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Development of Risk-Based Environmental Assessment and Remediation Guidelines for Salt Releases to Peatlands and Other Wetland Settings

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Overall Objectives

- **Work being conducted on behalf of CAPP Freshwater Salinity Working Group and AEnv.**
- **This is a three-phase project.**
  - **Phase I: Summary of State of Knowledge and Development of Conceptual Models for Northern Boreal Wetlands Risks Associated with Salt Releases**
  - **Phase II: Field Studies to Address Data Gaps for "Valued Ecosystem Receptor" Sensitivity to Salt Releases**
  - **Phase III: Follow-up Laboratory Toxicity Testing as Needed and Derivation of Peatlands Salt Environmental Guidelines**

Phase I Objectives

- "identify key ecological characteristics of western Canadian peatland environments
- review available literature on salt toxicity to peatland flora and fauna and to identify scientific knowledge gaps
- review wetland management guidelines and policies in place in other jurisdictions
- review current restoration and remediation techniques for disturbed peatlands: those approaches that have been found to be successful for restoring perturbed peatlands back into functioning ecosystems
- develop a set of preliminary conceptual models for the subsequent development of environmental risk-based guidelines for assessing and remediating salt-affected peatlands"

Brief Outline

- **What do we mean by “wetland” and “peatland”?**
- **Controls on peatland functioning.**
- **Identification of important ecological receptors.**
- **Ecological protection goals: *is it soil, water, or….?***
- **Review of existing knowledge regarding salt toxicity to wetlands biota, and knowledge gaps**
- **Where to next?**

This project is intended to develop contaminated sites assessment and remediation approaches for saline water releases to western Canadian wetland environments.

Formal approaches have been established for the remediation of salt ion releases to terrestrial soils or fish bearing waters; however, wetland ecosystems - and especially peatland ecosystems – are sufficiently different in their geochemical and ecological characteristics/functioning that established regimes are of doubtful applicability.

An obvious question, therefore, is what are wetlands. and how might they be distinguished from terrestrial agricultural systems or fish-bearing waters?

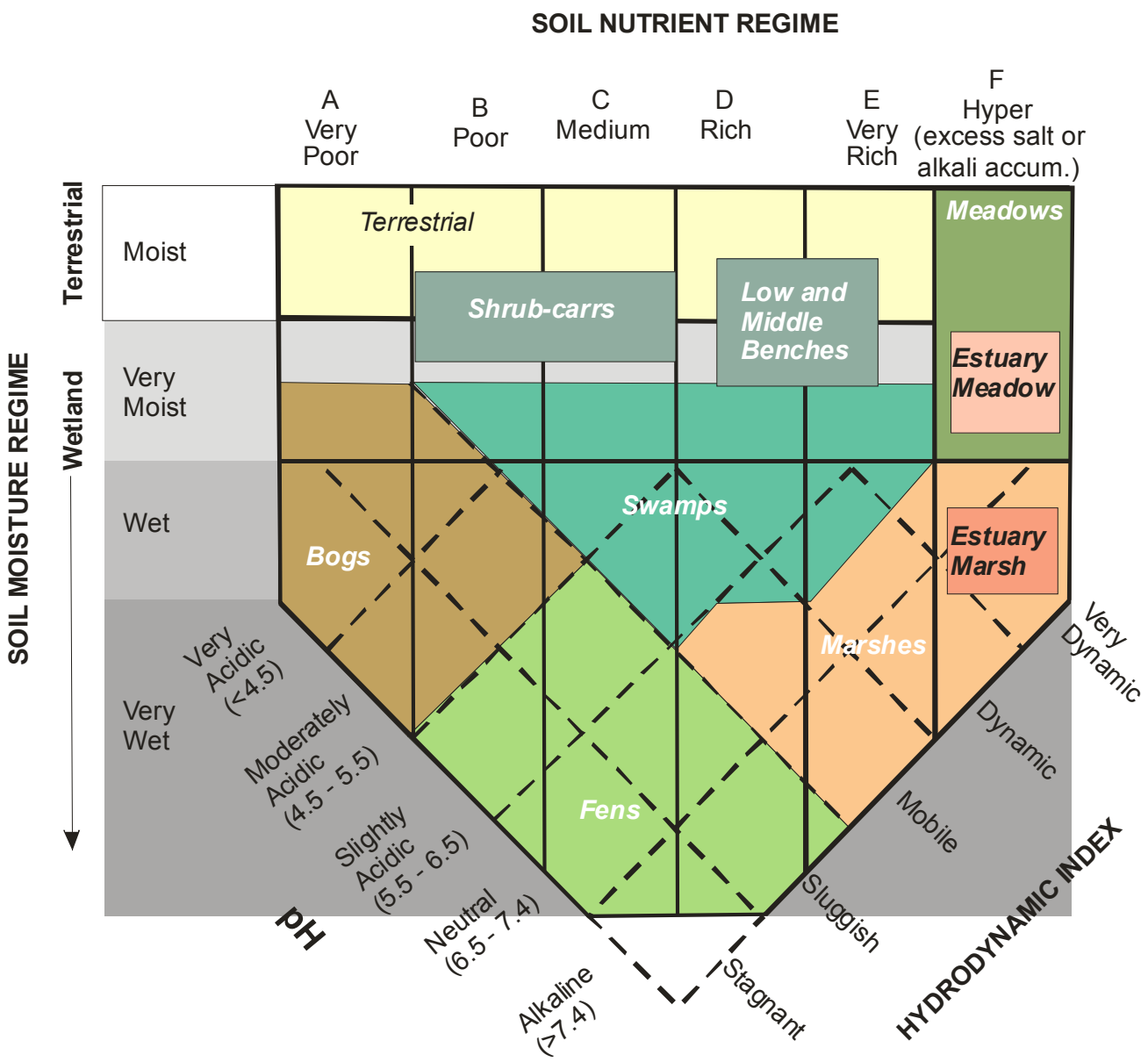
Mackenzie and Moran (2004) define wetlands as –

