6.2 (Kantrud et al. 1989a).

Substrate requirements

Schoenoplectus tabernaemontani can occur in a variety of soil types, although all would likely be characterized as poorly drained (Favorite 2003). Kadlec and Wentz describe sand, clay, and marl substrates for the species (Kadlec and Wentz 1974). It is tolerant of fine, medium, and coarse textured soils (USDA NRCS 2004). Soils in many sites remain saturated for most of the growing season and often have an anoxic gleyed layer (Carsey and others 2003). In some communities, substrates consist of thick layers of organic ooze (sapric histosol) (Crowe et al. 2004). In the oil sands region, *S*. *tabernaemontani* has successfully colonized and expanded in reclaimed wetlands with a peat/mineral mix cap over tailings sand substrate (Golder Associates 2005).

Reproduction and establishment requirements

Schoenoplectus tabernaemontani flowers from June to September (Thunhorst 1993). Seed can be collected on site or is often available commercially. Propagation can be by seed or springs, but seedling vigor is low (USDA NRCS 2004). Its seed bank is a key adaptation to the marsh environments it occupies. During drought years, water levels recede allowing the germination of a variety of emergent species including *S. tabernaemontani*; when precipitation returns to normal, marshes refill, and emergent species expand (van der Valk and Davis 1978). Populations often decline after several years, apparently caused in part by the failure of *S. tabernaemontani* to continue to reproduce vegetatively. Planting guide lines for the species include sowing in a cold frame in a pot or tray standing in approximately 3cm of water; germination should occur fairly quickly. Transplant seedlings into the field or into larger containers in the summer (PFF 2005).

Associated species

Schoenoplectus tabernaemontani occurs with a variety of plant associates in fresh to brackish marshes, fens, bogs, lakes, stream banks and bars. Often, it is a pioneering species in disturbed places (Smith 2005a). The *Schoenoplectus acutus* var. *acutus*-*S. tabernaemontani* is a characteristic marsh community. Associated species include *Schoenoplectus acutus*, *Typha latifolia*, *Eleocharis palustris*, *Rorippa palustris* ssp. *Hispida*, *Rorippa nasturtium-aquaticum*, *Lemna minor*, and *Epilobium ciliatum* (Carsey and others 2003). Crowe et al. report a similar community in the Northwest dominated by *S. tabernaemontani*. Associate species there included *Carex vesicaria*, *Carex utriculata*, *Utricularia macrorhiza*, *Sparganium angustifolium* (Crowe et al. 2004).

Scolochloa festucacea (Willd.) Link (common rivergrass)

General description

Scolochloa festucacea is a cool season perennial grass (Poaceae) widely distributed throughout the north central and northwestern United States and Canada (NatureServe 2005). Synonyms include *Arundo festucacea* Willd., and *Fluminia festucacea* (Willd.) A.S. Hitchc. (ITIS 2004, ITIS 2004, USDA NRCS 2004). Common names include common river grass, whitetop rivergrass, and sprangletop. *Scolochloa festucacea* is ranked globally (G5) and apparently secure (S4) in Alberta (NatureServe 2005, ANHIC 2005, NatureServe 2005).

Water level tolerance

Scolochloa festucacea is an obligate wetland species *sensu* (Reed 1988). Stands dominated by this species occur on sites with standing water for part of the growing season. The water table may be above the soil surface for only a few weeks in spring after heavy rains or constantly until mid-summer. For example, water levels in the lacustrine marsh fringing Lake Manitoba and supporting a distinct *S. festucacea* community, typically drop between 20 and 50 cm over the growing season (Ignacio Galinato and Van Der Valk 1986, Squires and van der Valk 1992). Working in Manitoba, Canada, Neill (1994) found a strong plant growth response to experimental flooding, concluding that management that conserves or mimics the natural spring-flooded hydrologic regime can increase *S. festucacea* forage production and control invasion by undesirable species. Kantrud et al. (1989) describe it as occurring in palustrine wetlands with seasonally flooded (shallow-marsh zones) moisture regime (Kantrud et al. 1989a). Neill describes *S. festucacea* communities as occurring in intermittently flooded sites (Neill 1990). Hammer (1992) included *S. festucacea* among a list of species tolerant of transitional to seasonally flooded hydrologic regimes. *Scolochloa festucacea* was most abundant in the seasonally flooded zone around Lake Manitoba with average water table depths from 8 to 24 cm below ground surface (Grosshans and Kenkle 1997).

Water quality tolerance

The USDA NRCS report a pH range of 5.0-8.0 for *S. festucacea* (USDA NRCS 2004). Neill found that nitrogen limited growth of *S. festucacea* at the Delta Marsh, Manitoba (Neill 1990). Fertility requirements are reported to be medium (USDA NRCS 2004).

Salinity tolerance

Along with hydrologic regime, salinity is a principal gradient shaping the distribution of marsh vegetation (Dix and Smeins 1967, Stewart and Kantrud 1971, Costa et al. 2003). Stands dominated by *S. festucacea* can be found on marginally fresh to moderately saline sites. Although it is most common in fresh water, it may also occur in wetlands with oligosaline and mesosaline regimes. Mean EC in wetlands supporting *S. festucacea* was 3.4 mS/cm, although values ranged form <0.5 to 12.1 (Kantrud et al. 1989a). The USDA (2004) indicates medium salinity tolerance for *S. festucacea*. High levels of salinity may inhibit seed germination. For example seed germination of *Scolochloa* was reduced significantly by the addition of 1000 mg/l of NaCl (Ignacio Galinato and Van Der Valk 1986). Grosshens and Kenkle (1997) found that *Scolochloa fustucacea* occurs in salinities ranging from 0.6 to 14.7 mS/cm and is most abundant in salinities between 2.5 and 7.5 mS/cm.

Substrate requirements

At the Delta Marsh, Manitoba, Neill examined the effect of nutrient addition (N and P) on emergent macrophyte productivity, and found that nitrogen limited growth of both *S. festucacea* and *Typha x glauca* (Neill 1990). In *S. festucacea* meadows, nitrogen significantly increased productivity in the year following application; however, *S. festucacea* biomass decreased dramatically while biomass of other species (particularly the annual *Atriplex patula*) showed a dramatic increase. This reduction, Neill hypothesized, may have been due to the accumulation of a thick litter layer. Soils in *Typha* stands are typically medium to fine-textured and often have an accumulation of organic matter, although the species can exist in coarser textured soils.

Reproduction and establishment requirements

Seeding is the principal method of establishment. Seeds are light, numbering near 80,000/kg and should be applied at a moderate spread rate. In Manitoba, *S. festucacea* seeds germinated best in light, but stratification did not increase germination rates (Ignacio Galinato and Van Der Valk 1986). They also were highest in alternating 15/25°C and 20/30°C temperature regimes and lowest in a 5/15°C regime. Smith found maximum seedling survival occurred when *S. festucacea* seeds were planted 1 cm deep and were more tolerant of $MgCl_2$ than NaCl in germination media (Smith 1973). Germination declined sharply when seeds were covered by as little as 1 cm of sand (Ignacio Galinato and Van Der Valk 1986). Once established, it is reported to spread at a moderate rate vegetatively (USDA NRCS 2004).

Associated species

Scolochloa festucacea was reported as a characteristic species in the shallow-marsh zone of prairie potholes along with species such as *Glyceria grandis* (tall mannagrass), *Sparganium eurycarpum* (giant burreed), *Carex atherodes* (slough sedge), *Beckmannia syzigachne* (American sloughgrass), *Eleocharis palustris* (common spikerush), and *Scirpus americanus* (common three-square)(Sloan 1970). Tiner (Tiner et al. 2002) identified *S. festucacea* as an indicator of seasonally flooded hydrologic regimes in prairie pothole wetlands along with species such as *Eleocharis palustris*, *Sparganium* eury*carpum, Alisma plantago-aquatica, Carex atherodes, Phalaris arundinacea, Glyceria grandis*, and *Beckmannia syzigachne*. Competition, particularly with the invasive hybrid cattail *Typha* x *glauca* appears to be an important factor influencing *S. festucacea* distribution and dynamics. Neill described a *S. festucacea* community in intermittently flooded sites (Neill 1990). *S. festucacea* dominated herbaceous vegetation is common in the prairie region of the United States and Canada; *S. festucacea* is dominant, and abundant species include *Carex atherodes*, *Carex laeviconica*, *Eleocharis palustris*, *Glyceria grandis, Juncus balticus, Sium suave,* and *Typha latifolia* (NatureServe 2005).

Sium suave Walt. (hemlock water-parsnip)

General description

Sium suave, a native, perennial forb in Apiaceae family, occurs in wetlands and riparian environments throughout most of Canada and the United States (NatureServe 2005). Common names include hemlock water-parsnip, False hemlock, and water-parsnip. Synonyms include *Sium cicutifolium* Schrank, *Sium floridanum* Small, *Sium suave* Walt. var. *floridanum* (Small) C.F. Reed (USDA NRCS 2004). It is considered secure globally (G5), as well as at the national level in Canada and the United States, and regionally in Alberta (S5) (NatureServe 2005).

Water level tolerance

Sium suave is an obligate wetland species *sensu* Reed (Reed 1988, USDA NRCS 2004). There are few data directly or indirectly addressing the hydrologic requirements of the species, although numerous anecdotal accounts of its habitat occur. In the prairie pothole region, Kantrud et al. (1989) characterized it as a common emergent macrophyte of palustrine wetlands with a seasonally flooded moisture regime. This corresponds to the shallow-marsh zone described in the literature (Dix and Smeins 1967, Kantrud et al. 1989a). *Sium suave* is described from the drawdown zone of Montana wetlands, inundated in the early portion of the growing season but typically drying later in the summer. This zone is interposed between the drier meadow zone above and marsh and aquatic zones below and may include the entire basin of smaller, temporary ponds (Cooper and Jones 2003). Thunhorst (1993) recommends planting in sites with a regularly to permanently inundated hydrologic regime, where plants are saturated up to 15 cm for approximately 26-100% of the season.

Water quality tolerance

Sium suave is reported from habitats with moderately acidic to slightly alkaline pH. No quantitative pH ranges are available.

Salinity tolerance

Sium suave occurs in fresh to slightly brackish water (Thunhorst 1993). Kantrud et al. (1989) report a mean conductivity of 1.8 mS/cm, ranging from 0.1 to 4.0 mS/cm (Kantrud et al. 1989a). There are no quantitative salinity guidelines for *Sium suave*.

Substrate requirements

Sium suave is generally found in mineral soils ranging from fine to coarse texture, but has been reported from sites with shallow peat deposits (Nicholson 1993, Carsey and others 2003, Christy 2004).

Reproduction and establishment requirements

Sium suave can be propagated via seed or by dividing rootstock from wild or nursery stock. If starting materials in a nursery, seeds should be sown in late winter to early spring in a cold frame; seeds can be slow to germinate (PFF 2005). Germination rates are generally low; Shipley and Parent report 18% (Shipley and Parent 1991). Seedlings should be transferred to individual pots once large enough and planted out in the summer. Division of rootstock should be done in early spring immediately prior to the start of new growth for the season (PFF 2005). *Sium suave*, along with *Eleocharis*

palustris, *Alopecurus aequalis*, *Beckmannia syzigachne*, and *Glyceria* gra*n*dis, was identified as an indicator of disturbance in Saskatchewan wetlands (Walker and Wehrhahn 1971). Although *Sium suave* was a common emergent species of natural wetlands they were absent from restored wetlands studied in the great plains, suggesting that active revegetation may be required if establishment is desired (Galatowitsch and van der Valk 1996).

Associated species

Sium suave is often found in riparian areas in Colorado; for example it occurs in a *Populus angustifolia* association located on upper terraces and outer edges of floodplains in medium to wide valleys (Carsey and others 2003). It occurs along wetland margins, on shallow peats, and in areas recently flooded by beaver along with *Carex aquatilis*, C*arex rostrata, Carex atherodes, Beckrnannia syzigachne*, *Hordeum jubatum*, *Glyceria grandis*, *Calamagrostis canadensis*, and *Polygonum amphibium* (Nicholson 1995). In the eastern U.S., *Sium suave* has been documented with *Acorus calamus*, *Aster puniceus*, *Bidens frondosa*, *Bidens laevis*, *Cyperus strigosus*, *Cyperus refractus*, *Iris versicolor*, *Ludwigia alternifolia*, *Lycopus virginicus*, *Mentha arvensis*, *Orontium aquaticum*, and *Zizaniopsis miliacea* (Anderson et al. 1968). In Montana, it occurs in drawdown communities along with *Eleocharis palustris* , *Eleocharis acicularis*, *Alopecurus aequalis*, *Glyceria borealis*, and Po*l*ygonum *amphibium* (Cooper and Jones 2003). In the Great Plains, it occurs in a *S. festucacea*-dominated herbaceous vegetation associated common in the prairie region of the United States and Canada; abundant species include *Carex atherodes*, *Carex laeviconica*, *Eleocharis palustris*, *Glyceria grandis, Juncus balticus,* and *Typha latifolia* (NatureServe 2005).

