Recommendations for a Wetland Crossings Monitoring Protocol

A report for the Foothills Stream Crossing Partnership

Prepared for:
fRI Research

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Executive Summary

Wetlands are highly valuable ecosystem features because of the numerous ecosystem services they provide (e.g., water filtration, groundwater recharge, carbon sequestration) and because of the habitat they provide for many organisms. Wetlands are prominent throughout the boreal region of Alberta and in many cases overlap areas of natural resource interest for forestry and oil and gas companies. Permanent resource roads may therefore be built through wetlands, and these "wetland crossings" may have environmental impacts if not designed appropriately. Such wetland crossings pose unique challenges with respect to operational and structural performance, and may benefit from a regular, formalized monitoring system. However, monitoring systems currently in place for wetland crossings rely on protocols designed for stream crossings. Streams and wetlands are markedly different landscape features that have unique ecological characteristics, and therefore require different monitoring and management approaches.

To ensure that wetland crossings are properly maintained and minimize their impacts on surrounding ecosystems, the Foothills Stream Crossing Partnership (FSCP) expressed an interest in developing a protocol for evaluating wetland crossing performance and prioritizing repairs to crossing structures. The FSCP therefore engaged Fuse Consulting, Circle T Consulting, FPInnovations, and Ducks Unlimited Canada (DUC) to develop a suite of recommendations to inform a potential wetland crossings monitoring protocol.

The main focus of this report is to provide recommendations regarding what parameters could be measured in the field to assess the environmental and structural performance of wetland crossings. A secondary focus of the report is to make general recommendations for structuring a potential monitoring program, including factors such as frequency/timing of monitoring, personnel/training considerations, and reporting and data management. To collect the information required to make these recommendations, we completed a literature review, six interviews with resource extraction companies and regulatory agencies, and field tours of two forestry companies' wetland crossings.

A brief summary of our core recommendations is as follows:

1. Invest in wetland education to improve wetland expertise within resource companies.

Wetlands are diverse and often quite complex in the boreal region of Alberta. However, very little training has been given to help communicate this degree of complexity to on-the-ground crews who are making decisions about wetland crossing designs. In the interviews completed as part of this project, many individuals acknowledged that this knowledge gap is likely causing a barrier to appropriate planning, construction/design, and monitoring of current wetland crossings. We suggest that a short course or training session could be used at each company to educate and orient staff prior to the implementation of a wetland crossings monitoring protocol, and to communicate more generally about wetland systems in the boreal region of Alberta.

2. Use a common language to facilitate effective management of wetland crossings.

We acknowledge that many companies are already strongly familiar with stream crossings, and subtle differences in definitions and language between wetlands and streams may present a barrier to uptake of a wetland crossings monitoring protocol. For example, within our suite of recommendations we provide a clear definition of a wetland crossing, which is different from the definition of a stream crossing. We define wetland crossings as the entire length of road that intersects the wetland, meaning that wetland crossings are longitudinal features (not point features, like stream crossings). Without clear communication of these types of differences (e.g., wetland classifications, crossing definitions), it is possible that wetland crossings may be mismanaged. We recommend that the FSCP establish a common vocabulary related to wetland crossings and prioritize consistency in their communications to optimize the effectiveness of the wetland crossings monitoring protocol.

3. Match the monitoring protocol to the wetland class.

Different wetland classes require different monitoring and management approaches. Each class of wetland has unique characteristics, meaning that the potential impacts of crossings may be different depending on what class they are traversing. For example, lack of water flow through a resource road crossing a fen could result in gradual ponding of water and dieback of vegetation on one side of the road over time, whereas lack of water flow through a class of wetland with greater seasonal fluctuations in the water table, such as a marsh or swamp, could result in flood damage to crossing structures and the road surface.

The effects of roads can be different depending on wetland class, so a wetland crossings monitoring protocol should be designed with these differences in mind.

4. Prioritize maintenance of hydrology to preserve wetland function.

Hydrology is a critical component of a healthy wetland. Many of the ecological problems related to poorly constructed wetland crossings, such as dieback/release of vegetation, flooding, and alteration of wetland classes, are direct results of disrupted hydrology. Hydrological characteristics such as water flow, water level, and seasonal flooding patterns determine the physiochemical environment of a wetland, which in turn determine the biota present on that wetland. Hydrology underlies much of the ecological functioning of wetland ecosystems, and we therefore recommend that maintaining wetland hydrology should be the main outcome of a wetland crossings monitoring protocol. Put another way, we suggest that hydrology should occupy the same level of importance in the wetland crossings protocol as fish passage does in the FSCP stream crossings protocol.

A detailed list of the parameters we recommend including in a potential wetland crossings monitoring protocol can be found in the *Key parameters to measure* section of this report, including justification and rationale for the inclusion of each measurement.

Contents

Introduction

Why this project?

The Foothills Stream Crossing Partnership (FSCP) has been working successfully in the foothills of Alberta to help resource extraction companies inventory stream crossings and prioritize them for repairs. The FSCP stream crossings program strives to have a lasting impact on important fish-bearing streams and to reduce the impact of stream crossings on key foothills ecosystems. Building on the success of the stream crossings program, FSCP partners are now interested in expanding their work to the boreal region of the province. However, partners recognize that boreal ecosystems are different from foothills ecosystems and will require a broader evaluation than the current stream crossing evaluation protocol. Specifically, the boreal region contains a significant number of wetlands in comparison to streams, and these wetlands require a different focus for evaluation and monitoring. In addition, a provincial wetland policy has recently been established in Alberta which aims to maintain wetland function across the landscape (Government of Alberta, 2013). This policy may entail different regulatory expectations or requirements for operations on wetlands compared to streams.

For these reasons, FSCP partners commissioned this expert review, aimed at gathering science-based recommendations to help inform a potential monitoring protocol to evaluate the performance of boreal wetland crossings in Alberta.

For the purposes of clarity in this report, the following definition of wetlands is used (Government of Alberta, 2013):

> "Wetlands are land saturated with water long enough to promote formation of water altered soils, growth of water tolerant vegetation, and various kinds of biological activity that are adapted to the wet environment."

Why a focus on wetland crossings?

Linear features such as roads, stream crossings, and wetland crossings can cause large ecological impacts. The main potential ecological impacts of wetland crossings include:

- Disruption of natural water flow through the wetland
- Fragmentation of habitat used by both aquatic species and species-at-risk (e.g., boreal caribou)
- Impacted water quality through erosion and sedimentation
- Increased greenhouse gas emissions due to loss of carbon sequestration in the wetland

- Disruption of predator-prey interactions due to roads acting as travel corridors for predators
- Increased road mortality of wildlife due to vehicle collisions
- Disruption of wildlife behaviour (e.g., breeding calls) due to noise disturbance

In particular, hydrologic impacts on wetlands due to road crossings can be drastic on a landscape scale (Figure 1).

Figure 1. Poorly designed wetland crossings can result in a blockage of surface and/or subsurface water flow through the wetland. When water flow is not maintained properly, the wetland on one side of the road may dry and experience active tree growth, while the other side of the road becomes wetter and experiences ponding and vegetation dieback. Images courtesy of Ducks Unlimited Canada (DUC).

In boreal Alberta there are 15.2 million hectares of wetlands (33% of the boreal landbase), which means wetlands are very prevalent and often hard to avoid (Figure 2).

Wetland crossings may also have as-yet unstudied impacts on amphibians in the boreal region of Alberta. Generally, literature from studies in other regions indicate that roads are linked to declines in amphibian populations (Cunnington et al. 2014). Roads in wetlands can cause mortality of amphibians due to vehicle collisions, fragmentation of amphibian populations, bisection of amphibian movement pathways, and exclusion of animals from critical habitats (Hamer et al. 2015). Traffic and industrial noise may also affect amphibian calling behaviour (Parris et al. 2009), and rural road networks have been shown to act as barriers to gene flow for amphibians (Garcia-Gonzalez et al. 2011).

Construction on wetlands is challenging compared to upland sites due to the poor bearing capacity of the parent material (e.g., peat). The inherently saturated soils and the presence of peat require construction techniques that differ from traditional upland road building. There can be structural challenges that require specialized techniques (e.g., working in frozen conditions, pre-loading/peat consolidation) and materials (e.g., use of geotextiles and geocells). Ongoing monitoring and maintenance are common in the first few years after construction to ensure the performance of the road and safe operations. Wetland crossings also tend to be far more complex than traditional stream crossings. As an example, wetland crossings can extend from hundreds of metres to several kilometres, while most stream crossings may only extend for 20-50 metres.

In addition, wetlands transport water above and/or below ground and water levels may fluctuate seasonally and/or annually. During drought cycles and dry periods, wetlands in the boreal plains store and redistribute water across the landscapes. During wet cycles or periods, an enormous amount of water can be transported below and above ground through boreal wetlands in Alberta. A wetland crossing designed and constructed during a dry cycle may therefore not perform well during a wet cycle.

Wetlands can be challenging to manage because there are different types of wetlands that have different ecological characteristics (e.g., soils, hydrology, vegetation, wildlife). In Canada, there are a few different wetland classification systems. For the purposes of clarity in this report, we use the Alberta Wetland Classification System (AWCS; Alberta Environment and Sustainable Resource Development 2015), which is the system we recommend for a potential wetland crossings monitoring protocol. At the highest level of classification, there are five main wetland classes: bogs, fens, swamps, marshes, and shallow open water (see Table 1 for an overview). According to the AWCS, these wetlands can be further classified into 12 forms (e.g., shrubby fen, wooded bog).

This wide variation in wetland appearance, including the presence of thick vegetation on some wetland types, can lead to wetlands not being recognized or managed for by resource extraction companies. The problems produced by crossings may also be slightly different depending on wetland class. Crossings therefore need to be monitored and managed in a manner that is specific to the class of wetland they are traversing.

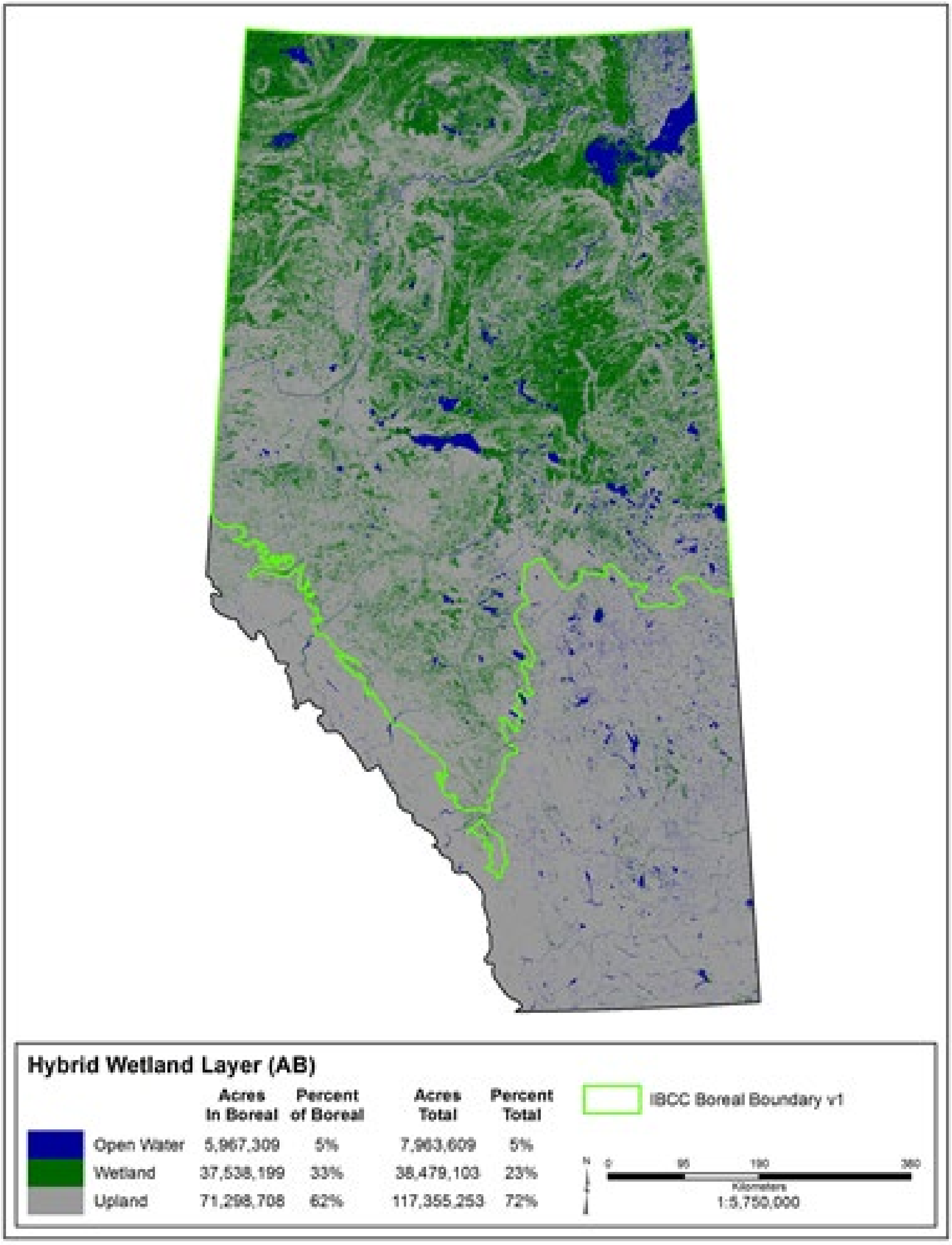

Figure 2. Area of the Alberta landbase occupied by wetlands and open water. Wetlands are particularly abundant in the boreal, occupying 33% of the region. Image courtesy of DUC. *Note: 37.5 million acres is equivalent to 15.2 million hectares.*

Table 1. A summary of the five main wetland classes found in the Alberta boreal region (adapted from Ducks Unlimited Canada et al., 2014). Images courtesy of DUC.

Soil type	Wetland class	Description	Examples of potential problems at crossings
Organic (peatlands)	**Bog** 	• Deep (> 40 cm) deposits of peat • Elevated above surrounding terrain • Receive water and nutrients from precipitation • Most nutrient-poor class • Wooded, shrubby, or graminoid • Possible vegetation: black spruce, sphagnum moss, Labrador tea, bog cranberry, sedges	• Damage to peat integrity during construction • Altered water chemistry due to sedimentation or erosion of road surface • Ponding on road due to settlement of substrate • Improper road design if not recognized as a wetland
	Fen 	• Deep (> 40 cm) deposits of peat • Influenced by slow, lateral water movement; amount of water flow can increase significantly during wet cycles • More biodiverse/productive than bogs • Wooded, shrubby, or graminoid • Possible vegetation: tamarack, dwarf birch, sweet gale, sedges, buckbean	• Impeded water flow due to culvert blockage • Inadequate number of culverts causing ponded water • Improper road design if not recognized as a wetland
Mineral	**Swamp** 	• Typically < 40 cm of peat or organic matter from decaying shrubs and trees • Common, diverse group • Often transitional between upland forest and other wetlands • Water table can fluctuate seasonally; can move significant amounts of water • Wooded (conifer, deciduous, or mixedwood) or shrubby • Possible vegetation: black spruce, tamarack, white birch, balsam poplar, willow, dogwood, sedges, grasses	• May not be recognized as a wetland crossing, especially if wooded • Upland construction techniques may be used, resulting in crossings that cannot tolerate water table fluctuations • Flooding of road surface and/or vegetation dieback due to lack of water flow

Soil type	Wetland class	Description	Examples of potential problems at crossings
Mineral	**Marsh** 	• Often transitional between open water and shorelines • Water tables can fluctuate seasonally • Water sources from precipitation, run-off, groundwater and stream inflow • Possible vegetation: emergent (cattail, bulrush, sedges) and floating (pondweed, milfoil)	• Inadequate depth of culvert embedment to manage fluctuating water levels • Blocked crossing structures may cause differences in water levels, development of different wetland classes • Beaver activity may result in blocked crossing structures
	Open water 	• Water depths < 2 metres, but too deep for emergent marsh vegetation to establish • Appear to be shallow lakes • Possible vegetation: submerged aquatic (e.g., water-milfoil) and floating (e.g., pond-lily)	• Sometimes wetlands of this type are formed due to blocked crossing structures in other wetland classes/types • If naturally occurring, these wetlands are normally avoided during construction

Different classes/types of wetlands may also be present along a single crossing because wetlands in the boreal are highly connected, often in the form of wetland complexes (Figure 3). Roads crossing through wetland complexes therefore must be designed to deal with the ecological conditions and requirements of a variety of wetland classes.

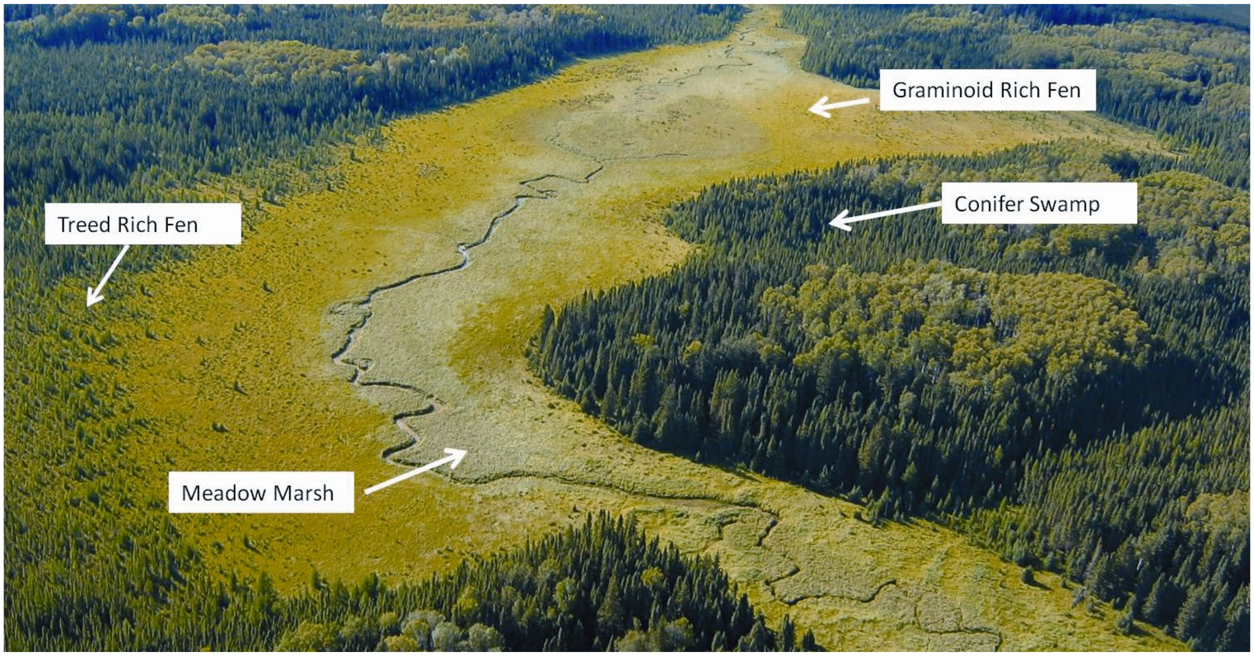

Figure 3. A wetland complex including three different classes of wetland (fen, marsh, and swamp) as well as two different types of fen (treed rich and graminoid rich). Image from Ducks Unlimited Canada (2015).

What makes wetland crossings different from stream crossings?

A separate boreal wetland crossings protocol is needed because wetland crossings are very different from fluvial stream crossings, which are more common in the foothills of Alberta. The hydrology (patterns of water flow) of the boreal plains is different than that of the foothills. The topography, surficial geology, soil depth, and soil types of the boreal plains have resulted in wetland types with unique hydrological characteristics (e.g., water level, flow rate/frequency, connectivity to other water bodies and to the uplands). Maintaining wetland surface and subsurface flows is therefore essential for wetland function in the boreal. Blocking or disrupting wetland surface and/or subsurface water flows can result in changes to the quality and quantity of upstream and downstream water flows, which has the potential to alter plant and animal communities (Figure 4).