"areas where soils are water-saturated for a sufficient length of time such that excess water and resulting low soil oxygen levels are principal determinants of vegetation and soil development. Wetlands will have a relative abundance of hydrophytes in the vegetation community and/or soils featuring "hydric" characters."

Canadian Wetland Classification System

Five wetland classes are recognized:

1. Bogs: *Sphagnum* dominated wetlands that receive water only from rainfall and snow melt (ombrogenous). They are acidic and nutrient poor, therefore, vascular plant production is limited.
2. Fens: dominated by bryophytes (mosses) and are influenced by the chemistry of the surrounding mineral soils. …extremely rich have pH above 7.0 (marls)
3. Swamps: forested or shrubby, non-peaty wetlands, with a poorly developed bryophyte layer. Peat accumulation is limited by higher decomposition rates.
4. Marshes: open, non-peat forming wetlands dominated by sedges (Cyperaceae) and other monocots
5. Shallow open waters: *non-peat forming wetlands with less than 2 m depth of water at midsummer*



British Columbia (Mackenzie and Shaw, 1999) Wetland and Riparian Ecosystem Classification (WREC) framework

–

Builds on Canadian Wetland Classification System

Important Controls on Wetland Structure

1. **Climate** – peatlands complexes are generally correlated to gradients of precipitation and temperature.
2. **Hydrology** – (i) ombrogenous/geogenous; (ii) seasonal and interannual fluctuations in water level (beavers)
3. **Chemistry –** N, P in peatland waters are low, relative to the broader range of wetland ecosystems. Reduced water flows and nutrient-poor substrates surrounding bogs and fens result in oligotrophic conditions.

Table 3-1: Average chemical composition of surface water in various peatlands in west-central Canada (Zoltai and Johnson, 1987). All data are from point measurements at mid-summer. Standard error of the mean in brackets.

