A GAP ANALYSIS OF KNOWLEDGE AND PRACTICES FOR RECLAIMING DISTURBANCES ASSOCIATED WITH IN SITU OIL SANDS AND CONVENTIONAL OIL & GAS EXPLORATION ON WETLANDS IN NORTHERN ALBERTA

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Abstract

Wetlands perform many ecosystem services such as water filtration and flow regulation. Wetlands are also important permanent and seasonal habitats for numerous flora and fauna. Interest has been intensifying in developing sound practices for reclamation of industrial features such as roads and well pads built in wetlands, as well as for exploring construction alternatives for those features when constructed in wetlands. However, the knowledge base is somewhat sparse and lacks continuity due to the relative newness of this area of study, especially in Alberta's boreal. Our goals are to: 1) investigate and compile present knowledge regarding reclamation or restoration of non-minable petroleum exploration disturbances in wetland environments (e.g. roads, well pads), including past, presently ongoing, and anticipated research; 2) identify and prioritize gaps in this knowledge; and 3) design and implement a research program that addresses some of the gaps and accelerates the development and use of construction and reclamation practices leading to maintenance and restoration of wetland ecosystem function. This document is a synthesis of our gap analysis aimed at achieving the first two goals. We also introduce our plans for addressing the third. The gap analysis consisted of two parts. First a literature review of relevant research to date in the area of wetland restoration and reclamation, specifically as is pertains to energy industry disturbances was completed. Second, a series of interviews was completed with researchers or industry representatives to document what research is presently underway or planned for reclamation or restoration of petroleum exploration disturbances in wetlands. The information from these two sources was synthesized and gaps remaining in present knowledge were identified and summarized in this document. In addition a suggested research path is presented, which includes some initial plans to be completed by the project sponsors.

Disclaimer

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1.0 Introduction

New criteria for reclamation of oil and gas wellsites and associated facilities are forthcoming from Alberta Environment. Drafts of the new criteria indicate a shift from the previous reclamation paradigm of emphasizing “equivalent land capability” to emphasizing “ecological function” (ASRD 2007, RCAG 2008). Historically, equivalent land capability focused primarily around the ability of land to produce agricultural crops, with less recognition of site ecology or economic value of non-agricultural lands. Consequently, reclamation in forests and wetlands of the Green Area of Alberta often did not result in ecologically, or even economically, productive lands. The new criteria however, particularly as they pertain to forests and wetlands, will have a greater emphasis on understanding and maintaining the ecological functions of these lands. While the new criteria may attempt to redefine what constitutes successful reclamation on wetlands and forested land, they will not directly address the use of specific practices in achieving desired the outcomes. Recently, practices in construction and reclamation of features associated with energy exploration on forested lands have been progressing toward meeting the new emphasis on restoring ecological function. Winter construction of wellsites on wetlands can be accomplished in a manner that avoids major disruption of ecological function. However, very little practical knowledge is presently available regarding how to effectively reclaim well pads and roads constructed from borrowed clay fill deposited onto wetlands. Our intent is to fill in some of the gaps in that knowledge and accelerate the development and implementation of effective wetland reclamation practices.

The new reclamation criteria reflect a recently intensified public and government interest in conservation of wetlands as demonstrated in the provincial “Water for Life Strategy” (Alberta Environment, 2003) and the anticipated implementation of the revised Wetland Policy (Alberta Wetland Policy 2009). Wetlands perform many ecosystem services such as water filtration and flow regulation. Wetlands are also important permanent and seasonal habitats for numerous flora and fauna. Such services justify regulation of industrial disturbances and reclamation on wetlands, but regulation should be based on the best available knowledge to ensure that the intent to conserve wetlands is achieved and to avoid practices of that do not contribute to that achievement. Proactive investigation of wetland reclamation priorities, and initiation of that research by the energy industry, will provide an opportunity for industry to collaborate with government in developing and recommending practices that are based on sound information and have a high likelihood of achieving the desired reclamation goals of maintaining or restoring ecological function to the wetland ecosystems industry affects by its operations.

While interest in developing sound practices for construction and reclamation of roads and well pads in wetlands and is strong and growing, the knowledge base is somewhat sparse and lacks continuity due to the relative newness of this area of study. Our goals are to: 1) investigate and compile present knowledge regarding reclamation or restoration of non-minable petroleum exploration disturbances in wetland environments, including past, presently ongoing, and anticipated research; 2) identify and prioritize gaps in this knowledge; and 3) design and implement a research program that addresses some of the gaps and accelerates the development and use of construction and reclamation practices leading to maintenance and restoration of wetland ecosystem function. This document is a synthesis of our gap analysis aimed at achieving the first two goals. We also introduce our plans for addressing the third. The gap analysis was completed in three phases. The first phase was a workshop among energy and forestry industry representatives, representatives from Alberta Environment and Alberta Sustainable Resource Development, representatives from Ducks Unlimited Canada, and several researchers in wetland ecology and management. The purpose of the workshop was to establish initial priorities for courses of investigation based on industrial operational issues, regulatory goals, and present knowledge. The second phase was a literature review that documented the relevant research to date in the area of wetland restoration and reclamation, specifically as it pertains to energy industry disturbances. The third phase of the gap analysis was a series of interviews with researchers or industry representatives to document what research is presently underway or planned for reclamation or restoration of energy industry disturbances in wetlands.

2.0 Definitions and Assumptions

The terminology used in describing termination of industrial use of a piece of land and to returning it to a desired vegetatively productive state varies considerably and various people may attach different connotations to similar terms. For example, words such as reclamation, restoration, natural recovery, rehabilitation, equivalent land capability, etc. may mean different things to different people. Graf (2009) reviews such terms in detail in the literature review that accompanies this document and offers some simple definitions for reclamation, rehabilitation, and restoration. She defined *restoration* as a focus on the return of the previous ecosystem's structure and function; *rehabilitation* as a restoration attempt that is not completely successful; and *reclamation* as the conversion of land to some other but more productive condition. Alberta Environment (Alberta Environment 2002) offered these definitions of the same terms: *Reclamation*, the process of reconverting disturbed land to its former or other productive uses; *Rehabilitation*, returning land to a form and productivity in conformity with a prior land use plan, including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values; and *Restoration*, the process of restoring site conditions as they were before the land disturbance.

Unfortunately, none of these definitions seems to completely capture the spirit of the draft reclamation criteria produced by the Reclamation Criteria Advisory Group (RCAG 2008) as it applies specifically to peatlands, or to the focus of this gap analysis. For the reclamation criteria to apply to peatlands, they cannot be converted to another purpose or use, thereby eliminating completely Graf's (2009) definition of reclamation and the reference to "other productive uses" in Alberta Environment's (2002) definition. The Alberta Environment (2002) definition for rehabilitation is also inadequate because the phrase "in conformity with a prior land use plan" does not necessarily exclude a change of land use. Referring to an "unsuccessful attempt at restoration," the Graf (2009) definition implies a negative connotation and is doubtful to be undertaken as a goal for returning disturbed land to a desired condition. No one will say, "Our goal is to make an unsuccessful attempt at restoration." The focus of this gap analysis, as well as the draft reclamation criteria, is on returning ecological processes and functions characteristic of wetlands or peatlands to areas of former wetlands or peatlands disturbed by construction of industrial features, specifically well pads or roads, with the ultimate goal of eventual establishment of a community compatible with the surrounding area. Of the definitions described above, the Alberta Environment (2002) definition for reclamation, in absence of the "other productive uses" reference, as well as the Graf (2009) definition for restoration seem to fit best. Indeed, as discussed in the remainder of this document, returning ecological processes and functions to wetlands or peatlands implies the restoration of hydrologic processes. Therefore, for the purpose of this document, we are defining restoration as, "restoring ecological function and processes to the site consistent with what might be expected within the natural range of variability for the wetland ecosystem within which it resides;" and reclamation as, "the process by which restoration is achieved." This does not mean that the site will necessarily be actively restored to its original pre-disturbance state, but that the basic functions are in place such that the site could likely reach that state overtime. Neither does this imply that the site will be converted to some other land use or function, visually or ecologically incompatible with the surrounding ecosystem.

3.0 Workshop Summary

The workshop was held on 7 May 2008 with representatives of the following companies or agencies attending:

Alberta Environment
Alberta Sustainable Resource Development
Ducks Unlimited Canada
McMaster University
University of Alberta
Alberta-Pacific Forest Products
ConocoPhillips Canada
Devon Canada
Husky Energy
Imperial Oil
Japan Canada Oil Sands
MEG Energy
Nexen
Suncor

The objective of the workshop was to establish priorities for courses of investigation relating to planning, construction and reclamation of oil & gas wellsites and associated facilities on wetlands based on industrial operational issues, regulatory goals, and present knowledge (completed and ongoing research).

Four overall themes were identified at the workshop as priorities of concern:

1. Pre-site planning and research
2. Design, monitoring, and feedback systems (adaptive management)
3. Post-reclamation monitoring
4. Pad and road reclamation techniques

3.1 Pre-site Planning and Research

Specific questions and comments related to this theme seemed to centre on risk assessment and risk avoidance. That is, the concerns expressed identified the need to better understand the wetlands that exist in the landscapes in which industry operates, and then use that knowledge to develop a hierarchy of wetland sensitivity and operational costs associated with locating facilities in various wetland types. This would in turn drive operational and site location planning. Additional comments related more specifically to societal and ecological values such as socially acceptable levels of wetland disturbance/disruption, local and regional threshold effects of disturbance on water quality, movement, etc., and ecologically and socially acceptable levels of restoration (e.g. to what stage must wetlands restoration efforts be taken?).

3.2 Design, Monitoring, and Feedback Systems (Adaptive Management)

This theme tended to focus on information systems and information sharing. In other words, using present knowledge to help design facilities with the end land use in mind to facilitate timely and effective reclamation or restoration. Information sources would include that described in the Pre-site Planning and Research described above, as well as learnings from past, present, and ongoing research or innovations by others. Ideally, facilities should be constructed such that reclamation or restoration could occur in stages over the life of a facility, to reduce the effort and the successional time required for final reclamation, Finally, it was expressed that information gathered through research and monitoring in the interim be linked to final reclamation certification.