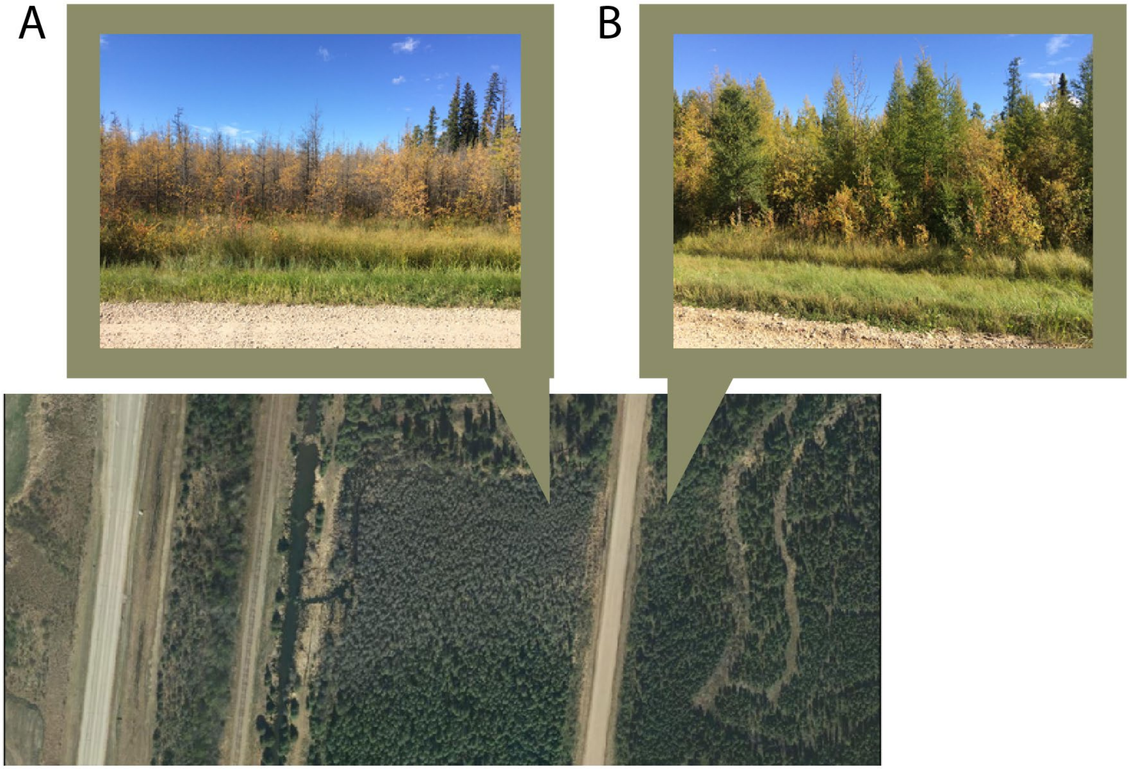

Figure 4. Roads that cross wetlands can have a damming effect that interrupts water flow, causing different hydrologic conditions on either side of the road. This water imbalance can result in drastic differences in vegetation between sides of the road. **A:** up-flow side of the road where water has accumulated and caused anoxic conditions, resulting in vegetation dieback and reduced vigor. **B:** down-flow side of the road where more mesic conditions has resulted in growth release and increased vigor. **C:** satellite image of crossing showing visible differences in vegetation on either side of road. Photos courtesy of DUC.

While there is recognition of the site parameters which may result in the need to repair, redesign and replace fluvial stream crossing structures, especially due to their impacts on fish, there is comparatively less understanding of wetland crossing site parameters and how they should be best managed. Furthermore, since wetland crossings have not historically been distinguished from stream crossings, resource extraction companies often lack specific information on their wetland crossings (e.g., locations, number, type) and typically do not have standardized monitoring protocols. These information gaps suggest there is an opportunity for expert support to ensure wetland crossings are appropriately evaluated and managed.

Currently, many resource extraction companies are using the existing FSCP protocol for stream crossings to evaluate wetland crossings. This approach may be a viable interim strategy to ensure some data are collected, but development of a separate protocol for wetland crossings will ensure more appropriate management decisions are made to maintain wetland function in compliance with the Alberta Wetland Policy.

This project strives to address the above knowledge gaps by providing a theoretical and practical foundation for monitoring wetland crossings.

Objectives

This project was guided by two sets of objectives: those of the current project and those of the overall wetland crossings monitoring protocol. The first set of objectives is provided to ensure clarity of the scope of this document, while the second set of objectives guided project decisions and approaches throughout the process.

Project objectives

1) Perform a detailed review and scoping exercise regarding wetland crossing monitoring in Alberta's boreal region. Information was gathered through a literature review, interviews with company representatives and regulators, and field tours to view current wetland crossings.
2) Use the information gathered to form recommendations for a potential wetland crossings monitoring protocol for the Alberta boreal region.

Monitoring protocol objectives

In line with the objectives of the existing FSCP stream crossing protocol, the wetland crossings monitoring protocol that will be built with the support of the recommendations of this report should be able to achieve the following:

1) Evaluate the environmental and structural performance of wetland crossings.
2) Use the data collected from evaluations to prioritize crossings for upgrade, repair, or replacement.

Approach

Kick-off

A kick-off meeting was held between the project team and FSCP Program Lead, Ngaio Baril, to confirm project goals and scope. During this meeting, the key deliverable of the project was confirmed to be a suite of recommendations for how to evaluate the performance of wetland crossings. As part of this meeting, key areas of concern related to wetland crossings that had been identified by FSCP members were also shared. These key areas served as the foundation for literature searches performed during the project's information gathering phase.

Information gathering

Because there are few published research articles or reports on the topic of wetland crossings, a variety of information sources was used to build the recommendations in this report. Three different methods were used to collect information related to impacts and monitoring of wetland crossings in the Alberta boreal: i) a literature review; ii) a series of interviews with industry representatives, consultants, and regulators (Alberta Energy Regulator [AER], Alberta Environment and Parks [AEP]); and iii) field tours at West Fraser's Slave Lake operations and Al-Pac's operations near Wabasca-Desmarais. By combining academic reports with practical, on-the-ground perspectives, our team was able to capture a broad range of perspectives and expertise on which to base our recommendations.

Literature review

Keyword searches were performed in Google Scholar to retrieve literature related to four key knowledge gaps identified during the kick-off meeting. Each of these were defined as a topic of the literature search, and searches related to specific subtopics under each topic were conducted as needed:

1. Ecological value of wetlands
    - Example subtopics: Do wetlands outside of defined stream channels act as fish habitat?, Tools for assessment of wetland value/quality
2. Operational/structural performance of crossings
    - Example subtopics: Which crossings should be prioritized for repair?, Monitoring road performance
3. Environmental performance of crossings
    - Example subtopics: Effects of sedimentation and runoff, Impacts on fish/amphibian passage

4. Compliance with current and future regulations
    - Example subtopics: Avoidance and minimization of impact

Interviewees from forestry and energy companies were also asked to suggest and/or provide internal documents related to wetland crossings (e.g., best management practices [BMPs], existing monitoring protocols). This request resulted in the acquisition of four documents from one company.

All documents were compiled and ranked by relevancy to the project in order to facilitate an efficient review. Out of 509 documents retrieved, 104 were reviewed. The pertinent points of these papers with respect to the impacts and monitoring of wetland crossings were compiled together and classified by subtopic, including a brief listing of potential outstanding knowledge gaps in each subtopic. This information was used to inform the development of interview questions as well as the content of this report. The full literature review is included in Appendix C of this report, and the full reference list is included in Appendix D.

Interviews

A total of six interviews with companies performing natural resource extraction (herein ‘resource companies’), independent consultants, and provincial regulators were conducted to gain an understanding of resource companies’ current approaches to designing, monitoring, and maintaining/repairing wetland crossings and of regulators’ current and future expectations related to wetland crossings. Both sets of interviews were also used to get input on the development of a practical wetland crossing monitoring system that could work well for both the regulators and industry. In total, we interviewed two representatives associated with the energy sector (one energy company, one independent consultant), four representatives from the forestry sector (three forestry companies), and one representative from the provincial government (Alberta Energy Regulator). Representatives from Alberta Environment and Parks submitted a collective written response.

Themes representing our team’s goals for each interview group are summarized below in Table 2. A full list of the questions used to guide these conversations can be found in Appendix B.

Table 2. Themes addressed in interviews with resource companies, independent consultants, and provincial regulators.

Interview Group	Interview Themes
Resource Companies	• Determine companies' understanding of wetlands and how that understanding may play a role in wetland crossing monitoring protocols. • Learn what responsibilities companies have in wetland crossing monitoring from both a regulatory and operational perspective. • Understand current monitoring protocols; the information collected, why and how; and company satisfaction with present protocols.
Independent Consultants	• As above
Regulators	• Understand the nature of and rationale for any regulations or guidelines for wetland crossing monitoring directed by regulators. • Understand the relationship between the regulatory agencies and the respective industries in establishing standards or criteria for wetland crossing monitoring.

All resource companies engaged in this project were current members of the FSCP. The representatives interviewed represented a wide range of experience within companies, and occupied the following positions within their companies:

- Senior Environmental Coordinator
- Road Specialist
- Harvest Planner
- Operations Superintendent
- Planning Forester

This range of experience greatly benefited our team's process, as we were able to understand perspectives from different levels of management and build a broad picture of how company systems work to coordinate, design, and execute their monitoring programs.

Field tours

Two field tours were conducted on September 25 and 26, 2019. The tours were organized with West Fraser near Slave Lake and Al-Pac near Wabasca-Desmarais. Four to five people attended each of the field days: Clayton Gillies (FPInnovations), Terry Osko (Circle T Consulting), Ngaio Baril (FSCP), and a guide or two from the respective companies.

The purpose of the field tours was to view and discuss three to four wetland crossings at each operating area. Project team members discussed with company representatives the concept and development of a field protocol for assessing the effectiveness of wetland crossings. Key parameters to assess for wetland crossings were also discussed. By including discussions related to operational feasibility, the team was able to gain an appreciation of practical options for on-the-ground repairs to wetland crossings. For example, the assessment of sunken culverts (see Appendix A for example photos) was discussed with company staff, leading our team to conclude that such culverts should not be replaced or removed due to the amount of site disturbance involved with removal operations. During the field tours, the team visited a variety of wetlands, including marshes and bogs (Figure 5).

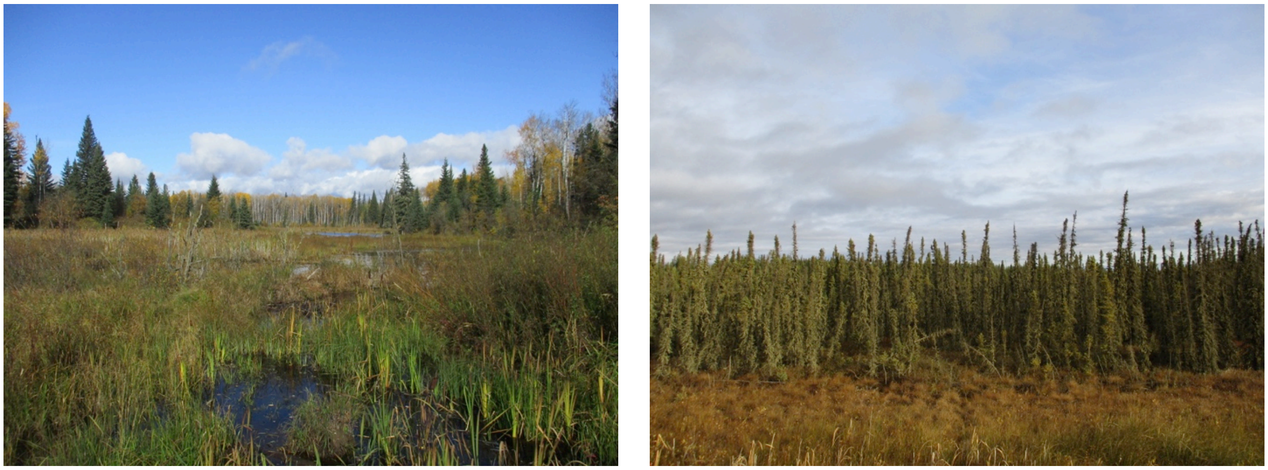

Figure 5. **Left:** view of a meadow marsh with emergent vegetation (i.e., cattails) at the culvert outlet visited during the field tour. **Right:** a bog visited during the field tour. The differences between wetland classes are an important consideration with respect to field assessments. For example, the presence of open water in a marsh is to be expected, yet in a bog the presence of open water may suggest peat disturbance during construction (not shown).

Most of the wetland crossings visited had culverts in place as the conduit for hydraulic connectivity. The use of corduroy, log bundles, and aggregate seams/mattresses was also discussed during field tours. One of the wetland crossings visited near Wabasca-Desmarais has been well documented as a research trial, which provided the group with some important background and construction history.

Information synthesis

In order to collate the information collected and identify themes, we used the following approaches:

- Literature review was read by our team and used as a key reference document for developing interview questions and this report
- Interview responses were organized into summary tables to identify themes in the responses
- Key observations from the field tours were shared with our team and discussed in terms of their alignment with the interviews and literature review
- A project working session was held with our team, including Ngaio Baril (FSCP Program Lead), to discuss and prioritize the report recommendations

A final key source of information leveraged during the writing of this report was our team's expertise, knowledge, and experience in the field of wetland crossings. As we found that that the published literature on the topic of wetland crossings was sparse and often lacked consensus, it was important to draw on our own experiences as professionals. When drawing on our professional experience and opinions, the team kept a focus on the Alberta boreal context and the goal of providing credible advice that can be reliably generalized or adapted for a variety of crossing types and wetland classes.

Key Project Themes

Current state of monitoring

A key objective of our information-gathering process was to assess current monitoring practices used by resource companies and current monitoring requirements in place by provincial regulators. Our aims were to learn from and leverage any existing BMPs, to assess the current state of knowledge with respect to road impacts on wetlands, and to understand current and future regulatory requirements. This information informed our recommendations by helping us understand how a new wetland crossings monitoring protocol might best integrate with current practices, what training or education might be needed to support adoption of a new protocol, and how such a protocol might need to be structured to ensure regulatory compliance. The main findings of our project with respect to the current state of monitoring are presented below.

Wetland crossings represent a substantial knowledge gap within resource companies

Our interviews revealed that consideration of wetland crossings is only in its infancy among resource companies in Alberta. No resource company representative stated their company had a specific wetland crossing monitoring program in place, and many representatives had incomplete knowledge of their wetland crossings (e.g., locations, number, condition, type). Interviewees frequently stated they felt wetland knowledge is a prominent gap for resource companies, and that they would like to obtain more knowledge of wetlands through increased training or hiring of wetland specialists. Only one company indicated they were aware of the five wetland classes and used this information to characterize their wetland crossings.

Interviewees acknowledged that a lack of understanding about how to define, classify, and delineate wetlands could be limiting their capacity for fine-scale management and monitoring. Examples of how knowledge gaps might be impacting wetland management include:

- Different wetland classes (i.e., bog, fen, swamp, marsh, or open water) may be recognized, but the knowledge or processes required to manage classes differently is lacking, so they are all treated the same
- Wetland classes may not be properly recognized, delineated or classified at the planning stage, which can lead to inappropriate construction and monitoring programs (i.e., approaches based on upland construction and monitoring techniques) (Figure 6)
- Resource roads through wetlands may not be recognized or conceptualized as wetland crossings, especially for roads through peatlands (bogs and fens) and deep

peat conifer swamps, which can lead to an inappropriate level of monitoring and maintenance

- In particular, peatlands (bogs and fens) may not be recognized as wetlands based on most companies' wetland definitions in their Operating Ground Rules (e.g., 'open water' or 'waterbody')

Figure 6. Two short sections of road with multiple wetland crossings, demonstrating the complexity of delineating and recognizing wetlands on boreal industrial landscapes. Proper identification of crossings requires accurate delineation of the surrounding wetlands, and each crossing may require slightly different construction, management and monitoring depending on wetland class. **Top:** four wetland crossings and one stream crossing on a single road. **Bottom:** a road surrounded by four different classes of wetland (image courtesy of DUC).

During interviews with company representatives there was particularly poor recognition of peatlands (bogs and fens) as wetlands. However, several interviewees emphasized avoidance or winter construction/use as primary strategies for the management of peatlands. This management approach may suggest that companies are aware of the ecological sensitivity of peatlands, or it may reflect risk aversion, as peatlands are especially challenging and costly construction surfaces. However, peatlands are a ubiquitous feature across the boreal landscape and therefore difficult to avoid during resource extraction activities.

Several interviewees highlighted a need for education, research, and tool development with respect to wetland management. Some specific questions and gaps highlighted by interviewees were:

- How should we set thresholds related to wetland disturbance (e.g., how much ponded water is "too much")?
- How can we measure road settlement?
- What are the effects of water chemistry/pH on building materials (e.g., "disintegration" of corrugated steel pipe at some sites)?
- Spatial tools/spatial layers to enable planning based on wetland classification
- How should we measure ecosystem health on each side of road (i.e., what measurements would be the best indicators)?
- Impacts of winter crossings (especially across bogs and fens; e.g., effects on thawing and freezing rates) and potential remediations
- A system for ranking wetland value, including baseline assessments of crossings, in order to prioritize crossings for monitoring and repairs
- Are there impacts of pollution (e.g., fuel/debris deposits)?

In the long term, more research and trials are needed to address some of the above questions (e.g., effects of water chemistry on building materials, impacts of winter crossings). Some gaps may be addressed by future regulations and policy implementation. For example, a field-based wetland value ranking system (Alberta Wetland Rapid Evaluation Tool [ABWRET-A]) has been developed by Alberta Environment and Parks for Parkland-Grassland and Boreal-Foothills Natural Regions (Creed et al., 2018; Government of Alberta, 2019), and it is possible this part of the Alberta Wetland Policy will be implemented more intensively in the future. In particular, the expansion of ABWRET spatial tools to the Green Area of the province ('ABWRET-E'; currently only available in the White Area) would likely allow companies to assess and manage relative wetland value at a landscape scale.

Current monitoring relies on stream crossing protocols

Despite not having a specific wetland crossing monitoring protocol, some company representatives interviewed reported they were still attempting to monitor their wetland crossings. In these cases, they used the FSCP stream crossings protocol or the AER watercourse crossing inspection form to monitor wetland crossings. Both of these initiatives are mainly focused on fluvial stream crossings, which are mostly found in the foothills region. Interviewees usually recognized this approach as being a “better than nothing” solution until a more wetland-specific approach can be developed.

In these cases where a wetland crossing monitoring program was present, but not specifically tailored to wetlands, we found the following themes in interviewee responses:

- Monitoring was often coordinated by consultants external to the resource company, especially in the energy sector
- Crossing assessments were often done by summer students or temporary field staff
- Frequency of monitoring was highly variable among companies: some companies assessed all their crossings multiple times per year, others assessed annually, and others had a range of frequencies that were driven by risk rankings
- Assessments were mainly focused on culvert/cross-drain function (e.g., checking for culvert blockages, settlement, and evidence of water flow)

Awareness is increasing

There is increasing awareness about the importance of wetland crossings, and some companies are currently inventorying their crossings in preparation for potential regulatory changes. Many company representatives also recognized a need for the expertise of wetland specialists to help manage crossings.

All company representatives interviewed recognized wetlands as potentially valuable/sensitive areas, and often expressed that avoidance is their primary strategy. Companies strongly preferred to avoid construction on peatlands (bogs and fens), and often stated they only operate on peatland surfaces during frozen ground conditions to take advantage of the improved bearing capacity of the otherwise weak soil. The avoidance approach is in line with the Alberta Wetland Policy, which emphasizes avoidance as the first step in its mitigation hierarchy (avoid, minimize, replace).

Regulatory requirements are evolving

Similar to the trend of increasing wetland awareness within resource companies, regulator guidelines for wetland crossings are also evolving as relevant knowledge increases. AER is currently developing inspection forms specific to the boreal region, which include considerations for wetlands. A pilot program was run during the spring/summer of 2019 to test the effectiveness of the new forms, and this pilot will be reviewed by AER and the FSCP in the fall/winter of 2019/2020. It is likely that the strong engagement of AER will lead to improvements in wetland crossing monitoring within the energy sector.

In response to our interview request, AEP representatives provided a written commentary reflecting statements in the Alberta Wetland Policy (Government of Alberta, 2013). We are therefore unable to comment thoroughly on the level of engagement that AEP may have with wetland crossings going forward; however, the implementation of the Alberta Wetland Policy will continue, and the FSCP should therefore be aware of the main target outcomes of this policy:

- Wetlands of the highest value are protected for the long-term benefit of all Albertans
- Wetlands and their benefits are conserved and restored in areas where losses have been high
- Wetlands are managed by avoiding and minimizing negative impacts, and, where necessary, replacing lost wetlands
- Wetland management considers regional context

To support the achievement of these outcomes, the following regulatory requirements are currently in place:

- A Water Act authorization is required for roads crossing wetlands
- The wetland's delineated area and relative value must be determined by an authenticating professional using the ABWRET tool
- If wetland impacts cannot be avoided or reclaimed, the proponent must meet wetland replacement requirements in one of two ways:
    - Restoring or constructing a wetland
    - Paying a wetland replacement fee to AEP

Additional specific regulatory requirements that may be developed in order to achieve the Alberta Wetland Policy target outcomes are currently unclear. The FSCP should remain attentive to any forthcoming communications from AEP as the agency continues to gather information.

Possible challenges for adoption of a new protocol

To help the FSCP anticipate challenges that may emerge when developing and implementing a wetland crossings monitoring protocol, we also recorded possible barriers to adoption of a new protocol during our interviews. A few possible issues were raised by interviewees and are summarized below.

The main barrier preventing more detailed monitoring and management of wetland crossings is a lack of wetland knowledge and expertise, both within resource companies and the research community. In general, company representatives are not well versed on wetland classification and principles of wetland ecosystems, which reduces their ability to manage crossings in an evidence-based way. Many companies are also unaware of all their crossings (e.g., location, type). This information is often missing because wetland crossings have not traditionally been a part of companies' asset management programs. Wetlands may also not have been recognized during the construction of legacy and inherited dispositions (i.e., dispositions constructed prior to policies and BMPs aimed at avoiding wetlands). The FSCP should anticipate that a significant amount of time will need to be invested early in the process of implementing a new protocol to improve company knowledge of wetlands and to document existing wetland crossings.