	Bogs	Poor Fens	Moderate rich-fens	Extreme-rich fens
No. of sites	71	33	147	18
Depth to water table below surface (cm)	37 (1.8)	12 (4.0)	11 (1.2)	5 (1.6)
pH	4.5 (0.02)	4.8 (0.04)	5.8 (0.05)	6.5 (0.12)
Reduced conductivity* (µS/cm)	62 (3)	53 (7)	212 (12)	374 (33)
Ca (mg/L)	2.04 (0.18)	2.90 (0.63)	24.98 (1.59)	53.60 (5.29)
Mg (mg/L)	0.87 (0.12)	1.19 (0.32)	10.16 (0.69)	14.20 (1.24)
Na (mg/L)	2.59 (0.28)	3.89 (0.93)	4.75 (0.36)	6.54 (0.87)
P (mg/L)	0.17 (0.018)	0.14 (0.024)	0.13 (0.046)	0.12 (0.020)
K (mg/L)	1.42 (0.10)	1.26 (0.19)	1.42 (0.11)	0.97 (0.20)

*Conductivity minus the effect due to hydrogen ions (Sjörs, 1952)

Important Controls on Wetland Structure (cont'd)

4. **Substrate**:Bogs hydrologically separated from influences of local groundwater, often by near-surface layers of lacustrine and glacial silt-clay tills. In contrast, fens are seasonally in contact with surface water and/or groundwater.

5. **Vegetation:** Type and diversity emerges from the previous four factors. *Sphagnum* (peat moss) creates secondary structure in bogs, and microhabitats, although overall diversity is low

Types of Biota Present in Peatlands (Bogs and Fens)

1. Bacteria and fungi
2. Algae

Table 4-2: Number of taxa of microalgae and cyanobacteria per site in ombrotrophic bogs along a coastal-continental gradient from Manitoba to Newfoundland (n is the number of sites). Data from Yung *et al.* (1986).

	Coastal n=19	Maritime n=3	Continental n=9	Common Taxa
Desmids	29	23	11	*Actinotaenium cucurbita, Cylindrocysstis brebissonii, Netrium digitus, Penium silvae-nigrae*
Other green algae	24	19	15	*Spirogyra, Mougeotia, Binuclearia*
Diatoms	8	4	5	*Eunotia exigua, Pinnularia viridis, Tabellaria fenestrate, Frustulia rhomboids, Navicula subtilissima*
Cyanobacteria	7	8	6	*Anabaena, Nostoc, Calothrix, Microchaete, Scytonema, Stigonema Hapalosiphon*
Other	7	9	5	*Chrysophyta, Cryptophyta, Pyrrhophtya, Rhodophyta*
Total	75	63	42	
Cl^- in mire water (µeq/L)	>250	100-250	<60	

3. Lichens (terrestrial lichens, arboreal lichens)
4. Bryophytes

Table 4-3 Number of *Sphagnum* and other bryophyte species in peatlands in central Sweden (Sjörs, 1948) and continental western Canada (Vitt and Belland, 1995)

	Central Sweden			Continental Western Canada			
	Intermed. and rich fen	Poor fen	Bog	Extremely rich fen	Moderately rich fen	Poor fen	Bog
Sphagnum	23	27	10	9	7	16	12
Other Bryophytes	51	35	26	58	28	28	41
Total	74	62	36	67	35	44	53

5. Vascular plants
6. Invertebrates

Table 4-7: Number of species of terrestrial arthropods collected in pan traps in peatlands in Ontario, based on Blades and Marshall (1994).

	Rich Fen	Poor Fen	Bog
Systematic Groups			
Class Arachnoidea; spiders and mites	100	78	78
Class Crustacea, Isopoda; hog louse	2	0	0
Class Diplopoda; millipedes	8	0	1
Class Chilopoda; centipedes	0	1	1
Class Insecta with following orders:	760	791	654
Ephemeroptera; mayflies	3	1	1
Odonata; dragonflies, damselflies	4	8	5
Plecoptera; stoneflies	5	0	0
Dictuoptera; cockroaches, etc.	0	1	0
Dermaptera; earwigs	1	0	0
Grylloptera; crickets	2	2	2
Orthoptera; grasshoppers	6	1	2
Pscoptera; bark lice	7	4	2
Hemiptera; true bugs	26	21	23
Homoptera; aphids, etc.	58	52	40
Neuroptera; lace wings	1	2	0
Coleoptera; beetles	193	174	189
Diptera; flies, mosquitoes	19		
Siphonaptera; fleas	2		
Trichoptera; caddiflies	8		
Hymenoptera; ants, bees, wasps, etc.	24		
Trophic groups			
Herbivores	15		
Predators	19		
Omnivores	12		
Parasitoids	19		
Detritivores	4		
Fungivores	3		
Epiphytic grazers	2		
Others and unknown	9		
Habitat Preference groups			
“Bog species”	3		
“Non-bog species”	6		
“Widespread species”	34		
“Unknown species”	42		