3.3 Post-reclamation Monitoring

Concerns relating to this theme focused on what period of time and what indicators are required to determine whether reclamation efforts have been successful. Full restoration of a wetland site may take some time given naturally slow rates of recovery, such as for re-accumulation of peat for instance. However, certification could occur much earlier provided it was evident that the site appeared to be on a successional trajectory that would lead to the desired recovery outcome. The key is to know what indicators would be looked for and how soon they could be measured. A suggested solution was to establish benchmark sites that would provide the required information over time. Additionally, the benchmarks would indicate which practices have the greatest potential for success.

3.4 Pad and Road Reclamation Techniques

Concerns expressed related to this theme centred primarily on specific practices such as whether to remove the entire pad or just the fill to a depth near the water table, whether geotextile should be removed, how fill material chemistry might affect water chemistry and subsequent paludification or other natural recovery processes, whether amendments are necessary, etc. One major point of agreement however, was that roads associated with wellsites and other facilities likely have the largest impacts on wetland ecosystems, given their propensity to interrupt natural drainage patterns over large expanses of land. Therefore it was agreed that roads should be given priority in our research plans.

3.5 Synthesis of Themes:

We reorganized the four themes identified into 2 major themes with a third theme that bridges the two. Specifically, the Pre-site Planning and Research theme were integrated as a process within the Design, Monitoring, and Feedback Systems theme such that these two themes really represent a single over-arching theme. This theme, or course of investigation, represents a “higher-level” planning approach that, when implemented, would probably require greater integration or collaboration among departments within companies to coordinate facility location and construction followed by monitoring and final reclamation.

The second major theme is the Pad and Road Reclamation Techniques theme, which would deal with specific “on the ground” practices that can be immediately implemented and results measured. The bridge between the two is the Post-reclamation Monitoring theme, which will provide information to feed into the adaptive management approach of the Design, Monitoring, and Feedback Systems theme, as well as indicate which practices have the best potential for success.

Proceeding with a focus on immediate practices and monitoring of the results would likely be the easiest approach to take, but the longer-term adaptive management and planning approach will likely be more fruitful in the long run in terms of minimizing the industrial footprint. In any case, the need for information gathering identified in the Design, Monitoring, and Feedback Systems theme, specifically investigation of past, present, and ongoing research and practices, was considered important. The remainder of this document summarizes the results of that investigation.

4.0 Literature Review Summary

A comprehensive literature review on restoration of boreal wetlands was completed by Graf (2009), which accompanies this report. Below are the highlights from the review.

4.1 Impacts of Energy-Sector Disturbances on Wetlands

Wetlands form a large proportion of the landscape in boreal Alberta, of which peatlands comprise about ninety percent. Construction of industrial features within wetlands can have some general impacts regardless of the feature type. These include physical and chemical changes to the surrounding environment such as changes in water flow patterns, thermal regimes, water chemistry, and nutrient cycling. Industrial features are also commonly associated with habitat fragmentation. For the purposes of this report, discussion of fragmentation will be limited to fragmentation of vegetation communities and hydrologic processes. To a lesser or greater extent, almost all energy sector disturbances contribute to such fragmentation. However, linear features have greater potential to do so than other types because of their proportionally larger edge to area ratio. Any feature that requires draining of a peatland area will cause subsidence of the peat. This compaction will alter the hydraulic conductivity of the peat and reduce its water holding capacity. These in turn reduce the ability to re-establish peatland plants after the feature is reclaimed.

4.2 Seismic Lines

Seismic lines probably have the least effects on wetlands because the intensity of surface disturbance is typically the least compared to other disturbance types. However, impacts such as tree removal from treed bogs and fens appear to be slow to recover. In addition, sometimes removal of trees and leveling of surface micro-topography can increase surface moisture, leading to changes from drier woody communities to wetter sedge-dominated communities. Mosses are key to peat accumulation, but it is unknown to what degree mosses are damaged or to what degree they recover on their own after seismic line disturbance.

4.3 Pipelines

Pipelines create more physical disturbance than seismic lines due to digging of the trench, as well as generally requiring a wider right of way than most seismic lines. Digging of the trench can alter hydrology, thermal regime, soil structure, and vegetation composition. If excavated peat is on the surface for extended periods the material dries and shrinks, leaving less volume to fill the trench than was originally removed. The remaining depression along the trench can contribute to channelization of surface flow and potential erosion of the trench. Mixing of peat layers or alteration of soil structure also changes the hydraulic conductivity of the peat within the trench, thereby altering water flow paths. Such alterations may lead to fragmentation of local or regional water patterns.

4.4 Roads

Of linear features, roads probably have the largest impacts on wetlands due to their greater potential to fragment the landscape. Roads can potentially interfere with regional water flow by damming or re-directing surface movement over long distances. In addition, roads may also potentially impede or re-direct ground water flows. Changes in water movement patterns can alter the water table, as well as water chemistry, both locally and beyond, depending on connectivity to regional flows. Vegetation communities can thereby be altered by changes in these hydrologic and chemical regimes. Other potential effects of roads include degradation of permafrost if water is ponded, compaction of underlying peat, and contamination of nearby vegetation by dust from the road. While winter roads are assumed to have fewer impacts than permanent roads, they can influence the thermal regime and surface flow because of deeper and longer lasting frost penetration below the road surface.

4.5 Well Pads

The impact of well pads constructed from borrowed fill on top of wetlands has not been well assessed. Altered hydrology may be one potential impact. Certainly compaction of the underlying peat or its removal prior to construction may have some impact on local water flow. Construction of drainage ditches and berms will also affect local surface hydrology, as well as create potential sources of contamination by introduced mineral material or operational contaminants.

4.6 Restoration

Restoration success for peatlands was defined by Rochefort (2000) as the re-establishment of a) plant cover dominated by *Sphagna* or brown mosses and b) diplotelmic layers that characterize “active” peatlands. This implies adequate productivity, nutrient cycling, and the return of vegetation structure and microhabitats that are resistant to biological invasion.

There are two primary components to wetland restoration: hydrology and vegetation. Restoring the hydrologic regime is essential to establishment of target vegetation. Restoring hydrology is key to establishing and maintaining the desired wetland types and properties because the hydrology influences the chemical and physical properties of the wetland such as nutrient availability, soil salinity, sediment properties, pH, oxygen availability, and hydroperiod. As important as re-establishing the pre-disturbance hydrologic regime appears to be, it seems to have received the least attention in available literature on wetland restoration. On the other hand, much more work has been done on techniques to restore vegetation.

Several options for revegetation of wetlands have been explored, including natural revegetation, transfer of seed bank material (e.g. seeds, rhizomes, stolons, diaspores of various species) from donor locations, transplanting individual plants, seeding, and transplanting “sods” or large intact portions of acrotelm. Natural revegetation can be very slow in peatlands, leaving the sites prone to weed invasion. Not all species propagate well via seed and some seeds require prior treatment (scarification, etc.). Repeatable success has been achieved by introduction of seed bank material to mined peatlands. Transplant of whole acrotelm layers shows promise in revegetating mined peatlands also.

The Peatland Ecology Research Group (PERG) at Université Laval has developed a detailed procedure, referred to as the “North American Approach” (Rochefort et al. 2003) for revegetating mined peatlands by collecting seed bank material from a donor site and applying it to a recipient site (Quinty and Rochefort 2003). The surface of the donor site is shredded to a depth of about 10 cm with a rotovator or similar piece of equipment and then the plant fragments are collected and hauled to the recipient site. They are then applied to the recipient site with a manure spreader in a 1:10 donor to recipient area ratio. The material is then covered with straw crimping and fertilized with a light application of phosphorous. This method has been used successfully in revegetating a number of mined bogs in Ontario and Quebec. Early indications are that this practice will be effective in revegetating fens (perhaps more so) in those provinces also.

Acrotelm transplants in a 1:1 donor to recipient ratio have been attempted to a lesser degree than the seed bank material applications, but good results have been achieved in Ontario with transplants to newly denuded mineral surfaces (bedrock) exposed by peat mining. Transplanted material readily establishes itself and begins accumulating carbon relatively quickly (Cagampan and Waddington 2008b, Michael Waddington, pers. comm.).

4.7 Best Management Practices

Best management practices (BMPs) were cited from various sources such as government environmental or energy agencies, energy industry associations, academic texts, and consultant reports for a number of feature or disturbance types. However, it was not clear to what degree the recommended practices were based on empirical study. Nevertheless a number of the practices recommended seemed quite intuitive. For example, recommendations for pipeline construction emphasized avoiding mixing of peat or soil layers. Recommendations were to install pipelines during frozen conditions, to remove the acrotelm separately from the catotelm, and to store the layers in separate piles. If mineral layers were encountered, these should also be stored separately and all layers should be replaced in the same sequence in which they occurred within the trench prior to excavation. Another recommendation was to not open any more trench in a day than could be filled that day to avoid drying and subsidence of the removed peat layers.

Similarly, recommendations for roads included avoiding wetlands if possible, reducing the number of roads required, constructing roads parallel to surface flows, and salvaging acrotelm so it could be transplanted to nearby sites requiring restoration. However, some of the recommended BMPs for roads were not as intuitive and raised questions. For instance, one recommendation was to reduce the road width, which raises a number of questions. First, what are the design limitations, especially regarding proper drainage to maintain roadbed integrity, associated with a narrow road? Second, how do these design limitations affect the surrounding hydrology and for what distances from the road? Finally, does restricting road width restrict options for road construction methods? For example, will a narrow roadbed built on underlying mineral deposits from which the overlying peat was excavated be favoured over a wider "floating" roadbed that may influence hydrology for a shorter distance from the road? Another recommended road construction BMP that raised questions was to preserve natural hydrology by creating cross-drainage to maintain natural surface and subsurface flows. This could be accomplished by using construction methods that allow free water flow throughout the roadbed or by placing adequately sized and adequate number of culverts along the road. What are construction methods that allow free water flow throughout the roadbed and where have they been tested? Also, has culvert size and number been sufficiently studied in peatland environments to provide sound recommendations? Finally, how is channelization of water flow prevented on the downstream side of culverts?

There were fewer recommendations for well pads constructed within wetlands overall, and most emphasized avoidance techniques such as drilling in winter to eliminate the need for a pad or to drill multiple wells from a single pad. Other recommendations related to prevention of contaminating the surrounding wetland with borrowed mineral fill material or operational contaminants. Finally, salvage and storage of the acrotelm layer for restoration of nearby disturbances was recommended, but no information was provided regarding how long this material could be stored in a useful living state.