Finally, there is a lack of knowledge from a research perspective. Many questions about wetland crossings remain unanswered (see *Current state of monitoring* and potential research gaps in Appendix C), and the results of our team's literature review revealed only a few peer-reviewed articles on the topic of wetland crossings. More research is required to enable adaptive and progressive management of wetland crossings. The FSCP should be aware that this area of research is in its early stages and that the wetland crossings monitoring protocol should be continuously updated over time to ensure consistency with the best available science.

A few other issues were raised by interviewees; these, however, were less frequently mentioned and may not represent significant barriers. These other issues included:

- Financial limitations due to current economic climate:
  - Companies may be seeking to do the minimal amount of monitoring required to operate within guidelines/regulations
  - Time may be limited for field assessments prior to construction
- Difficulties and inefficiencies while merging old and new data management systems (e.g., internal company systems transferring to Government of Alberta forms or FSCP app)
  - Some interviewees expressed an interest in having an interface for transferring data from previously developed systems to the current FSCP system
- Lack of direction/clarity regarding legal requirements from Alberta Environment and Parks has caused some frustration, as proactive construction and maintenance efforts of forestry companies may not be recognized (e.g., a well-designed crossing may be considered identical to a poorly designed crossing when it comes to regulatory approvals)

- Challenges with prioritizing crossing repairs at a large scale (e.g., watershed level) due to differences in planning horizons among industries (e.g., forestry vs. energy) and lack of coordination among companies
- Uncertainty and potential concerns related to winter roads across wetlands, especially peatlands (unsure of the impacts or if potential remediations are required)

Interviewee recommendations for a monitoring protocol

During our interviews and field tours, we asked representatives from companies and regulatory agencies what they would like to see represented in a wetland crossings monitoring protocol. From company staff, we sought to understand what common problems were noted in the field and what they felt could practically be measured. From regulators, we sought to understand what information was desired from a compliance perspective. Both groups provided their opinions based on field, academic, and regulatory experiences, including their insights on requirements related to personnel, training, and data management.

What information should be collected?

Without question, a key point of consensus among all interviewees was **the importance of maintaining natural hydrology**. Interviewees recognized hydrology as a key ecosystem component that is integral to all wetland classes. The importance of hydrology is also consistently recognized in both the published and grey literature on boreal wetlands. Interviewees pointed out several problems they have observed at wetland crossings in terms of contrasts between one side of the road and the other, which are likely related to disrupted hydrology (e.g., impeded water flow). These included ponded water, dead trees/vegetation, and drying out of the wetland.

A wetland crossings monitoring program should therefore strive to assess hydrological characteristics and indicators of hydrologic disruption due to the presence of a road. Three potential parameters to measure were frequently suggested by interviewees:

- Evidence of water flow
- Presence of ponded water/drying out of wetland on one side of the road
- Presence of dead or dying vegetation on one side of the road

Figure 7. Examples of problems at wetland crossings likely related to hydrologic disruption. **Left**: flooding on one side of road, causing die-off of vegetation and potential development of an open water wetland. **Right**: flooding over top of road, likely leading to saturation of the road base and increasing proneness to rutting; differences in vegetation on either side of road also suggest that wetland flow may be impeded.

Several interviewees also expressed that wetland value (e.g., presence of species-at-risk, sensitivity of the area) should be considered during monitoring. Two interviewees independently suggested similar systems, whereby wetland value would be the main factor used to determine the structure of a monitoring program (e.g., frequency and intensity of monitoring needed at each crossing). Under this type of program, a thorough baseline assessment would be carried out at each site prior to the establishment of a long-term monitoring program, which would be informed by the baseline assessment. This assessment would include a wide variety of factors to assess wetland value, such as hydrology, connectivity to fish-bearing streams, wildlife habitat, soils, and vegetation. This proposed approach is in line with the Alberta Wetland Policy, which emphasizes triaged wetland management based on relative wetland value.

Apart from the two major themes above, our interview process also generated a list of other potential parameters that could be measured during monitoring. There was no clear consensus among interviewees as to the relative importance of these factors. The full list is provided in Table 3 below.

Table 3. Potential parameters to measure in a wetland crossings protocol, as suggested by interviewees. This list excludes two broad themes that were mentioned by multiple interviewees: hydrology and wetland value.

Category/theme	Parameters
Site description	• Wetland class • Type of conduit/crossing structure (e.g., culvert, log bundle) • Dimensions of crossing (length and width) • Substrate/fill material • Presence of wildlife/species-at-risk
Condition of structure	• Structural damage (e.g., disintegration of pipe, deformation of culvert) • Seasonal damage (e.g., heaving of silt soils) • Road settlement • Culvert function (e.g., presence of culvert blockage) • Winter roads only: rebounding of road surface/peat heaving up
Condition of surrounding wetland	• pH • Water quality/chemistry • Erosion/sedimentation • Changes in vegetation over time • Peat disturbance within right-of-way (e.g., gouges, scalps, ruts, ditches) • Balance of water depth on either side of road • Pollution

Who should collect the information?

Four company interviewees agreed that junior staff or temporary summer staff (e.g., students), with the appropriate training and tools, would be fully competent to do regular wetland crossing monitoring assessments. Three interviewees supported the idea of having a two-tiered approach where a junior staff member would complete an initial routine field assessment and flag potential problems, then a more experienced staff member would revisit flagged crossings later to diagnose the problems and design an approach to repair the crossing. These interviewees indicated a desire to have a wetland specialist handle the follow-up assessments, who could be an internal company employee or an external consultant.

The Qualified Wetland Science Practitioner (QWSP) designation was mentioned several times as an example of how to determine who is qualified to do these more thorough crossing assessments; however, it is important to note that the QWSP designation no longer exists. This designation has been superseded by a system wherein each of the professional regulatory bodies (e.g., Alberta Society of Professional Biologists [ASPB], Alberta Institute of Agrologists [AIA]) set competencies within their respective professions for wetland practitioners (Government of Alberta, 2017). Therefore, there is not currently an official designation on which to base the screening of candidates for wetland specialist positions in Alberta.

A common theme in the interviews was the importance of training to support personnel. All company interviewees saw value in having a training session/short course to educate their staff about how to perform wetland crossing evaluations. One interviewee said they saw a basic training component as being “absolutely required” for a wetland crossings monitoring program to work. Two interviewees highlighted the importance of such a training session to encourage changes in practice, as some workers may be resistant to changing their current approaches.

Some interviewees also expressed that there is a broader need for wetland education in general (e.g., wetland definition, how to classify wetlands). One interviewee who has worked for a wide range of energy companies indicated that understanding wetland classes is “an evolving process.” Company employees may also use out-dated maps when more recent spatial data is not available, resulting in poor decision-making based on a lack of understanding of current conditions.

One interviewee suggested that an annual calibration session should be used to help ensure consistency in monitoring assessments. The calibration session would be a field trip including both regulators and company representatives where the group practices field assessments together using common tools. This session would not be a formal training but would rather serve as an opportunity to practice and to ensure everyone is on the same page before the field season begins.

How should the information be collected?

There are several other aspects to consider besides what data to collect and who to hire when designing a monitoring program. Some of these considerations include frequency of monitoring, duration of monitoring period, how to select/define monitoring locations, and how best to collect/store the information. We briefly discuss interviewee insights on each of these aspects below.

Frequency of monitoring: Company interviewees indicated a wide range of variation in monitoring frequencies under their current programs, ranging from multiple times per year to once every five years (based on risk ranking). There was no clear consensus among interviewees when asked for a recommended monitoring frequency; however, two interviewees did propose similar systems whereby monitoring frequency would be determined by wetland value (e.g., high-value sites are visited more frequently than low-value sites).

Monitoring duration: One interviewee suggested that wetland crossing monitoring may need to occur over a longer timeframe than stream crossing monitoring. This modification was suggested due to the slow build-up of issues that can occur in a wetland, especially those related to hydrology/water flow (e.g., ponding of water and/or changes in vegetation over time). Several years of monitoring effort may be required before such issues become evident.

Selecting/defining monitoring sites: All company interviewees indicated that spatial tools are a core part of their planning process. Typically, spatial tools are used to delineate wetlands and wet areas, and construction plans are then designed to avoid or minimize contact with such areas. A Planning Forester interviewee suggested that wetlands may not always be recognized properly at the planning stage, which would inhibit appropriate construction and hinder identification of wetland crossings for monitoring. The interviewee indicated that new spatial tools are needed to integrate wetland classification better at the planning stage, which will lead to more accurate and comprehensive identification of wetland crossings within companies.

Collecting/storing information: Most resource company interviewees supported continuing with the FSCP for collecting and storing information, particularly due to the benefits associated with data/asset management and prioritization of repairs. One interviewee also suggested that maintaining a consistent approach (e.g., digital/app-based, similar process for data entry, similar training/type of personnel hired) would help to ensure a wetland crossings protocol is adopted by industry.

Our Recommendations for a Monitoring Protocol

Summary

Our core recommendations for a wetland crossings monitoring protocol can be broadly summarized into four key themes:

1. Invest in wetland education to improve wetland expertise within resource companies.

Wetlands are diverse and often quite complex in the boreal region of Alberta. However, very little training has been given to help communicate this degree of complexity to on-the-ground crews who are making decisions about wetland crossing designs. In the interviews completed as part of this project, many individuals acknowledged that this knowledge gap is likely causing a barrier to appropriate planning, construction/design, and monitoring of current wetland crossings. A wetland crossings monitoring protocol will be most successful if it is paired with training programs about boreal wetland ecosystems, including the road planning and construction techniques commonly used for wetland crossings. We suggest that a short course or training session could be used at each company to educate and orient staff prior to the implementation of a wetland crossings monitoring protocol, and to communicate more generally about wetland systems in the boreal region of Alberta.

The key areas that such a training session should address include:

- Definition of a wetland
- Definition of a wetland crossing
- How to identify the five classes of wetlands
- An overview of the unique flow characteristics of each wetland class (e.g., seasonally fluctuating, stagnant, slow lateral flow)
- An overview of common planning and construction phases unique to wetland crossings
- Key monitoring priorities for roads crossing each class of wetland

Other options to help increase wetland literacy could also include:

- An annual calibration session with regulators and companies (practice using the monitoring protocol as a group)
- Encouraging companies to hire wetland specialists or develop in-house expertise to supervise their monitoring program
- Encouraging companies to take advantage of existing resources (e.g., field guides, DUC Wetland BMP Knowledge Exchange services)

We discuss options for wetland education and training in more detail in the section *Personnel and training* (pg. 56).

2. Use a common language to facilitate effective management of wetland crossings.

We acknowledge that many companies are already strongly familiar with stream crossings, and subtle differences in definitions and language between wetlands and streams may present a barrier to uptake of a wetland crossings monitoring protocol. For example, within our suite of recommendations we provide a clear definition of a wetland crossing, which is different from the definition of a stream crossing. We define wetland crossings as the entire length of road that intersects the wetland, meaning that wetland crossings are longitudinal features (not point features, like stream crossings). Without clear communication of these types of differences (e.g., wetland classifications, crossing definitions), it is possible that wetland crossings may be mismanaged. We recommend that the FSCP establish a common vocabulary related to wetland crossings and prioritize consistency in their communications to optimize the effectiveness of the wetland crossings monitoring protocol.

In particular, the FSCP should ensure that they use consistent definitions for the following terms/concepts:

- Wetland
- Wetland classes
- Wetland crossing
- Crossing structure/conduit
- Types of crossing structures/conduits
- Road class
- Road attributes (e.g., road embankment, road base, road surface material)

We discuss these definitions in more detail in the section *An operational definition of wetland crossings* (pg. 29) and suggest references to use in the section *Personnel and training* (pg. 56).

3. Match the monitoring protocol to the wetland class.

Different wetland classes require different monitoring and management approaches. Each class of wetland has unique characteristics, meaning that the potential impacts of crossings may be different depending on what class they are traversing. For example, lack of water flow through a resource road crossing a fen could result in gradual ponding of water and dieback of vegetation on one side of the road over time, whereas lack of water flow through a class of wetland with greater seasonal fluctuations in the water table, such as a marsh or swamp, could result in flood damage to crossing structures and the road surface.

The effects of roads can be different depending on wetland class, so a wetland crossings monitoring protocol should be designed with these differences in mind.

We discuss in more detail how a wetland crossings monitoring protocol could be structured to address the differences in wetland classes in the section *Key parameters to measure* (pg. 32).

4. Prioritize maintenance of hydrology to preserve wetland function.

Hydrology is a critical component of a healthy wetland. Many of the ecological problems related to poorly constructed wetland crossings, such as dieback/release of vegetation, flooding, and alteration of wetland classes, are direct results of disrupted hydrology. Hydrological characteristics such as water flow, water level, and seasonal flooding patterns determine the physiochemical environment of a wetland, which in turn determine the biota present on that wetland. Hydrology underlies much of the ecological functioning of wetland ecosystems, and we therefore recommend that maintaining wetland hydrology should be the main outcome of a wetland crossings monitoring protocol. Put another way, we suggest that hydrology should occupy the same level of importance in the wetland crossings protocol as fish passage does in the FSCP stream crossings protocol.

We discuss in more detail what parameters related to hydrology should be considered in the sections *Other monitoring considerations* (pg. 52) and *Key parameters to measure* (pg. 32).

An operational definition of wetland crossings

Wetland crossings differ markedly from stream crossings in two key ways:

- Wetlands vary in size from tens to thousands of m^2. In addition, wetlands are often interconnected as wetland complexes. As a result, unlike a stream crossing, a wetland crossing may extend hundreds of meters to several kilometers.
- Since wetland crossings are longer, they may not have a single conduit or crossing structure (e.g., culvert, bridge). Multiple crossing structures may be needed along the length of the crossing (see Appendix A8).

Given these key differences, we propose that it is appropriate to have a distinct definition for wetland crossings. Our recommended definition is: **the entire length of road that intersects a wetland** (Figure 8), which may include multiple crossing structures/conduits.

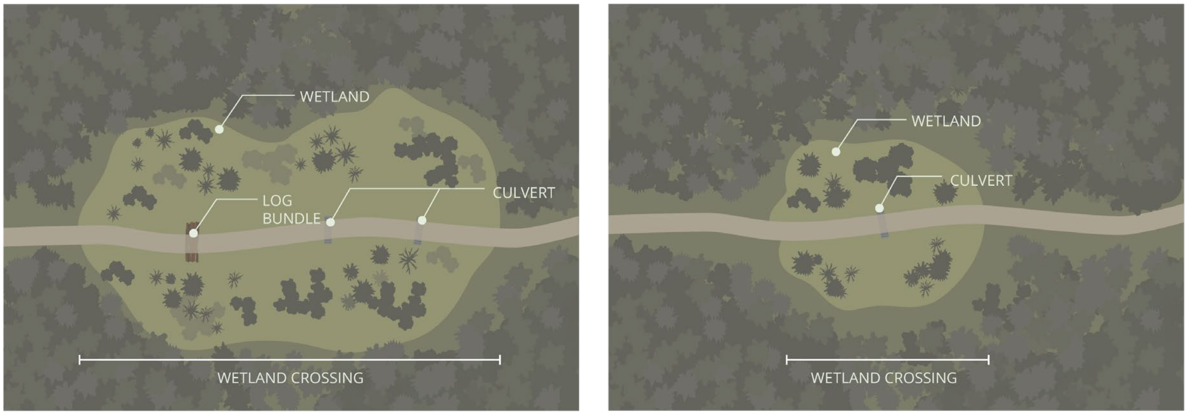

Figure 8. Conceptual diagrams to demonstrate our proposed definition of a wetland crossing. Each hypothetical crossing is defined as the entire length of the road that overlaps with a delineated wetland (light green). **Left:** a long wetland crossing including three crossing structures/conduits (a log bundle and two culverts), as may be observed in fens. **Right:** a short wetland crossing with one culvert, as may be observed in swamps.

Wetland crossings may also traverse defined stream channels, meaning that stream crossings may occur within the stretch of road defined by the wetland crossing (Figure 9).

Figure 9. This section of road crosses a large wetland complex (wetland crossing; indicated by white bracket) which also contains a defined stream channel (stream crossing; indicated by black bracket).

Importantly, our wetland crossing definition includes crossings that may have **no crossing structures or conduits**. Due to knowledge gaps regarding wetland identification, resource roads often cross wetlands erroneously identified as uplands. In these cases, there may be no conduit or crossing structure in place. A wetland crossing monitoring program should strive to include these crossings in its scope, as these roads may be of high priority for assessment and potential upgrading (e.g., installing a crossing structure).

Key parameters to measure

This section of the report describes in detail the parameters that we recommend measuring for monitoring of wetland crossings, including both desktop and field assessments. Monitoring parameters on wetlands can be divided into four broad categories:

1. **Contextual parameters (wetland class, crossing size, etc.)**
2. **Structure functional parameters (integrity, number, size, and function of crossing structures)**
3. **Road integrity parameters (erosion and sedimentation)**
4. **Ecological parameters (evidence of water flow/impediment)**

Although structural parameters are related to wetland hydrology, it is important to note that water flow across roads may be poor even though all structures are functioning and in good condition. The issue may be that the structures are too few, too small, or not ideally placed. Impeded water flow may also result in prolonged wetting of the road foundation by ponded water, affecting road integrity and safety. Additionally, similar to the stream crossing protocols, erosion and sedimentation are important monitoring parameters; however, in wetlands, the effects of these are not primarily on fish habitat. Instead, erosion and sedimentation mainly have impacts on wetland chemistry and associated vegetation, which may in turn impact habitat of other species (e.g., amphibians).

Our team considered fish habitat parameters to be optional. We provide additional discussion of fish habitat in the sections to follow. Briefly, most boreal wetlands are likely not productive fisheries, but some may have potential to be fish-bearing. It is important to understand however, that wetlands are the primary sources of water within boreal landscapes. Properly functioning wetlands are vital to the health of streams and rivers in the boreal.

In the following sections we provide a brief discussion of each category, including our rationale for including the category in the monitoring protocol. We break down each category into a list of potential parameters to measure, which is presented in an accompanying table for the category. Note that some recommended parameters are discussed only in the tables provided.

Contextual parameters

Completing these identifications or observations prior to the detailed inspection will help set expectations or the context for the inspection, enabling the inspector to focus on the relevant questions for each site. These observations can be made as part of a desktop exercise prior to field inspections using visual tools such as aerial or satellite imagery, wetland classification maps, and the Alberta Wetland Classification System guide as a reference. However, it is important to note that field verification may be helpful or required to support accurate measurement of several of these parameters (e.g., wetland class, presence of wildlife). A full list of contextual parameters is provided in Table 4, where we have also indicated which parameters would benefit from supplemental work in the field.

Table 4. Contextual parameters. These characteristics should be assessed prior to a field inspection, and can be identified using spatial tools. For example, wetland class/type can be identified using DUC's Enhanced Wetland Classification or the Alberta Merged Wetland Inventory.

Parameter	Observation/Measurement	Sub-Classifications	Relevance
Wetland Class/type (via desktop exercise; confirm during field inspection using Alberta Wetland Classification System or other appropriate field guide)	Wetland class on both sides of the crossing should be identified. It also may be possible to identify if the wetland being crossed is part of a large wetland complex.		Wetlands vary in soil type, peat depth, surface water abundance, chemistry, and vegetation. Knowledge of these characteristics will inform the inspector regarding expected road, structure, and drainage performance within crossings, as well as the cues to look for to identify potential deficiencies. Crossings that appear to traverse different wetland classes could indicate hydrologic impairment.
	Bog Fen	Graminoid	
		Shrubby	
		Wooded	
	Marsh	Meadow	
		Emergent	
	Swamp	Conifer	
		Tamarack	
		Hardwood	
		Mixedwood	
		Shrub	
	Shallow open water		

Parameter	Observation/Measurement	Sub-Classifications	Relevance
Wetland Location	Boundary of wetland; location of the wetland within the watershed		Wetlands lower in the watershed may move more water (and therefore be higher priority) than those higher in the watershed.
Crossing Length	Tens of meters to thousands of meters; length can be verified in the field and used to help identify the extent of the wetland boundary		Wetland crossings include the length of road intersecting the wetland. Longer crossings are more susceptible to drainage and water flow problems, and may require more crossing structures/conduits. This measure will help inform the inspector regarding the potential types of structures to look for, as well as some of the cues for identifying deficiencies.
Location of Crossing within Wetland	Is the road fully within a specific wetland or is it at the edge or transition to another land type?	Inner Edge/Transition	Contrasts in vegetation across roads are important indicators of drainage issues. However, roads may be constructed along edges of wetlands or transitions between them to avoid construction on the poorest ground. In such cases, observed contrasts in vegetation across roads may be natural artifacts of a change in land type intersected by the road rather than a road-induced drainage issue. Understanding this context will help prevent misinterpretation of observations.
Age of Crossing	Years		Age of crossing can help estimate severity of identified issues. For example, subtle vegetation changes over many years between sides of the road indicate minor flow impediment, whereas dramatic changes over fewer years may indicate higher flows and greater impediment.