Sparganium eurycarpum Engelm. ex Gray. (broadfruit bur-reed)

General description

Sparganium eurycarpum (Sparganiaceae) is a native, semi-aquatic, perennial herb found in wetlands throughout most of Canada and the United States (NatureServe 2005). Synonyms include *Sparganium californicum* Greene, S. *eurycarpum* Engelm. ex Gray var. *greenei* (Morong) Graebn, and *S. greenei* Morong (USDA NRCS 2004). It is ranked secure globally (G5) and regionally (S4) in Alberta (NatureServe 2005).

Water level tolerance

Sparganium eurycarpum is found in hydrologically diverse environments, ranging from lowland marshes, lake and pond shores, to ditches. Kantrud (1989) listed S. *eurycarpum* among the common emergent macrophytes of palustrine wetlands with seasonally flooded hydrologic regimes (Kantrud et al. 1989a). Tiner et al. (2002) identified *S. eurycarpum* as an indicator of seasonally flooded hydrologic regimes in prairie pothole wetlands along with species such as *Eleocharis palustris, Alisma plantago-aquatica, Carex atherodes, Phalaris arundinacea, Glyceria grandis*, and *Beckmannia syzigachne* (Tiner et al. 2002). Kadlec and Wentz (1974) suggest that standing water <120 cm deep is needed by *S. eurycarpum* (Kadlec and Wentz 1974). It is reported to be moderately tolerant of some desiccation (USDA NRCS 2004).

Water quality tolerance

Sparganium eurycarpum occurs over a fairly wide pH gradient. The USDA reports a range of pH from 5.0-8.5 and medium alkalinity tolerance. Kadlec and Wentz (1974) report a narrower pH range of 6.7-8.8 and alkalinity from 35.3-376.0 ppm $CaCO_3$ (Kadlec and Wentz 1974). *Sparganium eurycarpum* has been characterized as a typical species in areas of low sulfate, low alkalinity, and hardness (Ulrich and Burton 1988).

Salinity tolerance

It is locally common to abundant in fresh to somewhat brackish waters (Kadlec and Wentz 1974). Kantrud et al. (1989) reports a mean conductivity of 1.8 mS/cm, ranging from <0.5 to 4.6 mS/cm (Kantrud et al. 1989a).

Substrate requirements

Sparganium eurycarpum is adapted to fine, medium, and coarse textured soils and is found on mud, sand, or gravel, sometimes among boulders on wave-washed shores (USDA NRCS 2004).

Reproduction and establishment requirements

Sparganium eurycarpum typically flowers from June to July in the northern part of its range. Seed production has been reported to be 930 kg/ha. Propagating S. *eurycarpum* can be difficult, as seeds have low germination rates, seedlings have special growth requirements, and germination requires special stratification procedures. Other challenges can include a lack of seed producing plants, difficulty of collection (e.g., submerged seed heads), and processing difficulty (Hagen 1996). Payne suggested establishing *Sparganium* using transplants, digging up and dividing the rhizomes for planting on site or into containers. This approach could likely also be used with *S. eurycarpum* (Payne 1992). Conditions mimicking a natural water level drawdown, as observed during drought years in prairie marshes, may help promote establishment from

soil seed banks. Favorite (2002) suggested that large divisions can be planted directly into their permanent positions while allowing smaller potted divisions to grow in a cold frame until they are well established and ready for summer out-planting. It is also recommended that seeds be sown as soon as they mature, as they lose viability quickly if allowed to dry out (Favorite 2002a). Once established, *S. eurycarpum* can persist vegetatively. Its functional guild was characterized by Keddy as matrix clonal dominant (Keddy et al. 1994).

Associated species

Sparganium eurycarpum is a characteristic species in the shallow-marsh zone of prairie potholes along with species such as *Scolochloa festucacea*, *Glyceria grandis*, *Carex atherodes*, *Beckmannia syzigachne*, *Eleocharis palustris*, and *Scirpus americanus* (Sloan 1970). In Idaho, S. *eurycarpum* is associated with *Carex vesicaria* on sites with long periods of standing water, and occurs with *Eleocharis palustris*, *Juncus balticus*, *Sparganium emersum*, *Glyceria borealis*, *Equisetum fluviatile*, *Zizania aquatica*, *Carex atherodes*, *Polygonum* spp., *Phalaris arundinacea*, and *Utricularia* spp. (USDA NRCS 2004). It dominates the *S. eurycarpum* herbaceous vegetation association described by NatureServe (2005). *Sparganium eurycarpum* was reported as a characteristic species in the shallow-marsh zone of prairie potholes along with species such as *Beckmannia syzigachne*, *Glyceria grandis*, *Carex atherodes, Scolochloa festucacea, Eleocharis palustris,* and *Scirpus americanus* (Sloan 1970). Tiner (2002) lists *S. eurycarpum* as an indicator of seasonally flooded hydrologic regimes in prairie pothole wetlands along with species such as *Eleocharis palustris, B. syzigachne, Alisma plantago-aquatica, Carex atherodes, Phalaris arundinacea, Glyceria grandis,* and *Scolochloa festucacea* (Tiner et al. 2002).

Spartina gracilis Trin. (alkali cordgrass)

Common names

Alkali cordgrass

Synonyms

General description

Spartina gracilis is a facultative wetland perennial graminoid that occurs in western Canada, the Northwest Territories, and the north-central and western U.S. (NatureServe 2005). It grows to a height of 100 cm (USDA NRCS 2004).

Water level tolerance

Spartina gracilis has medium tolerance to flooded, anaerobic soil conditions and medium tolerance to drought (USDA NRCS 2004).

Water quality tolerance

The range of tolerable pH for *Spartina gracilis* is between 7.0 and 9.5 (USDA NRCS 2004).

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Spartina gracilis* occurred in wetlands with a mean specific conductivity of 9.0 mS/cm, a minimum of 0.7 mS/cm and a maximum of 20.1 mS/cm (Kantrud et al. 1989a).

Substrate requirements

Spartina gracilis performed well on fine and medium textured soils, but not on coarse substrates (USDA NRCS 2004).

Reproduction and establishment requirements

The recommended planting density is between 6,670 and 11,860 plants per hectare (USDA NRCS 2004).

Associated species

Muhlenbergia asperifolia, *Bromus tectorum*, *Hordeum jubatum*, *Schoenoplectus pungens*, *Elymus repens*, *E. cinereus*, *E. trachycaulus*, *Melilotus officinalis*, *Glycyrrhiza lepidota*, *Poa pratensis*, *Dactylis glomerata*, *Panicum virgatum*, *Carex pellita*, *C. nebraskensis*, *C. praegracilis*, *Distichlis spicata*, *Eleocharis palustris*, *Juncus balticus*, *Vitis riparia*, *Pascopyrum smithii* (Ecological Society of America 2005).

Spartina pectinata Bosc ex Link (prairie cordgrass)

Common names

Fresh water cordgrass, prairie cordgrass, tall marshgrass, sloughgrass, ripgut

Synonyms

Spartina michauxiana A.S. Hitchc.
Spartina pectinata Bosc ex Link var. *suttiei* (Farw.) Fern.

General description

Spartina pectinata is a facultative/obligate wetland warm-season sod-forming graminoid that is widely distributed across most of Canada and the U.S. It grows to heights of 1 to 3 meters and its roots can reach depths of 3.3 m (Walkup 1991b). It is listed as critically imperiled in the province of Alberta (NatureServe 2005).

Water level tolerance

Spartina pectinata is tolerant of high water tables but is excluded by prolonged flooding (Walkup 1991b).

Water quality tolerance

Spartina pectinata is often found in poorly drained, alkaline fens in prairie landscapes (Walkup 1991b). It grows in areas where water pH ranges from 6.0 to 8.5 (USDA NRCS 2004).

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Spartina pectinata* occurred in wetlands with a mean specific conductivity of 3.0 mS/cm, a minimum of 0.1 mS/cm and a maximum of 33.5 mS/cm (Kantrud et al. 1989a). In Alberta, Purdy et al. (2005) note the presence of *S. pectinata* in strongly saline wet and dry meadow communities.

Substrate requirements

In Indiana, *Spartina pectinata* occurred on soil textures ranging from fine clays to silt loams (Walkup 1991b).

Reproduction and establishment requirements

Spartina pectinata reproduces both sexually by seed and asexually by rhizomes. Most reproduction is via rhizomes; seedlings are intolerant of shade and require bare soil to establish (Weaver 1954). The dense network of rhizomes and culms excludes most other plants from stands of *Spartina pectinata*. Broadcast seeding followed by light surface scoring is an effective means of planting (USDA NRCS 2004). The recommended planting density is between 6,670 and 11,860 plants per hectare (USDA 2005). Planting of various sized root-shoot plugs may be the fastest way to achieve natural densities of *Spartina pectinata* (Fraser and Kindscher 2005).

Associated species

It is codominant with *Calamagrostis canadensis* in wet prairies and alkaline fens of Indiana, U.S. (Walkup 1991b). *Pascopyrum smithii, Poa compressa, P. pratensis, Symphoricarpos occidentalis, Rosa woodsii, Rhus trilobata, Euphorbia esula, Salix amygdaloides, S. exigua, Elymus lanceolatus, Carex pellita, Cirsium arvense, C.*

atherodes, Apocynum androsaemifolium, Eragrastis pilosa, Vitis riparia, Schoenoplectus pungens, Xanthium strumarium, Bromus japonicus, Eleocharis palustris, Equisetum arvense, Scirpus microcarpus, Panicum virgatum, Glycyrrhiza lepidota, Scolochloa festucacea, Juncus balticus (Ecological Society of America 2005).

Triglochin maritima L. (seaside arrow-grass)

Common names

Arrowgrass, seaside arrowgrass, shore arrowgrass

Synonyms

Alternate accepted spelling: *Triglochin maritimum* L. (NatureServe 2005)
Triglochin concinnum Burtt-Davy var. *debile* (M.E. Jones) J.T. Howell
Triglochin debile (M.E. Jones) A.& D. Löve
Triglochin elatum Nutt.
Triglochin maritimum L. var. elatum (Nutt.) Gray

General description

Triglochin maritima is an obligate wetland perennial graminoid that is widespread throughout Canada and the northern and western U.S. (NatureServe 2005). It grows to a height of 5 to 60 cm. It is a halophyte, indicative of saline conditions, and competes poorly in fresh water situations. Individual plants live 15 to 20 years, but large clones are probably much older (Davy and Bishop 1991).

Water level tolerance

At a salt spring in Northern California *Triglochin maritima* occurred in areas with perennial saturation (personal observation). Golder Associates (2005) report a preferred water table depth range of 0 to 1 cm below ground for *T. maritima*, also noting the species' ability to tolerate seasonal flooding.

Water quality tolerance

At a salt spring in California *Triglochin maritima* occurred in microsites ranging from pH 4.21 to 9.39 (Cooper and Wolf, unpublished data).

Salinity tolerance

In the Prairie Potholes region of North Dakota, Minnesota, and Manitoba *Triglochin maritima* occurred in wetlands with a mean specific conductivity of 12.5 mS/cm, a minimum of 0.7 mS/cm and a maximum of 50.9 mS/cm (Smeins 1967, Kantrud et al. 1989a). In Poland, the *Triglochin maritima* dominated community is an indicator of salinity > 12 mS/cm (Piernik 2003). At a salt spring in Northern California *Triglochin maritima* occurred in areas with a spatial and temporal range of salinity from 5 mS/cm to 60 mS/cm, centering around a value of about 20 mS/cm (Levine et al. 2002). In the British Isles *Triglochin maritima* occurred in wetlands with calcium concentrations between 240 mg/L and 561 mg/L and sodium concentrations between 5750 mg/L to 12880 mg/L (Davy and Bishop 1991). *Triglochin maritima* tolerates extremely low osmotic pressures and may help overcome this by storing sodium and chloride ions in leaf vacuoles (Davy and Bishop 1991). In the oil sand region of Alberta, Purdy et al. (2005) noted the presence of *Triglochin maritima* in wet-meadow communities in strongly saline landscapes.