5.0 Interview Summary

A list of prospective people to interview was compiled from consultations among the partner companies involved in this project as well as provincial government agencies and the interviewees themselves. The list included experts in hydrology, ecology, and restoration. They were queried regarding their past, present, and planned research and were asked for an overview of their findings and how they would apply to our objectives. We also asked about their insights and suggestions with respect to questions specific to our preliminary priorities. Finally, any recommendations they might give regarding what they see as research priorities or strategies were also sought. Prospective interviewees were contacted to make appointments for interviews and interviews were completed with those who consented to be interviewed. The following individuals were approached to provide interviews:

Michael Waddington, McMaster University	Carl Mendoza, University of Alberta
Dale Vitt, Southern Illinois University	Dennis Gignac, University of Alberta
Garth vander Kamp, Environment Canada	Lee Foote, University of Alberta
Maria Strack, University of Calgary	Kevin Devito, University of Alberta
Line Rochefort, Université Laval	Suzanne Bayley, University of Alberta
Jonathan Price, University of Waterloo	Carol Elliot, Shell Canada
M. Anne Naeth, University of Alberta	David Cooper, Colorado State University

Information obtained from the interviews is compiled below, along with information regarding each of the interviewee's backgrounds. Obviously, no information was obtained from those that did not consent, however some of the individuals in the list above either were not presently engaged in relevant projects or their information was supplementary and integrated with the work of others on the list. Therefore they do not appear separately in the compilation below. In addition to these interviews, information regarding a reconstructed fen project by Syncrude was obtained from a presentation by Ron Lewko of Syncrude at the annual meeting of the Alberta Chapter of the Canadian Land Reclamation Association in February of 2009 at Red Deer, AB, as well as additional comments from Carla Wytrykush, also of Syncrude.

5.1 Michael Waddington, Ph.D.

Professor, School of Geography and Earth Sciences

McMaster University, Hamilton

Dr. Waddington's research focuses on ecohydrology and carbon cycling in peatlands. He has studied hydrological and ecological processes associated with greenhouse gas dynamics, groundwater-surface water interactions, and water quality in undisturbed, cutover, and restored peatlands. Dr. Waddington has studied a number of factors in relation to peatland restoration such as carbon emissions, the influence of vegetation succession on peatlands, energy exchange, surface moisture dynamics, and the effects of decomposing straw mulch on carbon flux. Dr. Waddington has also developed models describing peatland hydrology and greenhouse gas movement through peat.

Current Projects

Dr. Waddington is presently working on a number of projects relating to recovery of post-disturbance peatlands. One study focuses on rehabilitation or establishment of rich fens on limestone quarries in Ontario. The project involves partial transplantation of acrotelm material from an area undergoing new disturbance to the quarry, where the substrate consists of exposed bedrock and no residual organic matter. These are partial transplants in the sense that there is not enough transplant material to cover all of the quarry area. The goal is to transplant the material to key locations to initiate the revegetation process, which will hopefully continue to eventually recolonize the entire quarry site. Another acrotelm transplantation project involves removing the acrotelm prior to peat excavation for fuel and then replacing the acrotelm onto the underlying bedrock, which again, is devoid of residual organic matter. Initial results indicate promising expectations for this practice (Cagampan and Waddington 2008a, 2008b). Other projects involve monitoring the trajectory of vegetation recovery after fire or logging for the purpose of developing models to predict post-disturbance revegetation trajectories, as well as measuring the responses of peatland to fire and drought in the context of cumulative effects of these and other disturbances (e.g. roads).

There are parallels between the acrotelm transplantation on quarries or mined peatlands and restoration of clay pads or roads on wetlands. Dr. Waddington believes acrotelm transplants should work well on partial removal of clay pads in Alberta provided sufficient donor material is available within the vicinity. However, hydrology will be a key element to be managed. While pre-disturbance hydrologic conditions need not be fully restored initially, restoration of basic hydrologic processes may enable eventual site recovery and re-establishment of functioning ecology. He stated that the top 30 to 50 cm of surface material is the most important in re-establishing a functioning hydrology and ecology. The timing, duration, and degree of wetting need to be managed to prevent extreme drought or extreme flooding. Once a moss layer as deep as a typical acrotelm establishes, it is pretty much self-sustaining due to its ability to retain wetness and resist brief extreme events. In fact, the ability of a moss layer to retain wetness might be a useful indicator that a restoration has been successful.

Additional Comments

Roads constructed within wetlands can potentially have a substantial impact and therefore have a high priority for management. Not only should the initial impact be considered, but also the impacts that might arise if a road, or portions of a road, is eventually removed. How can roads be built to minimize initial impacts as well as reduce recovery efforts if they are removed? Dr. Waddington suggests focusing on the hydrologic and ecologic effects of roads and determining how various recovery starting points affect recovery outcomes. In other words, how do recovery time, trajectory, and success (however defined) vary with the degree of hydrologic fragmentation caused by the road?

A related factor may include the amount of time since the initial disturbance and the cumulative change in ecology, hydrology, and water chemistry. For example, simply removing the damming effects of a road may not re-establish pre-disturbance hydrologic function if trees on the downstream side of the road have grown so large that they permanently lower the water table. Furthermore, recovery after road removal may also be complicated by variables associated with rates of water flow and rapidity of re-flooding, as well as changes in water chemistry from one side of the road to the other. A final comment was that indicators that recovery is on track both in terms of time and vegetative trajectory have not been extensively studied and should be addressed.

5.2 Dale Vitt, Ph.D.

Professor and Chair, Department of Plant Biology

Southern Illinois University, Carbondale

Dr. Vitt is interested in ecosystem dynamics, biogeochemistry and development of peatlands, particularly in response to climatic changes. He has studied moss ecology and systematics in tropical, temperate and arctic regions and is especially interested in biodiversity, habitat preferences, and the study of population establishment in response to environmental conditions.

Current Projects

Dr. Vitt is involved in several projects in Alberta relevant to wetland restoration. Two projects have been initiated in cooperation with Shell Canada. The first of which is a bog restoration near Peace River after partial removal of a clay well pad. Partial removal means that the height of the pad is reduced such that the surface is at or near the water table. Restoration to a bog is not expected immediately because the pad material is likely to increase water pH, thereby resulting in an unfavourable environment for bog vegetation (*Sphagna*). However, the goal is to revegetate the pad with wetland species that are adapted to the site conditions and which would eventually succeed to bog vegetation as conditions change over time. Applied treatments include planting of several classes of plants (graminoids, shrubs, trees) along a gradient of moisture conditions (wet, mesic, dry). Plant species include various sedges that are being transplanted, willows that are being planted as cuttings, and larch that are started in a nursery and then planted on site. The objective is to incorporate structure within the plant community from the outset. The moisture gradient was achieved by varying the amount of fill removed along strips that run along the length of the pad site. Dr. Vitt expressed that the key variable to manage is the water level. If the site is too wet, it will be dominated by cattails. If too dry, there will be no peat development. The second Shell-partnered project is a study of water level and ecological changes in response to corridor development across a fen in the Wabasca area. Shell will be constructing a road perpendicular to water flow across the fen. Pre and post construction measurements will be recorded to document the changes in surface hydrology and vegetation.

Dr. Vitt is also involved in a fen construction project undertaken by Syncrude (see section 5.8 below). Dr. Vitt's involvement includes selection of species that may be suitable for establishment on the available substrate, as well as determining the best options for obtaining and propagating the appropriate plant materials. For example, he is examining which of the suitable species can be propagated by seed, which can or should be transplanted, which can be propagated from plant parts, and so on. He is also studying the moisture conditions that will need to be maintained for proper establishment.

5.3 Lee Foote, Ph.D.

Professor, Department of Renewable Resources
University of Alberta, Edmonton

Dr. Foote

Dr. Foote specializes in wetland ecology and management. His research focuses on creating waterfowl habitat, reclaiming disturbances using adaptive management, manipulating wildlife habitat using natural processes, and sustainable use of renewable resources. Other interests include trophic dynamics in wetlands, sustainable use of northern wildlife, and social sustainability in African savannah ecosystems.

Current Projects

Dr. Foote is involved in a number of wetland restoration projects in Alberta relating to various disturbance types and addressing various aspects of restoration. Some of these include the establishment of a wet meadow on an old peat-mined field, establishment of a sedge community after coal mine reclamation, monitoring of the effects of pipeline construction, and several studies of biofilm establishment and properties as a stage of initial post-disturbance succession. Dr. Foote is also collaborating in the Syncrude fen construction project (section 5.8).

Several treatments were evaluated in attempting the establishment of the wet meadow on the former peat-mined site. The site required preparation in the form of breaking up the crusted peat at the surface to allow transferred plant material to access moisture from below the surface. Sedge material was scraped from the surface of a donor site during the spring, when the surface material had thawed but the soil was still frozen. The material consisted of rhizomes, roots, seeds, and other plant parts, as well as resident microbes living within the surface material. The donor material was then loaded and spread onto the treatment sites with a standard box manure spreader. Treatments included a moisture gradient within the site from dry to wet, application of commercial chemical fertilizer, and application of straw mulch. The goal of the project was to establish productive habitat for the eventual development and return of a peat producing area succeeding from a wet meadow to a peat accumulating sedge meadow, and finally to the establishment of bryophytes. Thus far, moisture appears to be the most important variable. Fertilization has had limited effects on establishment and growth of the transferred plant material, while the straw mulch has provided some benefits.

The establishment of a sedge community within the coalmine area is similar in principle to the peat-mined site. Live sedge material is being transferred to the mine area from a donor site and applied along a moisture gradient. A related coalmine study examines whether application of stockpiled peat to mine tailings is necessary or beneficial, or whether planting of wet meadow emergents is sufficient to initiate a peat accumulating community.

The pipeline-monitoring project examines a time sequence using aerial photography to document changes in vegetation, water quality, and sedimentation. Another aerial photo interpretation project combines field measurements and photo interpretation to monitor vegetation changes in the open water, emergent, and wet meadow zones of wetlands with the goal of developing a process to scale up from plot to landscape scales in addressing wetland study and management. Finally, a number of Dr. Foote's students are investigating the role of biofilms or the slime that often develops on the water surface in shallow water. The biofilms are a layer of organic matter consisting of algae and other microorganisms that are autotrophic with a high turnover rate. These provide food, substrate, and habitat for a number of other organisms. The focus of the biofilm studies is whether or not they can be transferred from one site to another to kick-start primary production and accelerate carbon accumulation within a wetland. Typical questions are how they respond to handling, how they respond to various substrates (e.g. oil sands mine tailings), whether they influence dissolved oxygen levels within a wetland, whether that level is different than a level produced by macrophytes, and whether species composition of resident microbes change in response to transferred biofilms.