Parameter	Observation/Measurement	Sub-Classifications	Relevance
Presence/Proximity of Wildlife Species (via desktop exercise if spatial layers are available; otherwise during field inspection)	Visual observation or evidence of these species (e.g., game trails, scat, dens, houses, dams, feathers) should be recorded at crossings during field inspections. Note if multiple individuals are observed and estimate group size.		Wetlands provide key habitat for wetland-associated wildlife. This can include migratory stopovers and feeding sites for migratory birds, breeding habitat for amphibians, and food/cover for mammals. The presence of certain wildlife may also be of importance to local Indigenous groups and other land users (e.g., rat root, moose) or from a regulatory perspective (e.g., species-at-risk, invasive species, fish). Finally, beavers may present an operational challenge at wetland crossings (i.e., debris from beaver activity may block crossing structures/conduits), and are therefore important to be aware of.
	Presence of species of special concern	Species of conservation concern (e.g., boreal caribou, Canadian toad)	
		Subsistence species (e.g., moose)	
	Presence of species of cultural importance (e.g., rat root)		
	Presence of invasive species		
	Presence of other species of regulatory and/or operational interest	Beaver	
		Fish	
Weather, Climate and Season (during field inspection)	Note the weather conditions (e.g., rainy, foggy, sunny)		Weather conditions and season provide context for interpreting the results of the field inspection. Noting of climate conditions may help to interpret whether inspection was conducted during a wet or dry cycle.
	Note the season (fall, winter, spring, summer) - can be inferred from field inspection date		
	Note if conditions have been drier or wetter than normal		

Structure functional parameters

For the most part, these parameters would be assessed in the field similarly to the existing FSCP stream crossing protocol, but some additional factors or interpretations may be unique to wetlands, such as:

Depth of culvert embedment (Figure 10): culverts in peatlands and swamps should be sufficiently embedded to accommodate both surface and subsurface flows. Percent embedment should be measured from the wetland substrate (e.g., peat, water) surface downwards, and may have to be estimated approximately in locations where peat has been removed during culvert installation. Culvert diameter is related to embedment depth since an adequate diameter is required to facilitate sufficient embedment. Culvert diameter has been linked to flow characteristics of wetland classes (e.g., stagnant, slow lateral flow, seasonally fluctuating; Partington et al., 2016). For example, culverts 800mm in diameter and greater have been suggested to accommodate water flows in seasonally fluctuating wetlands.

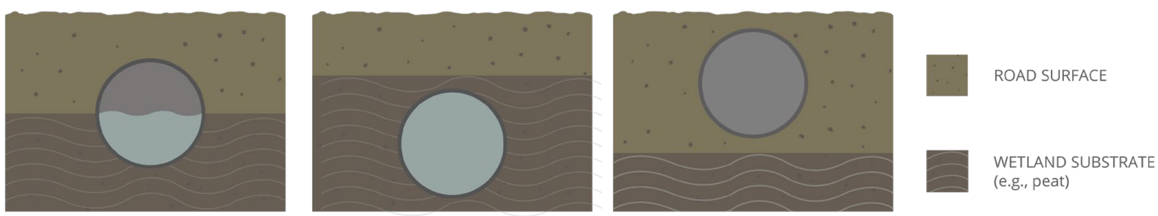

Figure 10. Cross-section of road with examples of an embedded culvert as opposed to sunken or perched culverts. **Left:** 50% embedded culvert allowing surface and subsurface flows. **Middle:** sunken culvert; culverts may sink below the wetland substrate (e.g., peat, water) over time. **Right:** perched culvert; culverts may become perched above the wetland substrate over time.

Number and spacing of culverts (Figure 11): similar to the existing FSCP stream crossing protocol, it is important to record the number of crossing structures used within a wetland crossing. However, it is also important to record the space between the crossing structures within a wetland crossing. Because subsurface and surface waterflow through a wetland is not often channelized, but rather occurs throughout the wetland, multiple crossing structures may be needed across the length of the wetland crossing to ensure waterflow is not impeded (Figure 11). Too few culverts can cause ponded water or an elevated water table on the up-flow side (Figure 11B), leading to differential moisture conditions across the road and ecological impacts described in the *Ecological parameters* section (pg. 41). Too few culverts can also cause “fire-hosing” by concentrating water flow, resulting in channeling of flow on the down-flow side of the road (Figure 11D).

Bowing or other culvert distortion: bowing is far less likely to occur on upland stream or shallow peatland crossings, but can be very common in deeper peatlands.

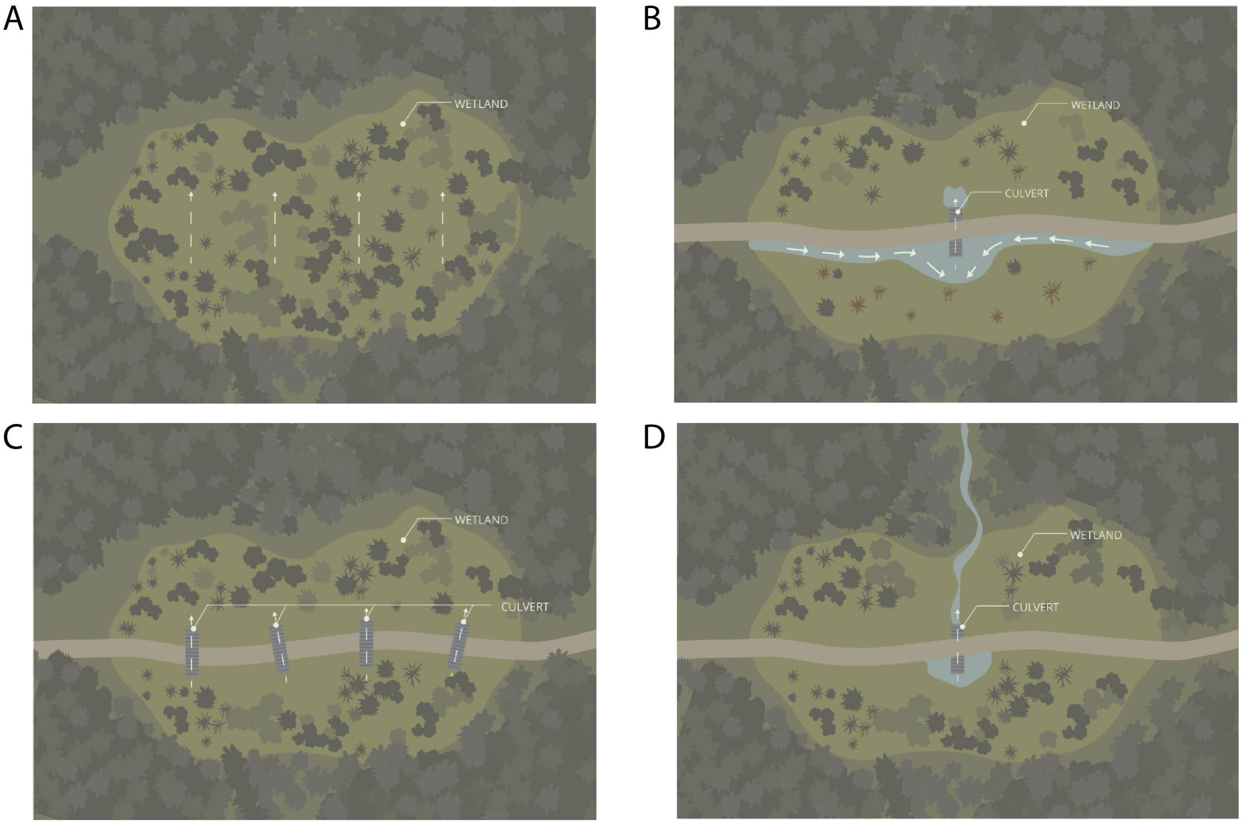

Figure 11. Aerial view of hypothetical wetland crossing showing three different scenarios related to number of crossing structures/conduits. White arrows indicate water flow. **A:** natural water flow across the wetland prior to construction. **B:** too few culverts causing impeded water flow, resulting in ponding of water and dieback of vegetation on one side of the road. **C:** multiple culverts allowing water to flow across the road at multiple locations, resulting in similar vegetation on either side of road. **D:** too few culverts causing impeded water flow, resulting in “fire-hosing” (channelization of culvert outlet) on the up-flow side of the road.

Table 5. Structure functional parameters. These parameters relate primarily to the physical integrity and performance of specific individual structures encountered within crossings. For the most part, these field observations could be completed according to the existing stream crossing protocols. Some of the stream crossing parameters are identified specifically based on concerns associated with various wetlands. The *Class-Specific Observations* column lists conditions that might be observed as well as recommendations for best practice.

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance
Structure Size/Dimensions	Length and width of structure; can follow existing stream crossings protocol	All	Observations are common to all wetland classes	Basic measures of expected structure performance and safety
Evidence of Physical Damage	Damage, wear, corrosion, etc.; can follow existing stream crossings protocol	All	Observations are common to all wetland classes	Basic measures of expected structure performance and safety
Structure Type	Name/Identify the structure type, including material composition (e.g., corrugated steel solid steel, HDPE/plastic, aluminized)	Bog Fen Swamp Marsh	Structures may include culvert, log bundle, pipe bundle, rock drain, wick drain, drainage blanket, corduroy, bridges, etc. Bridges may be more appropriate for marshes.	Inspector awareness of possible drainage structures in use not common to stream crossings
Embedment	Proportion of culvert diameter below peat surface	Bog Fen Swamp Marsh	Culverts may be embedded 0-100%; we recommend roughly 50% embedment	Culvert embedment must accommodate both surface and subsurface flow
Culvert Diameter	Total diameter of culvert, measured in any unit (e.g., inches, millimetres)	Bog Fen Swamp Marsh	Culverts come in a range of sizes; we recommend a minimum diameter of 24 inches/600mm	A sufficiently large culvert is required for adequate embedment and to allow for anticipated type of flow

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance
Number/Spacing of Structures	Count or number per unit distance or unit distance between structures (in metres)	We recommend the following spacing for each wetland class:		Multiple adequately spaced structures may be needed to maintain water flow, and legacy crossings may have only one or no crossing structures. Recommendations dependent on many variables. Consult ecological cues to infer whether number/spacing of structures is adequate.
		Bog	200 m max spacing	
		Fen	150 m max	
		Swamp	100 m max	
		Marsh	100 m max	
Bowing/Distortion of Culverts or Similar Structures	Measured angle of deflection of culvert ends, or classification (e.g. mild, moderate, severe), and/or estimated reduction of flow (%)	Bog Fen		Structures within deep peat are highly susceptible to bowing and thereby not flowing to design.

Ecological parameters

Water imbalance caused by flow impediment across roads will result in changes in wetland function, with possible impacts on local and regional hydrology, water availability, water quality, and habitat value for plants, insects, and animals. Furthermore, elevated water tables or ponding of water caused by roads can increase release of methane, a potent greenhouse gas, from wetlands (Saraswati, Parsons and Strack 2018).

An obvious indicator of flow impediment across roads is observation of ponded or pooling of water on one side of the road and not the other. The size of the ponded or pooled area is a function of the flow rate, the degree of impediment, and length of time the impediment has been occurring. The size of the ponded area can also have implications on road integrity, as discussed in the *Road integrity parameters* section (pg. 46).

Another indicator of flow impediment is obvious elevation of the water table from one side of the road to the other, which sometimes can be accompanied by obvious elevation of the vegetation surface in peatlands and swamps.

Figure 12. Marked differences in vegetation height and colour and pooling of water on one side of the road are indicators of flow impediments at this crossing. Image courtesy of DUC.

Changes in vegetation growth and health from one side of the road to the other are indications of moisture differences caused by impeded flow (Figure 12). Prolonged soil saturation or flooding on the up-flow side of the road will produce anoxic conditions for tree roots, thereby causing poor growth, tree mortality, or shifts in plant communities. On the other hand, more mesic conditions on the down-flow side will result in superior growth and health of trees. Typical symptoms include:

- Stunted growth of trees on the up-flow side
- A greying tinge to black spruce and tamarack trees on the up-flow side
- An increase in lichen growth on trees on the up-flow side
- Obviously dead trees on the up-flow side
- Tall, green, healthy trees on the down-flow side by comparison.

Changes in vegetation composition can also occur as a result of differential moisture conditions across roads caused by impeded flow. These can be subtle and might require repeated vegetation surveys over a longer period, which is likely beyond the scope of routine monitoring, but could be of value for long-term interval inspections.

Obvious changes in vegetation composition or presence of key species can be indicators of ponded or pooled water, particularly occurrences of species not typical of the wetland. For example, cattails and bulrush are not normally associated with peatlands, but can sometimes occur near culverts or along roads in peatlands (Figure 13). The presence of such emergent vegetation is a sign of open water and an indicator that water may have been ponded or pooling because of impeded flow. Small areas immediately near culvert openings may be of little concern, whereas larger expanses of cattails clearly indicative of prolonged pooling over a larger area are symptoms of greater degree or duration on flow impediment.

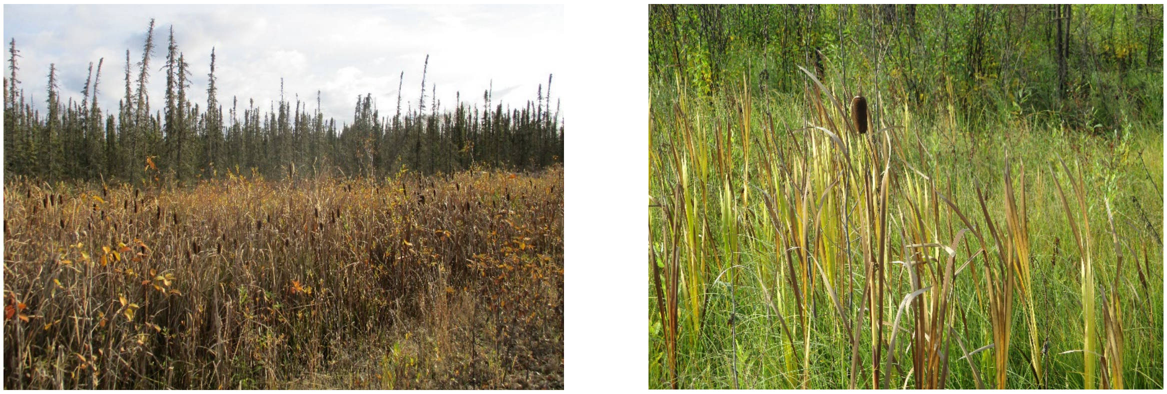

Figure 13. Water loving vegetation can become colonized in areas prone to water accumulation. Cattails commonly grow where there is ponded water likely indicating impeded flow.

Changes in wetland class can also occur with impeded flow. For example, impeded flow of a watercourse through a meadow marsh dominated by grasses and grass-like plants can raise the water table and result in development of an emergent marsh dominated by cattails and with larger areas of open water on the up-flow side (Figure 14).

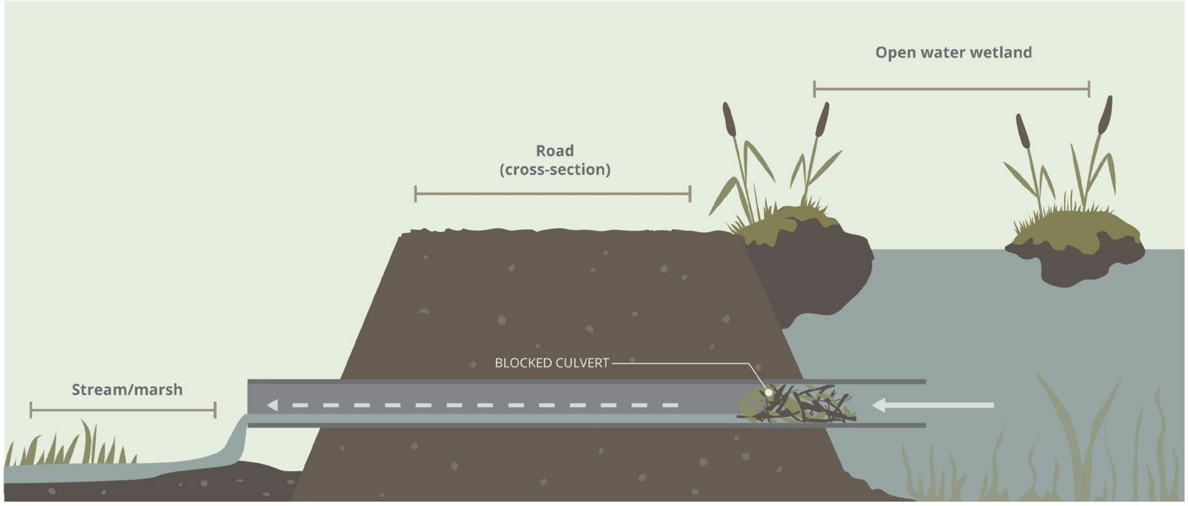

Figure 14. A partially blocked culvert has altered the natural water flow across this marsh, causing a stream to develop on the downflow side and ponded water to accumulate on the up-flow side. Over time the accumulation of ponded water has increased the water depth on the up-flow side dramatically, creating an open water wetland where it was previously absent.

Table 6. Ecological parameters. Observed ecological changes are symptoms of impaired water flow across the road. Extent, severity, and duration are indicators of the degree and duration of the impairment.

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance	Notes
Pooled or Ponded Water	Compare both sides of the road in terms of size, location (e.g., nearness to crossing structures), and distribution	Marsh	Pools of water may naturally occur in marshes. Compare relative size, areal proportion, and distribution as clues to impeded drainage	Overall potential indicator of impeded drainage. Size, extent and permanence of pools are related to flow volume, degree of impediment, and duration of impediment.	
		Bog Fen Swamp	Water ponding on the up-flow side of roads indicates impeded drainage. Pools on the down-flow or both sides of the road may have resulted from construction damage		
Water Table Elevation	Compare relative height of observable water on either side of the road	All types	If open water is observable, estimate relative height	Elevated water table on the up-flow side of the road is indicative of impeded flow	It can be useful to know the relative surface elevations prior to road construction to eliminate the possibility of naturally occurring contrasts in surface elevation.
	Compare relative height of vegetation surface if possible.	Bog Fen	Peatlands swell with increasing water content, therefore elevated peatland surface can be an indicator of elevated water table		
Atypical Vegetation	Observe and compare dominant species both sides of the road; note if vegetation is indicative of different wetland classes/types on either side of road	Bog Fen Swamp	Cattails, bulrush, other emergent vegetation	Indicators of ponded or pooled water and associated flow impediment	
		Marsh	Vegetation consistency across the road. Cattails on the up-flow side and not on the down-flow side indicate impeded flow and transition between marsh types across the road	Indicator of impeded flow and possible rise in the water table on the up-flow side. Rising water table and inundation near the road base raise road integrity concerns.	

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance	Notes
Vegetation Growth and Health	Relative tree height	Bog (wooded) Fen (wooded) Swamp	Compare relative tree height between sides of road (up-flow as proportion of down-flow)	Evidence of flood-induced stunting	Contrasts from one side of the road to the other are indicators of impeded flow. Flooding on the up-flow side will impair health and growth by drowning roots, while drier conditions on the down-flow sides will allow trees to flourish
	Tree colour		Hue of green – dark rich vs. greying	Green indicates healthy, grey indicates sick	
	Lichen abundance		Proportion of individual trees covered with lichen, proportion of tree community covered in lichen	Less lichen indicates healthy, more lichen indicates sick	
	Mortality		Proportion of dead trees/shrubs	Dead trees are a strong indicator of an unhealthy wetland	
	Extent of symptoms		Estimated areal extent and/or distance symptoms reach beyond road into peatland	Indicator of severity or duration of impairment	

Road integrity parameters

While erosion and sedimentation are concerns that are common to both stream and wetland crossings, sedimentation concerns for fish are likely limited to crossings of defined watercourses within wetlands. However, sedimentation is also a contamination concern within peatlands, and more specifically bogs. Bogs are typically acidic and low in nutrients with plant species adapted to those conditions. Road fill can often contain abundant calcium, thereby resulting in neutral to alkaline soil chemistry. Road fill can also be a source of nutrients such as nitrogen and phosphorous. Therefore, sediment washed into bogs adjacent to roads can alter the pH of the bog, as well as disrupt natural nutrient cycling, which in turn can alter plant and animal communities within the bog (Figure 15). Symptoms of erosion and sedimentation include:

- Rills and gullies along the road shoulders/embankment (Figure 16)
- Deposition of sediment into the adjacent peatland
- Extension of non-peatland vegetation from the road into the peatland
- Changes in peatland vegetation composition between areas closer to the road than farther away

Over time, natural ingress of vegetation on the road shoulders will provide abundant litter to armour the soil surface and a root network to increase soil stability, thereby preventing most erosion and sedimentation from the road embankment.