Table 4-6: Density of invertebrates in peat in a dwarf shrub dominated pine bog in Finland, based on data in Vilkamaa (1981)

Phylum		Individuals / m^2
Tardigrada		5,000
Arthropoda, Insects	Thysanoptera	60
	Collembola	4,200
	Blattodea	1
	Psocoptera	1
	Hemiptera	158
	Lepidoptera (larvae)	11
	Diptera (larvae and adults)	137
	Coleoptera (larvae and adults)	92
	Hymenoptera, ants	164
	Other Hymenoptera	8
Arthropoda, Spiders	Oribatid mites	106,100
	Other mites	22,300
	True spiders	169
	Pseudoscorpionida	4
Arthropoda, Centipedes		9

	Number of aquatic species in Canadian fauna			Newfoundland bog pools	
	Total	Bogs	Fens	No of Taxa	Density
Arthropoda, Insects					
Ephemeroptera	301	1	0	0	
Plecoptera	250	0	0	0	
Odonata	195	63	22	13	66.6 m^{-2}
Hemiptera	138	33	61	10	3.2 m^{-2}
Coleoptera	579	107		27	13.4 m^{-2}
Trichoptera	546	9	2	9	20.2 m^{-2}
Diptera	866	84	60	31	135.6 m^{-2}
Arthropoda, crustacean	N/A	N/A	N/A	16	16.5 L^{-1}
Annelida, mostly Enchytraeidae	N/A	N/A	N/A	4	13.5 m^{-2}

7. Vertebrates

- Fish (?)
- Amphibians and Reptiles
- Birds
- Mammals

Table 5-1: Potential Receptors of Concern

	Bogs	Fens	Non Peat Forming Wetlands
Non-vascular plants	*Sphagnum* moss Lichen	Brown mosses Lichen	Desmids and other green algae
Vascular Plants	Black spruce Bog cranberry Labrador Tea Leatherleaf Other common bog species	Tamarack Grasses Sedges Birch Other common bog species	Bladderwort Pond Lily Bulrushes Cattails Sedges Common submergent species
Invertebrates	Nematodes Orbatid and Other Mites Carabid beetles	Nematodes Orbatid and Other Mites Carabid beetles	Water beetle Mayfly larvae Dragonfly larvae Chironomids Cladocerans
Amphibians	Wood frog Chorus frog	Wood frog Chorus frog	Wood frog Chorus frog
Reptiles	Garter snake	Garter snake	Garter snake
Birds	Common yellowthroat Palm warbler White throated sparrow Lincoln's sparrow Savannah sparrow Woodpeckers Spruce grouse Northern Harrier Great Gray Owl Short eared owl	Common yellowthroat Palm warbler White throated sparrow Lincoln's sparrow Savannah sparrow Woodpeckers Spruce grouse Northern Harrier Great Gray Owl Short eared owl	Mallard duck Canada goose Sandhill crane, Common snipe, Greater yellowlegs Lesser yellowlegs
Mammals	Bog lemming Shrews Bats Fox	Bog lemming Shrews Bats Fox	Muskrat Mink

Important Exposure Pathways

The major exposure pathways that merit consideration include –

- Direct contact with salt ions in unsaturated areas in higher elevations within the overall microtopographic relief;
- Direct contact with salt ions in soil solution;
- Direct contact with salt ions in standing water
- Indirect exposures of higher trophic order animals based on salt uptake into plants and animals of lower trophic orders.

1.1.1 Determining the Vertical Direction of Groundwater Flow

In determining if a wetland is performing a groundwater recharge or discharge function, there are at least two approaches that have been used:

- measurement of the hydraulic gradient, and
- analysis of groundwater or pore-water chemistry.