Substrate requirements

At a California salt spring *Triglochin maritima* can tolerate coarse to fine textured substrates (Cooper and Wolf unpublished data).

Reproduction and establishment requirements

Triglochin maritima spreads from rhizomes by forming an expanding circle of genets (Davy and Bishop 1991). *Triglochin maritima* can be established via transplants or direct seeding; growth rate is slow (ERO Resources, Inc. 1997). Golder Associates (2005) observed *T. maritima* naturally colonizing reclaimed wetland sites in the oil sands region.

Associated species

Carex lasiocarpa, *C. utriculata*, *C. buxbaumii*, *C. aquatilis*, *C. diandra*, *C. nebraskensis*, *C. simulata*, *Menyanthes trifoliata*, *Limprichtia revolvens*, *Utricularia intermedia*, *Sphagnum* sp., *Rhynchospora alba*, *Potamogeton gramineus*, *Juncus longistylis*, *J. balticus*, *Pentaphylloides floribunda*, *Puccinellia nuttaliana*, *Eleocharis palustris*, *Schenoplectus pungens*, *Distichlis spicata*, *Sarcobatus vermiculatus*, *Panicum virgatum*, *Muhlenbergia asperifolia*, *Thalictrum alpinum* (Ecological Society of America 2005).

Triglochin palustris L. (slender arrow-grass)

Common names

Marsh arrowgrass, slender bog arrowgrass

Synonyms

Alternate, accepted spelling: *Triglochin palustre* L. (NatureServe 2005)

General description

Triglochin palustris is an obligate wetland perennial graminoid that is widespread throughout Canada and the northern and western U.S. (NatureServe 2005). It grows to a height of 15 to 70 cm.

Water level tolerance

In Colorado *Triglochin palustis* occurred in sites with up to 4 cm of standing water, where the water table never dropped more than 2 cm below the surface (Johnson and Steingraeber 2003). In the Athabasca Oil Sand region *Triglochin palustri*s demonstrated a preference for saturated conditions with a water table at 0 cm, and was tolerant of seasonal flooding (Golder Associates 2005).

Water quality tolerance

Triglochin palustris can withstand a range of pH from 4.02 to 7.54, but is typically found in water with pH ranging from 5.38 to 7.08 (University of York 2005).

Salinity tolerance

Triglochin palustris occurred in tidal marshes with salinity of ~33 mS/cm (Person and Ruess 2003).

Substrate requirements

Reproduction and establishment requirements

Golder Associates (2005) observed *Triglochin palustris* naturally colonizing reclaimed wetland sites in the Oil Sands region.

Associated species

Equisetum arvense, *Carex utriculata*, *C. pellita*, *C. aquatilis*, *C. limosa*, *C. simulata*, *C. scirpoidia*, *Juncus balticus*, *Allium schoenoprasum*, *Poa pratensis*, *Stipa arctica*, *Gentiana affina*, *Cerastium arvense*, *Limprichtia revolvens*, *Pentaphylloides floribunda*, *Eleocharis pauciflora*, *E. palustris*, *Potentilla fruiticosa*, *Schoenoplectus pungens*, *Puccinellia nuttiallana*, *Lolium arundinaceum*, *Scirpus microcarpus* (Ecological Society of America 2005).

Typha latifolia L. (common cattail)

General description

Typha latifolia is an herbaceous, rhizomatous perennial plant widely distributed throughout marshes in the eastern and western hemispheres. The cattail family (Typhaceae) in North America consists of a single genus with three species: *Typha latifolia*, *T. angustifolia* (narrow-leaved cattail) and *Typha domingensis* (Dominican cattail), whose distributions overlap considerably over their range (Smith 2005b). Hybrids between *Typha latifolia* x *T. angustifolia* hybrids (*Typha x glauca*.), commonly known as Hybrid or glaucus cattail, and can be particularly aggressive and problematic weeds where they occur. *Typha latifolia* is typical in early successional stages in wetlands where it rapidly colonizes exposed wet mineral soils through seed and clonal expansion. *Typha latifolia* is ranked globally (G5) and secure (S5) in Alberta (NatureServe 2005, NatureServe 2005). Common names include common cattail, broadleaf cattail, and cattail (USDA NRCS 2004).

Water level tolerance

Typha latifolia is an obligate (OBL) wetland species *sensu* Reed (Reed 1988), although it occurs in a variety of wetland types differing in hydrologic function. *Typha latifolia* occurs in both tidal and non tidal hydrologic regimes (Smith 2005b). In non-tidal systems, it occurs in sites experiencing flooding and inundation on an irregular, seasonal, or nearly permanent basis. It can tolerate both deep inundation and extended drought, although it is the least tolerant of deep inundation of the three North American *Typha* species (Grace 1989). Grace and Wetzel (Grace and Wetzel 1982) found *T. latifolia* and *T. angustifolia* plants showed a modest increase in height with increasing depth of inundation. *Typha latifolia* was documented over a wide water level gradient of 50 cm below the ground surface to inundation under 24 cm of water (Shay et al. 1999). Research in Alberta fens and marshes indicate that high water levels promote decomposition and suggest that differences in the decomposition rates between marshes and fens may ultimately be controlled by hydrologic conditions versus nutrient dynamics. Nutrient dynamics and concentrations differed between wetland classes (Bayley and Mewhort 2004). The mean low water level preference for *Typha latifolia* in the Midwest US was less than 30 cm below ground (Kadlec and Wentz 1974). Hammer (1992) included *T. latifolia* among a list of species tolerant of seasonally flooded to permanently flooded hydrologic regimes, with maximum water depths ranging from 15-50 cm. Golder Associates (2005) suggested that, along with air temperature, water depth is an important factor in determining *Typha* height and cover, with the preferred water table range of 0 to 32 cm of standing water above the ground surface.
It has also been suggested that *Typha* can be detrimentally affected by overwinter draining (Motivans and Apfelbaum 2003). *Typha latifolia* seedlings can be killed by water depths of 45 cm, while mortality of mature plants has been reported at depths greater than 63.5 cm (Steenis et al. 1958).

Water quality tolerance

Typha latifolia can occur in wetlands with acidic or alkaline soils (Payne 1992). The USDA NRCS (2004) list a pH range of 5.5-7.5 for the species, while Kadlec and Wentz (1974) report a pH range from 4.0 – 9.0. High concentrations of metals such as Cu or Zn

can negatively affect *T. latifolia*. The species showed a 30% inhibition of root length and 9% inhibition of leaf elongation when exposed to 0.79 mM of Cu and decreases of 61% and 74% in root and leaf elongation, respectively, when grown at 15.29 mM of Zn (Ait Ali et al. 2004). *Typha latifolia* and *Phragmites australis* have been successfully used for phytoremediation of Pb and Zn mine tailings under waterlogged conditions (Deng et al. 2004).

Salinity tolerance

High levels of salinity may inhibit seed germination. For example seed germination of *T. latifolia* was reduced significantly by the addition of 1000 mg/l of NaCl (Ignacio Galinato and Van Der Valk 1986). *Typha latifolia* is associated with fresh, not extremely saline or brackish water (Payne 1992). Kantrud report a mean EC value of 2.1 mS/cm, ranging from <0.05 to 13.6 mS/cm (Kantrud et al. 1989a). Salinity values reported for *T. latifolia* by Kadlec and Wentz (1974) range from fresh (0 – 5 ppt) to brackish (2-25 ppt) (Kadlec and Wentz 1974). They report alkalinity of 10.0-376.0 ppm $CaCO_3$. Mean conductivity in Manitoba *Typha* stands was 3510 µmhos, with a range of 2963 – 4660 µmhos (Shay et al. 1999).

Substrate requirements

T. latifolia occur in a variety of edaphic settings, but is most common in peat or organic rich mineral sediments (Kadlec and Wentz 1974). *Typha* stands produce enormous quantities of litter, contributing organic matter to soils they grown in (Atkinson and Cairns 2001). Reclamation studies in oil sands wetlands appeared to be successful on sites capped with a peat/mineral mix (1 m CT, dyke capped and control) (Golder Associates 2005). The authors found that after 5 years, *T. latifolia* establishes easily on all landforms; it has continued to increase in ground cover has tripled on all landforms excluding dyke capped landforms and has increased seven fold on several landforms (Golder Associates 2005). Cattails can grow on a wide range of substrates including sand, peat, clay and loamy soils (Motivans and Apfelbaum 2003).

Reproduction and establishment requirements

Typha species may be planted from bare rootstock, seedlings from container or directly seeded into the soil (Stevens and Hoag 2002). Where there is moving water, planting bare rootstock or seedlings is preferred. Payne suggested establishing *T. angustifolia* using transplants or rootstock, digging up and dividing them for planting on site or into containers; an approach used with *T. latifolia* (Payne 1992). The species is also very well-adapted to establishment via seed as seed crops are large (as great as 222,000 seeds/18 cm spike) following maturation in late summer and seeds easily dispersed. *Typha* seeds germinate readily and are a cost-effective means to propagate cattail on moist soils (Stevens and Hoag 2002). Select seed collection sites where continuous stands with few intermixed species can easily be found. Harvest with hand clippers by cutting the stem off below the seed heads or stripping the seed heads off the stalk. Clean seed following collection and store seeds dry in brown paper at room temperature (Payne 1992). Seeds can be harvested when they are slightly immature and should be harvested before staminate stalks dry and seeds disperse.

Typha seeds should be planted in the fall in a clean, weed - free, moist seed bed. Flooded or ponded soils will significantly increase seedling mortality. Broadcast seed and roll in or rake 6-13 mm from the soil surface (Stevens and Hoag 2002). Seed can also be germinated in a greenhouse. Stevens and Hoag recommend plant seeds 6 mm below the soil surface in small pots maintained with moist soils and warm temperature. Seeds initiate germination following a couple of weeks. Plants can be out planted as

plugs after 100 - 120 days (Stevens and Hoag 2002). Plugs may be split into smaller units, generally no smaller than 6 x 6 cm, and planted at approximately 1 m spacing with healthy rhizomes and tops. Key to successfully making live collections is ensuring either plugs or rhizomes contain a live bud. Roots should always be kept moist or in water until planted. After installation, clip leaves and stems from 15 to 25 cm to allow plants to allocate more energy into root production. Ideally, plants should be planted in moist soils in late fall just after the first rains (usually late October to November). Moderate fertilization may be used to increase production and reproduction (Stevens and Hoag 2002).

While many wetland species require mudflat conditions to germinate (van der Valk 1981), *T. latifolia* seeds can germinate in flooded conditions (Keddy and Ellis 1985, Kellogg et al. 2003). Variables such as particle size and organic matter content, interact with hydrology to cause differential germination (Keddy and Ellis 1985, Keddy and Constabel 1986). Golder Associates (2005) recommended *Typha* as a good candidate for aquatic CT reclamation after observing significant expansion and natural colonization in reclaimed sites.

Vegetative growth by broad-leaved cattails of 518 cm (1y ft) annually have been recorded (McDonald 1951), and plants grown from seed flowered the second year (Smith 1967, Yeo 1964). Cattails can produce 20,000-700,000 fruits per inflorescence (Prunster 1941, marsh 1962, Yeo 1964); sexual reproduction is important for colonization (McNaughton 1968), but colonies are maintained by vegetative reproduction.

Associated species

Typha latifolia can occur in both fens and marshes, although it is more common in the latter. In fact, the presence of *T. latifolia* was one indicator identified for separating marshes from fens in lacustrine wetland complexes in Alberta (Bayley and Mewhort 2004). In addition to *T. latifolia*, marshes supported *Carex utriculata, C. atherodes,* and *Lemna minor*. It is common in depressional wetlands throughout the Great Plains, typically in dense, uniform monocultures. Associated species in Washington wetlands include *Potamogeton pectinatus*, *Ceratophyllum demersum*, common water milfoil *Myriophyllum exalbescens*, *Scirpus acutus*, *Eleocharis macrostachya*, *Scirpus pungens*, and *Juncus arcticus* (Tiner et al. 2002).

D.4 Synthesis

Table 1 summarizes available information on the hydrologic regime and salinity tolerances of the 40 study species. For this summation, we chose three hydrologic regimes. The first category includes sites with a water table near the soil surface for most of the summer, and little water table variation. These sites have water levels similar to fens. The second category has a larger range of water table variation, including varying depths of standing water. These sites would typically be considered marshes, or pools/ponds within fens. The third category includes sites with seasonal water level fluctuations, but little or no standing water, and potentially deep water tables in some years or seasons. These sites would typically be called wet meadows. We retained the salinity categories that appear in Table F4, page F-7 of the Guideline for Wetland Establishment on Reclaimed Oil Sands Leases, Appendices, September 1999.