Prolonged saturation of the road base can cause failures or erosion of the road base, which pose safety concerns and can represent high costs of repair. Observations of large areas of ponded or pooled water by any of the cues noted in the above sections may be of concern to road integrity. Additionally, the road should be inspected for obvious signs of weakness or failures.

Figure 15. Road erosion delivering sediment into peatland. Road fill may cause nutrient loading and alter peatland chemistry, thereby changing the environment and affecting the habitat of peatland plants and animals (e.g., amphibians).

Figure 16. Erosion is highest during the first couple of years after a road is built until embankments become armoured/vegetated and the flush of fine soil particles is completed. **Left:** erosion from road embankment towards the right-of-way, showing sediment deposition where overland flow is impeded. **Right:** Close-up of erosion (rilling) and the beginning of self-armouring due to aggregate exposure.

In peatlands, pooled water may be observed on either side of the road. Pooled water on the up-flow side may be caused by impeded flow or by damage to the peat surface during road construction (e.g. rutting or breaking through the peat). Pooled water on the down-flow side might be caused by damage to the peat surface (Figure 17) or by flow pressures at culvert outlets if too few culverts are installed. Too few culverts can also result in channeling of flow within the peatland beyond culvert outlets.

Excessive road settlement can also be an indicator of impending road failure within deep peatlands. Corresponding symptoms may be rutting or pounding out of the road near culverts or other structures.

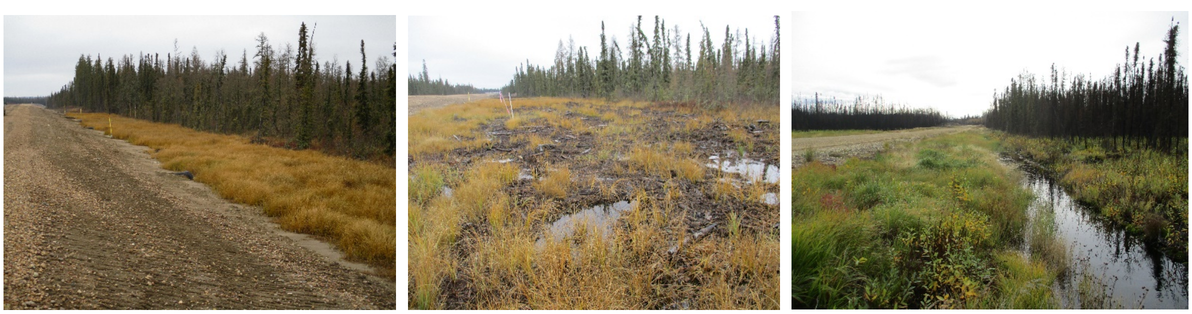

Figure 17. Peatlands adjacent to roads with various levels of intactness. **Left:** intact peatlands outside of the road footprint are typically the goal during winter clearing and road construction. **Middle:** disturbed peat can occur during construction activities where the surface has been gouged/scalped (middle). **Right:** ditches can be built to help accumulate water away from the road where otherwise the water would accumulate and cause the road base to be saturated, which can lead to poor road performance and safety concerns. It is important to note that ditches are a temporary solution to a symptom of the problem (i.e., the crossing blocking the natural flow of water through the wetland).

Table 7. Road integrity parameters. Some parameters are redundant with *Ecological parameters*; they are listed here if there is a concern specific to road integrity.

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance
Erosion	Rills and gullies – size of affected area, depth of rills/gullies, location with respect to crossing and crossing structures	All types		Indicator of likely sedimentation into adjacent wetland. Indicator of potential future road failure (safety, road performance)
Sedimentation	Evidence of road material entering adjacent wetland - location of sediment deposition relative to crossing and crossing structures; amount and extent of deposition	All Types	Estimate size of affected area, estimate volume of material	Evidence of road erosion
		Bog Swamp Marsh Fens (not always)	Change in vegetation species composition	Road material may bury native vegetation or cause changes in site chemistry, resulting in vegetation atypical of the specific wetland. Changes in rich graminoid fens may be less obvious
		Marsh	Sediment deposition in watercourses or small pools	
Road Settlement	Road grade low in comparison to wetland grade, bowed drainage structures, inconsistent road grade (swale section) across crossing	All types, but bogs and fens more specifically	Measure height of road above wetland grade, note bowed structures as in previous table	Continued settlement over time can be a sign of impending road failure or future performance issues

Parameter	Observation/Measurement	Wetland Class	Class-Specific Observations	Relevance
Ponded or Pooling Water Adjacent to Road	Water collecting along the road that would be atypical of the wetland	Bog Fen Swamp Marsh	Estimate size, extent, and distance from road of pooled water; include ecological cues from table below in observations; note orientation to road if applicable (parallel vs. perpendicular)	Continuous pooling or ponding of water next to the road can eventually saturate the road foundation, leading to future road failure. Pools of water can result on the up-flow side of roads from impeded drainage and on either side of the road from construction damage to the peat surface.
		Marsh	Differentiate naturally occurring pools from suspected road or construction-induced pools.	
Right-of-way Condition	Breaches of peat surface (ruts, gouges, equipment traffic-induced breaks in surface)	Bog Fen	Record incidences of breaches of the peat surface and possible causes (e.g., construction damage) and estimate size extent	Breaches in the peat surface can be sources of ponded or pooled water that can affect road integrity and peatland ecology. Where breaches are abundant they can contribute to an increase in overland flow during wet periods.
	Channelization of flow	Bog Fen	Record incidences and estimate length and width of channels	Channeling of flow at culvert outlets due to fire-hosing is a symptom of too few structures for the flow at the crossing. Any ponding caused by channels can affect road integrity and peatland ecology
Road Failure	Excessive erosion, especially near structures, slumping, excessive rutting, pounded out depressions	All types	Identify symptom type, estimate size of affected areas, number of areas affected	Safety and road performance; road failure can make the section of road difficult to traverse and costly to maintain

Potential fish-bearing wetlands

The question of impacts on fish passage is likely still an open one for boreal wetland crossings. Existing literature on fish passage has a singular focus on stream and river crossings, and no documents on wetland crossings were detected during this project. However, since there is documentation of fish presence in isolated boreal wetlands (Hornung and Foote 2006), this question may merit further consideration. For wetlands that are connected to other surface waters, impassable crossings are likely to limit fish access to feeding habitats that can also provide a function of protection from predators. Some wetlands are only temporarily connected to other streams, lakes, and rivers due to seasonal changes in water level; during times of flooding, these wetlands may serve as important temporary habitats for fish (Henning et al. 2007). Wetland crossings may therefore impact fish habitat use and have the potential to fragment fish populations, but there do not appear to be any current assessments of these potential impacts in the boreal region.

It is also important to note that under the Alberta Wetland Policy, resource companies pursuing developments in wetland areas must ensure that an authenticating professional delineates the wetland area in accordance with the Alberta Wetland Identification and Delineation Directive (Government of Alberta, 2015) and conducts an assessment to determine the wetland's relative value using the ABWRET tool (Government of Alberta, 2016). The ABWRET tool uses spatial data and field observations to assess 15 wetland functions, including fish habitat potential, to determine the relative value of a wetland to inform decision-making. The Fish Habitat Function Model assesses fish habitat potential on a scale of zero to 10 using the following parameters:

- If fish species-at-risk are present, the wetland receives the highest score (10)
- If the wetland contains surface water for less than four consecutive weeks annually, the wetland receives the lowest score (zero) unless it is known to contain fish
- If neither of the above are true, five factors are assessed using spatial data and field observations (wetland productivity, wetland permanence, habitat structure, availability of dissolved oxygen, and the presence of other stressors) and the values are averaged to determine fish habitat potential

Resource companies are required to complete an ABWRET assessment for any new wetland crossings to determine the relative value of the wetland, including fish habitat, to inform decision-making.

A final piece of context worth discussing is that wetland crossings may have greater impacts on amphibian passage than on fish passage (Hamer et al. 2015, Garcia-Gonzalez et al. 2011). We have abstained from making any specific recommendations related to amphibian monitoring in this report due to the lack of studies on crossing impacts on amphibians in Alberta. It is presently unclear whether boreal resource roads, which have low traffic volumes and low levels of industrial noise, present strong risks to amphibians in terms of road mortality and/or disruption of calling behaviour. However, there may be a higher potential risk that such roads could have habitat fragmentation impacts on amphibians. This topic may be an important area of future research, as roads have been shown to have a variety of negative impacts on amphibians in other regions (Cunnington et al. 2014, Griffin 2015). For more information on potential considerations related to amphibians, please refer to Appendix C of this report.

With regards to our recommendations for the wetland crossings monitoring protocol, we advise that it is possible that permanent or ephemeral watercourses connected to shallow open water wetlands may be fish-bearing. Such watercourse crossings could be assessed in a manner similar to the existing FSCP stream crossing protocol. Incidences of fish observations should be recorded. Peatlands and swamps are not likely to be productive fisheries, so crossings through these classes of wetlands would not typically include monitoring for fish habitat parameters. However, it is possible for fish to be observed within peatlands or swamps. Such observations are likely incidental hatchings from eggs transported by waterfowl or raptors. Nevertheless, if fish are observed within peatlands or swamps, it would be prudent to track water flow from culverts to establish whether there is connectivity with a potentially productive fishery. A competent professional might be required to assess the viability of potential fish habitat.

We include below a potential table of parameters to record with respect to fish habitat in boreal wetlands (Table 8). We advise that these measurements are most important to record in wetlands with open water (e.g., marshes, open water wetlands) or that have connectivity to other waterbodies with fish-bearing potential.

Table 8. Parameters to assess fish-bearing potential of boreal wetlands.

Parameter	Observation/ Measurement	Wetland Class	Class-Specific Observations	Relevance
Fish Habitat	Relevant measurements from FSCP stream crossing protocol	Open water wetland Marsh	As applicable based on watercourse and structure type	Open water wetlands and watercourses within marshes may have fish-bearing potential
	Fish presence, connectivity to potential fish-bearing habitat	Bog Fen Swamp	Record observations of fish (likely at culvert outlets) and identify species if possible Track flow into wetland to determine of connected to potentially productive habitat	Fish observations are likely incidental hatchings from eggs transported by waterfowl or raptors. Fish are not expected to flourish or be productive in these locations unless culvert outflow is connected to productive habitat elsewhere.

Other monitoring considerations

In addition to the precise parameters to measure in the field, these recommendations represent a few big-picture items (e.g., monitoring frequency, integrating spatial tools) that will likely need to be considered when designing the broader monitoring program.

Incorporating spatial tools

Integrating spatial tools into a wetland crossings monitoring protocol could help to:

- Inventory wetland crossings;
- Delineate and identify wetlands; and
- Flag potential problem crossings.

Spatial tools can be used to view the crossing and the surrounding landscape, which can also provide important context for the locations of landscape features. For example, one can see if the road was planned to be positioned adjacent to the wetland boundary, as opposed to travelling through or across it (see Appendix A9).

There are a number of spatial tools available in Alberta that could be incorporated into a wetland crossings monitoring protocol, including high resolution photo and satellite imagery (e.g., Google Earth), LiDar (e.g., wet areas mapping), and wetland inventories (e.g., DUC's Enhanced Wetland Classification (EWC) Inventory, the Alberta Merged Wetland Inventory). A hydrologic risk mapping tool is also currently in development by DUC.

We recommend that a combination of spatial tools is used to assess crossings prior to field inspections, as the data gleaned from desktop assessments can be used to inventory crossings and to potentially help prioritize monitoring efforts (Figure 18).

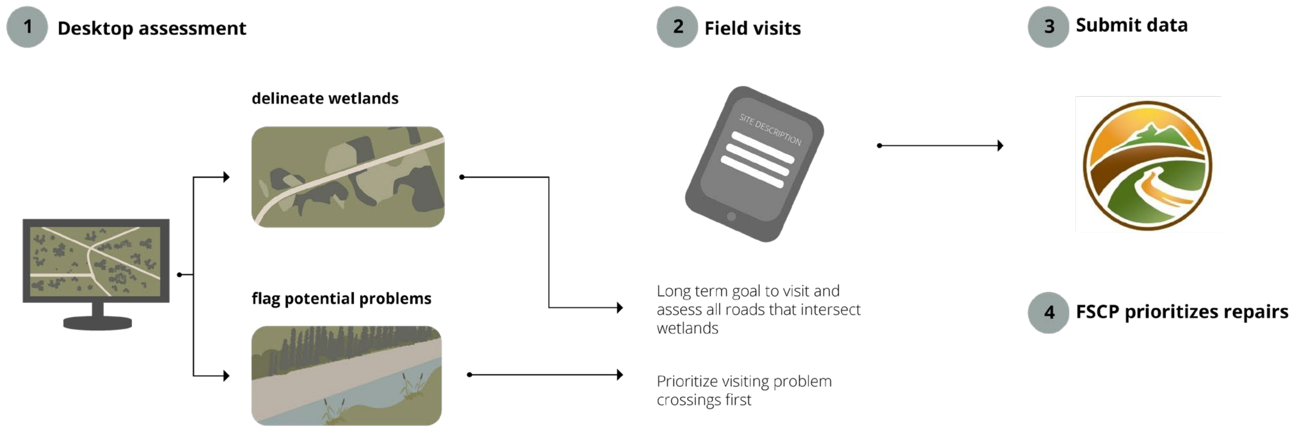

Figure 18. A possible workflow for integrating spatial tools into a wetland crossings monitoring program. Spatial tools can be used to delineate wetlands and identify crossings, and may also be used to prioritize field visits (i.e., crossings that have visible impacts in aerial imagery).

Frequency and timing of monitoring

It is expected that monitoring will occur at intervals over time. Therefore, initial observations can serve as baseline data for subsequent observations to gauge the severity, worsening, or improvement of apparent issues. For example, comparing the size and distance from the road of ponded water areas over time can indicate whether a drainage problem is worsening, stabilizing, or improving. Likewise, comparing depth of sunken culverts or estimates of road settlement (height of road above grade) over time can provide evidence of worsening or stabilizing problems.

We recommend that all newly installed wetland crossings be monitored annually for a period of 4 years after construction. If crossing structures are going to deform and become uplifted at their ends or sink below the installed elevation, these symptoms will be most evident during the time period immediately post-construction. After a period of time, peat consolidation comes to an equilibrium and site settlement slows or ceases. It is also during the first few years after construction that erosion potential is highest, which could be detected using a more frequent monitoring schedule. Older roads tend to self-armour and become vegetated along their embankments (Figure 19).

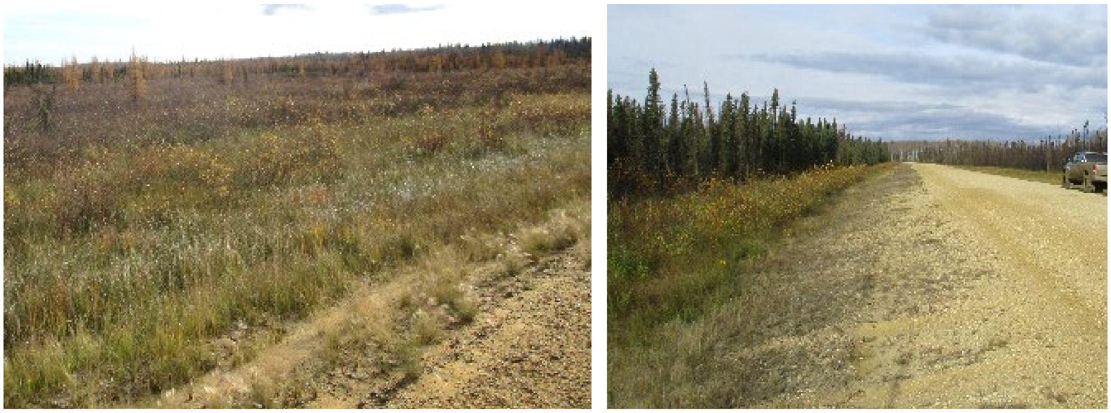

Figure 19. Erosion tends to decrease over time after construction as road embankments self-armour and become vegetated. **Left**: an older road where vegetation has established along the roadside, trapping sediments that may otherwise spread further into the wetland. **Right**: over time vegetation will establish up the road embankment, which will help to reduce erosion from rainfall impact. Roads less than two years old tend to have high erosion potential due to loose and unarmored soil.

For older/legacy wetland crossings, we recommend that monitoring frequency is based on ecological, economic and social considerations. Ecological considerations can include observable signs of hydrological impairment, risk of hydrological impairment (e.g., a crossing through a fen is more likely to impede water flow than a crossing through a bog; presence of beaver may increase risk of conduit/crossing structure blockage due to debris), location in the watershed (wetlands lower in the watershed may move more water than those higher in the watershed), habitat for species of special concern, and rarity of the wetland class on the landscape. Economic considerations can include need for industrial access and costs of road maintenance. Social considerations can include need for community access and concern over subsistence or cultural species within wetlands. These considerations could be used to develop a priority ranking system that could then inform decisions regarding monitoring frequency.

High priority crossings should be monitored more frequently, and could also be prioritized for monitoring during critical periods related to the above considerations. For example, critical periods for community access may be during non-frozen periods or during spring thaw when the soils are weaker and may pose a hazard to emergency access. Regardless of high or low priority ranking, all crossings should be monitored.

We recommend two possible monitoring schedules depending on crossing priority ranking:

- High priority site: annual monitoring
- Low priority site: monitoring every 2 or 3 years; this monitoring schedule would allow time between assessments for symptoms of poor flow to become evident (e.g., common pooled water locations, dead or dying vegetation).

With respect to time of year for assessments, we recommend monitoring during the spring, as this is the time of year when water flows can be highest due to seasonal water table fluctuations. Monitoring during the spring may also allow for gains in operational efficiency, as problem crossings could potentially be addressed and repaired within the same season as the initial field inspection (i.e., during the non-frozen period). In general, monitoring during the non-frozen period will allow for an assessment of flow, which is considered a key indicator for hydraulic connectivity.

Follow-up assessments during frozen periods could be useful in specific cases. Returning to a crossing during the winter could help to provide additional information on problems potentially extending beyond the road/right-of-way, as wetlands can be difficult to traverse on foot during the spring/summer. For example, it may be deemed necessary to walk into the wetland to assess how far sediment is traveling or how far concentrated flow from a culvert is traveling (i.e., further than what can be seen from the road).

Dry vs. wet periods

Wetlands transport water above and/or below ground and water levels may fluctuate seasonally and/or annually. During drought cycles and dry periods, wetlands in the boreal plains store and redistribute water across the landscape. During wet cycles or periods, an enormous amount of water can be transported below and above ground through boreal wetlands in Alberta. A wetland crossing designed and constructed during a dry cycle may therefore not perform well during a wet cycle (i.e., years of prolonged above-average precipitation). It may also be difficult to observe surface and ponded water when monitoring crossings during dry cycles.

Based on these considerations, we propose two recommendations for the FSCP to consider:

- Increase monitoring frequency during wet cycles to ensure that potential problems are identified and can be resolved
- Note weather, season, and climate during monitoring evaluations to enable comparison of current evaluations to past ones at the same crossing.

We have proposed specific parameters to measure with respect to weather, season, and climate in the *Key parameters to measure* section (pg. 32)

Personnel and training

We recommend following the two-tiered approach proposed by interviewees in this project: initial field inspections can be carried out by junior staff or temporary summer staff (with adequate training), while follow-up inspections to diagnose problems and design solutions should be carried out by qualified professionals with a strong understanding of wetland systems.

We recommend that adequate training for temporary summer staff (e.g., students) and junior staff should include:

- **An online or classroom session covering key definitions and concepts:**
    - Definition of a wetland - recommended resource: *Alberta Wetland Policy* (Government of Alberta, 2013)
    - Wetland classification - recommended resource: *Alberta Wetland Classification System* (Government of Alberta, 2015)
    - Definition of a wetland crossing - recommended resource: this report
    - Types of crossing structures/conduits - recommended resource: *Resource Roads and Wetlands: A Guide for Planning, Construction and Maintenance* (Partington et al., 2016)
    - Road construction and resource road terminology – recommended resources: *Resource Roads and Wetlands: A Guide for Planning, Construction and Maintenance* (Partington et al., 2016); FPInnovations technical reports and field notes (e.g., Partington, 2015; Gillies, 2014a, b)
    - Water management techniques during resource road planning and construction - recommended resource: *Water management techniques for resource roads in wetlands* (Gillies, 2011).
    - Key concerns for each class of wetland - recommended resources: this report, *Operational Guide: Forest road wetland crossings. Learning from trials in the boreal plains ecozone of Manitoba and Saskatchewan, Canada* (Ducks Unlimited Canada, 2014).
    - Examples of crossings (field photos), including well-functioning and poor-functioning examples - recommended resource: Appendix A of this report
- **A field trip with a supervisor covering practical skills:**
    - Identifying the entire length of the crossing
    - Measuring the parameters indicated in the monitoring protocol

  - Recognizing frequent symptoms of poor-functioning crossings

The classroom/online component of this training could likely be partially delivered through or supplemented by two currently available training resources:

1. *Wetlands 101: An Introduction to Boreal Wetlands* online training by DUC
2. *Best Practices for Managing Resource Roads Across Wetlands* series by FPInnovations (see FPInnovations (2018a-d) in Appendix D)

For each resource company, we recommend that an experienced biologist, preferably with a specialization in wetlands, should oversee the monitoring program. This person could also be an external consultant, as this model is already used by some companies to manage stream crossings. Since there is no official designation in Alberta on which to screen applicants for wetland specialist positions, we advise that company staff be attentive to relevant education and experience listed on resumes and the wetland practitioner standards set by relevant regulating bodies (e.g., ASPB, AIA). These experienced wetland specialists would be responsible for:

- Hiring and training of junior staff/summer crews
- Undertaking field visits to underperforming crossings (i.e., those that have been identified as a potential problem by junior staff/students) in order to discern root cause of problem and develop a solution
- Developing repair strategies for underperforming crossings in collaboration with construction professionals
- Supporting the coordination of repairs, remediations, and decommissioning of crossings
- Annually reviewing the data collected to identify trends in problem crossings and help inform better crossing placement/design, including choice of crossing structures

Because repair work is often managed separately under an operations department within each company, while land identification and land-use planning are under a different department, we recommend that companies form multi-departmental committees in order to manage their crossings. This structure would allow for collaborative identification of structural problems and solutions as well as planning to avoid and minimize impacts of developments on wetlands in the first place. In particular, we highlight the importance of collaboration between wetland specialists (who have knowledge of potential cause of the problem) and construction professionals (who have knowledge of structural options to solve the problem).