The biofilm studies are relevant to fen construction projects such as those at Suncor and Syncrude discussed below. Another relevant study examines whether the consolidated tailings substrate or the chemistry of the water influenced by the tailings limits plant establishment and growth. The study attempts to make this determination by comparing the performance of plants growing in tailings soil transferred to an undisturbed wetland to the performance of plants growing in natural wetland soil transferred to the constructed fen area. The plants are planted in buckets containing either the tailings or natural soil. The natural soil buckets are then planted into the tailings matrix of the constructed fen area, while the buckets containing tailings extracted from the fen area are planted into the natural wetland. All buckets are perforated to allow water transfer between the buckets and their surrounding matrix. Thus far, plant growth does not appear to be influenced by the water chemistry, but plant growth is reduced in the buckets containing tailings. Other studies applicable to fen construction include examination of water quality, specifically salinity, within the root zone of established plants and investigations of responses of various biota to the submersed aquatic environment.

Additional Comments

Dr. Foote made several suggestions for addressing present gaps in practical knowledge regarding wetland restoration, one of which was knowledge that would give us the ability to predict water supply to the restoration area based on the hydrologic setting and physical morphology of the basin in which it exists. He also remarked on scale issues and cumulative effects, stating that mapping of surface flows, including direction, rate, and water quality was important. He was of the opinion that mapping of these was more important than mapping of subsurface flows. Dr. Foote also cautioned that restoration goals should not be restricted to restoring to the conditions that existed prior to disturbance. It may not always be practically possible or economically expedient to restore to pre-disturbance conditions. In such cases, what suits the present conditions best and what may lead to acceptable potential outcomes should be considered. Finally, there must also be consideration of the duration that energy developers are held financially accountable for reparation of environmental damages, however that reparation may be defined. Acceptable standards for indicators of restoration success need to be agreed upon that provide reasonable confidence that a desirable successional trajectory has been established for a given restoration project.

5.4 Jonathan Price, Ph.D.

Professor, Department of Geography and Environmental Management

University of Waterloo, Waterloo

Dr. Price's research addresses wetland hydrology, wetland hydrogeology and chemistry, and peatland restoration. Projects have included techniques to estimate the water flux to new growing sphagnum in hummocks, post restoration hydrological functioning in harvested peatlands, and the effects of lowering the water table on peat decay and how this relates to the carbon cycle. Dr. Price has also performed modeling of hydrological flow in peatlands as well as assessed different restoration techniques, including using diaspores from two different types of fens, using straw mulch treatments, mechanical versus manual reintroduction of plant material, and the use of large and small scale shallow basins as plant reintroduction sites.

Current Projects

Dr. Price recently completed the development of a fen creation feasibility model for a post-mined oil sands landscape (Price et al 2007) and has presently initiated a laboratory and greenhouse study in collaboration with Suncor that will assist the selection of suitable plant species for use in establishing a fen environment on reclaimed oil sands mines. Naphthenic acids and sodium within oil sands mine process-affected water is of particular concern because little is known about the specific toxicity of these chemicals to fen plants as well as how these contaminants are transported within a fen environment. The study will examine the movement of process-affected water through peat substrate; the survival, growth and regeneration/germination of fen species grown in peat treated with process-affected water; and the changes in microbial community structure in the contaminated peat under the cover of different fen plant species. This information will be used to inform the design of created fens and make recommendations for initial species establishment. Additional collaborators on this project are Line Rochefort (U Laval) and James Barker (U Waterloo).

In Ontario, Dr. Price is presently involved in a hydogeologic study investigating the effects of aquifer depressurization on a surface peatland. DeBeers Canada's Victor Diamond Mine will be drawing 130 million litres of water from the aquifer daily for at least 10 years (present permit period is 5 years). Dr. Price, in collaboration with Drs. Vicki Remenda (Queen's U) and Brian Branfireun (U Toronto) will be measuring water pressure and quality in the surrounding peatland and in the underlying limestone aquifer. Dr. Price expects some parts of the 1000 – 3000 km^2 study will drain while others will flood. The researchers will monitor vegetation changes over the area, as well as releases of carbon dioxide and mercury. Dr. Price believes this research will enhance environmental management practices and predictions of long-term effects of diamond mining, in addition to improving restoration of the peatlands affected by such disturbances.

5.5 Line Rochefort, Ph.D.

NSERC Senior Industrial Research Chair in Peatland Management

University of Laval, Quebec

Dr. Rochefort has studied peatland restoration for many years and is co-author of the Peatland Restoration Guide, second edition, published by the Canadian Sphagnum Peat Moss Association and the New Brunswick Department of Natural Resources and Energy. Her research has focused on techniques for restoring peat-accumulating plant species to disturbed sites, including site preparation techniques, how and when to collect plant propagules, and how to protect transplanted propagules to ensure establishment.

Current Projects

Dr. Rochefort has worked extensively with the Canadian Sphagnum Peat Association in restoration of mined peatlands and has developed considerable expertise in restoration of bogs after mining of peat. The Peatland Restoration Guide (Quinty and Rochefort 2003) co-authored by Dr. Rochefort has become widely accepted as a guide to standard practice in the Canadian peat industry, particularly in eastern Canada. Dr. Rochefort has recently focused on fen restoration in addition to bog restoration, but her efforts have primarily addressed restoration of mined peat fields. The decision to restore to a fen or bog depends more on the conditions presently existing on the site (e.g. surface substrate, water quality) than on what occupied the site previously. Restoration techniques used for re-establishing bog vegetation on mined peatlands appear to be applicable to establishment of fen vegetation as well, as indicated by Graf and Rochefort (2008). Dr. Rochefort is currently collaborating with Jonathan Price (see above) and Maria Strack (U Calgary) on a project to establish fen vegetation on a mined out peat bog in Quebec. Present work involves pre-restoration monitoring of water balance and quality to determine what factors may limit restoration efforts, as well as similar monitoring within an undisturbed area to establish baseline conditions as potential targets. The only energy sector work in which Dr. Rochefort is presently involved is the collaboration with Jonathan Price and James Barker, described above, studying the effects of oil sands process-affected water on fen plants.

5.6 Suzanne Bayley

Professor, Department of Biological Sciences

University of Alberta, Edmonton

Dr. Bayley studies biogeochemistry, ecology, and management of wetlands and lakes, as well as interactions between hydrology and nutrient cycling in boreal and prairie wetlands and lakes.

Current Projects

Dr. Bayley has not been directly involved in wetland restoration research, but has completed extensive monitoring of numerous wetlands throughout Alberta, including restored and reconstructed wetlands. One of her students is presently studying salt effects on potential peat accumulation in constructed wetlands in the oil sands region, while two other students are working on developing indices of biotic integrity (IBIs) which eventually could be used for setting reclamation targets and tracking reclamation success. The IBI research is potentially of considerable relevance to restoration of energy sector-disturbed wetlands if IBIs could be used to determine whether restoration efforts have achieved the establishment of a successional trajectory likely to result in the desired ecological outcome. The students are comparing a number of environmental variables within wetlands along a gradient of disturbance levels in order to develop indices of “wetland health.” Such indices would provide a standard gradient to which any given wetland can be compared to assess its health at a particular time. The disturbance gradient includes “pristine” wetlands, wetlands that have been disturbed but not affected by oil sands process waters, and oil sands process-affected wetlands. Environmental variables include water nutrient levels, turbidity, chlorophyll levels, gross changes in water level, and presence of hydrocarbons and naphthenic acids. These will be correlated with wetland vegetation responses so that ultimately the indices can be determined from simple measures of vegetation.

5.7 Kevin Devito and Carl Mendoza

Kevin Devito, Ph.D.

Associate Professor, Department of Biological Sciences

University of Alberta, Edmonton

Dr. Devito is studying wetland water chemistry and the role wetlands play in buffering moving water. He is striving to describe detailed biogeochemical processes in nutrient transport in order to develop a geologic framework to generalize the role of wetlands in influencing landscape-scale water chemistry, especially in response to landuse practices. Dr. Devito is also determining the landscape and time scales at which hydrological responses occur to land disturbances in order to develop hydrogeologic models that can predict changes in water quality and quantity resulting from surface disturbances based on a region's climate and landforms.

Carl Mendoza, Ph.D.

Associate Professor, Department of Earth and Atmospheric Sciences

University of Alberta, Edmonton

Dr. Mendoza's research examines groundwater and wetland hydrology of the western boreal plain. He has developed numerical models of groundwater flow and transport processes at various scales. Such models are used to assist in the interpretation of field and laboratory experiments conducted in collaboration with researchers from the University of Alberta and other universities.

Drs. Devito and Mendoza collaborate in the Hydrology, Ecology, and Disturbance (HEAD) research program that examines and documents the basic hydrogeologic processes at play within the boreal plain region and applies this knowledge to predicting and managing the effects of various landuse practices on water and vegetation resources.

Current Projects

Drs. Devito and Mendoza have focused on process-oriented research geared to understanding the hydrogeologic processes that sustain wetlands in the boreal plain's sub-humid environment. By understanding the key variables that drive water flow within the hydrologic system, they hope to predict how both natural and anthropogenic disturbances will influence hydrology and subsequent expression of surface vegetation. The researchers suggest that there are probably 3 to 5 prescriptive measures that can be determined from measurement of key variables and applied to management of the effects of disturbances. They have developed a framework for broad scale classification and assessment of hydrologic resources (Devito and Mendoza 2007, Devito et al 2005) that uses a hierarchy of landscape factors to predict surface water and groundwater connectivity. These include climate, bedrock geology, surficial geology, soil type and depth, and finally topography. While the researchers have not worked on restoration research to a large extent, they have begun to test the body of process knowledge they have produced by completing experiments that measure various hydrological responses to disturbances. The initial disturbance they are examining is forest harvesting. They are measuring the impacts of clear-cut harvesting and secondary succession of vegetation on the hydrologic systems. These include evapotranspiration, soil moisture, soil temperature, canopy interception, streamflow, streamflow path, water chemistry, and carbon dioxide fluxes. The researches suggest that their initial analyses indicate that spatial variability and road construction may have more influence on hydrological systems than clear cutting. They are presently contemplating implementation of an experiment to examine the effects of road construction.