Establishment of vascular plants in wetlands classified into each of the 12 boxes in Table 1 could be approached in a different manner for each box.

Stable water level, fresh. These sites would be poor to rich fens based upon their water chemistry. Direct placement could be used in an experimental trial, but first the soil seed bank present should be analyzed. Decomposition of the placed soil should be analyzed to ensure that excessive mineralization of organic matter does not produce high nutrient levels. Seed rain could produce propagules of *Eriophorum vaginatum* and other desirable species, but this should be monitored. Direct seeding could also be tried, but does not seem promising. Rhizome transplants from a donor area or seedlings grown for revegetation could be additional methods used. Key species to introduce would be *Carex aquatilis, Carex utriculata, Calamagrostis canadensis* and *Eriophorum vaginatum.*

Stable water level, moderately saline. These sites would be rich fens, or extreme rich fens based upon their water chemistry. Relatively few species are in this category, and a donor soil likely would likely not be available. Revegetation could be attempted by direct seeding, or by the growth of seedlings for transplant.

Stable water level, saline. These sites would be rich fens, or extreme rich fens based upon their water chemistry. Relatively few species are in this category, and a donor soil would be unavailable. Revegetation could be attempted by direct seeding, or by the growth of seedlings for transplant.

Stable water level, hypersaline. These sites would be rich fens, or extreme rich fens based upon their water chemistry. Only one species from our list is in this category, and a donor soil would likely be unavailable. Revegetation could be attempted by direct seeding, or by the growth of seedlings for transplant. It is likely that other species should be added to this category, including *Glaux maritima*.

Fluctuating water level with flooding, fresh. These wetlands would be classified as fresh water marshes. Donor soils may be available and could be successfully used, as many marsh species germinate well from the soil seed bank. Some species, particularly *Typha latifolia* and *Equisetum arvensis,* could arrive by seed/spore rain and competition with *Typha* could make it difficult to establish other species. Direct seeding could be

used for species of *Calamagrostis, Eleocharis, Juncus, Phragmites, Scirpus*, and *Scolochloa.*

Fluctuating water level with flooding, moderately saline. These wetlands would be classified as brackish marshes. Donor soils may be available and could be successfully used, as many marsh species germinate well from the soil seed bank. *Typha latifolia* could arrive by seed rain, and competition with *Typha* could make it difficult to establish other species. Direct seeding could be used for species of *Calamagrostis, Eleocharis, Juncus, Phragmites, Scirpus*, and *Scholochloa.*

Fluctuating water level with flooding, saline. These wetlands would be classified as saline marshes. Some of these species could establish from a soil seed bank of a donor soil, if one could be found. Direct seeding of all species should be attempted in field trials. It would be worthwhile to add *Scirpus maritimus* (*S. paludosus*) to the list for this category.

Fluctuating water level with flooding, hypersaline. These wetlands would be classified as hypersaline marshes. No species from our list would fall into this category, but we suggest adding *Scirpus maritimus* (*S. paludosus*), and *Distichlis stricta.*

Fluctuating water level without flooding, fresh. Wetlands in this category would be classed as freshwater wet meadows. Several of the species could likely be established from the soil seed bank in donor soils, or by direct seedlng, particularly *Deschampsia cespitosa, Juncus balticus,* and *Poa palustris.* Other species could be introduced as rhizome transplants, or seedlings grown for planting.

Fluctuating water level without flooding, moderately saline. Wetlands in this category would be classed as brackish wet meadows. It is unlikely that a donor soil could be found, although several species in this group could likely be established from a soil seedbank, including *Calamagrostis inexpansa, Juncus balticus,* and *Puccinellia nuttalliana.* All of these species could be grown as seedlings for outplanting.

Fluctuating water level without flooding, saline. Wetlands in this category would be classed as saline wet meadows. Several of the species in this category could likely be established from direct seeding, including *Calamagrostis inexpansa, Juncus balticus, Puccinellia nuttalliana* and *Triglochin maritima.* In addition, all of these species could be established from nursery grown seedlings.

Fluctuating water level without flooding, hypersaline. Wetlands in this category would be classed as hypersaline wet meadows. Attempts should be made to establish the two species in this category from direct seeding. However, the growth of seedlings for outplanting may be more successful considering the severe soil conditions that seedlings will face. It is suggested that *Distichlis stricta, Plantago eriopoda, Salicornia europaea,* and *Suaeda maritima* be added to the list in this category.

Table 1 Summary of the hydrologic and salinity tolerances of the 40 study species

Salinity	Hydrologic Regime Categories		
	Perennial saturation/stable water table	**Seasonal saturation/moderate deep flooding/ fluctuating water table**	**Seasonal saturation/ no flooding/fluctuating water table**
Fresh <2 mS/cm	*Acorus calamus, Calamagrostis canadensis, Carex aquatilis, Carex aurea, Carex norvegica, Carex raymondii, Carex rostrata, Carex utriculata, Eleocharis acicularis, Equisetum arvense, Eriophorum vaginatum, Glyceria striata, Menyanthes trifoliata, Muhlenbergia glomerata, Poa palustris, Sarracenia purpurea, Scirpus cespitosus*	*Acorus calamus, Beckmannia syzigachne, Calamagrostis canadensis, Calamagrostis inexpansa, Carex rostrata, Carex utriculata, Carex atherodes, Eleocharis palustris, Equisetum arvense, Glyceria borealis, Glyceria grandis, Glyceria striata, Juncus balticus, Kobresia simpliciuscula, Phragmites australis, Poa palustris, Scirpus microcarpus, Scirpus pungens, Scirpus validus, Scolochloa festucacea, Sparganium eurycarpum , Sium suave, Typha latifolia*	*Deschampsia cespitosa, Equisetum arvense, Juncus balticus, Kobresia simpliciuscula, Poa palustris*
Moderately saline 2-15 mS/cm	*Calamagrostis inexpansa, Carex utriculata, Kobresia simpliciuscula, Muhlenbergia glomerata*	*Beckmannia syzigachne, Calamagrostis inexpansa, Eleocharis palustris, Juncus balticus, Phragmites australis, Scirpus pungens, Scirpus validus, Scolochloa festucacea, Sparganium eurycarpum, Spartina pectinata, Typha latifolia*	*Calamagrostis inexpansa, Juncus balticus, Puccinellia nuttalliana, Spartina gracilis*
Saline 15-45 mS/cm	*Carex chordorrhiza, Triglochin maritima, Triglochin palustris*	*Juncus balticus, Phragmites australis, Spartina pectinata, Triglochin maritima*	*Juncus balticus, Spartina gracilis, Puccinellia nuttalliana, Triglochin maritima*
Hypersaline >45 mS/cm	*Triglochin maritima*		*Puccinellia nuttalliana, Spartina gracilis*

D.5 References

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Appendix E

Fish and Wildlife Considerations for Wetland Creation

by Ken Lumbis[1], John Martin[2], and Larry Rhude[2]
[1] Ducks Unlimited, Grande Prairie, AB
[2] Alberta Environment, Fort McMurray, AB

This appendix was written for the first edition of the Wetlands Guideline and has not been altered except to format layout to match other appendices. It refers to opportunistic and constructed (flood control, water treatment, habitat) wetlands, which likely were intended to correspond with marsh or shallow open water wetlands in this revised edition.

E Fish and Wildlife Considerations for Wetland Creation

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E.1 Wetland Design Criteria for Waterfowl

E.1.1 Overview

The annual life cycle of waterfowl can be broken down into distinct phases. Each phase of the life cycle can be defined by a key activity that the waterfowl are involved with. The phases of the life cycle are: spring migration, pair and territory establishment, nesting period, brood season, moulting period and fall migration. During each phase, waterfowl require wetland habitats. Some wetland types can provide habitat throughout the entire annual life cycle while other wetlands provide suitable habitat only during a specific portion of the year.
The potential wetland types in the reclaimed landscape are: 1) Altered, 2) Opportunistic; 3) Flood Control, 4) Water Treatment; 5) Habitat; 6) Vegetated Watercourses and 7) Littoral Zones. The different types of wetlands to be created in the reclaimed landscape will have different abilities to provide waterfowl habitat and, accordingly, will have different design considerations.

E.1.2 Spring Migration Habitat

Wetland Function: Spring migration habitat provides resting areas for waterfowl that are migrating through the study area to more northerly breeding grounds. As waterfowl are moving north as quickly as possible in order to reach their breeding grounds, the length of stay on spring migration habitat is of a much shorter duration than what might occur during the fall migration period.

Wetland Description: Typically, early spring migration habitat tends to be those shallow wetlands that first appear on the landscape as open water because of spring runoff (e.g., Opportunistic and Flood Control Wetlands). As the snow melts, it collects in low-lying areas and often provides open water prior to the permanent wetlands becoming ice-free. These shallow waters warm up quickly and food resources for waterfowl, such as invertebrates, become readily available. Waterfowl use these temporary wetlands for resting, feeding and courting. The size of these temporary wetlands obviously determines the number of staging waterfowl that can utilize any particular area at one time. Later spring migration habitat will be provided by the larger, permanent wetlands that become ice-free (e.g., Littoral Zones in lakes and many of the Constructed Wetlands). The littoral zone of lakes, such as Base Mine Lake, will be most valuable. The large open areas beyond the littoral zone can also be important as resting areas for spring-migrating waterfowl.

Wetlands Working Group Equivalents: early spring staging habitat - Opportunistic and Flood Control Wetlands; late spring staging habitat – all Constructed Wetlands and Littoral Zone Wetlands.

Wetland Design: For the most part the early, temporary habitat should generally be less than 30 cm deep. For Opportunistic Wetlands, it is likely that the overall sizes will not be that large and therefore, their overall importance to migrant waterfowl may not be great. These Opportunistic Wetlands however, do provide some migration habitat and should be left in the landscape if other criteria for wetland suitability are met. It is possible that Flood Control Wetlands, flood attenuation wetlands, could be designed to provide a secondary function of spring staging habitat. If a wetland area is to be used for water storage during spring runoff, it would appear that the hydraulic retention time for these wetlands is such that it will provide some period of time where the wetland area would provide staging habitat. Water depths in the

30 cm range should be planned for and wetland areas greater than 10 acres have the potential for significant staging use. Hydraulic retention times should be designed to coincide with peak waterfowl and shorebird migration periods (late April to the end of May). Gradual drawdown through outflow and/or evaporation will prolong the availability of invertebrates to birds. Once ice-free, the littoral zones of large wetlands like Base Mine Lake will also provide valuable migration habitat.

Landscape Distribution: Opportunistic Wetlands providing spring migration habitat should be left throughout the landscape area as they opportunistically arise, especially those that are of a larger size. Spring migration habitat does not necessarily have to be associated with other wetland types and can function on its own.

Preferred Vegetation Communities: A range of wetland conditions from sparsely vegetated mudflats to moderately vegetated open shallows provide productive migration habitat. Grasses, sedges and low-lying forbs that are tolerant to some flooding are preferred vegetation communities for this wetland type. As these wetland areas generally have shallow water depths, very dense, tall vegetation, such as cattail and bullrush will for the most part make any shallow water unavailable to waterfowl. Vegetation is not necessarily essential and shallow water areas without any communities can provide spring migration habitat for waterfowl and a variety of other wetland-associated birds.

E.1.3 Spring Pair Habitat

Wetland Function: For most species of waterfowl, a breeding territory can incorporate a number of different wetland types. Wetlands, ranging from temporary roadside ditch water to large lakes, can all provide some component of a breeding territory. For the purposes of this document, spring pair habitat will refer to the ephemeral and temporary spring water that will occur throughout the landscape. Many of the comments made in the spring migration section with regards to wetland functions also apply here. The invertebrate populations that often bloom in these early wetlands are important food sources for hens that require protein rich diets for egg production. Additionally, these temporary wetlands provide additional pair space across the landscape. Given that waterfowl are very territorial at this time of year, additional wetland area helps to disperse waterfowl and increase the pair population within a landscape. The pair season is also much longer than the spring migration period. Different species arrive on the breeding grounds at different times during the spring. Mallards are the first to arrive with blue-winged teal and gadwall being the last to arrive.