Reporting and data management

Through our interviews we found that resource companies, regulatory agencies, and independent consultants alike saw value in a central data management forum like the FSCP. The main advantages of such a forum are that data are collected in a repeatable and standardized manner, data input and querying can be done quickly and efficiently, and there is a potential for data to be shared among companies to facilitate learning and landscape-level management. Wetland crossing monitoring data collected by the FSCP could be leveraged to enhance landscape-level management opportunities, but this would likely require the development of at least one additional tool: a common base map that all companies can access, which can be integrated with spatial data from the FSCP database.

A potential stumbling block that the FSCP should be aware of moving forward is the issue of integrating companies' internal databases with the FSCP databases. Some interviewees highlighted that this was a challenge for them when joining the FSCP, and that it would be valuable if there was an interface or some technical support for migrating data over. For companies that wish to maintain their own internal databases in addition to or in lieu of contributing to the FSCP database, it may also be valuable for the FSCP to encourage consistent management. Such companies should be encouraged to embrace current methods and to be aware of the most up-to-date protocols.

In terms of reporting, we recommend that wetland specialists who are hired by companies to supervise or assist with the wetland crossing monitoring program should be responsible for creating annual reports aimed at improving wetland crossing design, monitoring, and decommissioning based on the data collected through the monitoring protocol. Within these reports, the wetland specialist should summarize recent assessments, document and present learnings from well functioning crossings, and provide clear direction on how to improve underperforming crossing designs and construction practices if possible. These reports could be acted upon internally to improve company practices, and may also provide value to the FSCP in order to continuously improve the wetland crossings monitoring protocol. Distributing the reports externally and internally would facilitate shared learning which could lead to improved operational and environmental performance of wetland crossings.

Conclusions

There is significant opportunity for the FSCP to support and help improve the monitoring and management of wetland crossings by resource companies. The main issue that the project team identified as a barrier to implementation of a successful wetland crossings monitoring protocol is the lack of wetland knowledge within resource company staff and temporary field crews. This knowledge gap can likely be overcome using appropriately designed training sessions that include both classroom and practical field components. Such a training program could represent an important opportunity to increase wetland knowledge and expertise within resource companies, allowing for long-term improvement of all aspects of wetland crossings, such as road planning, construction, monitoring, repairs, and decommissioning.

An important outcome of increased wetland knowledge of staff from resource companies should be an improvement in their ability to recognize crossings on all the different wetland classes on the landscape. The FSCP should anticipate that there are substantially more crossings present in the boreal than those that company staff are currently aware of, and that there may be roads requiring additional construction (i.e., installation of crossing structures/conduits). We recommend that the wetland crossings monitoring protocol developed by the FSCP should strive to address **all roads that intersect wetlands**, regardless of whether a crossing structure/conduit has previously been installed.

To help support this transition to more comprehensive inventorying and monitoring of wetland crossings, we have also recommended a consistent set of terminology for the FSCP to use when discussing wetland crossings with resource companies and regulators. By developing and consistently using a common language, the FSCP can help to ensure that all stakeholders involved understand one another and are using an up-to-date understanding of wetlands (e.g., wetland classes).

We have stressed the importance of wetland classification throughout this report. It is our recommendation that the Alberta Wetland Classification System be integrated into the FSCP wetland crossings monitoring protocol, as the wide variation in the hydrology, vegetation, and biota among wetland classes may easily cause confusion and mismanagement when it comes to the design, monitoring, and repairs of crossings. If practitioners are provided with a strong basis to understand the differences and similarities among wetland classes, they will be empowered to use the monitoring protocol, to recognize symptoms of poor-functioning crossings, and to manage and improve the performance of their crossings.

Finally, we have recommended that the maintenance of wetland hydrology be used as the core driving outcome of the FSCP wetland crossings monitoring protocol. There is strong consensus among the company representatives interviewed, within our team of experts, and in the published literature that hydrology is a driving force behind wetland form and function. Further, it is sensible to embrace the most recent work in this field of study, as practical field guides have presented the concept of managing wetland hydrology based on the flow characteristics of different wetland classes (e.g., seasonally fluctuating, slow lateral flow, stagnant). If a wetland crossings monitoring protocol focuses on maintaining wetland hydrology and addresses issues related to hydrologic disruption, it is our belief that many ecological problems related to wetland crossings can be reduced or eliminated in the boreal region of Alberta.

Appendix A. Example photos of wetland crossings and potential problems to note during monitoring

Figure A1. Well-functioning culvert crossing a peatland. **Left:** culvert inlet is embedded about 50% compared to the original peatland grade. A trench was dug into the peat and the culvert installed on piles within it. The open water area in front of the culvert is the end of the trench. Notice that the water level is below the peat surface. This culvert is functioning well by draining both surface and subsurface flow and delivering it to the other side of the road, preventing upwelling of the subsurface flow. **Right:** culvert outlet.


Figure A2. Condition of conduits will vary. **Left:** Sunken culvert which should be monitored on an ongoing basis. This culvert may function well if unobstructed, or may have restricted flow if obstructed. **Right:** Partially sunken culvert which should be monitored on an ongoing basis. Seasonal fluctuations in water levels may affect the ability of this culvert to function properly.


Figure A3. Peat should be considered intact even if covered with felled trees or stockpiled topsoil (left; topsoil stored for use during reclamation). Tree stems and branches from winter clearing activities may also be present across the surface of the peat, which may vary from sparse (right) to a thickness where peat may not be visible.

Figure A4. Erosion/sedimentation around log bundles may negatively impact water quality of the surrounding wetland. **Left**: erosion and sediment possibly impeding water flow through a log bundle. Geo-fabric also potentially impeding flow. However, the fabric on top of the logs is also preventing the voids between logs from becoming clogged by sediment. **Right**: logs should be embedded into the peat as shown to allow for continuous subsurface flow, but sedimentation should be controlled.

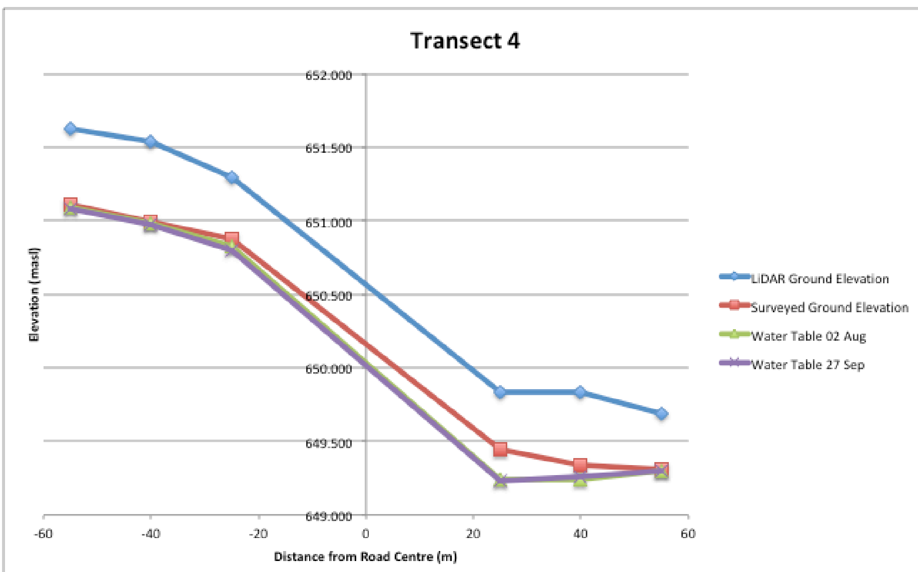

Figure A5. Example of water table elevation compared with ground surface elevation. It might be necessary to install some water wells on either side of the road to compare the water table on either side of the road to infer if drainage is impeded, if this is not clear from a visual assessment. This approach is not without pitfalls, as shown above. The water table elevation tracks the pre-construction ground surface elevation, which is lower on one side of the road than the other. In the absence of the pre-construction ground surface elevation observations, the water table elevations would give the illusion that the road is impeding flow. However, in this case, the road was built over a natural topographic gradient and was not the root cause of these observations (from Osko and Gillies, 2018).

Figure A6. Wetland flow along the road embankment moving towards the nearest downslope conduit can flow with enough energy to erode both deposited sediment and the lower road embankment. In this case the sediment produced from the road embankment was re-suspended from its initial depositon location (right and left photo are the same site in opposite directions), meaning that the initial deposition area may therefore not be the only or final receiving environment.

Figure A7. Sunken culvert (left) is not problematic if it is not plugged, as it will drain subsurface flow. Righthand photo is outlet of the same culvert. It may actually be desirable to install culverts in pairs separated by a distance of 10 m or so, with one culvert below the surface and one embedded 20-30%.

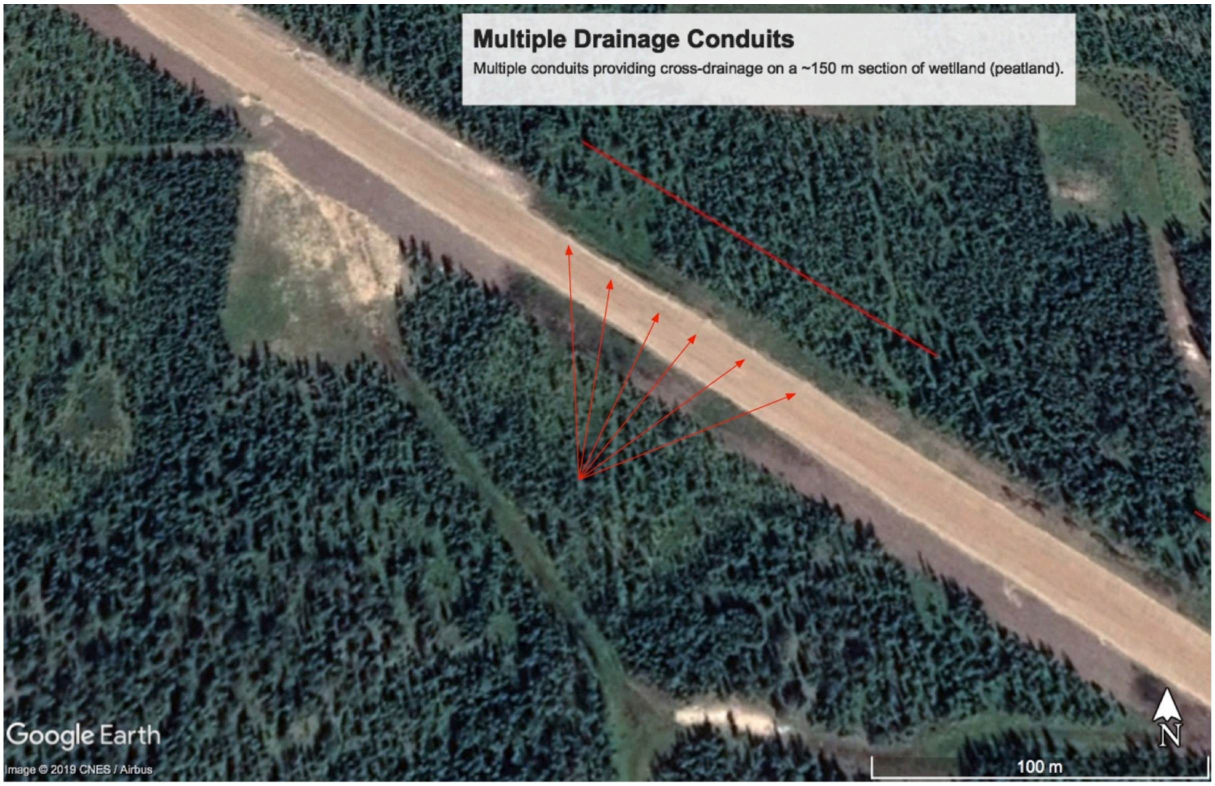

Figure A8. Multiple conduits at close spacing along relatively short wetland crossing. Conduits include culverts, log bundles, and HDPE pipe bundles. The potential presence of multiple conduits in wetland crossings may cause some confusion among practitioners in terms of defining a "crossing," as stream crossings typically only have a single conduit.

A

B

Figure A9. An example of how satellite imagery may be helpful to determine if differences between sides of the road were due to the road being built along natural features. **A:** When driving along this road (inset photo provided as an example), observation of trees on the east side being much shorter and somewhat sparser than on the west might give the impression that there is stunting of trees on the east side due to a raised water table caused by road induced flow impediment. The crossing is about 1.2 km long. **B:** However, observation of satellite data might show that the road may have been built along a natural feature where the trees just happen to be larger on one side than the other.

Appendix B. Interview questions used to guide conversations with resource companies and regulators

Regulator Questions

1. **Context for wetland crossing-related regulations/guidelines (AEP):**
    a. We are aware of the Alberta Wetland Rapid Evaluation Tool (ABWRET). To our knowledge this has been developed and applied in the White Area only. Are there plans to expand this tool to the Green Area?
    b. Will there be regulatory expectations around the use and application of ABWRET and the Relative Value Map in the Green Area?

2. **Context for wetland crossing-related regulations/guidelines (AEP and AER):**
    a. Are there legislative requirements for monitoring road crossings on wetlands?
    b. If so, what are the responsibilities of resource companies in monitoring/reporting?
        i. Are there routine and non-routine reporting requirements?
            1. What needs to be routinely reported and what is the schedule?
            2. What might be reported non-routinely?
    c. Are there non-legislative guidelines for wetland crossing monitoring in addition to/in absence of legislative requirements?
        i. If so, what are the monitoring practices or parameters recommended in the guidelines?
    d. In either case, are there prioritization criteria for wetland crossing monitoring or repair? For example:
        i. Wetland classification/type, function, quality, value?
        ii. Crossing function/performance parameters?
        iii. Presence of critical habitat/species at risk?
    e. If no prioritization criteria are used, would your agency be open to establishing prioritization criteria for monitoring or repair of wetland crossings?
        i. What would you consider the most important parameters when prioritizing crossing monitoring/repair?

3. **Collaboration with industry:**
    a. Has your agency worked with industry to develop a standardized practical monitoring system (does it plan to, or is it willing to)?
    b. Does your agency have any requirements regarding how data are collected?
    c. Is your agency familiar with what industry presently has in place in terms of monitoring programs? Are these considered to be sufficient?
    d. Is your agency familiar with monitoring requirements required for certification by various standards agencies such as Sustainable Forestry Initiative, Forest Stewardship Council, etc.? Do you see any challenges in integrating these requirements with provincially regulated requirements?

4. **Performance of present monitoring systems/protocols:**
    a. Are the present systems/protocols for wetland crossing monitoring and reporting working well?
        i. Are they providing relevant information in a timely manner?
        ii. Are compliance levels acceptable?
        iii. Are identified crossing problems addressed appropriately and in a timely manner?

5. **What would an ideal monitoring protocol look like?**
    a. What kind of information would be collected?
        i. Wetland response info (e.g., water quality, water flow, vegetation response)
        ii. Structural performance info (e.g.. integrity, functionality)
    b. How would information be collected and reported?
        i. Logistical factors – time, repeatability, standardization
    c. What factors could improve compliance or reporting performance?
    d. What qualifications would be required for staff or contractors completing the monitoring?
    e. Would such a monitoring protocol be expected to integrate into pre-construction and post-decommissioning assessments as well?

Resource Company Questions

1. **Wetland Knowledge:**
    a. Does your company use a standard definition for what land types are identified as wetlands? If not, does your company have a system for identifying watercourse/stream crossings?
        i. What is that definition?
        ii. How are wetlands identified during planning?

        iii. How are wetlands identified during field operations?
   b. Does your company recognize or classify wetlands by various types?
        i. Given what you know (or what you have just been told) about wetlands, do you think impacts (and therefore management/monitoring protocols) should differ among types?
   c. What symptoms of wetland impacts does your company look for?
        i. What evidence is typically used to determine if a wetland crossing is functioning well from an environmental performance perspective?
        ii. What evidence is typically used to determine if a wetland crossing is functioning well from an operations/road performance perspective?

2. **Wetland Crossing Monitoring Responsibilities:**
   a. What industry responsibilities regarding wetland crossing monitoring are driven by government policies, regulations, guidelines etc.?
   b. What operational or business responsibilities influence wetland crossing monitoring?
   c. Is integrated land management a factor for your company? For example, do you foresee any challenges or opportunities for conducting monitoring and repairs under shared access plans?

3. **Current Practices:**
   a. Please describe the wetland crossing monitoring/repair program that is in place now for wetlands at your company.
        i. Was the present monitoring program developed specifically for wetlands or is it the same as or modified from a stream-crossing program?
   b. How often are crossings monitored?
   c. How are decisions made regarding repair?
   d. Are crossing monitoring/repair activities prioritized based on any ecological or operations criteria? For example:
        i. Wetland type, function, quality, value?
        ii. Number of crossings/unit area?
        iii. Road performance or impacts on wetlands?
   e. Is an asset management system in place for bridges and major culvert crossings and is it integrated into the monitoring system?
   f. How well is the present monitoring system performing?
        i. Is it timely and effective for collecting the required information?
        ii. Does it adequately meet regulatory needs?

4. **What would an ideal monitoring protocol for your company look like?**

a. What kind of information would be collected?
    i. Wetland response info (e.g., water quality, water flow, vegetation response)
    ii. Structural performance info (e.g., integrity, functionality)
    iii. Asset management
b. Who would complete monitoring activities?
    i. Company staff – would they need training?
    ii. Contractors – what qualifications would be required?
c. How would information be collected and reported?
    i. Logistical factors – time, repeatability, standardization

Appendix C. Literature review

Note: the following document was previously submitted as a separate report entitled Wetland Crossings Literature Review: A document to support the development of a rapid evaluation tool (Nason and Pyper 2019). *It has been adapted to serve as a supplement to this report. All references within this supplement can be found in Appendix D of this report.*

Contents

Context

Wetlands are considered highly valuable ecosystems for the numerous ecosystem services they provide and for their value in harbouring biodiversity and critical wildlife habitat. Permanent resource roads built through wetlands have many confirmed and potential environmental impacts and pose operational/structural performance challenges for maintenance. To ensure that wetland crossings are properly maintained and minimize their impacts on surrounding ecosystems, a project has been initiated by the Foothills Stream Crossing Partnership (FSCP) to develop protocols for evaluating wetland crossing performance and prioritizing repairs to crossing structures. The following literature review has been developed in order to support the project team in developing recommendations for how to rapidly evaluate the performance of permanent wetland crossings in Alberta's boreal region. This project is being conducted in partnership by FPInnovations, Fuse Consulting Ltd., Circle T Consulting, Ducks Unlimited Canada and fRI Research.

The topics, subtopics and questions outlined in this review were determined through group discussion with the project team at a kick-off meeting. These areas were highlighted as potential gaps in knowledge and key concerns for the membership of the FSCP. Systematic searches were carried out in Google Scholar to address these topics and identify what research currently exists to help answer outstanding questions.

Ecological value of wetlands

Do wetlands outside of a defined stream channel act as fish habitat?

Only one study was found to document the presence of fish in western boreal wetlands (Hornung and Foote 2006). Brook stickleback (*Culaea inconstans*) were monitored as part of a study on aquatic invertebrates at 24 peatlands near Slave Lake, Alberta. *C. inconstans* was found to be present in four out of 24 peatlands and was the only fish species caught using Gee minnow traps. The authors noted that fish persisted over winter because most wetlands were deep enough so that they did not freeze to the bottom, and most were also not connected to other surface waters. The presence of *C. inconstans* was associated with a decrease in predatory, non-predatory (excluding omnivores) and gatherer-collector functional groups of aquatic invertebrates, suggesting that these organisms serve as an important part of the species' diet. While the study did not analyze factors associated with fish presence/absence statistically, it could be inferred from this study that water depth and presence of certain aquatic invertebrates are important factors for identifying brook stickleback habitat in boreal wetlands.