The large body of process-based hydrologic knowledge Drs. Mendoza and Devito have been compiling has also been put to use in assisting the design of the constructed fen planned by Syncrude. The researchers are collaborating on the design aspects relating to initiating and sustaining the water supplies needed to establish and perpetuate the constructed fen.

5.8 David Cooper, Ph.D.

Professor, Department of Forest, Rangeland, and Watershed Stewardship

Colorado State University, Fort Collins

Dr. Cooper's research entails study of wetland ecosystems and wetland vegetation ecology. He is also active in wetland restoration and wetland creation projects. Wetland hydrology is also a key element of his wetland work.

Current Projects

Dr. Cooper is involved in numerous restoration projects in the United States addressing disturbances from a variety of sources such as mining, wetland drainage, severe overgrazing or other disturbances leading to local extinction of wetland plants, and land development associated with skiing and recreation. In Alberta, Dr. Cooper is collaborating in development of a constructed fen prototype with Suncor. The primary question to address is how to develop a perennial groundwater flow system. Related questions include how to build a watershed that captures precipitation, allows for soil infiltration, and discharges into the desired area; what should the wetland to upland area ratio be; how to address the chemistry of water coming out of the tailings sediments (high sodium), and what size of watershed is needed to ensure a large enough water supply. Vegetating the watershed and resultant wetland also raises questions such as what plants will be tolerant of the conditions produced, what establishment techniques can be used, and what kind of soil substrate is best to start with (e.g. a peat mix or raw mineral soil).

Additional Comments

Key knowledge requirements for wetland reclamation are hydrology and plant ecology. Most wetland disturbances are hydrologic disturbances, so the primary goal of restoring wetlands is to restore hydrologic processes. Unfortunately, this is the aspect of reclamation that we are the least knowledgeable. For any project, time needs to be invested in understanding the landscape and properly thinking the project through. A watershed-scale analysis should be completed so that a three-dimensional model or understanding of the landscape and its inherent water flow patterns can be developed. Once an acceptable hydrologic regime is re-established, plants can be matched to the resultant moisture and chemical conditions. Furthermore, vegetation can also be incorporated into the structural design of a project (i.e. bioengineering) to accomplish various erosion control or structural support objectives.

Knowledge of revegetation and bioengineering techniques is generally more common than knowledge of hydrologic restoration. Nevertheless, a desired future vegetation community or outcome must be targeted and the combination of re-established hydrology and initial vegetation must set the trajectory toward that community. Furthermore, sufficient time (e.g. 3-7 years) must be allowed to demonstrate that a stable hydrologic regime and vegetation community have been established and that soil organic matter is accumulating (i.e. a carbon-accumulating system has established).

Specific features such as roads should avoid deep cuts into peatland and be engineered with permeable bases. Drainage features such as culverts produce channels and do not reproduce natural flow patterns. Alternatives are to build road bases with sand, gravel, or cobbles reinforced with geotextile. Dr. Cooper’s experience is that engineers can accomplish what is required if they properly understand the goals.

Finally, Dr. Cooper recommends that any prototypes, such as the Suncor Fen, must have realism built into them. That is, a prototype needs to be constructed in a fashion that realistically addresses the elements at hand, thereby making it transferable to other applications.

5.9 Syncrude Fen Prototype

Construction of Syncrude’s reconstructed fen is a response to approvals issused by Alberta Environmental. The Guideline for Wetland Establishment on Reclaimed Oil Sands Leases (2007) was consulted during the design phase, and research findings will be communicated to CEMA to update this document. A primary objective of the project is to create an instrumented watershed on a sand-capped consolidated mine tailings deposit. Related objectives are to test the viability of techniques for soft-tailings reclamation and fen development, as well as to develop technologies for operational implementation. Challenges include water chemistry, challenging (with conventional earth moving equipment) trafficability of the tailings substrate, and paucity of knowledge with respect to fen reclamation. The saturated underlying materials present a challenge for conventional earth moving equipment. The sand cap has been placed to improve trafficability for conventional equipment, and for water table control. Because this is a relatively large research watershed (51 ha), and there is limited information guiding techniques for fen reclamation, Syncrude has sought the assistance of numerous experts in related fields of science and engineering, some of whom are listed above.

One of the first priorities is to establish a suitable hydrologic regime. Questions that may be addressed through watershed scale research, include whether or not the watershed and its hydrology can supply enough water to support a wetland, whether these supplies will be sustainable, what level of salt loading can be predicted, and how established plants will respond to the changing environment. Another key priority is to establish the potential for a carbon-accumulating wetland, which leads to additional questions associated with techniques for revegation of fen wetlands. Research to answer some of these questions is being completed by a combination of greenhouse and field trials. Some of the projects have been described above (for example, see Dale Vitt). Other work includes a study of live peat sod transplants examining the depth of peat to collect, how and when to collect, techniques for placement, and response to water quality differences.

The reconstruction of a fen in the oil sands mined landscape is a considerable challenge and a daunting task, but it is also an incredible learning opportunity. The learning acquired in the process of developing successful techniques for wetland restoration in the mined oil sands will be a boon to future reclamation projects.

6.0 Knowledge Gaps or Questions Arising From Literature Review

6.1 Hydrology

Re-establishing natural hydrology was identified as the key element to restoring site ecology and target vegetation, yet this aspect of wetland/peatland restoration has been the least addressed in the restoration literature. Part of this paucity of attention paid to re-establishment of hydrology may be due to the fact that most of the restoration research has occurred within the humid eastern boreal regions where precipitation exceeds evapotranspiration. These peatlands have relatively shallow soils underlain by crystalline bedrock. The hydrology, controlled predominantly by topography, is not particularly complex (Price et al. 2005). In these cases, hydrologic conditions are restored and maintained by blocking the drainages previously installed to facilitate peat mining and by crimping the surface with straw to reduce evaporative losses (Quinty and Rochefort 2003, Holden 2005). On the other hand, hydrology in the sub-humid boreal plain of Alberta where glacial deposits are deep and surface relief is low, is much more complex. Here evapotranspiration exceeds precipitation, therefore water supply to peatlands relies more heavily on the interaction between groundwater and surface water. However, this interaction is highly variable depending on landscape position and texture of surficial mineral deposits (Price et al. 2005). Not only has little restoration research been done in this environment, but none has been done that documents the response of restoration efforts to the inherent environmental variability. Techniques aimed simply at capturing runoff as is practiced in the humid eastern boreal may not be sufficient for re-establishing hydrology and vegetation affected by energy industry features in the sub-humid boreal plain. Therefore, broad terms or phrases such as “restoring hydrologic function” or “hydrologic regime” are non-specific, requiring refinement and increased specificity. What processes need to be targeted and what techniques should be used? What techniques are practically feasible? To what degree must practices be site specific and how can guesswork be reduced or eliminated? Are there any universal treatments or practices that should or can be applied?

Another reason for the lack of literature describing how to restore the natural hydrology potentially disrupted by roads or well pads in the boreal plain is that very little has been documented regarding the specific effects of these features on hydrology in the first place. The damming effects of roads are often cited, but the topic appears to have received little empirical attention, specifically in the boreal plain. Unknown is whether or not all roads produce damming effects. If not, what are the construction and hydrogeologic factors that contribute to damming? Other research that is absent is whether roads or pads influence ground water flows or only surface/near-surface flows. For example, has a given feature disrupted ground water connectivity, and what are the effects beyond the feature? How far beyond the feature are hydrology and ecology influenced (local, regional)? Does the feature influence the source of water to the area or just its distribution? Given the relatively isolated nature of well pads, and in some instances roads, will re-establishing surface/near surface connectivity between the restored and intact areas mitigate the effects of localized disconnectivity with ground water? How can surface connectivity be best established? Given the potential effects on both hydroperiod and water chemistry, efforts in restoring the hydrology required for establishing and maintaining target vegetation may be misdirected or wasted without proper understanding of these questions. Best management practices for road construction will also be influenced by answers to these questions. For instance, should construction methods differ based on the surficial geology and groundwater connectivity inherent within the vicinity of a given site?

6.2 Vegetation Restoration

Vegetation restoration practices developed for the humid eastern boreal will likely work within the sub-humid boreal plain once the hydrology is addressed appropriately, but this has not yet been confirmed by empirical study. In any case, some basic questions remain regarding these and other potential options. A question that applies to any method is whether the original hydrologic regime should be returned or whether a new regime should be established. Questions that apply to both the North American approach developed by PERG and the acrotelm transplant method investigated by Cagampan and Waddington (2008) relate to selection of donor sites based on the substrate to which the transferred plant material will be applied. If, for example, the chemistry of the fill material used for a constructed well pad or road is not compatible with the surrounding wetland, will material from adjacent donor sites adapt to the conditions on the recipient site or will plant material need to be imported from elsewhere? If importation is required, from where should material be imported? The location of suitable donor material may also raise logistical questions related to transportation of material and associated costs. Questions regarding other plant establishment methods include which plants are suitable for transplanting or establishment from seed? When are the best times or seasons to collect seeds or transplant individual plants? Are there specific seed or substrate treatments that are required? Should plant or soil protection measures be taken? Should seedlings be established in a greenhouse and then out-planted to the restoration site? None of these questions appear to have been addressed in the literature.

Perhaps the most difficult questions relate to the succession of vegetation to the desired target community. An example is whether the target should be the community that existed before the disturbance or whether a different, more practically achievable target should be strived for. In either case, what are the indicators that the restoration effort has been a success or is on the right path, and how long will it take for these indicators to appear?

6.3 Seismic Lines and Pipelines

No literature was found by Graf (2009) regarding the effects of pipelines on wetlands in the boreal, however, there is some indication that they may influence peatland hydrology and thermal regimes (Carl Mendoza, pers. comm.). This is an area that may warrant further investigation. While the effects of seismic lines on tree cover and recovery has been investigated to a considerable extent in boreal Alberta, the effects of seismic lines on ground cover within peatlands have been less studied. Mosses contribute most to peat accumulation, but it is not known whether they recover naturally along seismic lines in peatlands or whether they require active re-introduction.

