RESOURCE ROADS AND WETLANDS:
A GUIDE FOR PLANNING, CONSTRUCTION AND MAINTENANCE

SPECIAL PUBLICATION SP-530E

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FPINNOVATIONS

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(Photo courtesy of Ducks Unlimited Canada.)

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FOREWORD

THE ISSUE

The focus of this guide is on the planning, construction, and maintenance practices for resource roads that cross wetlands. Poor bearing capacity soils and an abundance of water are characteristic of wetlands. This guide focuses on two primary issues:

- Ensuring that resource roads that cross wetlands function at the required design and performance levels to allow forest access and hauling operations in a cost-effective manner
- Reducing the impacts of resource roads on the flow characteristics of wetlands.

THE PROBLEM

The typically saturated and poor bearing capacity soils found in wetlands present unique challenges for road designers and construction crews. Because the bearing pressure of a road embankment can far exceed the bearing capacity of subgrades built on wetlands, designs need to be adapted for these difficult conditions. Resource roads built over wetlands are generally subject to settlement and compaction of on-site soils, impacting road performance, construction, and maintenance costs. In addition, these roads may result in alterations to wetlands that can impact the wetlands' hydrologic processes. The continued hydrologic connectivity of a wetland system may be compromised by the settlement and compaction of the wetland soils.

WHAT THIS GUIDE IS

This guide contains practices to aid with planning, constructing, and maintaining high-performing resource roads; these practices also minimize the impacts of resource roads on wetland hydrology and processes. Guidance for the selection and implementation of these practices is provided. An overview of wetlands, their function, and their value are also provided to enhance knowledge and understanding of the purpose and application of the practices presented. The practices mentioned throughout this guide are commonly referred to as best management practices (BMPs), which have been developed based on the knowledge that is currently available.

Not all BMPs are applicable in all situations, so local knowledge and experience should also be used to determine the most appropriate practice for a given condition. The implementation of BMPs is an important component of sustainable forest management, which includes consideration of the functions and processes of wetlands.

WHAT THIS GUIDE IS NOT

This guide does not provide detailed installation procedures for the practices presented. The challenges of constructing and maintaining resource roads in regions where permafrost conditions are present are not addressed. Not all interactions of resource roads and wetlands are addressed in this guide; the focus of the guide is on the practices that maintain surface and subsurface water movement. This guide is not a substitute for any relevant federal, provincial, or municipal requirements that may be applicable.

WHO THIS GUIDE IS FOR

This guide is directed at road managers, planners, and construction crews who are engaged in the planning, construction, and maintenance of resource roads across wetlands. The guide is also intended to assist anyone concerned with the management of resource roads and those involved in mitigating the impact of forest management activities on wetland processes and values. This guide aims to bring awareness to the interactions between resource roads and wetlands, and it may be of interest to those involved in implementing practices that support wetland protection and management.

02.
BUILDING A RESOURCE ROAD ACROSS A WETLAND

BUILDING A RESOURCE ROAD ACROSS A WETLAND REQUIRES TWO PRINCIPAL CONSIDERATIONS IN THE PLANNING, CONSTRUCTION, AND MAINTENANCE PHASES:

- ENSURING THAT RESOURCE ROADS THAT CROSS WETLANDS FUNCTION AT THE REQUIRED DESIGN AND PERFORMANCE LEVELS TO ALLOW ACCESS AND OPERATIONS IN A COST-EFFECTIVE MANNER
- REDUCING AND MITIGATING IMPACTS OF RESOURCE ROADS ON THE HYDROLOGIC PROCESSES OF WETLANDS.

THERE ARE MANY FACTORS AND DECISIONS THAT NEED TO BE CONSIDERED WHEN ACCOUNTING FOR OPERATIONAL AND ENVIRONMENTAL PERFORMANCE, AND THE FOLLOWING SUMMARIZES A NUMBER OF KEY DECISIONS THAT NEED TO BE TAKEN WITHIN THE OVERALL DECISION PROCESS FOR EACH RESOURCE ROAD PROJECT.

STEP 1

Identify the presence of wetlands as part of the road location planning. Plan the road to meet operational and safety requirements and, when possible, avoid and minimize the amount of road built across any wetlands. *Refer to Planning considerations*.

STEP 2

Identify the type of water movement at all wetland crossing locations and apply the four wetland flow consideration categories. *Refer to Knowing your wetlands: Wetland flow considerations*.

STEP 3

Determine the season and duration (permanent or temporary) for which the road will be used. Some wetlands, based on their flow characteristics, may be suitable for crossing only in frozen conditions. *Refer to Practical applications: Temporary winter crossings*.