The Government of Alberta has also developed a rapid wetland value evaluation tool that takes into account fish habitat (Government of Alberta 2016). The tool is called the Alberta Wetland Rapid Evaluation Tool (ABWRET) and it can be applied using GIS data (ABWRET-Estimator, ABWRET-E) or using on-the-ground site assessment data (ABWRET-Actual, ABWRET-A). Fish habitat is incorporated as a component of a larger model that estimates the relative value of wetlands. The fish habitat component is scored on a scale of one to 10 using the following parameters:

- Automatic 10 if wetland hosts a fish species-at-risk
- Automatic zero if wetland contains surface water for less than four consecutive weeks annually (unless it is known to contain fish)
- For all other wetlands the score is the average of other scores estimated by the tool: wetland productivity, wetland permanence, habitat structure, avoidance of anoxia, and avoidance of other stressors

ABWRET-E has only been developed for the White Area of Alberta so far (Creed et al. 2018), and it is unclear how regularly ABWRET-A may be applied in the Green Area.

Models to identify fish habitat in wetlands do exist, but these are specific to other regions; in Canada in particular, there are many studies and assessments of fish habitat quality of coastal wetlands in the Great Lakes region (e.g., Seilheimer and Chow-Fraser 2005).

Potential gaps in this subtopic:

- Broader survey for fish presence/absence and analysis of influencing factors in boreal wetlands
- Field validation of subcomponents incorporated into the ABWRET fish habitat component
- Application of ABWRET-E and ABWRET-A in the Green Area

Other established values of wetlands

Approximately 20% of Alberta's surface is covered in wetlands, 90% of which are peatlands (Government of Alberta 2013). These ecosystems provide a variety of valuable ecological functions, some of which have indirect value to humans (Government of Alberta 2013; Wilson, Griffiths and Anielski 2001):

- Sustain large populations of migratory waterfowl
- Provide flood mitigation by storing surface runoff
- Provide shoreline stabilization
- Absorb stormwater
- Act as natural filtration systems, cleansing surface waters prior to discharge
- Act as groundwater recharge zones
- Support biodiversity
- Sequester carbon

In addition, wetlands provide a number of functions of direct value to humans (Government of Alberta 2013):

- Recreation (e.g., bird-watching, hunting)
- Ecotourism
- Cultural and traditional use by Indigenous peoples
- Peat mining

Tools for assessment of wetland value/quality

A wide variety of tools and systems exist to gauge wetland value, condition/functioning, and quality. The Alberta Wetland Policy (Government of Alberta 2013) acknowledges that some wetlands provide more benefits and functions that others, emphasizing wetland management and conservation based on the concept of 'relative wetland value.' A rapid evaluation tool (Alberta Wetland Rapid Evaluation Tool; ABWRET) has been developed that compares wetlands across a common list of metrics related to biodiversity and ecological health, water quality improvement, hydrologic function, human uses, and relative abundance (Creed et al. 2018). The purpose of this system is to allow planners and decision-makers to understand the broader importance of an individual wetland on the landscape.

Several tools and resources for wetland assessment, in addition to the ABWRET tools, have been developed to support the Alberta Wetland Policy and are available online (https://www.alberta.ca/alberta-wetland-policy-implementation.aspx):

- Alberta Wetland Identification and Delineation Directive
- Alberta Wetland Classification System
- Alberta Wetland Assessment and Impact Report Directive
- Alberta Merged Wetland Inventory
- Relative Wetland Value Map (White Area only)

Other relevant systems, tools, and documents to assess wetland condition in Alberta and the boreal are listed below:

- Eaton and Charette (2016): a systematic evaluation of drivers, stressors, and indicators of wetland change in Alberta's oil sands region. These variables were identified to support the development of a regional wetland monitoring program in the oil sands region. The study emphasizes the inclusion of anticipatory variables (those that indicate impending major impacts than can be mitigated or avoided by corrective management).
- Hornung and Rice (2003): use of Odonates (dragonflies and mayflies) as indicators of wetland condition in Southern Alberta. Odonate species richness was positively correlated with vegetation species richness, suggesting that this taxonomic group may be effectively used as an indicator group.
- Roy et al. (2019): use of plant functional traits as indicators of wetland ecological condition in Grassland and Parkland regions of Alberta. Non-native, upland, and annual plant abundance increased with degree of agriculture, suggesting that these functional groups could be used as indicators of disturbance (depending on wetland type).
- Wilson, Griffiths and Anielski (2001): an overview and economic valuation of ecosystem services provided by Alberta's wetlands and peatlands. As of 1999, the value of remaining wetlands was estimated at $5-30 billion and the value of remaining peatlands was estimated at $9.5 billion for water regulation services and $27.79 million for carbon sequestration services. The study also estimated the cost of losing approximately 60% of Alberta's wetlands (this is the amount that has been

estimated lost to date in 1999), which was considered to be $7.7 billion (7% of Alberta's GDP).

- Morissette et al. (2013): bird habitat delineated based on boreal wetland classification, with indicator species identified for each wetland class.

Other more generalized tools and models have also been developed for assessing wetlands, which do not have regional specificity for the boreal but may have relevance as generalized frameworks:

Assessment Type	Description	Relevant Citations
Hydrogeomorphic model	Rapid assessment tool designed to detect impacts due to human activities (e.g., alterations of water sources and hydrodynamics; changes in shape of wetland due to filling). Compares disturbed, constructed or restored wetlands to undisturbed reference wetlands of the same subclass	Brinson (1993) Smith et al. (1995) Brinson (1996) Brinson and Rheinhardt (1996) Hauer and Smith (1998) Smith and Wakeley (2001) Cole (2006) Weller et al. (2007)
Indices of ecological function (e.g., floristic quality assessment index, indices of biotic integrity)	An index developed for specific species or taxonomic groups of interest, either for conservation of species of concern or as an overall indicator of ecosystem health	Lopez and Fennessy (2002) DeKeyser, Kirby and Ell (2003) Stevenson and Jensen (2007) Seilheimer and Chow-Fraser (2007) Hanson et al. (2008) Wilson and Bayley (2012) Wilson et al. (2013)
Indicator species/assemblages	Presence and/or abundance of a particular organism is used to assess overall ecosystem health	King et al. (2000) Johnston et al. (2008) Sims et al. (2013)
Human values/economic valuations	Assessments of ecosystem services and human values are used to assess the economic value of wetlands	Woodward and Wui (2001) Brander, Florax and Vermaat (2006)

A few potentially relevant documents fell outside of the above categories. Akumu et al. (2018) mapped inland wetlands in Tennessee and used a weighted geospatial vulnerability analysis (incorporating variables such as roads, land use, and climate data) to predict potentially vulnerable wetland types. A similar analysis might be useful in Alberta's boreal region, although the provincial government likely has plans to produce a map of relative wetland value for the Green Area in the near future, which would likely be most useful for policy compliance.

A system has also been developed for early detection of pollutant impacts on wetlands with special focus on the wet-dry tropics of northern Australia (Van Dam et al. 1998). This study determined that phytoplankton are likely to be the most promising early indicators of wetland degradation due to pollutants since they are abundant, show predictable and rapid responses to a wide range of toxicants, respond to changing nutrient levels, and many rapid, reliable and sensitive techniques have already been developed for their assessment.

Potential gaps in this subtopic:

- Are ABWRET tools being used to guide land use planning and mitigation?
- Will ABWRET-E be expanded into the Green Area? Will a map of relative wetland value be produced?
- How are indicators of wetland condition (e.g., the metrics incorporated into cumulative scores, indicator species/taxa) affected by the presence of wetland road crossings? For example, do improved crossing designs have measurable positive impacts on wetland condition scores?

Operational and structural performance of crossings

Monitoring road performance

There are several structural and operational challenges to establishing road crossings through wetland areas. The soft soils and saturated conditions present in wetlands result in poor load-bearing capacity (Partington 2015), and can lead to the following structural issues:

- Settlement of the road over time

- Deformation of the road (e.g., humps and divots) and change in peat volume under embankment load due to high compressibility of peat
- Settlement or sinking of culverts below the water table
- Damage/deformation of culverts over time due to road settlement and heavy loads
- Flooding of the road or development of ponding on top of the road due to disruption of local hydrology
- Erosion/rutting of the road surface under heavy loads

Winter construction methods are therefore generally recommended to make use of the stronger load-bearing capacity of frozen ground (De Guzman and Alfaro 2016; Gillies 2014). Summer construction methods were tested by De Guzman and Alfaro (2016), but were not successful due to significant movement of the road, likely because of fill overstressing the ground and shearing the underlying peat.

In addition, there can be several structural issues related to the materials used to construct wetland roads:

- Heat accumulation and thawing of foundation soil due to fill material with high porosity/convection potential
- Inappropriate size of fill material resulting in structural problems with culvert stability and erosion/sedimentation
- Slippery texture of woven geotextiles may reduce road stability

Current efforts to monitor operational/structural performance of wetland roads therefore focus on monitoring of road/culvert settlement, culvert condition, effects on hydrology (e.g., water table depth on either side of the road), and erosion and/or rutting of the road surface (De Guzman and Alfaro 2016; FP Innovations 2016; Partington 2015, 2016; Badiou and Page 2014; Ducks Unlimited Canada 2014; Kochuparampil 2013; Blinn et al. 1999).

So far, these studies have not recorded consistent appreciable differences in the performance of different road designs or construction methods; however, some key findings are highlighted below which could help guide future research and validation studies.

- De Guzman and Alfaro (2016): studied the structural performance of two different road designs (geotextile only vs. geotextile with corduroy) on a peat foundation in Northern Manitoba; found that adding timber logs near the toe of the slope reduced settlement of peat foundation and reduced requirement for fill material to maintain road elevation.
- Badiou and Page (2014): studied effectiveness of newly developed wetland crossing designs in maintaining hydrology compared to traditional designs at shrub swamp,

conifer swamp, and treed fen at Manitoba/Saskatchewan border; found that water table levels appeared to be maintained in new designs, and documented evidence of upstream pooling and dead trees at a conventional culvert crossing.

- Partington (2015): studied use of geogrid and woven geotextile as a culvert foundation improvement for a resource road in Ontario; found that these materials did not improve culvert foundations over three years of monitoring, possibly due to the fine fill material used not properly interlocking with geogrid to provide support.
- Partington (2016): studied road and culvert settlement at a resource road across a treed bog in Northeastern Alberta; found that culvert ends settled into foundation soils after a period of two years, which corresponded to the direction of loaded truck traffic and may therefore be due to the effect of heavy loads on settlement.

Potential gaps in this subtopic:

- Assessment of pre-construction reference conditions to understand impacts of installing crossings
- Testing of crossing designs to permit water flow in a variety of wetland classes
- Long-term monitoring of performance
- Testing of proposed crossing designs that have not yet been implemented (e.g., rigid base reinforcement with corduroy: Landva 2007; berms at outer limits of embankment to trap 'mud waves': Raymond 1968)
- Summer construction methods
- Testing of new methods to support culverts and avoid culvert sinking (e.g., log cribs)
- Effects of different levels of traffic and load weights on road performance over time

Which crossings should be prioritized for repairs?

Several systems for prioritizing wetland restoration and road-stream crossing repairs are described in the literature, but it does not appear that a prioritization system specific to wetland crossings currently exists. Examples of approaches taken in other contexts include:

- Kauffman-Axelrod and Steinberg (2010): an automated GIS-based evaluation tool to prioritize wetland restoration in Oregon. This system is specific to tidal wetlands and assigns higher priority to wetlands with more favourable landscape-scale metrics and less cumulative hydrologic alteration. Parameters in the prioritization systems are weighted on three different tiers determined by regional experts; the parameters in the most strongly weighted tier are tidegates and road-stream intersections.

- Mills, Dent and Cornell (2007): a rapid survey system for evaluating forest road conditions and prioritizing road maintenance and repair activities. This tool incorporates a strong emphasis on impacts on fish-bearing streams and is applied in mountainous terrain of the Pacific Northwest.
- Weiter (2015): proposes a formulation for prioritizing repairs to crossings based on the number of organisms in the watershed and the amount and quality of accessible habitat. Method is applied to the Upper West Branch of the Westfield River in Massachusetts.
- Creed et al. (2018): the ABWRET system prioritizes wetlands with the greatest estimated relative value for restoration.
- Witmer, Stewart and Metcalf (2009): a sedimentation risk index was developed for road-stream crossings in the Choctawhatchee watershed, Alabama. The risk index incorporates 12 metrics and weighs factors involving soil erodibility, road sedimentation abatement features, and stream morphology alteration. Crossings are categorized into qualitative categories (excellent, good, fair, poor, very poor) to help prioritize repairs.
- Akumu et al. (2018): a GIS-based system for ranking the vulnerability of wetlands in Tennessee was developed; a similar approach could be used in Alberta to help prioritize repairs in wetlands predicted to be most vulnerable.

Systems for prioritizing wetland restoration (e.g., Government of Alberta, 2018; Kauffman-Axelrod and Steinberg, 2010) could be used one of two ways for evaluating wetland crossings:

- Use a score of wetland value and/or wetland restoration prioritization ranking as one component of an evaluation for each crossing (i.e., crossing is located in a high-value wetland and/or a wetland that has been prioritized for rehabilitation, therefore, crossing should be examined for potential repairs)
- Use the frameworks developed for these systems as a skeleton on which to build a similar wetland crossing prioritization system (e.g., could take the GIS tool/model developed by Kauffman-Axelrod and Steinberg (2010) and modify the parameter weightings, add/remove parameters, etc. to make it appropriate for the boreal)

Levine (2013) also conducted an economic analysis of improved road-stream crossings in the Adirondack region of New York. This study demonstrated that although installation of an improved crossing can be 50-100% more expensive than a traditional crossing, upgraded crossings require less maintenance in the long-term and are predicted to be more resilient to climate change. In general, it has been noted that improved inventories of road crossings will help to prioritize efforts for repairs (Januchowski-Hartley et al. 2013).

Potential gaps in this subtopic:

- Development of a prioritization scheme for wetland crossings, which may involve challenging adaptation of existing prioritization tools to the Alberta boreal context
- Incorporation of threats to species-at-risk or to critical habitat (e.g., caribou habitat, amphibian habitat)
- How are repairs currently prioritized by companies operating in the Alberta boreal region?

How do we differentiate wetland crossings from stream crossings?

A possible way to systematize the classification of crossing structures would be to use indicative features of the surrounding ecosystem. Fortunately, many baseline studies of the characteristics of boreal wetlands exist. For example, there are many studies on the vegetation, surface water chemistry, and peat chemistry of fens in Alberta (Vitt and Chee 1990; Chee and Vitt 1989; Slack, Vitt and Horton 1980). Boreal wetlands have also been classified and field guides have been produced at national and provincial levels, including the identification of flow characteristics, vegetation and peat depths typical of each wetland class (e.g., FP Innovations 2016; Ducks Unlimited Canada 2014; Smith et al. 2007).

Another option for classifying crossings structures could be based on the type of construction. Blinn et al. (1999) define several construction options for wetland crossings, and these have been elaborated on in several handbooks, field guides, and best management practices (e.g., FP Innovations 2016; Ducks Unlimited Canada 2014).

Potential gaps in this subtopic:

- Retroactive classification/identification of existing crossings
- Structured application of standardized construction, monitoring, and decommissioning practices for unclassified crossings

Tools for assessment of crossing performance

Very few standardized tools to assess the operational/structural performance of crossings appear to exist. Apart from the existing protocol for assessing performance of road-stream crossings in the Alberta Foothills region (Foothills Stream Crossing Partnership 2017; McCleary, Wilson and Spytz 2004), only one document was accessed in this review, which details a system for inventorying and assessing runoff/sedimentation processes for road networks that cross waterbodies (Black, Cissel and Luce 2012). The system is called the Geomorphic Road Analysis and Inventory Package (GRAIP) and it is mainly applied for road networks crossing hillslopes and streams. GRAIP can be applied at two scales:

1. Inventory an entire watershed's road network in order to determine where problems exist; determine how much sediment and mass wasting risk is associated with the network.
2. Small scale project monitoring by inventorying a road or set of roads prior to road treatment in order to assess effectiveness of treatment.

Potential gaps in this subtopic:

- What metrics are currently being used to assess wetland crossing performance? Are there any standardized tools or models being shared among companies for this purpose?
- Is there any opportunity to scale up current approaches to assessment (i.e., along the lines of GRAIP, could road networks be assessed at the watershed level)?

Environmental performance of crossings

Effects of sedimentation, erosion and runoff

Most studies on effects of sedimentation, erosion, and runoff have been focused on road-stream crossings. Erosion and sedimentation can negatively impact wetlands around roads by carrying pollutants into the water system, affecting water quality, and altering peak flows, benthic community structure, algal production, and trout/salmon fry emergence in associated stream networks (Loganathan, Vigneswaran, and Kandasamy 2013; Graf 2009; Forman and Alexander 1998). Adjacent land use has also been shown to degrade wetland water and sediment quality across long distances (2250-4000m; Houlahan and Findlay 2004), suggesting that linear land features directly within wetlands may have farther-reaching effects than might be assumed. Of particular relevance to wetland crossings, culvert construction has been shown to increase sedimentation and turbidity due to diversion and dewatering, as well as to increase water hardness due to concrete leaching (Huang and Ehrlich 2004).

Assessment of erosion has taken place for temporary wetland crossings, especially in terms of the depth of rutting on different crossing types (Blinn et al. 1999). These trials have mainly occurred in Florida, Michigan and Minnesota. Trials have shown variable performance of different crossing types, which may be due to their implementation in different wetland classes. Wood mats, wood planks, wood pallets, metal grating, tire mats, and PVC pipe mats have all been tested; in general, these options decreased the depth of rutting compared to bare soil controls. PVC pipe matting appeared to be particularly effective as a temporary crossing option, and has the added benefit of being reusable.

Witmer, Stewart and Metcalf (2009) designed a sedimentation risk index for the Choctawhatchee watershed in Alabama, which incorporates 12 metrics related to soil erodibility, road sedimentation abatement features, and stream morphology alteration. No significant differences in the index were detected among different crossing structure types (round culverts, box culverts, and bridges), which suggests that these different types of crossings perform similarly in terms of sedimentation outputs.

Several models are available to estimate surface erosion and sediment delivery for streams on unsealed roads. Seven of these models were reviewed by Fu, Newham and Ramos-Charron (2010), who also provide an overview of factors influencing surface erosion from MacDonald and Coe (2008). The key factors influencing erosion identified by their review were:

- Rainfall intensity and duration
- Snowfall

- Characteristics of surface materials
- Hydraulic characteristics of road surface
- Road slope
- Traffic
- Construction and maintenance
- Contributing road area

Of special relevance to wetland crossings, there is evidence that heavier vehicles (Sheridan and Noske 2007) and traffic during wet weather (Ziegler et al. 2001; Coker et al. 1993) result in higher sediment yields. In the boreal region, interaction with snowfall is also likely a key factor: surface erosion rates tend to be lower during snowmelt than rainfall events, because snow protects the road surface from raindrop energy and slows overland flows.

Fu, Newham and Ramos-Charron (2010) note that selection of a model to estimate sedimentation and erosion impacts can depend strongly on regional context. Empirical models have been developed for regions with steep slopes and intense rain events, and one model is available that incorporates snowfall; however, it is likely that a separate empirical model would need to be developed for boreal wetlands to account for environmental features like climate and topography. Alternatively, there are physics-based models that are not as dependent on specific environmental conditions; these may be successfully adapted across regions. For example, the U.S. Forest Service Water Erosion Prediction Project (WEPP) Road Model has been successfully applied to a pine plantation forest in Queensland, Australia, even though it was originally developed in the U.S. (Forsyth et al. 2006).

Recently, a Road Erosion and Delivery Index (READI) was developed and applied to the Simonette River Watershed in Alberta (Benda, Andras and Miller 2016). If local controls on erosion potential are not known and sediment yield data are not available, READI can be calculated as a dimensionless index; however, it can also be calibrated based on local data on sediment production if it is available. READI is integrated into a set of watershed tools called NetMap, and it can be used to predict sediment yields at the scale of individual road segments or for networks of road segments at the basin scale. While this index and system of tools are mainly designed for road-stream crossings (e.g., the tool has been applied to identify optimal locations to add drains in order to hydrologically disconnect roads from streams), there may be potential to adapt it to wetland crossings. Of note, the NetMap tools integrate two other road erosion models also mentioned in this review: the WEPP model (physics-based, cannot be adapted to local conditions) and GRAIP (incorporates potential factors of interest such as road surface type and maintenance level).

Erosion control systems, such as erosion mats and planting of vegetation, have mainly been trialled for road-stream crossings. Rehder and Stednick (2007) reviewed the effectiveness of 28 erosion and sediment control BMPs instated by the National Forest Service in the U.S. In general, they found that these BMPs were effective for revegetation of hillslopes, removal of roads, and installation/maintenance of stream crossings. In particular, the study showed that outsloping roads outperformed insloping roads for sediment control and that gravel/rock road surfacing reduced sediment from unpaved roads. A study on erosion control in Talladega National Forest, Alabama also demonstrated that native vegetation is equally effective as non-native vegetation and erosion control mats in reducing sediment yield (Grace 2002), suggesting a potential synergy between restoration and structural maintenance objectives.