6.4 Cumulative Effects

While the impacts of one or a few roads or well pads in a region may be isolated and relatively easy to address, what are the cumulative impacts of numerous features on local and regional hydrology and the resulting ecology? Does the cumulative effect constrain how individual sites should be reclaimed or restored or influence the level of responsibility a company may have in restoring a site? For example, if an industrial feature outside of an operator’s area has altered the hydrology within its operating area, will the operator be obligated to restore wetlands to their pre-disturbance state if that is no longer feasible given the new hydrologic regime?

7.0 Gaps Addressed by Work Presently Planned or Underway

7.1 Hydrology

The process-oriented studies lead by Devito and Mendoza have and will continue to contribute to the understanding of the hydrogeologic processes dominating areas within which given disturbances lie. Their hierarchical classification of the dominant factors controlling hydrologic processes (Devito et al. 2005) provides a means to conceptualize the hydrogeologic context within which a given disturbance exists. This context helps identify the dominant hydrologic factors operating within the vicinity of the proposed disturbance or a disturbance to be restored. While addressing hydrologic processes predominantly at a landscape scale, Devito and Mendoza believe the predictive numerical models they are developing will be transferable across the landscape and be informative at various scales. As informative as their research has been thus far, there still remain many questions regarding practical application of this knowledge to restoration of disturbances within wetlands. These are explored in the following section.

The aquifer depressurization being studied by Price and his associates will provide useful information regarding the ecological effects of changes in water supply and water chemistry resulting from changes to patterns of flow. While having distinctly different causes, the ecological effects of drawing large amounts of water from an aquifer may be analogous to other causes of flow pattern disruption such as roads. Furthermore, the information provided by the depressurization study should be directly applicable to the effects of ground water removal for steam generation.

The laboratory work investigating the movement of oil sands mine process-affected water through peat substrate conducted by Price and his colleagues in collaboration with Suncor will be informative regarding near-surface hydrology within peatlands. Such knowledge will be useful in understanding the relationships between surface water and peat vegetation, especially in establishing a resilient self-sustaining surface vegetation layer.

Study of a new road constructed within a fen by Dale Vitt will provide some answers regarding the effects of roads constructed within wetlands. Although the scope will be limited to the single road and whatever parameters he has chosen to measure, the project will initiate the development of a body of knowledge contributing to more thorough understanding of the various effects roads may have in wetland environments.

The Syncrude fen construction will operate as an outdoor laboratory with great potential to enhance hydrologic knowledge for some time. The project provides excellent prospects to test and adjust predictive numerical models of hydrologic behaviour, as well as a unique opportunity to study hydrologic processes as they evolve with the genesis of a new wetland system. The project will enable study of larger scale water delivery processes as well as smaller scale processes of water retention and distribution within and between local plant communities, in addition to providing opportunities to effectively and economically manage water levels artificially.

7.2 Vegetation Restoration

Wetland researchers are presently addressing a number of questions regarding establishment of vegetation. These include selection of various species that are adapted or can adapt to various environments, selection of species that can be grown from seed and what seed treatments might be necessary, and various methods of collecting and propagating vegetation. A number of studies will also provide some information regarding successional trajectories, which will aid in identifying indicators of restoration success. These include the model development by Waddington, the well pad removal and restoration by Vitt, the aerial photo/field plot comparisons by Foote, and of course the work in fen reconstruction by Syncrude. A potentially promising project for predicting successional trajectories and identifying indicators of restoration success is the development of indices of biotic integrity by the students of Suzanne Bayley. However, as indices of "wetland health" their usefulness may be limited to classifying wetlands with respect to how much disturbance they have experienced rather than how much recovery they have achieved. In other words, the indices of biotic integrity may be more representative of how far a particular wetland has been set back from pristine conditions rather than how far it has moved toward pristine because it cannot be assumed that a disturbed site will necessarily follow a predictable successional path back to its original state. Documenting the progression of a disturbed site to its present ecological stage will always be more informative than simply identifying its present stage.

8.0 Gaps Remaining

8.1 Hydrology

While the road study undertaken by Vitt will provide some information regarding the effects of roads, the information will be limited in scope by not examining various construction techniques or various hydrogeologic settings. Most of the questions regarding the hydrologic effects of roads or pads will remain outstanding. Identification of the types of roads and hydrogeologic settings most likely to contribute to disrupted water flows will enable better landscape planning and inform both construction and reclamation practices. The need to better understand the effects of roads and pads is closely linked with the process-oriented studies lead by Devito and Mendoza. The ability to predict water supply to the restoration site is important (Lee Foote, see interview section) not only for restoration purposes, but also to determine how the feature to be restored and other nearby features may be interacting with predicted flows. Numerical models able to make these types of predictions will presumably arise eventually from the work by Devito et al. However, the scale at which construction or reclamation issues should be addressed remains unclear. Foote and Waddington indicated in the conversations with them that they believed understanding and managing surface or near-surface flows were more important than sub-surface flows. On the other hand, Devito et al. (2005) suggested that the importance of surface or sub-surface flows would change with the nature of surficial geologic deposits. Devito et al. (2005) proposed that the factor within their hierarchical classification that explains the most variation in the dominant hydrologic processes without masking the influence of factors lower in the order should be used to identify the scale of interaction to be addressed. But in the case of constructing new or reclaiming existing features, perhaps the most important scale or factor to address is precisely the one with which the feature interacts while at the same time, examining the need to manage for other factors in the hierarchy. For example, if a given feature interacts solely with surface flows but the area's hydrology is dominated by ground water flows, the most prudent action would seem to be managing the feature's interaction with surface flows while considering how fluctuations in ground water supply may influence that management. In such a case, it may not make sense nor may it be possible to manage ground water flows despite them being the most dominant hydrologic process. Nevertheless, the effects of features such as roads and pads need to be better defined so that appropriate management actions can be taken, especially in the context of cumulative effects. This will not be achieved solely by Vitt's work, nor by Devito, et al. A key bit of information that would probably be of the most immediate practical value would be to define the most basic measurements that can be accomplished operationally that will help describe the hydrogeologic context and identify the hydrologic processes likely to dominate in an area of a disturbance. Such information would give construction or reclamation operators a starting point from which to make informed decisions based on the processes with which a feature may interact, both directly and indirectly.

8.2 Vegetation Restoration and Reclamation Techniques

Much past research, as well as much of the research presently undertaken or proposed, has focused on vegetation restoration. Nevertheless, there remains much still to be learned in this area, specifically with respect to energy sector disturbances such as roads, pads, or other earthen features constructed within a wetland environment. So far, we are aware of just the one study of vegetation re-establishment after removal of a well pad and no studies examining restoration of vegetation after road removal. While beneficial, the single study will provide limited information due to its limit in scope in terms of ecosystem type, hydrologic regime, and methods applied. The research regarding species selection and establishment in association with the artificial fen construction will also be of great benefit, but may also be limited to certain types of disturbances. Likewise, additional studies of vegetation re-establishment on mined peat will also be limited to certain disturbance types. While methods applicable to synthetic sites or mined peat sites may be applicable to conventional oil and gas or in situ oil sands operations, many questions will remain unanswered without practice in applying these and other techniques to practical applications. Therefore, additional studies examining options for restoring wetland vegetation to reclaimed roads, pads, or similar features should be pursued. Developing standards for indicators of restoration success that provide some confidence that recovery is on track in terms of time and vegetation trajectory will also be lacking without additional study. Therefore, monitoring or benchmarking studies should be coupled with restoration efforts to help fill this void.

8.3 Other Gaps

Research regarding the specific effects of pipelines and seismic lines remains outstanding. In addition, technical issues such as operating construction or reclamation equipment on wetlands could also be explored to a greater degree. Soft conditions are mitigated to a degree on mined peat sites by surface water drainage. On energy sector disturbances, operations requiring heavy equipment tend to be restricted to frozen conditions, which potentially creates another set of technical issues. Advancements in operating equipment in wet or soft conditions would be extremely beneficial.

Finally, while much interest has been expressed in wetland restoration, some context regarding the extent to which restoration efforts should be taken needs to be established. While the pre-disturbance condition might be the most desirable hypothetically, it may not always be possible or desirable in practical terms. Assessment of alternate landscape scenarios is lacking that could inform both construction and restoration planning. Some work in assessing changes within various landscape metrics would be useful in determining how much change can be accepted within given landscapes while maintaining overall ecosystem function. Such in formation would be helpful in planning and design of both construction and reclamation programs.

9.0 Gap Summary

A summary of the primary questions identified from the literature review and interview process follows below. The questions have been sorted into basic categories of commonality. Following the set of questions in each category is a brief statement of the degree to which the questions have been addressed and what additional actions should be taken. These questions, as well as an approach to addressing them are summarized visually in the appendix following this document.

9.1 Hydrologic Processes

- What hydrologic processes need to be targeted to restore pre-disturbance hydrologic function or hydrologic regimes and what techniques should be used to address them?
- Does a given feature influence the source of water to the area or just its distribution? In other words, has the feature disrupted ground water connectivity or merely disrupted surface flows?
- In either case, what are the effects beyond the feature and how far beyond the feature are hydrology and ecology influenced (local, regional)?
- Given the relatively isolated nature of well pads, and in some instances roads, will re-establishing surface/near surface connectivity between the restored and intact areas mitigate the effects of localized disconnectivity with ground water?
- How can surface connectivity be best established?

While most of these questions are site specific, they should be answerable in more general terms once interactions between industrial features and wetlands are better understood. The hierarchical framework developed by Devito et al. (2005) provides a model by which to address the question of what processes to address, but a practical method of applying the framework has yet to be developed. A great first step would be to define a basic procedure for measurements or information gathering that could be applied on an operational basis that would help define the hydrologic context within which a feature to be constructed or restored resides. Additionally, techniques to manage the processes identified in order to restore or establish specific hydrologic conditions have not yet been explored much and should be investigated.

9.2 Feature or Hydrologic-Driven Practices

- To what degree must construction or restoration practices be site specific and how can guesswork be reduced or eliminated? Are there any universal treatments or practices that should or can be applied?
- Do all roads produce damming effects? What are the construction and hydrogeologic factors that contribute to damming?
- Should construction methods differ based on the surficial geology and groundwater connectivity inherent within the vicinity of a given site?
- How does the longevity of a feature affect post-reclamation restoration success? For example Michael Waddington suggested that prolonged existence of a road may cause vegetation-driven hydrologic changes on the downstream side, such as deeply rooted trees drawing down the water table, thereby limiting successful introduction of mosses or sedges.