Wetland Description: For the most part the description of the wetlands for spring migration habitat applies to this period as well. An important difference, however, is that while migration habitat tends to be larger in area, pair habitat can range in size from a few feet across to areas that are measured in acres. All can all provide valuable pair space. As the pair period is longer, ephemeral wetlands that hold water for a short period of time in very shallow depressions in the early spring to temporary wetlands that may hold some water throughout the summer during the wettest years, all provide pair habitat. Ephemeral wetlands are typically characterized by upland vegetation or wet meadow communities. The length of flooding is not long enough to modify the vegetation found in these basins. Temporary wetlands, however, may develop distinct wetland vegetation communities that are characterized by their ability to withstand dry periods later in the summer.

Wetlands Working Group Equivalents: Opportunistic Wetlands and Flood Control Wetlands.

Wetland Design: Shallow wetlands, with depths of 30 cm or less, can provide valuable pair space. The longer the wetlands retain standing water the more useful they are for a variety of species. Design criteria for spring migration habitat apply here as well. For any Flood Control Wetlands, or for that matter any other constructed wetlands that may be designed to be temporary, the hydrology and design calculations should try to maintain water in the basin until mid-May. The basin contour should be relatively flat and maintain a water depth of 30 cm or so across much of the area. Irregularities within the basin such as large rocks, small mounds of earth or clumps of vegetation can provide valuable loafing spots for the pairs utilizing the wetland. Placing rock can be accomplished during winter periods when they can be placed on the ice.

Landscape Distribution: The ideal distribution for pair habitat is to have it located in proximity to more permanent wetlands. Temporary wetlands that are located within 3.2 km of permanent wetlands can be important components of a territory. While Opportunistic Wetlands are not being specifically designed for, landform replacement practices that promote the development of these wetlands could be utilized around constructed and Littoral Zone Wetlands. There is no real maximum wetland density that should not be exceeded. In parkland and prairie biomes where pond densities are often greater than 70 ponds per square mile, ephemeral and temporary wetlands can often constitute a major portion of those wetlands.

E.1.4 Nesting and Brood Period

Wetland Function: The primary function of wetlands during this period is to provide some permanent wetland habitat through to the early September when the last of the late broods have fledged. Because these wetlands exist throughout this time period, these wetland habitats often provide a variety of other functions.

Wetland Description: Wetlands that retain standing water until mid-June can be classed as temporary, while wetlands lasting to late July can be classed as semi-permanent and those that last beyond August can be classed as permanent. During the first part of the year after the ice starts to melt, all these wetland types provide pair space. Convoluted shorelines and well-established emergent communities are two wetland characteristics that can increase the number of pairs utilizing a particular wetland. Both of these characteristics reduce sighting lines, which in turn helps to reduce intra-specific territorial conflicts. During the nesting period, permanently flooded emergent vegetation provides secure nesting habitat for overwater nesting species. Once waterfowl broods have hatched, permanent water provides the critical function of brood water, that is, wetland areas where broods feed and mature until they can fly. Temporary wetlands are also important to broods as well. Cox et al. (1998) has shown that duckling growth is positively related to invertebrate numbers. Temporary wetlands adjacent to permanent wetlands may be important feeding sites for hens and their broods as they can have high numbers of invertebrates. Aquatic vegetation within wetlands is not only important for providing escape cover from predators, it is critical in determining the abundance and diversity of invertebrate populations. The increased surface area provided by plant vegetation results in increased invertebrate populations over those wetlands which only have bare mineral substrates.

Wetland Working Group Equivalents: All permanent types of wetlands established on reclaimed landscapes can provide some value as breeding habitat, assuming other wetland criteria for wildlife are met.

Wetland Design: This section will deal primarily with wetlands constructed for habitat. On average natural wetlands in northern Alberta lose 25 to 30 cm of water due to evapotranspiration. Spring water depths between 60 and 100 cm in depth should ensure permanent water throughout the brood period. Water depths will influence the development of vegetation communities. The upper portion of the littoral zone should have a shallow slope to encourage the development of wet meadow vegetation. This is the zone that should shallowly flood during the spring (0 to 30 cm) and dry out as the summer progresses.

Emergent species, such as sedge, cattail and bullrush, all have different tolerances to water depths. At stable water depths of 50 cm, emergent stands comprised of these species begin to thin out. Open water zones of wetlands are generally indicative of water depths that are greater than 75 cm in depth. Beyond one meter, emergent growth generally does not occur. These open water zones, however, are generally dominated by submerged macrophytes. While some species, such as White-stemmed Pondweed, can grow in water as deep as 3 metres, most species are adapted to shallower depths (generally <1.5 m).

The littoral zone of natural, fish-bearing lakes in northeastern Alberta ranges between 10 to 30% of the total surface area. For waterfowl habitat, 100% of the wetland should be within the littoral zone, with the deepest zones having water depths of 1 to 1.5 metres. A variety of water depths promotes a diversity in plant communities and consequently an increase in overall biodiversity.

If permanent wetlands that are suitable as wildlife are limited in number in the landscape, then any habitat wetlands that are constructed should have a bowl shaped basin. A wetland of this shape will ensure that the succession of plant communities from wet meadow to open water will develop. If there is an opportunity to develop a variety of Habitat Wetlands, some wetlands should have flatter basins that average 45 to 60 cm in depth. These wetlands have the potential to develop into hemi-marshes, wetlands with half of their area being covered by emergent vegetation and the other half being open water. On all wetlands constructed for habitat purposes, convoluted shorelines should be developed. Nesting islands, nesting structures, loafing bars and other similar habitat improvement techniques can also be incorporated in the wetland design.

Littoral Zone wetlands areas can also provide important breeding wetlands, especially if submergent and emergent communities become established. Vegetated Watercourses also support some use by broods. Brood success on watercourses is dependent on how intermittent the stream is and its size. Broods on narrow watercourses are more susceptible to predation than on larger wetlands.

Water fluctuation capabilities can be an important habitat tool if active management is being proposed for some Habitat or Littoral Zone wetlands. Water level fluctuation capabilities are most important for Habitat Wetlands with shallow, flat basin profiles or Littoral Zone Wetlands with significant portions with water depths less than 75 cm. Drawdowns can be used to promote the establishment of emergent zones across a much larger area of the wetland. Most species require exposed mudflats for seed germination. For wetlands without water management capabilities, the amount of area exposed due to natural drawdowns will be the chief factor controlling the amount of emergent vegetation.

Landscape Distribution: Permanent brood habitat needs to be distributed throughout the reclaimed landscape. It is especially important that spring pair habitat and brood habitat occur in the same parts of the landscape. Having pair habitat located in areas where brood habitat does not exist will result in low brood survival rates. Pairs will be attracted to the temporary

water, nest nearby and bring off a brood. If there is no permanent brood water within a reasonable distance, these broods will be susceptible to predation and other mortality.

Preferred Vegetation Communities: There is no single vegetation species or community that is preferred. Brood habitat should generally have emergent species such as cattail, bullrush or sedge as these species provide excellent escape cover for the broods. These species also provide suitable overwater nesting cover. The development of submergent communities within the wetland is also an important component of a successfully restored brood wetland. Submergents greatly increase the diversity of invertebrate populations that can occur in a wetland.

E.1.5 Moulting Period

Wetland Function: During mid to late summer, adult waterfowl undergo a moult to replace worn feathers. The females undergo their moult on the breeding habitat where they stay with their broods. Males typically undertake moult migrations to larger lakes where they can undergo their moults.

Wetland Description: Good brood habitat with well developed emergent zones that provide good escape cover also provides good moulting habitat for females. Males will likely leave the area, although littoral areas may be used if sufficient emergent habitat exists.

Wetland Working Group Equivalents: Habitat Wetlands (larger sizes) and Littoral Zones

Wetland Design: As detailed in the Nesting and Brood Period section.

Preferred Vegetation Communities: Emergent vegetation that provides good escape cover. Dense stands of sedge, cattail and bullrush all provide good moulting habitat. Flooded willow, both living and dead can also provide moulting habitat.

E.1.6 Fall Staging Period

Wetland Function: Waterfowl during the fall staging period will stop at large wetlands to feed and rest during their migration south. The fall staging period generally lasts from early September to freeze-up. Waterfowl may spend longer periods of time of staging habitat during the fall than time spent during the spring staging period.

Wetland Description: Generally, fall staging habitat is characterized by wetlands that are large and often have limited amounts of emergent habitat. Staging waterfowl will often form into large groups that will rest in the open water areas, sometimes at considerable distances from shore. Waterfowl remaining on the wetland to feed will require the same types of shallow littoral zones where invertebrate and macrophyte communities can develop. Sheltered bays are utilized during poor weather conditions. All constructed wetlands can provide staging habitat and their importance for this function will be directly related to their overall sizes.

Wetland Working Group Equivalents: Littoral Zones

Wetland Design: Littoral Zones of end pit lakes should be designed to promote the development of emergent and submergent communities in the littoral zone. In addition, large loafing bars, islands and other similar structures will be used by migrating waterfowl as resting

areas. Not all of the shoreline needs to have established emergent communities. Sand or rock shorelines will also be used as resting areas by migrating waterfowl.

E.2 Wetland Design Considerations for the Enhancement of Fish and Wildlife Habitat

E.2.1 Overview

Wetlands are dynamic, highly productive ecosystems which, in association with surrounding uplands, provide valuable habitat for a diverse array of fish and wildlife species. The value of wetlands as habitat depends on factors including vegetation structure and diversity, surrounding land use, spatial dispersion, vertical and horizontal zonation and water chemistry (Westworth 1993). Westworth (1993) further evaluates the value of wetlands as fish and wildlife habitat. In summary, providing habitat for waterfowl and other wetland wildlife is one of the most important functions of Alberta wetlands supporting numerous species of birds, mammals, fish, amphibians and reptiles. Many other species that are not directly dependent on wetlands habitat utilize wetlands for feeding, nesting or cover. Finally, there is the food chain value of wetlands. Many other species of wildlife, including insectivorous birds and higher order predators, rely on organisms produced in wetlands as an important food resource.

Boreal wetlands provide a domestic environment for various kinds of wildlife. The marsh and shallow water complexes are by far the most significant wetlands in this respect (National Wetlands Working Group 1988). This review will attempt to evaluate habitat requirements for various fish and wildlife species assemblages and provide wetland design criteria, as appropriate, to enhance wildlife values. Although it is expected wildlife will utilize, to varying degrees, all wetland types on a reclaimed landscape, recommendations will focus on Constructed Wetlands (Flood Control, Water Treatment and Habitat), Watercourse Wetlands and Lake Littoral Zone Wetlands. The wildlife enhancement of Water Treatment Wetlands and, to a lesser extent, Flood Control Wetlands is contingent on alleviating concerns related toxicity.

E.2.2 Fish

Lakes, streams and shallow seasonal/permanent wetlands are recognized as important habitats for fish with the latter providing important spawning and rearing habitat for species such as Northern Pike. Additionally, forage fish such as brook stickleback and Cyprinids (minnows), an important food resource for other fish and wildlife species, find suitable habitat in shallow marshes and small permanent and ephemeral streams. In the reclamation of wetlands the potential exists to create habitats in lake littoral zones, watercourses and marshes which provide good spawning, rearing, feeding and overwintering areas for sport and forage fish. Design considerations are provided (L. Rhude, pers. comm.) below.

E.2.2.1 Lake Littoral Zones

Design considerations for providing fish habitat in littoral zones include:

i. Littoral zone should comprise at least 20% of the lake area with a water depth of less than 3 metres.
ii. Littoral zone should gradually increase in depth to compensate for fluctuating water levels.

iii. Irregular shorelines with the development of shallow bays, shoals and islands should be provided to increase habitat edge and variety.
iv. Iirregular bottom contours with underwater structures including reefs, etc. should be provided, as well as the establishment of rooted and floating vegetation.
v. A diversity of quiet water and wave susceptible areas should be created.

E.2.2.2 Water-courses and Flood Control Wetlands

Design considerations for providing fish habitat in flood control wetlands include:

i. The lower reach of streams should be underdesigned to allow flooding during high water events.
ii. The gradient in water courses should be such to allow fish to travel from the lake into the stream (no barriers).
iii. Flooded areas should be designed to ensure that as water recedes fish would not get trapped (i.e. no berms).
iv. The development to sedges, wet meadow grasses and emergent aquatic macrophytes (i.e. cattails, bulrushes) should be promoted.
v. Watercourses should vary in shape and sinuosity with shoreline irregularities (e.g., inland projections, etc.) developed in channels and marshes to enhance habitat diversity.
vi. Pools (greater than 1 meter in depth) should be created to provide overwintering habitat.
vii. Cover should be provided in the form of woody debris, undercut banks, etc.