Direct exposures from either soil or soil solution might occur especially for –

- Bryophytes – especially the dominant sphagnum or brown moss species;
- Vascular plants, including shrubs and trees;
- Small bodied fauna that live within the substrate (soil invertebrates;
- Amphibians, through especially dermal contact; and
- Larger bodied animals such as moose and woodland caribou, through soil and water ingestion.

For the purpose of developing contaminant assessment and remediation approaches suitable for wetlands habitats in western Canada, the following draft definitions are provided:

1) **Aquatic Habitat – Fish Bearing:**

An area is formally defined as aquatic habitat – fish bearing where there is seasonal or permanent surface water, and where the potential presence of finfish including salmonids and other species would not be naturally precluded by either;

a) natural pH conditions of the standing water or interstitial water, where the pH is naturally depressed by organic acids, that would preclude the presence of most fish species, or

b) the presence of barriers to adult or larval fish passage between open waters with fish present and the area of interest (for example, soil and bryophyte presence in a manner that filters all available water flow; absence of open channels).

In practical terms, open water, swamps and marshes are much more likely to be fish-bearing or to communicate with fish-bearing streams, rivers and lakes than bogs and fens.

2) **Aquatic Habitat – Non-fish Bearing Wetlands:**

This includes all wetland habitat for which the presence of finfish is naturally precluded.

Bogs and fens are typically not fish-bearing waters. In applying this distinction, however, it is important to note that an overall area of interest might include several inter-connected wetland ecosystems, of which a bog or fen is only one component. For example, highly productive fish-bearing streams in northern and central Alberta are often flanked by swamps and marshes (with and beyond the riparian zone). Such swamps and marshes may grade into fens and bogs further away from areas of flowing or standing surface water. At a landscape scale, stagnant or sluggish water movement through bogs and fens may grade into more rapid fluxes through relatively smaller swamps and marshes, and then into open flows (streams and rivers).

Some fish species, especially sculpins, are found in higher pH, minerotropic rich fens.

3) **Terrestrial Habitat:**

As discussed in Chapter 2, terrestrial habitat is the area where actual soil moisture regime is categorized as very dry to moist. Water is not present in the rooting zone during the growing season. Rather, soils through the major portion of the rooting zone are unsaturated. Generally, such sites support forest stands (other than tamarack, black spruce and other wetland tree species) unless there are other limiting factors.

Toxicity of Salt Ions to Peatland Biota – Current State of the Knowledge

- **Bryophytes** – very limited data
- **Vascular plants** – massive literature on agronomic spp.; knowledge about peatland species is limited (NaCl toxicity data exist for birch, pine, spruce and cedar species)
- **Soil invertebrates** – nothing published that is not captured in Bright and Addison (2001)?
- **Aquatic inverterates** – reasonable amount of data, but should we use different data sets for bog/fen biota than lotic and lentic systems in general?
- **Amphibians** – NaCl tox data for 4-5 relevant spp.
- **Birds** – one study on lethal dose range in house sparrows. Limited data on toxic responses in comparison with brain sodium concentrations.

In summary, the major information needs for developing salt assessment and remediation guidelines for peatland environments include -

1. Salt ion tolerance thresholds of major fen and bog bryophytes species,
2. Salt ion tolerance thresholds of major fen and bog vascular plant species,
3. Concentration – response relationships of soil invertebrate assemblages in field plots established along gradients of salt contamination,
4. Relationship between the successful re-establishment of byrophytes in fens and bogs and depth to the major zone of salt contamination,
5. Relationship between the successful re-establishment of vascular plants in fens and bogs and depth to the major zone of salt contamination,
6. Salt ion tolerances of aquatic invertebrates of ecological importance in bogs and fens, including dipteran larvae and aquatic beetles.

Where to next?

- Meeting in Edmonton, end of month to finalize Phase 1 and begin Phase II.
- Desktop review of information available for existing produced water release sites in Alberta (case studies)
- Selection of candidate sites from CAPP members for establishment of field plots
- Further design and execution of field trials to address knowledge gaps about the relative sensitivities of various floral and faunal groups.