Conversely, rapid flooding as a result of road removal might also interfere with vegetation establishment or may kill desirable vegetation that already exists.

Presently there do not appear to be definitive answers to these questions. The Devito et al. HEAD and HEAD II work should eventually shed some light on them, but additional work directed specifically to understanding the interactions between industrial features and wetlands would be beneficial. In discussions with Devito and Mendoza they have indicated that damming will be less likely to occur with roads built upon coarse surficial deposits than on fine-textured surface deposits. No one has addressed the feature longevity issue. A synoptic comparison of road locations and construction methods would be useful to help identify the types of roads and hydrogeologic settings most likely to result in disrupted water flows. Such information would also help inform both construction and reclamation planning processes. Ultimately, the development of a decision tool by which disturbance and wetland characteristic combinations could be classified so that class-based generalized construction or restoration approaches could be prescribed, is desirable.

9.3 Restoration Targets and Cumulative Effects

- Should the original hydrologic regime be returned or should a new regime be established?
- Should the pre-disturbance plant community be the target for restoration community establishment, or should a more practically achievable target be strived for?
- What are the cumulative impacts of numerous features on local and regional hydrology and the resulting ecology?
- Do cumulative effects constrain how individual sites should be reclaimed or restored or influence the level of responsibility a company may have in restoring a site?
- If an industrial feature outside of an operator's area has altered the hydrology within its operating area, will the operator be obligated to restore wetlands to their pre-disturbance state if that is no longer feasible given the new hydrologic regime?
- What alternatives should be considered if a site will not be restored to pre-disturbance conditions?
- What degree of permanent landscape change is acceptable or can be tolerated without altering landscape function?

Some of these questions seem to be primarily addressable on a site-specific basis, yet overall, each of these questions should be addressed at a broader landscape-level planning scale. Disturbances on wetlands have a high potential for connectivity via hydrology. Furthermore, given potentially greater difficulty in restoring wetland disturbances as compared to upland disturbances, there may be a greater propensity to restore a wetland disturbance to an alternative post-disturbance condition. While a decision to do so may make sense on a site-specific basis, it may not make sense on a greater landscape basis if too many disturbances have already been restored to alternative conditions or if the feature has undesirable effects on hydrology or ecology elsewhere. These questions remain predominantly unanswered. Scenario modeling of various landscape alternatives should be completed to help provide direction regarding the desirability of potential restoration outcomes on a landscape basis, especially with respect to determining the appropriate blend of active landscape planning with piece-meal restoration approaches. It may also be useful to determine whether this blend might vary regionally, whereby some regions may tolerate a greater degree of site-specific efforts while others may require more active planning based on specific hydrologic or ecologic conditions within them.

9.4 Vegetation Establishment and Restoration Success

- If fill materials used for a constructed well pad or road are not chemically compatible with the surrounding wetland, will transplant material from adjacent donor sites adapt to the conditions on the recipient site or will plant material need to be imported from elsewhere?
- If importation is required, from where should material be imported?
- What are the logistical constraints related to transportation of material and associated costs?
- Which plants are suitable for transplanting or establishment from seed?
- When are the best times or seasons to collect seeds or transplant individual plants?
- Are there specific seed or substrate treatments that are required?
- Should plant or soil protection measures be taken?
- Should seedlings be established in a greenhouse and then out-planted to the restoration site?
- Is natural revegetation appropriate, and if so, in what circumstances?
- What are the indicators that restoration efforts have been successful or are on the right path, and how long will it take for these indicators to be measurable?

Much of the work conducted to date, and that which is underway or planned, is directed to addressing these questions. Despite this focus, the magnitude of potential combinations of conditions is so great, that many of these questions may remain unanswered for some time. Therefore, opportunities to study practical restoration methods on wetland disturbances should be actively pursued. There is much opportunity to learn from the research that is presently underway, but building upon and sharing new information will hasten the successful outcomes of future restoration efforts. Maintaining links among the various research efforts will be important to facilitate this information sharing. Furthermore, additional studies of practical reclamation work will also provide opportunities to fill in a number of the knowledge gaps related to hydrological processes and their interactions with disturbances. Continued monitoring of implemented practices will also help to develop appropriate restoration assessment protocols and identify indicators of restoration success.

10.0 Application to Removing the Wellsite Footprint Program Phase II

The discussion below is summarized visually in the appendix following this document.

10.1 Linking Research Priorities to Research Opportunities

While much study towards understanding wetlands and restoration of disturbances within wetlands has begun, many questions remain unanswered. Many of the questions originally raised in our initial workshop remain relevant despite the information acquired from the literature review and researcher interviews. The knowledge gap "themes" identified during the workshop also seem to still apply, but could be refined somewhat on the basis of the gap analysis. One of the workshop-identified themes related to developing better understanding of wetlands and how disturbances interact with them so that construction and reclamation operations could be better informed and better planned. This theme also sought to address broader decisions regarding the layout of disturbances and targets for their eventual restoration on the landscape based on societal and ecological values. A second theme related to "on the ground" practices for road and pad reclamation and construction. The third theme related to post-reclamation, and possibly post-construction, monitoring that served as an active adaptive management feedback loop into the first two themes. The three themes refined could be re-expressed as follows: a) a theme focusing on practical techniques for construction or restoration of roads and well pads; b) an effects analysis and documentation theme that examines what the hydrologic and ecologic effects of features are so that restoration needs are more clearly understood; and c) a landscape assessment and planning theme that addresses issues of cumulative effects and how to manage for them. The monitoring of restoration and construction projects that was identified as a theme during the workshop would be incorporated into the three themes as applicable in order to continually enhance knowledge. The effects analysis and practical techniques themes are of greater immediate priority than the landscape assessment and planning theme not only because they will provide much needed information for construction and restoration practice, but also because they will provide information to facilitate the landscape assessment and planning. In addition to prioritization based on apparent industry need, the research opportunities presently available based on logistical requirements and candidate sites available among contributing partner operations need to be considered in decisions of what specifically should be studied. Potential research opportunities presently available based on study site candidates include the following:

1. Evaluating practices for restoration of roads and pads
2. A synoptic study of the hydrologic and ecologic effects of roads and well pads
3. Evaluation of practices for new construction of roads and well pads
4. Assessment of alternative landscape scenarios

Evaluation of restoration practices would be completed on candidate sites presently available. Practices to be evaluated would be selected based on best present knowledge regarding site characteristics and applicability of practices or treatments. Such work could be engaged in immediately or as opportunities and candidate sites arise in the future. Pre and post-restoration assessments of hydrologic and ecologic responses would be completed to the extent possible given project scheduling. These evaluations fit into the “practical techniques” theme.

A comparative synoptic study of pad and road effects could also be initiated immediately if desired and would include a historical aerial photo analysis to identify roads that do and do not produce damming effects, as well as provide some initial characterization of such sites. The aerial photo exercise would be followed up with collection of existing mapped data describing the bedrock and surficial geology of the sites. Finally, field measurements of local hydrologic parameters and road construction variables would be taken. All of these pieces of information would then be collated to develop a decision tool for describing and predicting the construction and environmental factors likely to contribute to damming effects by roads. Such synoptic studies fit into the “effects” theme, and together with the HEAD and HEAD II work, could contribute information to construction of new roads, restoration of existing roads, or planning the layout of a road system on the landscape via development of criteria-based decision tools.

Evaluation of practices for new construction would occur as opportunities arise based on availability of suitable candidate sites. Such evaluations could fit into both the “practical techniques” and “effects” themes. Alternative practices used in new construction could be assessed in terms of their potential for minimizing undesired hydrologic or ecologic effects. Pre-and post-construction assessments would identify the effects of feature installation on hydrologic and ecologic parameters. Alternatively, the effects of innovations incorporated into recently constructed roads, or roads scheduled to be built before adequate pre-construction monitoring can be completed, could be assessed as part of the synoptic study discussed above. Though not as robust as a true before-after comparison, such assessments will still provide valuable information.

The alternative landscape scenario assessment will, of course, be part of the landscape assessment and planning theme and is likely to incorporate some form of computer-simulation modeling. Initial models need not be spatial but ultimately spatial models would be the most useful for evaluating the consequences of various scenarios. For example, some companies have proposed partial restoration of well pads whereby perimeter areas of the pad will be restored to wetlands, while the central portions will be converted permanently to uplands. What are the consequences of this proposal from the perspective of ecological function? Will these upland islands affect local or regional hydrology?

Will they alter the overall habitat matrix or simply redistribute habitat components? What is the resultant carbon balance? Is there a threshold number or proportion of wells that can be treated this way without adversely affecting ecological function? Can increase in upland islands be compensated for by enhanced wetland restoration in borrow areas? These are the types of questions that would require answers to properly assess the cumulative consequences of multiple dispositions with multiple disturbances on the landscape and to properly manage for them. A broader landscape approach is likely to be important in the long run to enhance the overall effectiveness of future restoration efforts. However, even without complex models, initial landscape assessments that describe the various landscape components and their proportions, together with increased understanding of feature effects, will enhance planning of feature construction, layout, and eventual restoration.

10.2 Removing the Wellsite Footprint Program Strategy

All of the opportunities described above are worthwhile and pursuit of any of them would address critical knowledge gaps. Therefore, a simple option might be to pick any one of them to start on, complete it, and then move on to a next. However, a more holistic approach would be to develop a longer-term strategy whereby sequential or concurrent projects feed into each other to provide more continuity to the learning and enhance applicability to operational practices. In this case, a project with good potential to supply answers to critical short-term questions while laying the foundations for future work could be selected. Planning and preliminary work for the next phase could be completed concurrently with the initial work so that the transition between phases occurs seamlessly. Continued monitoring would also provide a mechanism for evaluating future questions to address. Evaluation of restoration or construction practices, as well as the synoptic study, could be initiated almost immediately, while the landscape assessment modeling would likely require additional consultation among industry, government, and NGOs prior to initiating.

We are presently proposing to blend the two options described above. First, we are proposing to initiate a project to address the immediate concerns of both provincial regulators and industry with respect to development of sound practices for restoring hydrologic and ecologic function to decommissioned well pads and roads. Two features, a well pad on an Imperial Oil disposition and a road operated by Japan Canada Oil Sands, are scheduled for decommissioning in the near future and will provide the study sites for this project. Second, we will evaluate potential interest and funding sources available to pursue the additional research opportunities, as well as evaluate progress on the first initiative, in order to determine the feasibility of integrating those opportunities into our program. Following is a synopsis of the questions to be addressed in these studies.