E.2.3 Wildlife

The Eastern Boreal Forest Region supports a large diversity of wildlife species including at least 236 species of birds and 43 species of mammals (Westworth 1990). Wildlife species utilize a diversity of wetland types and associated terrestrial environments to satisfy basic habitat requirements related to food, cover and reproduction. Many wetlands types with specific habitat attributes may be required during the annual life cycle of many species. Notably, waterfowl utilize a diversity of habitat types ranging from temporary, shallowly flooded wetlands to large lakes for migration, breeding, brood rearing and moulting. Similarly, migrant and breeding shorebirds will opportunistically utilize a variety of boreal wetland types.

Comprehensive studies documenting the aquatic habitat requirements of wildlife in the Central Mixedwood Natural Subregion do not appear to exist for many species. Golder (1997) documented the potential and observed use of vegetation communities, including open water, marsh, gramminoid/shrubby fen, wooded fen/bog and riparian habitats, by bird, mammal, amphibian and reptile species on Shell Canada Ltd.'s Lease 13 (Report on Wildlife Baseline Conditions for Shell's Proposed Muskeg River Mine Project). Information provided by Golder (1997) for wetland habitats is presented in Tables 1, 2 and 3 in Appendix E1.

Wildlife habitat requirements and associated design considerations for wetland types on a reclaimed landscape will need to be provided based on available information. Because it is not possible to consider all species, Habitat Suitability Index (HSI) information available for aquatic wildlife species, including semi-aquatic furbearers and waterfowl will need to be utilized to develop design criteria which will optimistically benefit a broad range of wetland related wildlife. Also, it is reasonable to assume that wetland design considerations for waterfowl (see Section E.1) are consistent with those for a broad range of other wildlife species. Ultimately, the wildlife value and utilization of wetlands in reclaimed landscapes will be dependent on the diversity, distribution, abundance and productivity of the aquatic and terrestrial ecosystems which evolve over time.

E.2.3.1 Opportunistic

Wildlife utilization of wetlands which develop opportunistically throughout the landscape will be highly variable and largely dependent on factors including basin morphometry, water quality, hydrology, substrate and vegetation communities. Retention of these wetlands in the reclaimed landscape is recommended, where possible, to enhance habitat diversity and distribution.

E.2.3.2 Constructed Wetlands

Flood Control: Wetlands designed for flood control/attenuation have the potential to provide critical spring migration habitat for waterfowl and shorebirds. Shallow water depths are requisite to optimizing utilization. Migratory shorebirds and waterfowl use habitats of variable depth, vegetation height and density which harbour rich invertebrate food resources.

Design considerations for providing wildlife habitat in flood control wetlands include:

i. Wetlands should be designed to promote extensive shallow flooding (30 cm or less) over relatively large areas. Water depths for foraging shorebirds range from 0 cm (mudflat) to 18 cm. Waterfowl can utilize areas of greater water depth.
ii. Hydraulic retention time should be designed to coincide with peak waterfowl and shorebird migration periods (late April to the end of May).
iii. A range of wetland conditions ranging from sparsely vegetated mudflats to moderately vegetated open shallows provide productive migration habitat. Flood tolerant grasses, sedges and forbs will optimistically establish over time given favorable growing conditions.
iv. Gradual drawdown through outflow and/or evaporation will prolong the availability of invertebrates to birds foraging in shallow water and mudflats.

Habitat: Wetlands designed and constructed to function primarily as wildlife habitat are anticipated to develop into semi-permanent and permanent marshes. These areas have the potential to support a relatively high diversity and abundance of wildlife species if aquatic and terrestrial environments are favorable. Historically, semi-aquatic furbearers (beaver, muskrat, river otters, mink) and ducks (dabbler and diver species) have been selected as the representative target species for aquatic habitats.

Design considerations for wetlands with a primary function of providing wildlife habitat include:

i. Gently sloping basin and shoreline contours creating a bowl shaped basin will promote the establishment of open water, deep marsh, shallow marsh and wet meadow zones.
ii. Extensive littoral zones (generally <1.5 metres) with some areas of deeper water provide overwintering habitat for semi-aquatic furbearers (primarily muskrat) and forage fish. Bottom contours should include local irregularities to increase the interspersion of shoreline and shallow and open water areas (Green and Salter 1987).
iii. Convoluted shorelines, bays, peninsulas, shoals and islands increase habitat edge and provide a variety of habitats for wildlife (Green and Salter 1987).
iv. Wetland substrates should be relatively impervious and the transplanting of soil and substrates from existing wetlands should be undertaken to accelerate the establishment of aquatic macrophytes. The development of diverse and robust emergent, submergent and floating aquatic vegetation is critical to maximizing wildlife habitat values.
v. Relatively stable water levels are required to maintain muskrat and beaver populations.
vi. Vegetation communities dominated by deciduous shrub and tree species should be established in riparian and upland areas adjacent to wetland habitats being developed as beaver habitat.

Water Treatment Wetlands: As noted in the overview on design considerations, the provision of wildlife enhancement features in water treatment wetlands is contingent on the alleviation of toxicity concerns. Depending on the specifics for a particular water treatment wetland (e.g., types of contaminants, rate of toxicity attenuation over time) there will need to be a decision whether to include habitat features in the initial design and construction or defer them to a later date when the role of the wetland as a treatment system has declined or ceased.

Vegetated Watercourses: Searing (1979) states that streams are widely used and are probably the most important water bodies for semi-aquatic furbearer populations. Semi-aquatic mammals (beavers, muskrats, mink and river otters) are largely associated with riparian habitats which are maintained by the action of streams and lakes as secondary series or subclimax communities with a considerable edge effect. Riparian areas are wetlands associated with running water systems found along rivers, streams and drainageways (Golder 1998a). In addition to other wildlife values, riparian areas provide important habitats for breeding birds. Species richness and diversity was greatest in the dogwood-balsam poplar-aspen poplar (e1) stand, a riparian community type in the Suncor Millennium LSA (Golder 1998b). Watercourses and associated riparian areas have the potential to provide valuable food resources (browse species) and critical travel corridors for moose and other ungulates within a reclaimed landscape. Their value as travel corridors is contingent on their integration with existing natural travel corridors (river valleys, etc) in the area.

Design considerations for providing wildlife habitat in vegetated watercourses include:

i. Water course construction or enhancement for wildlife should involve three components (Green and Salter 1987): 1) water-course location and design, 2) channel and streambank stabilization, and 3) streambank enhancement.
ii. For maximum use by wildlife, a watercourse should have a shallow gradient (less then 11%) and a sinuous channel to slow water velocities. Sinuous channels eventually provide a variety of bank heights and shapes through natural erosion processes. Pools can be constructed at bends to provide deep areas for fish and aquatic mammals. In flatland areas, bends in the watercourse can be extended to create oxbow lakes and wetlands (Green and Salter 1987).
iii. Streams developed for beaver habitat should have low stream gradient (<15%), narrow width (<5m), located in U-shaped valleys, distinct channel morphology allowing the establishment of pools behind dams, banks with less than 45∞ slope, bank height of less than 2 meter and bank material consisting of clay soils (Bovar 1997).
iv. The establishment of vegetation along stream banks (sedges, grasses, bulrushes, cattails, etc.) provides bank stabilization, food and cover for wildlife and, through shading, moderates water temperatures (Green and Salter 1987).
v. In establishing riparian vegetation communities, plantings of preferred ungulate browse species, including red osier dogwood, saskatoon, choke cherry, and willow should be undertaken in addition to balsam poplar, alder, etc. to enhance habitat value and wildlife utilization of these areas.
vi. In establishing and revegetating riparian zones, soil replacement should be undertaken to the water's edge to promote rapid and successful establishment of vegetation.

Littoral Zones: Many of the design criteria previously provided for the lake littoral zone for fish habitat are consistent with those for wildlife species. Design considerations include:

i. Littoral zone should comprise a minimum of 20% of the lake area with a water depth less than 3 metres.

ii. Bottom contours should be irregular to provide a variety of bottom types. Narrow to wide shoreline shelves with gradual slopes (11-22%) and average depths of 0.5-1.5 metres encourage the growth of aquatic plants. In deep water areas and along some parts of the shoreline, steeper slopes (44-67%), should be used to provide access to deep water and limit plant growth (Green and Salter 1987).
iii. Irregular shorelines with the development of shallow bays have the potential to develop into marsh habitats.
iv. The development of a variety of shoreline characteristics sholuld be provided, ranging from emergent vegetation communities (waterfowl cover, nesting sites) to having mudflats, gravel bars (shorebird foraging, nesting sites).
v. Islands should be provided that are suitable for use by waterfowl as well as colonial birds (American white pelican, double-crested cormorant, common tern, etc). Design criteria for the creation of nesting islands for colonial birds can be found in Multi-Species Habitat Enhancement Techniques (Ewashcuk and Gurr 1992).
vi. Elevated nesting platforms should be provided for osprey and bald eagles.

E.2.4 Monitoring

Wetland design criteria and adaptive management will be employed in the progressive development of a variety of wetland types in reclamation landscapes. Ultimately, the final product will be largely determined by complex natural processes. In evaluating the relative success in providing viable productive habitats which will support a diversity of wildlife species, it is imperative that an ongoing monitoring protocol be established. Consistent with recommendations provided in Guidelines For Reclamation To Forest Vegetation in the Alberta Oil Sands Region (Oil Sands Vegetation Reclamation Committee 1998) a combined coarse filter – fine filter target approach is recommended to evaluate the re-establishment of aquatic plant communities and document whether the biophysical habitat requirements of several aquatic wildlife species are being provided in the reclaimed landscape.

E.3 Breeding Bird Densities of Non-Waterfowl Species Utilizing Wetland Habitats

Table 1 provides data that can be used to monitor and assess reclaimed wetland habitats. The breeding bird densities will provide a basis of comparison between species use of native habitats and those observed on reclaimed oil sands landscapes. In using this data, it must be recognized that variability in population densities in the same habitat will commonly occur from year-to-year. These temporal variations are due to factors such as weather patterns, habitat conditions on the wintering grounds and other population influencing effects which can increase or decrease returning breeding populations for a given habitat. These are not absolute densities but rather, they are indicators of habitat suitability.

Table 1 Breeding bird densities of native habitats in the oil sands region

Species	Density (territories per 100 ha)	Habitat type
Sora	68	sedge fen
Greater Yellowlegs	11	sedge fen
Lesser Yellowlegs	3	open bog
Common Snipe	4	tall bottomland willow
	12	shrub fen
Alder Flycatcher	12	tall bottomland willow
	18	shrub fen
Least Flycatcher	4	tall bottomland willow
Marsh Wren	247	*Phragmites* marsh
Black-and-white Warbler	28	tall bottomland willow
Tennessee Warbler	49	tall bottomland willow
Yellow Warbler	5	tall bottomland willow
	2	shrub fen
Northern Waterthrush	9	tall bottomland willow
Common Yellowthroat	5	sedge fen
	99	willow dominated fen
	72	swamp birch dominated fen
	25	whitetop meadow
Wilson's Warbler	4	tall bottomland willow
	69	willow-dominated fen
American Redstart	56	tall bottomland willow
Yellow-headed Blackbird	617	*Phragmites* marsh
Red-winged Blackbird	192	sedge fen
Common Grackle	39	sedge fen
Savannah Sparrow	80	whitetop meadow
LeConte's Sparrow	4	tall bottomland willow
	17	shrub fen
	25	shrubby marsh
Clay-coloured Sparrow	72	shrub fen
	39	whitetop meadow
White-throated Sparrow	65	tall bottomland willow
	2	shrub fen
Fox Sparrow	46	tall bottomland willow
Lincoln's Sparrow	35	shrub fen
	21	sedge fen
	7	tall bottomland willow
Swamp Sparrow	11	tall bottomland willow
	88	shrub fen
	237	willow dominated sedge fen
	94	shrubby marsh
Song Sparrow	11	tall bottomland willow
	46	*Phragmites* marsh

Sources: Erskine (1976) and Francis and Lumbis (1980)

E.4 Observed Waterfowl Densities For Northern Alberta Wetlands

The data presented in this section can be used in the monitoring and performance assessment of reclaimed wetland habitats. The waterfowl data presented in the following tables (Tables 2 – 4) provide a basis to compare species use of natural wetland habitats with that observed on reclaimed wetland habitat in oil sands landscapes.