Erosion controls appear to play a strong role in maintaining water quality: a study that monitored water quality of an adjacent wetland over the course of a road construction project showed that downstream water quality was consistent with upstream quality, except during one incident when erosion control measures were neglected (Huang and Ehrlich 2004).

Potential gaps in this subtopic:

- Impacts of sedimentation, erosion and runoff on wetlands (most studies are specific to streams)
- What are the main factors that would need to be incorporated into an empirical model to assess erosion and sedimentation for wetland crossings?
- How do different permanent wetland crossing types perform in terms of erosion/sedimentation?

Impacts on fish/amphibian passage

The question of impacts on fish passage is likely still an open one for boreal wetland crossings. Existing literature on fish passage has a singular focus on stream and river crossings, and no documents on wetland crossings were detected in this review. However, since there is documentation of fish presence in isolated boreal wetlands (Hornung and Foote 2006), this question may merit further consideration. For wetlands that are connected to other surface waters, impassable crossings are likely to limit fish access to feeding habitats that can also provide a function of protection from predators. Some wetlands are only temporarily connected to other streams, lakes, and rivers due to seasonal changes in water level; during times of flooding, these wetlands may serve as important temporary habitats for fish (Henning et al. 2007). Wetland crossings may therefore impact fish habitat use and have the potential to fragment fish populations, but there do not appear to be any current assessments of these potential impacts in the boreal region.

Some literature exists on the impacts of roads on amphibians in wetlands; however, no literature was found specific to the boreal region. Generally, roads are linked to declines in amphibian populations (Cunnington et al. 2014). Roads in wetlands can cause road mortality (Andrews et al. 2008), fragmentation of amphibian populations, bisection of amphibian movement pathways, and exclusion of animals from critical habitats (Hamer et al. 2015). However, road mortality may not be a great risk on resource roads due to the low volume of traffic (Forman et al. 2003). Traffic and industrial noise may also affect amphibian calling behaviour (Parris et al. 2009), and rural road networks have been shown to act as barriers to gene flow for amphibians (Garcia-Gonzalez et al. 2011).

Crossings to facilitate amphibian passage are often termed ‘ecopassages.’ Such ecopassages are typically pipe culverts and paired with fencing to avoid amphibians from crossing the road itself. In particular, slotted-drain culverts have been shown to facilitate amphibian crossings by allowing sunlight and air exchange (Doyle 2003). It has also been shown that culverts alone are not sufficient to reduce anuran (frog and toad) road mortality, and fencing is therefore essential; however, maintenance of fencing, especially in regions with heavy snowfall, is expensive (Cunnington et al. 2014). A research trial to test opportunities to improve amphibian use of ecopassages in New York showed that the location of the passages is likely more important than their sizing or design for the species studied (Spotted Salamanders and American Toads; Patrick et al. 2010). The authors therefore emphasize the importance of identifying crossing locations at ‘hotspots’ (known areas where amphibians prefer to cross, likely determined by physical characteristics of the site). In general, the following recommendations have been made to ensure road impacts on amphibians are mitigated (Hamer et al. 2015):

- Plan location of new roads in consultation with amphibian experts to avoid disruption of habitat and movement corridors
- Ensure road-crossing and mitigation structures (i.e., culverts and fencing) are installed where needed
- Avoid construction during time periods of high amphibian activity to avoid individuals being killed by machines; movement of animals (i.e., translocation) should be considered a last resort
- Maintain road-crossing and mitigation structures regularly, especially fencing which is prone to damage

- Employ long-term monitoring (pre- and post-construction for several amphibian generations) to ensure mitigation effectiveness

Further information on the effects of roads on amphibians, mitigation techniques and mitigation effectiveness in North America can be found in a review by Griffin (2015).

Potential gaps in this subtopic:

- Effects of boreal wetland crossings on fish habitat use/fish passage, especially during seasonal water level fluctuations
- What are the impacts of low-volume boreal resource roads on amphibians? Are road mortality, habitat fragmentation, or disruption of calling behaviour strong risks?
- How can we identify amphibian crossing hotspots?

Impacts on hydrological characteristics

Dutton et al. (2005) outline four major ways that forest roads may affect wetland hydrology:

- Affecting water movement
- Reducing the amount of water that enters soils
- Capturing and channelizing surface runoff
- Modifying subsurface flow paths

Hydrologic impacts are ultimately predicted to have impacts on water chemistry and vegetation. For example, a study of plant assemblages in the Pacific Northwest Region of the U.S. showed that minor changes in average water levels or variability can affect plant species assemblages and could trigger substantial shifts in plant communities (Magee and Kentula 2005). In the Canadian boreal, forest practitioners have noted ponding of water on only one side of wetland road crossings, which may also be associated with presence of dead and dying trees and shift to new vegetation (Bocking 2015; Gillies 2011). Tree dieback due to hydrologic disturbance has also been recorded in other regions, notably the mangrove-bearing wetlands of South America (Jaramillo et al. 2018). In extreme cases, ponding effects might even translate to the creation of a new wetland (Gillies 2011). Pooling/flooding on one side of the road could also increase surface water area of existing wetlands. In North Dakota, increased water surface area has been shown to interrupt regular drying out cycles, increase surface water connections to other wetlands, and improve conditions for certain fish species that consume aquatic invertebrates, which ultimately may decrease the productivity of the wetland (McCauley et al. 2015).

Roads may also affect hydrology by creating a barrier to surface and subsurface flows (Webster et al. 2015; Devito and Mendoza 2007). Hydrologic connectivity of boreal wetlands can be determined by topography, moisture conditions related to runoff, and hydrologic conductivity of substrates (Kusel 2014); connectivity may therefore be disturbed by linear features that affect these factors. Importantly, high degrees of hydrologic connectivity have been shown to confer greater resilience (i.e., ability to withstand disturbance without shifting to another state; Swedish Environmental Advisory Council 2002). Hydrologic connectivity to streams can also strongly influence the sediment and nutrient levels present in wetlands, indicating that roads affecting hydrologic connectivity may also have impacts on water quality (Wolf, Noe and Ahn 2013).

Soil compaction due to road development may also cause increased overland flow if the infiltration rate is lower than the rainfall rate, which can contribute to greater peak flows and runoff in associated stream channels (Webster et al. 2015; Coe, n.d.). A study in the Wrangell-St. Elias National Park and Reserve in Alaska showed that off-road vehicle trails had such effects on wetlands and streams: increased runoff on trails led to flow accumulation, channel shearing, and soil erosion. The authors noted that these changes will likely result in increased drainage density and possible alterations of downstream flow regimes, water quality and aquatic habitat (Arp and Simmons 2012).

Graf (2009) reviewed the environmental impacts of various forms of industrial disturbance in boreal wetlands and did not find any research that directly measured the effects of roads on wetland hydrology; the author inferred the following potential impacts based on existing literature related to wetland ecosystems (e.g., hydrology, chemistry, etc.):

- Diversion of nutrient-rich water from fens or mineral terrain onto bogs could lead to degradation of bog systems (high nutrients are toxic to Sphagna mosses)
- Roads through rich fens could block groundwater flows, causing downstream fens to become poor fens
- Frequent ponding in permafrost peatlands could degrade underlying permafrost, creating thermokarst terrain

Graf (2009) also described several important characteristics of peatland hydrology that are important to consider in determining the potential effects of linear disturbance. Peatlands are composed of two layers: an upper layer called the acrotelm that is mainly composed of live and slightly decomposing vegetation, which has high hydraulic conductivity and intense biological activity; and a lower layer called the catotelm that is composed of more decomposed peat, which has a constant water content, low hydraulic conductivity, and anaerobic conditions. This layered structure regulates the storage and discharge of water in peatlands, especially due to the water storage capacity of Sphagna mosses in the acrotelm. Carbon is sequestered by the submergence of organic matter at the base of the acrotelm. No studies were found on the disruption of peatland layers due to road development in this review, but it is likely that any hydrologic disturbances caused by roads could have consequent effects on peatland structure and carbon sequestration functions.

Similar to Graf (2009), another review of impacts of industrial activity on hydrology of boreal wetlands was conducted by Webster et al. (2015). Little new research had been conducted in the intervening time period, but Webster et al. (2015) highlight a key consideration that hydrologic impacts are likely to be different between the Western and Eastern boreal. In the Western regions topography is flatter and soils are deeper, resulting in water primarily flowing vertically and through deep subsurface pathways. In the Eastern regions, higher topographic relief and shallow upland soils lead to water flows that are regulated by the size and configuration of runoff-generating areas. These regional considerations are likely key for predicting road impacts and designing wetland crossings appropriately. For example, road effects on upslope vs. downslope water tables are likely of more relevance to the Eastern boreal, while impacts on subsurface flows are more relevant in the Western boreal.

There have been a few recent trials examining hydrologic impacts of wetland roads, summarized below:

- Petrone (n.d.) studied the impacts of a road build through a poor treed fen near Ft. McMurray, Alberta and found subtle effects on hydrology, which translated to a difference in carbon, nutrient dynamics and plant productivity. Removal of the road was shown to restore some, but not all, hydrologic functioning.
- Plach et al. (2017) followed up at the same Ft. McMurray site as Petrone (n.d.) and found that the road impeded groundwater movement across the site and caused clear differences in vegetation between sides of the road.
- Badiou and Page (2014) monitored water quality and movement upstream and downstream of several wetland crossing types in Manitoba and Saskatchewan, finding that new crossing structure designs were effective in maintaining water flow over a two-year monitoring period.
- Mader (2014) studied culvert spacing of several newly constructed roads in New Brunswick and Nova Scotia and found that in most cases, activities to clear the right-of-way before road construction appeared to cause a shift in hydrological balance that was then maintained after culvert installation.

- Saraswati, Parsons and Strack (2018) found that road-associated factors (e.g., proximity of sampling sites to road, proximity to culvert) affected water table depth in a bog where the road was perpendicular to direction of water flow, but not in a fen where road construction was parallel to water flow.

Potential gaps in this subtopic:

- Cumulative effects of several crossings within a watershed
- Measuring pre-construction reference conditions
- Field trials assessing hydrologic impacts of wetland roads
- Effective culvert placement/spacing to ensure water flow
- Management of subsurface flows
- Understanding wetland flow directions and planning construction accordingly
- Impacts of clearing right-of-way activities prior to road construction

Impacts on biodiversity and ecosystem services

There is a large amount of existing literature examining the impacts of roads and industrial disturbance on biodiversity and ecosystem services. In general, the following documented impacts of linear disturbance in the boreal are likely to also be factors for permanent wetland roads:

- Potential loss of wildlife biodiversity in surrounding areas due to restricted movement between populations, habitat fragmentation, and predator access (Findlay and Bourdages 2000)
- Loss of habitat in area occupied by road and potentially affected wetlands, contributing to decline of wetland species (Quesnelle, Fahrig and Lindsay 2013)
- Loss of habitat in buffer area surrounding road due to wildlife road avoidance behaviour (Schneider and Dyer 2006; Dyer et al. 2001)
- Contamination of nearby vegetation with road dust, which is especially damaging to mosses because they absorb water and nutrients directly through their tissues (no root system; Spatt and Miller 1981)
- Wildlife population fragmentation resulting in demographic and genetic consequences, especially for interior species (Forman and Alexander 1998)
- Increased impact compared to temporary or winter roads

Apart from these broader implications, a few regionally relevant studies are summarized below.

Impacts on wildlife and animal biodiversity

Kreutzweiser et al. (2013) evaluated the current and potential impacts of natural resource development on aquatic biodiversity in the Canadian boreal. They found a limited amount of literature on the topic and indicate that there is a strong need for more consistent, coordinated data collection for the bioindicators and disturbance types considered. In their review, they document the following key impacts:

- Fish: fine sediment loads in streams and problematic culverts have impacts on fish passage and productivity; roads can also increase fishing access and over-exploitation of game fish
- Amphibians: loss/reduction of critical habitat; forest practices showed little or no risk of adverse effects in five out of seven studies; Canadian Toad potentially at risk due to forest harvesting encroachment on critical habitat
- Macroinvertebrates: fine sediment loading, reduced canopy cover, increased solar radiation/water temperature, and changes to runoff/water quality can all have negative impacts; in boreal, impacts have been highly variable, from little to no effect to significant declines in community metrics
- Zooplankton: significant effects in boreal lakes due to harvest activities (decreased edible algae due to increased phosphorous); otherwise, impacts are few or transient
- Phytoplankton and periplankton: most studies (10/14) indicated measurable increases in algal community attributes (eutrophication)

The authors noted that the scarcity of studies on amphibians is concerning given the concern about global amphibian declines, their function as global indicator species, and the importance of the boreal as critical amphibian habitat (Houlahan et al. 2000). In addition to the Canadian Toad, another taxon of concern may be the Northern Leopard Frog, which is federally listed as Special Concern in the Western Boreal (COSEWIC 2009).

Impacts on vegetation and plant biodiversity

Miller, Benscoter and Turetsky (2015) studied the effects of upstream road construction on downstream fens, which dried out as a result. They found that three of four fens had a two to four-fold increase in total biomass, and that a shift was induced to a drier peatland regime with increased canopy and vascular density. Ground-layer mosses and understory species were reduced or lost, which will likely influence carbon sequestration and increase vulnerability to wildfire (loss of fire-inhibiting Sphagna mosses).

Bocking (2015) studied the impacts of a wetland road and culvert on hydrology and vegetation of a poor fen near Ft. McMurray using tree ring analysis. The road system was originally installed in 1977, and there was a large area of tree dieback within 220m up-gradient of the road. Tree ring growth patterns indicated that this dieback was likely caused by a single flooding event due to culvert blockage by beavers, and that disrupted hydrology in the area around the culvert has resulted in a vegetation shift towards non-hummock forming species. The researchers suggest that peatland disturbance due to roads could be reduced or eliminated by using road designs with multiple culverts that cannot easily be blocked by debris or beaver activity, or by pursuing underdrain systems that create more natural flow patterns (Bocking, Cooper and Price 2017).

Willier (2017) studied the impacts of roads on vegetation across 96 peatlands in Northeastern Alberta using LiDAR data and vegetation plots at a subset of 25 peatlands. In general, canopy cover and tree species composition increased on the downstream sides of roads and decreased on the upstream side. The upstream side of the road was characterized by the following indicator species in each wetland type studied:

- Fens: *Carex limosa* (bog-sedge)
- Swamps: *Carex canescens* (silvery sedge)
- Bogs: *Andromeda polifolia* (bog rosemary)

Other than these general trends, vegetation responses varied among sites depending on the following main factors:

- Road orientation
- Substrate texture
- Landscape position
- Peatland type

For example, species richness increased on the upstream side of roads in bogs, but had the opposite pattern in fens. In bogs, vegetation shifts varied depending on substrate: bogs over substrates with high sand content experienced vegetation shifts on the upstream side of the road, while vegetation communities were similar on either side of the road in bogs with very little sand. Roads perpendicular to the direction of water flow in swamps had a strong negative effect on species richness on the upstream side of the road. Overall, these results suggest that wetland characteristics, including wetland classification, are important factors for determining how hydrology and vegetation respond to road disturbances.

Outside of the boreal region, it is worthy to note a comprehensive survey of 70 wetland crossings that was conducted in Pennsylvania, examining long-term effects on habitat quality, water quality and vegetation (Miller et al. 1997). The authors assessed differences between sites upstream and downstream of the crossings, and only noted significant differences in 4% of cases. In these cases, stream bed fine sediments were higher, basal area lower, and herbaceous cover higher in areas immediately adjacent to the crossings.

Impacts on carbon sequestration and cycling

Sulman, Desai and Mladenoff (2013) simulated the effects of declining water tables on wetland carbon storage for a landscape in Northern Wisconsin. They found that biomass accumulation and soil decomposition were predicted to increase as a consequence of drying, but that the degree of these effects depended on the degree of water table decline and the type of wetland. In peatlands, declines of 40cm resulted in a net loss of total carbon, whereas in non-peat wetlands declines of 40cm or 100cm biomass accumulation consistently outweighed soil carbon loss. The time scale of simulation also mattered: peatland carbon storage was predicted to be stable or to increase during the first 50-100 years after drainage, but then to decrease due to soil carbon loss in later years. These findings could have implications for the long-term impacts of roads that disturb water table levels in peatlands.

Plach et al. (2017) studied peatland-atmosphere CO_2 exchange rates in a poor fen bisected by a semi-permanent road in the Athabasca oil sands region south of Ft. McMurray over one growing season. They found that subtle differences in productivity and respiration translated to significantly lower net CO_2 sequestration on the downstream side of the road.

Saraswati, Parsons and Strack (2018) found evidence of increased enzyme activity in road-disturbed areas of a bog in the Peace River region of Alberta, which suggests that roads may cause increased organic matter decomposition rates (i.e., increased release of carbon). These differences in enzymatic activity were absent in a fen that was also studied, where the road was built parallel rather than perpendicular to the direction of water flow. These findings suggest that maintenance of adequate water flow, either via culverts or parallel road construction, will help to reduce impacts on carbon cycling.

Potential gaps in this subtopic:

- What are the impacts of wetland roads on carbon sequestration, especially in peatlands? (moving beyond simulation studies)
- What are the impacts of wetland roads on amphibian biodiversity?
- How might wetland roads impact migratory bird habitat in the boreal?
- How might losses of Sphagna mosses impact carbon sequestration and wildfire risk?
- How do companies assess impacts of roads on biodiversity?

Compliance with current and future regulations

Avoidance and minimization of impact

The Alberta Wetland Policy (Government of Alberta 2013) emphasizes avoidance of impact as the first step of a mitigation hierarchy for management of wetlands. Under the policy, managers and land users should first strive to avoid impacts altogether, then to minimize impacts, and finally to replace wetlands or compensate for impacts as a last resort. This policy was developed to replace a previous policy from 1993, which was considered a failure due to non-compliance and inadequacy of wetland replacement mechanisms (Creed et al. 2018; Clare 2013).

Avoidance of building roads through wetlands is emphasized as the main mitigation strategy in many guiding documents and best management practices (BMPs) (FP Innovations 2016; Ducks Unlimited Canada 2014; Mader 2014; Government of Alberta 2013; Gillies 2011; Osko 2010; Graf 2009). In the U.S., demonstration of compliance with a set of 15 BMPs exempts companies from the requirement to apply for an Environmental Protection Agency permit (Mader 2014). However, it has been noted in many cases that impacts are often not avoided or minimized, and replacement/compensation is often accepted as the 'status quo' (Phalan et al. 2018; Clare 2013). Many projects that affect wetlands are also considered minor and do not trigger a formal environmental impact assessment (Noble, Hill and Nielsen 2011). A renewed focus on avoidance could help to limit impacts of large-scale industrial developments (Phalan et al. 2018).

A couple of stepwise processes have been proposed as frameworks to ensure avoidance and minimization of impacts:

- Noble et al. (2011): proposes a four-phase evaluation of linear development impacts on wetlands to be carried out throughout the planning process; includes scoping of wetland and baseline assessment, identifying potential project effects, mitigating potential effects, and identifying residual effects and follow up requirements
- Griffiths, Hird and Tomlinson (2000): proposes stepwise approach to designing rural drainage road designs for environmental protection; includes assessment of sensitive environments requiring special protection or avoidance, site survey of environmental values, consideration of mitigation methods, and ensuring decisions made during design and planning are carried forward into construction and maintenance

In the Western boreal region of Canada, some BMPs used by companies to minimize the impacts of permanent wetland roads include (Graf 2009):

- Decreasing the amount of roads required using integrated land management

- Building roads parallel to the direction of water flow
- Using timber mats to protect against compaction
- Removal of upper peat layer when constructing the road to protect this layer from compaction and contamination with mineral soils; vegetation is stored and used for later restoration projects
- Designing upland road approaches to wetlands so that the surface runoff carrying sediment is diverted before entering the wetland
- Avoiding constructing roads during times critical to local wildlife (e.g., mating, migration)
- Minimizing the width and length of road crossings
- Designing the road to follow landscape contours in order to decrease erosion
- Using cross-drainage methods to preserve surface and subsurface flows
- Installing culverts in peatlands that are a minimum of 61cm in diameter buried halfway below the soil surface (allows upper half of culvert to handle stormwater flows and lower half to handle every day subsurface flows)
- Constructing ditches to allow surface and subsurface water to flow to, through, and then away from culverts in order to minimize damage to the strength of the upper peat layer containing root material
- Constructing roads with clean fill or other suitable native materials to avoid introduction/spread of invasive species
- Controlling entry to operational areas to minimize access
- Ceasing use of equipment on frozen roads where rutting exceeds 15cm depth for continuous distances greater than 91m
- Removing and restoring roads that are no longer needed

Potential gaps in this subtopic:

- How will avoidance and minimization of impacts be enforced under the Alberta Wetland Policy? Will there be mandated BMPs, for example?
- How do companies make decisions about wetland avoidance?

Appendix D. References

Note: this section includes all references in the main text of this report, as well as the references used in the literature review (Appendix C).

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