10.2.1 Initial Study Sites

The Imperial Oil study site involves removal of a well pad constructed from clay fill within a treed rich fen. The fill material will be removed along a gradient from full to partial removal. Material left in place will be sloped so that the lower and upper ends of the slope straddle the water table, thereby producing a hydrologic gradient. Specific questions are:

1. What water table conditions are required to sustain specific passive or active revegetation efforts?
2. How can those water table conditions be sustained?
3. What influence will remaining fill chemistry have on recovery outcomes and species selection for active revegetation?

Active revegetation practices, in addition to passive natural revegetation, may include any or all of the following: whole acrotelm transplantation, transplantation of plant diaspores, transplantation of plant plugs.

The Japan Canada Oil Sands study site is a 450 m long road constructed across a treed poor fen that will also be removed. There is a gradient in peat depth from one end of the road to the other, ranging from about 1 m at one end and 6 m at the other. Questions will be similar to the pad removal study, but may also compare the results of partial versus complete removal of the road from both deep and shallow peat locations.

10.2.2 Potential Future Work

These are some of the potential questions to be addressed by future integration of the additional research opportunities:

1. Are “floating” roads (those constructed on top of peat covered by a geotextile liner or some other form of separation) truly floating? In other words, are they truly buoyant or suspended without making contact with the underlying mineral soil, or do they eventually sink as fill is added incrementally until they finally rest on the underlying mineral surface? How far do they sink and what are the hydrologic consequences?
2. Within a given hydrogeologic setting, do “floating” roads have the same impact on hydrologic and ecologic variables as roads constructed on the base mineral soil underlying peat?
3. Are there hydrogeologic settings where one or the other of these practices produce fewer negative impacts?
4. What other construction alternatives are there for building roads within wetlands?

11.0 Conclusion

Much interest has recently been generating in studying the problems of construction and reclamation of industrial features in wetlands, and rightly so given the number of outstanding questions remaining in this regard. While growing interest and activity in this area is laudable, change in practices will most rapidly be effected if sufficient networking is achieved among those studying or applying new practices. Therefore greater communication, and perhaps collaboration, should be encouraged among researchers and practitioners in this area.

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Appendix: Visual Summaries of Knowledge Gaps, Consolidating Themes, and Proposed Research

See Figures A.1 and A.2 below.

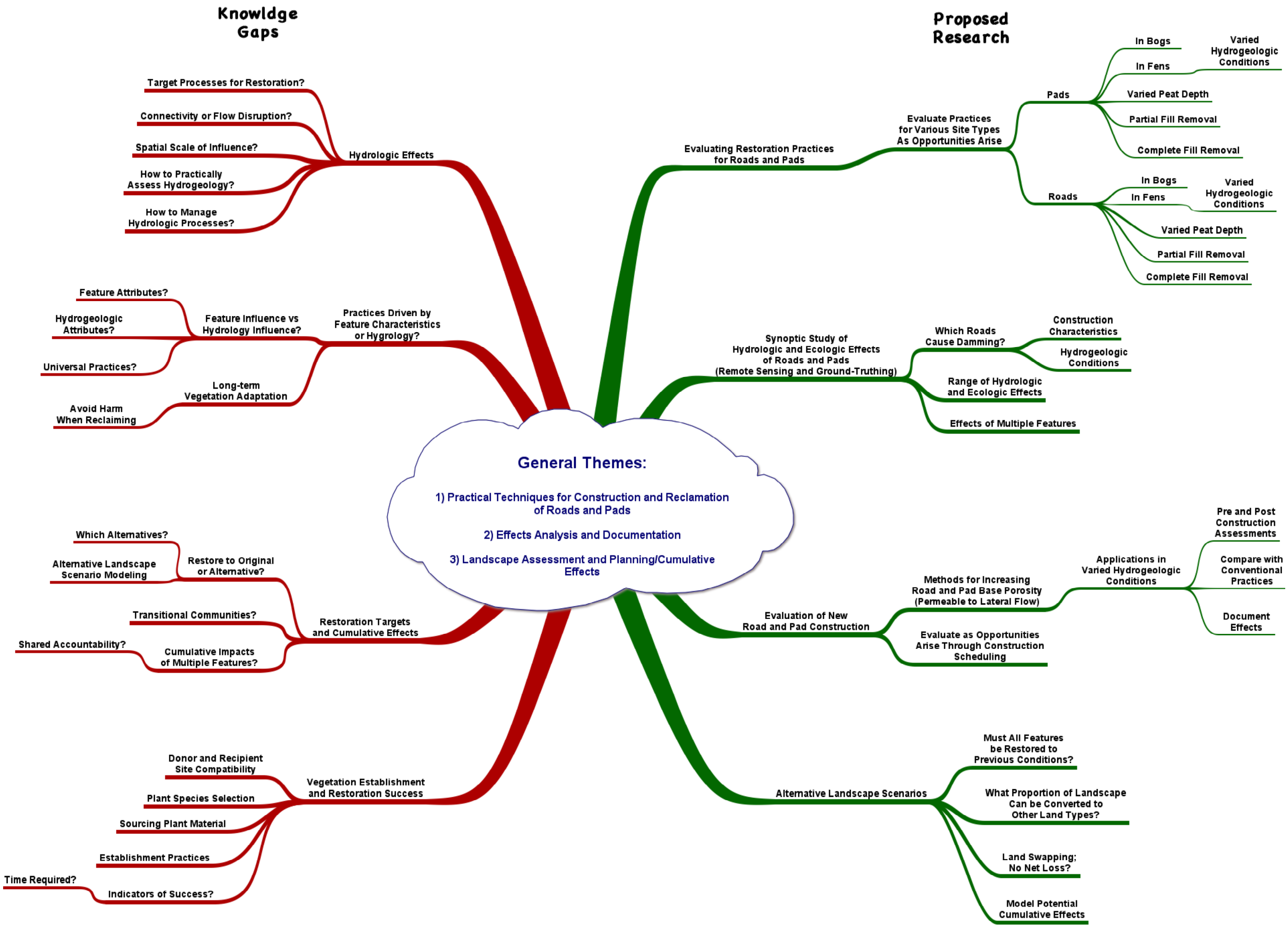

Fig A.1. Map summary of knowledge gaps (red), general themes arising from them (blue), and proposed research to address the themes (green).

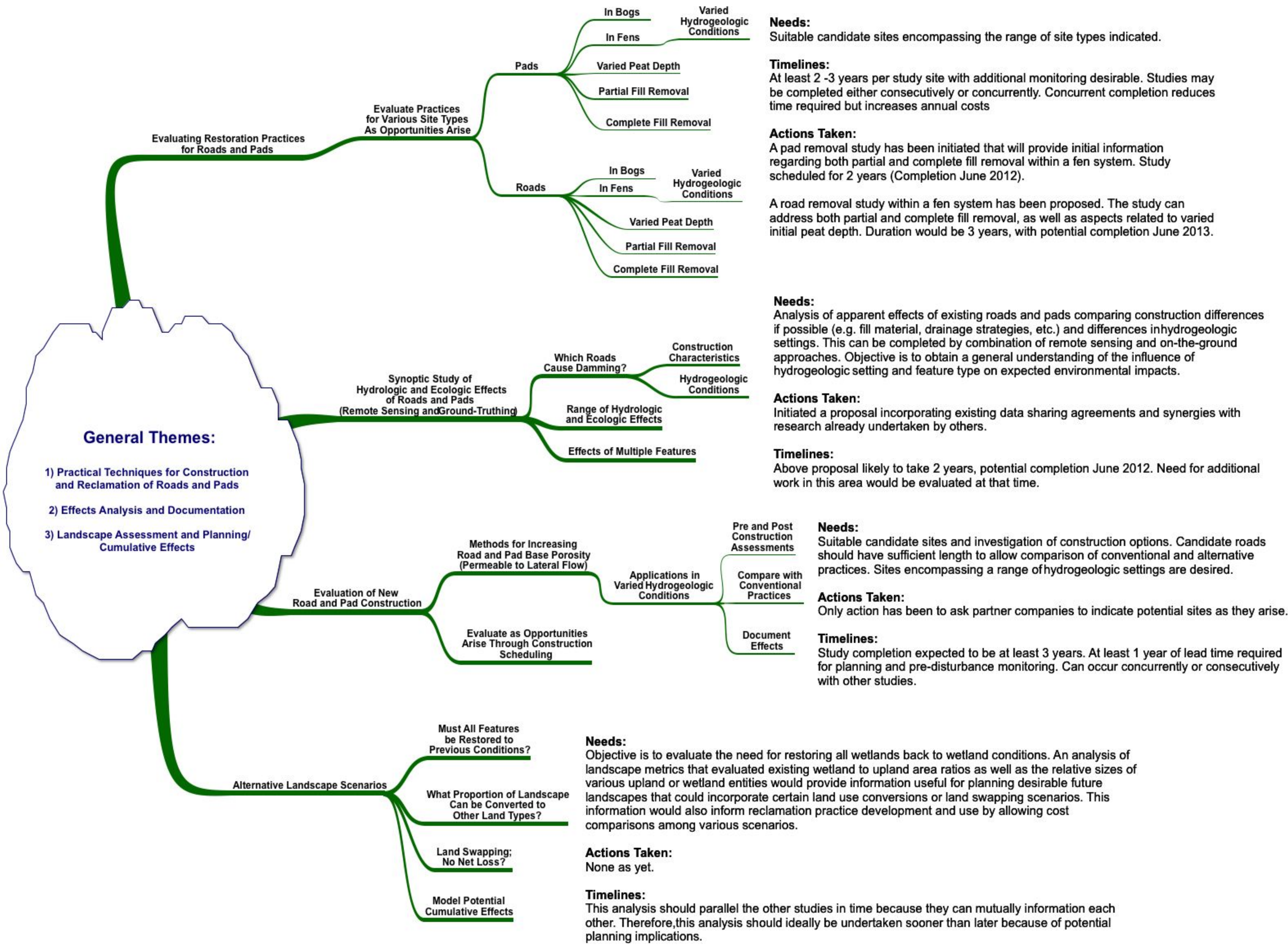

Fig. A.2. Notes on needs, actions, and timelines for proposed research.