Table 2 Pair densities and brood densities of waterfowl in natural shoreline wetlands of North-eastern Alberta

Vegetation community	Dabblers (pairs per mile)	Divers (pairs per mile)	Total (pairs per mile)
Pair densities - lakes			
Cattail	16.6	15.4	32.0
Sedge	8.6	9.0	17.6
Sedge/shrub	10.6	7.7	18.3
Flooded shrub	14.0	4.8	18.8
Sedge/ sedge-shrub/ flooded shrub	10.9	7.3	18.2
Wooded edge	4.0	4.0	8.0
Pair densities - streams			
Mostly sedge, some wooded	9.2	10.0	19.2
Wooded edge	15.4	6.3	21.7
Brood densities - lakes			
Cattail	1.8	3.4	5.2
Sedge	0.4	5.8	6.2
Sedge/shrub	0.9	2.8	3.7
Flooded shrub	0.0	1.0	1.0
Sedge/ sedge-shrub/ flooded shrub	0.6	4.5	5.1
Wooded edge	0.5	2.2	2.7

Source: Donaghey (1974)

Table 3 Species composition of waterfowl observed on natural wetlands in the oil sands area

Species	Percent composition	
	1976	**1977**
Dabblers		
Mallard	13.3	6.4
Wigeon	5.0	0.03
Green-winged teal	3.0	0.7
Blue-winged teal	2.3	0.9
Shoveler	2.1	1.1
Pintail	0.8	0.6
Gadwall	0.3	0.4
Unidentified	2.2	4.9
Total dabblers	**29.0**	**15.0**
Divers		
Scaup	32.7	9.5
Ringneck	14.2	3.0
Bufflehead	7.4	4.4
Goldeneye	3.5	3.2
Merganser	0.7	0.5
Canvasback	0.4	0.2
redhead	0.2	0.2
Ruddy	0.2	0.1
Unidentified	7.3	17.9
Total divers	**66.6**	**39.0**
Unidentified ducks	4.5	46.0

Source: Hennan and Munson (1979)

Table 4 Summary statistics for breeding waterfowl in north-western Alberta

Mean density of breeding pairs	3.3 pairs/ha
Mean density of broods	**1.7 broods/ha**
Total Dabbler broods	**66 %**
Total Diver broods	**34 %**

Source: Sankowksi and Joynt (1992)

E.5 Artificial Nesting and Habitat Structures

E.5.1 Nesting Islands for Ducks

In general, the use of islands by nesting ducks is negatively correlated with potential upland nesting cover. Therefore, the justification for constructing islands should include an evaluation of upland cover types and areas, as well as the wetland's brood-use potential. In reclaimed landscapes where the uplands are to be returned to various cover types which approximate

existing native habitats, there should not be a lack of upland nesting cover. Islands may be a useful tool where wetlands may be restored prior to significant upland reclamation having been completed.

There are two types of earth islands that can be constructed. Large islands, that have a flat top surface area of 10m by 25m and 5:1 side slopes, are generally constructed in large wetlands, for example the littoral zone of end pit lakes. They should be located 100 m offshore and constructed in water varying in depth from 30 to 100cm. These islands should be re-vegetated with various species of grass, forbs and shrubs such as snowberry or willow. Islands such as these provide other functions for waterfowl. Islands constructed in littoral zone areas are likely to receive heavy loafing use by not only breeding waterfowl but also migrants during spring and fall migrations. Islands in larger littoral zones should be constructed in those areas that are sheltered from the prevailing winds. Islands in erosion prone locations may have to be armored with rock. Another alternative for preventing erosion is to promote the growth of fibrous rooted vegetation on the windward side of the island.

Small earth mounds are more appropriate for the constructed wetlands (for flood control, water treatment, or habitat) being created in the reclaimed landscapes. These are generally small mounds of earth that have a 2m diameter flat top. These mounds should be placed in those portions of the wetland that will have water throughout the breeding season. When available, rock can be used to create small nesting islands. Rock can be dumped on the ice in sufficient quantities to create a rock mound. In addition, a load of soil should be dumped on top in order to provide a substrate for vegetation to grow in. The rock will settle to the bottom during the spring thaw.

For large and small islands there are certain design and construction criteria that are common to both. They are as follows:

i. Both should have a freeboard of .9m above the spring water level.
ii. Islands should be constructed with good clay type of soils that can withstand wave action.
iii. Islands should be constructed with a moat around their perimeter. This helps to deter access by non-avian predators.

E.5.2 Artificial Nesting Structures

This category of nesting structure includes nesting rafts, boxes and baskets. One of the most significant aspects to be considered when placing these types of nesting structures is the issue of long-term management. These structures require on-going maintenance such as the replacement of nesting material or the removal of old materials. Various references are available on the design and construction of these nesting structures.

E.5.3 Loafing Spots

Pairs, broods, moulting and migrant waterfowl all make use of loafing spots. For littoral zones, large loafing structures such as rock islands can be used. In constructed wetlands (for flood control, water treatment or habitat) loafing spots can be created by placing a variety of structures in the wetland. Large rocks, logs or tree stumps placed along the edge of the wetland can provide important loafing areas for waterfowl. Offshore, logs can be anchored in open water areas to provide suitable loafing areas.

E.6 Artificial Habitat Structures for Fish

The most common natural cover is rooted aquatic plants growing in the littoral zones of lakes and wetlands. The amount of natural cover will be one of the factors determining the carrying capacity of a waterbody. Artificial reefs or fish shelters in lakes can increase the carrying capacity by providing a base on which minute plant and animal forms can attach themselves. This aquatic life provides the basis for a food chain which can support fish. Artificial reefs also provide protective cover for fish.

In deciding when and where to place artificial structures, the following points should be considered:

i. Consider which areas lack natural shelter structures or spawning materials.
ii. Consider which fish species are involved and their requirements.
iii. Determine the type of bottom substrate (should be firm enough to support the reef).
iv. Consider the seasonal fluctuation in water levels in the particular wetland.

Artificial reefs can be constructed from a broad range of materials. Materials such as auto bodies, parts and tires are not recommended. The following materials can be used to create artificial reefs:

i. Rock, concrete, broken tile: Reefs constructed out of this material will serve as spawning substrate as well as a shelter for forage fish and game fish juveniles. The material is stacked in a loose pile in 2 to 5 metres of water. The height of the pile can be variable; however, allowances should be made for settling so that a metre or more of material protrudes above the wetland bottom.
ii. Bundled brush structures: Bundles of brush are bound together with synthetic rope and ballast is attached to the bundle. This is placed on the ice and allowed to sink to the bottom at spring break-up.
iii. Stacked brush frame: A 1.5 by 3 metre frame of lumber, logs or poles is constructed. Brush is stacked to a height of about 2 metres on top of the frame and fastened securely with No. 9 galvanized wire or light steel cable. Ballast is fastened to the frame and placed on the ice.
iv. Christmas Tree Unit: This habitat unit is made by drilling a 10mm hole in the butt of a conifer and inserting a steel bar 30 cm long in the hole. The butt is then placed in a 5 gallon can which is then filled approximately three quarters full with concrete. The unit is placed in an area of the wetland which has a flat bottom. Three or more of these units should be strapped together at one location to prevent tipping. Avoid using discarded Christmas trees which may have toxic substances such as artificial snow or tinsel.
v. Tree Stumps: Tree stumps from recently cleared land can provide cover that is suitable for both large and small fish. When thoroughly waterlogged they will last for many years. The stumps should be weighted so that the roots will be uppermost after the structure has sunk. Stumps can be put out in groups or singly depending on the area of cover required. Stumps can be placed by boat or left on the ice.

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APPENDIX E1 POTENTIAL AND OBSERVED USE OF VEGETATION COMMUNITIES BY BIRDS, MAMMALS AND AMPHIBIAN AND REPTILE SPECIES IN THE SHELL LEASE 13 LOCAL STUDY AREA

Table E1. Potential and Observed Use of Vegetation Communities by Bird Species in the Shell Lease 13 Local Study Area (Golder 1997)

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
Red-throated Loon	X				
Arctic Loon	X				
Common Loon	X		P		
Pied-Billed Grebe	X		P	X	
Horned Grebe	X		P	X	P
Red-necked Grebe	X		P	X	
Eared Grebe	X			X	
Western Grebe	X				
American White Pelican	X		P		
Double-crested Cormorant	X		P	X	
American Bittern		X	P	X	P
Great Blue Heron	X	X	P	X	
Great Egret	X	X		X	
Tundra Swan	X				
Trumpeter Swan	X				
Goose	X				
Snow Goose	X				
Ross' Goose	X				
Canada Goose	X		P		P
Wood Duck	X	X		X	
Green-winged Teal	X	X	P	X	P
American Black Duck	X	X		X	
Mallard	X	X	P	X	P
Northern Pintail	X	X	P	X	P
Blue-winged Teal	X	X	P	X	P
Cinnamon Teal	X	X		X	
Northern Shoveler	X	X	P	X	P
Gadwall	X	X	P	X	P
Eurasian Wigeon	X	X		X	
American Wigeon	X	X	P	X	P
Canvasback	X	X	P	X	P
Redhead	X	X	P	X	P
Ring-necked Duck	X	X	P	X	P
Greater Scaup	X	X		X	
Lesser Scaup	X	X	P	X	P
Harlequin Duck					
Oldsquaw	X				
Surf Scoter	X	X		X	
White-winged Scoter	X	X		X	
Commom Goldeneye	X	X	P	X	
Barrow's Goldeneye	X	X		X	
Bufflehead	X	X	P	X	
Hooded Merganser	X	X	P	X	P
Common Merganser	X	X	P	X	

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
Red-breasted Merganser	X	X	P	X	
Ruddy Duck	X		P	X	P
Osprey	X		P		
Bald Eagle	X		P		
Northern Harrier		X	P	X	P
Sharp-skinned Hawk					X
Cooper's Hawk					
Northern Goshawk					
Broad-winged Hawk					P
Swainson's Hawk					
Red-tailed Hawk					
Rough-legged Hawk					
American Kestrel					
Merlin					
Peregrine Falcon	X		P	X	P
Gyrfalcon					
Spruce Grouse					
Willow Ptarmigan					P
Ruffed Grouse					
Sharp-tailed Grouse			P		P
Sora		X	P	X	P
American Coot	X	X	P	X	P
Sandhill Crane		X	P	X	P
Whooping Crane					
Black-bellied Plover					
Lesser Golden Plover					
Semipalmated Plover					
Killdeer			P		
American Avocet	X			X	
Greater Yellowlegs		X		X	P
Lesser Yellowlegs		X		X	P
Solitary Sandpiper		X	P	X	P
Willet				X	
Spotted Sandpiper			P	X	X
Upland Sandpiper					
Whimbrel					
Hudsonian Godwit					
Marbled Godwit			P		P
Ruddy Turnstone					
Sanderling					
Semipalmated Sandpiper					
Western Sandpiper					
Least Sandpiper			P		P
White-rumped Sandpiper					
Baird's Sandpiper					
Pectoral Sandpiper					
Dunlin					
Stilt Sandpiper					
Buff-breasted Sandpiper					
Short-billed Dowitcher					P
Long-billed Dowitcher					

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
Common Snipe		X		X	P
Wilson's Phalarope	X	X	P	X	P
Red-necked Phalarope	X	X		X	
Red Phalarope	X	X		X	
Franklin's Gull	X	X	P	X	P
Bonaparte's Gull	X	X	P	X	P
Mew Gull	X		P	X	
Ring-billed Gull	X		P	X	
California Gull	X		P	X	
Herring Gull	X		P	X	
Iceland Gull	X			X	
Glaucous Gull	X			X	
Caspian Tern	X				
Common Tern	X	X	P	X	P
Arctic Tern	X			X	
Black Tern	X	X	P	X	P
Rock Dove					
Mourning Dove					
Great-horned Owl			P		P
Snowy Owl					
Northern Hawk Owl		X			P
Barred Owl					
Great Gray Owl		X	P		P
Long-eared Owl					
Short-eared Owl		X		X	
Boreal Owl					P
Common Nighthawk					
Belted Kingfisher		X	P	X	P
Yellow-bellied Sapsucker					
Downy Woodpecker					
Hairy Woodpecker					
Three-toed Woodpecker					X
Black-backed Woodpecker					X
Northern Flicker					
Pileated Woodpecker					
Olive-sided Flycatcher		X	P		P
Great-crested Flycatcher					
Western Wood-Pewee		X	P	X	P
Yellow-bellied Flycatcher					X
Alder Flycatcher			P		X
Least Flycatcher					X
Eastern Phoebe		X	P		P
Say's Phoebe			P		
Eastern Kingbird		X	P		P
Horned Lark					
Tree Swallow		X	P	X	P
Bank Swallow			P	X	
Cliff Swallow			P	X	
Barn Swallow			P	X	
Gray Jay					X
Blue Jay					

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
Black-billed Magpie			P		
American Crow					P
Common Ravern			P		P
Black-capped Chickadee					
Boreal Chickadee			P		X
Red-breasted Nuthatch					X
Brown Creeper					
House Wren					
Winter Wren					
Marsh Wren		X	P	X	P
Golden-crowned Kinglet					
Ruby-crowned Kinglet					X
Mountain Bluebird					P
Veery					
Gray-cheeked Thrush					
Swainson's Thrush			P		X
Hermit Thrush					X
American Robin			P		
Northern Mockingbird					
Brown Thrasher					
American Pipit					P
Bohemian Waxwing			P		
Cedar Waxwing			P		X
Northern Shrike					
European Starling					
Solitary Vireo					
Warbling Vireo					
Philadelphia Vireo					X
Red-eyed Vireo			P		
Tennessee Warbler		X	P	X	P
Orange-crowned Warbler			P		X
Yellow Warbler		X	P		X
Magnolia Warbler			P		X
Cape May Warbler					
Yellow-rumped Warbler					X
Warbler					
Palm Warbler		X		X	
Bay-breasted Warbler					P
Blackpoll Warbler					X
Black-and-White Warbler			P		P
American Redstart			P		X
Ovenbird					X
Northern Waterthrush		X	P	X	P
Connecticut Warbler					X
Mourning Warbler					
Common Yellowthroat		X	P	X	P
Wilson's Warbler			P		P
Canada Warbler			P		P
Western Tanager					X
Rose-breasted Grosbeak					
Indigo Bunting					

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
American Tree Sparrow			P		P
Chipping Sparrow					X
Clay-colored Sparrow		X	P		P
Vesper Sparrow					P
Savannah Sparrow		X		X	P
LeConte's Sparrow		X		X	X
Sharp-tailed Sparrow		X	P	X	P
Fox Sparrow			P		P
Song Sparrow		X	P	X	P
Lincoln's Sparrow		X	P	X	P
Swamp Sparrow		X	P	X	P
White-throated Sparrow			P		X
White-crowned Sparrow			P		P
Harris' Sparrow					
Dark-eyed Junco					X
Lapland Longspur					
Smith's Longspur					
Snow Bunting					
Bobolink					
Red-winged Blackbird		X	P	X	P
Western Meadowlark					
Yellow-headed Blackbird		X	P	X	P
Rusty Blackbird		X	P		P
Brewer's Blackbird		X	P		P
Common Grackle		X	P		P
Brown-headed Cowbird		X			
Northern Oriole					
Pine Grosbeak					
Purple Finch					
Red Crossbil					
White-winged Crossbill					X
Common Redpoll					P
Hoary Repoll					
Pine Siskin					X
American Goldfinch					X
Evening Grosbeak					
House Sparrow					
Species Richness	63	70	97	78	112
Richness Index	0.23	0.34	0.77	0.47	1.00

X indicates species observed on Lease 13 Local Study Area
P indicates species potentially on Lease 13 Local Study Area

Table 2. Potential and Observed Use of Vegetation Communities by Mammal Species in the Shell Lease 13 Local Study Area (Golder 1997)

Common Name	Open Water	Graminoid or Shrubby Fen	Riparian	Marsh	Wooded Fen/Bog
Masked Shrew					X
Dusky Shrew			P		P
Water Shrew		P	P	X	
Arctic Shrew					P
Pygmy Shrew					P
Little Brown Bat	P	P	P	X	
Northern Long-eared Bat	P	P	P	X	P
Silver-haired Bat	P	P	P	X	
Big Brown Bat	P	P	P	X	
Hoary Bat	P	P	P	X	X
Snowshoe Hare					P
Least Chipmunk					
Woodchuk					
Red Squirrel					P
Northern Flying Squirrel					P
Beaver	X	X	P	X	
Deer Mouse					
Southern Red-backed Vole					P
Heather Vole			P		P
Meadow Vole		P	P		P
Muskrat	X	X	P	X	P
Northern Bog Lemming		X	P		P
Meadow Jumping Mouse		X	P		P
Porcupine					
Coyote			P		P
Gray Wolf					P
Red Fox			P		P
Black Bear					P
Marten		X		X	
Fisher		X		X	
Ermine					P
Least Weasel					P
Mink		X	P	X	P
Wolverine					X
Striped Skunk					
River Otter	X	X	P	X	P
Canada Lynx					P
Mule Deer					
White-tailed Deer					
Moose		X	P		P
Species Richness	8	16	18	10	28
Richness Index	0.20	0.40	0.50	0.10	1.00

X indicates species observed on Lease 13 Local Study Area
P indicates species potentially on Lease 13 Local Study Area

Table 3. Potential and Observed Use of Vegetation Communities by Amphibian and Reptile Communities in the Shell Lease 13 Local Study Area (Golder 1997)

Common Name	Open Water	Fen	Riparian	Marsh	Treed Bog Black Spruce
Canadian Toad		X	P	X	P
Stripped Chorus Frog		X	P	X	P
Wood Frog		X	P	X	P
Red-sided Garter Snak		X	P	X	P
Species Richness	0	4	4	4	4
Richness Index	0.00	1.00	1.00	1.00	1.00

X indicates species observed on Lease 13 Local Study Area
P indicates species potentially on Lease 13 Local Study Area

Appendix F

Traditional Plants

by John Gulley
Golder Associates, Calgary, AB

This appendix was written for the first edition of the Wetlands Guideline. Additional traditional names have been added from Garibaldi A. 2006. (Report on traditional environmental knowledge input into wildlife habitat reclamation recommendations. Unpublished report prepared by Garibaldi Heritage and Environmental Consulting for the Cumulative Environmental Management Association (CEMA), Biodiversity and Wildlife Subgroup of the Reclamation Working Group. August/06).

F Traditional Plants

Table F1 Plants gathered for food, medicine, cultural and spiritual purposes in the oil sands region

Traditional Name	Common Name	Scientific Name	Location [(a)]					
			Non-wetland ecosites	Shallow open waters	Marshes	Swamps	Fens	Bogs
	balsam fir	*Abies balsamifera*	X					
	beaked hazelnut	*Corylus cornuta*	X			INF		
muskeg wire-grass, stoneberry, chicken-berry	bearberry kinnikinik	*Arctostaphylos uva-ursi*	X					
	birch - red (bog birch)	*Betula pumila*						X
	birch - white *(paper)	*Betula papyrifera*	X					
	black currant *	*Ribes hudsonianum*	X			X		
	black gooseberry	*Ribes oxacanthoides*	X			X	X	
Black poplar	balsam poplar	*Populus balsamifera*	X			X		
	black spruce	*Picea mariana*				X	X	X
	blueberry	*Vaccinium myrtilloides*	X					
	bog cranberry	*Vaccinium vitis-idaea*	X				X	
	bracted honeysuckle	*Lonicera involucrata*	X			INF		
	buffalo berry	*Shepherdia canadensis*	X			INF		
	bulrush	*Scirpus spp.*			X			
Pin berry, chicken-berry, mustache berry	bunchberry	*Cornus canadensis*	X			X		
	cattail	*Typha latifolia*			X			

Traditional Name	Common Name	Scientific Name	Location [(a)]					
			Non-wetland ecosites	Shallow open waters	Marshes	Swamps	Fens	Bogs
	chamomile	*Matricaria matricariodes*	X (DL)					
	chokecherry	*Prunus virginiana*	X					
Frog berry	cloudberry	*Rubus chamaemorus*					X	
Cow root	cow parsnip	*Heracleum lanatum*	x			x		
Otterberry	crowberry	*Empetrum niguim*					x	x
	dewberry	*Rubus pubescebs*	X			X	INF	
Red willow	dogwood - red osier	*Cornus stolonifera*	X			X		
	dwarf birch	*Betula pumila var. glandulifera*				X	X	X
	dwarf raspberry	*Rubus acaulis*	INF transitional sites			X	X	X
	fly honeysuckle	*Lonicera caerulea*	X			X	X	X
	fungi - dry dead wood (red touchwood)	*Echinodontium tinctorium*						
	fungi – ground (puffball)	*Lycoperdon spp.*						
	fungi - bracted	*Fomes officinalis / F. pinicola*						
	goldenrod	*Solidago canadensis*	X			INF		
	green alder *	*Alnus crispa*	X			INF		
	harebell	*Campanula rotundifolia*	X					
	high bush cranberry	*Viburnum opolus*	X			INF		
	huckleberry	*Vaccinium spp.*	INF					
	horsetail	*Equisetum spp.*	X transitional sites			X	X	X
	jack pine	*Pinus banksiana*	X					

Traditional Name	Common Name	Scientific Name	Location [(a)]					
			Non-wetland ecosites	Shallow open waters	Marshes	Swamps	Fens	Bogs
	juniper	*Juniperus communis*	INF					
Muskeg tea	Labrador tea	*Ledum groenlandicum*	X			X	X	X
Caribou moss	lichen							
	lodgepole pine	*Pinus contorta* var. *latifolia*	INF			INF		
Moose-berry	low bush cranberry	*Viburnum edule*	X			X		
	marsh cinquefoil	*Potentilla palustris*						
Frying pan plant	marsh marigold	*Caltha palustris*						
	meadow rue	*Thalictrum venulosum*						
	mint	*Mentha arvensis*			X	INF		
Muskeg plant	Club moss	*Selaginella spp.*	Habitat varies depending upon species					
	nettle	*Urtica dioica ssp gracilis*	X transitional sites			INF		
	northern bedstraw	*Galium boreale*	X			X	X	X
	pin cherry	*Prunus pensylvanica*	X					
	pink wintergreen	*Pyrola asarifolia*	X					
green frog plant, frog pants, ayekita	Pitcher plant	*Sarracenia purpurea*					X	
	plantain *	*Plantago major*	X (DL)					
Itchy berry	prickly rose	*Rosa acicularis*	X			INF		
Beaver pineapple	Pond lily (yellow)	*Nuphar lutea variegata*		X	X			
	raspberry	*Rubus idaeus*	X			INF	INF	
	red currant	*Ribes triste*	X transitional sites			X		
	river alder	*Alnus tenufolia*	X			X		
	rock stripe	*Umbilicaria spp.*	X					
	saskatoon *	*Amelanchier alnifolia*	X			INF	INF	
	Seaside arrowgrass	*Triglochin palustris*		x	x		X	

Traditional Name	Common Name	Scientific Name	Location [(a)]					
			Non-wetland ecosites	Shallow open waters	Marshes	Swamps	Fens	Bogs
	senega snakeroot	*Polygala senega*	X					
	showy aster	*Aster conspicuus*	X			X		
Buckbrush	snowberry	*Symphoricarpos albus*	X			INF		
muskeg	sphagnum moss	*Sphagnum spp.*					X	X
	stiff clubmoss	*Lycopodium annoitinum*	X transitional sites			X	X	X
	strawberry	*Fragaria virginiana*	X			INF	INF	
Rat root	sweet flag	*Acorus calamus / A. americanus*			X			
Itch plant	Sweet gale	*Myrica gale*			x	x	X	
	sweet grass	*Hierochloe odorata*	X			X		
	Sweet potatoes		X					
	sweet-scented bedstraw	*Glaium trifolia*	X			X	INF	
	tamarack (larch)	*Larix laricina*				X	X	X
	tansy	*Tannesetum vulgare*	X (DL)					
	trailing raspberry	*Rubus pubescens*	X			X		
	trembling aspen *	*Populus tremuloides*	X			INF		
	canadian tuckahoe fungus	*Polyporus tuberaster*	X					
Honeysuckle fly	twinning honeysuckle	*Lonicera dioica* var.*glaucescens*	X			INF	X	X
	twisted stalk	*Streptotus amplexifolius*	X transitional sites		X	X		
	western dock	*Rumex occidentalis*				X	X	
	white spruce	*Picea glauca*	X			INF		
	white wintergreen	*Pyrola elliptica*	X			INF		
Rabbit root	wild sarsaparilla	*Aralia nudicaulis*	X					
	willow	*Salix spp.*	X			X		

Traditional Name	Common Name	Scientific Name	Location [a]					
			Non-wetland ecosites	Shallow open waters	Marshes	Swamps	Fens	Bogs
	willow fungus							
	yarrow *	*Achillea millefolium*	X			X	X	X

[a] X = typically found in the location.
INF = infrequent, but may be present.
DL = disturbed land (i.e., these tend to be introduced species like chamomile).