STEP 4

Based on the duration (permanent or temporary) and season of use of the road, determine which soil bearing capacity improvement options will be used. When choosing from the options, consider the possible requirements for road decommissioning and site rehabilitation.
Refer to Practical applications: Road construction on wetland soils.

STEP 5

Determine the water passage requirements of the road as directed by the wetland's flow characteristics to minimize the road's impact on wetland hydrology, and choose an appropriate conduit to match the wetland flow (e.g., corduroy, log bundle, aggregate mattress, etc.).
Refer to Water management: Surface and subsurface flow.

STEP 6

Identify all watercourse crossings in the wetland and determine which type of structure (culvert, open-bottom arch, or bridge) will be used and which foundation improvement method will be implemented.
Refer to Water management: Watercourse crossings in wetlands.

STEP 7

Implement a road construction plan, ensuring that all standard operating procedures are identified and implemented, and that regulatory requirements are met.

STEP 8

Monitor road performance and conduct maintenance actions to ensure that the road performs to operational and safety requirements, and that impacts to the wetland are mitigated.
Refer to Practical applications: Monitoring road performance.

03. INTRODUCTION

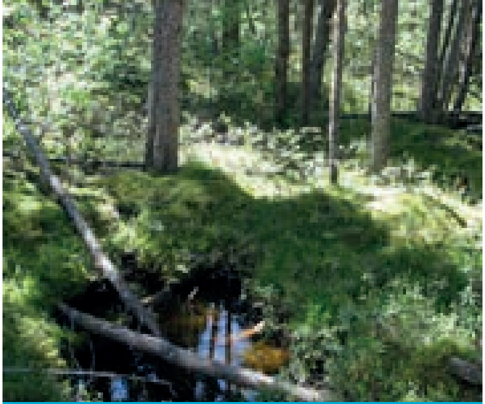


FIGURE 1A. *The presence of water, including areas that are permanently or seasonally waterlogged and water that is at or near the surface.*

CONSTRUCTION OF RESOURCE ROADS ACROSS WETLANDS CAN PRESENT ENVIRONMENTAL AND OPERATIONAL CHALLENGES FOR ROAD MANAGERS. THE INHERENT NATURE OF A WETLAND ENVIRONMENT IS UNIQUE COMPARED TO OTHER LANDSCAPE FEATURES. THE IMPACT OF RESOURCE ROADS ON THE MANY ECOLOGICAL FUNCTIONS OF WETLANDS IS OF INCREASING CONCERN TO CANADA'S RESOURCE-BASED INDUSTRIES, GOVERNMENTS, AND NON-GOVERNMENTAL ORGANIZATIONS. WITH CAREFUL PLANNING AND KNOWLEDGE OF HOW WETLANDS FUNCTION, IT IS ANTICIPATED THAT BOTH THE WETLAND AND THE RESOURCE ROAD CAN FUNCTION AND PERFORM AS EXPECTED.

WHAT IS A RESOURCE ROAD?

Resource roads are unpaved roads built to provide access to natural resources, such as the roads required for forest management. The planning, construction, and maintenance of resource roads are required in support of various industrial and recreational activities. The resource roads principally addressed in this guide are those managed in support of forest harvest and hauling operations. These roads are typically constructed from locally available material, may require a service life of 5 to 50 years, and are primarily used by heavy industrial vehicles. The design and use conditions of resource roads built for forestry are similar to the design requirements for other natural resource industries. Resource roads are often the primary access for public recreational experiences and backcountry adventures.

WHAT IS A WETLAND?

Wetlands are an abundant landscape feature across Canada. Wetland systems can be connected for great distances and may occupy a significant percentage of a natural resource company's operating area. Wetlands provide numerous benefits, including water purification, flood moderation, carbon storage, serving as fish and wildlife habitat, and having unique cultural value. Some forested wetlands also support the growth of merchantable tree species, providing significant value to the forest industry.

There are different kinds of wetlands in the forested regions of Canada, and the physical, chemical, climatic, and biological characteristics of different wetlands may mean some are particularly sensitive to roads and other industrial activities.

Being able to identify and classify wetlands and having a basic understanding of typical water flow characteristics will assist resource road planners and operators in making decisions to mitigate potential impacts on wetlands and ensure that roads perform according to expectations.

In Canada, wetlands are defined in various ways. There is no single definition that is legally recognized across all municipal, provincial, and federal jurisdictions. In cases where wetlands are not specifically defined, they often fall under broader definitions, such as "water body" or "surface water." The Canadian Wetland Classification System (CWCS) provides a widely accepted definition that is applicable to all regions:

> *Land that is saturated with water long enough to promote wetland or aquatic processes as indicated by poorly drained soils, hydrophytic vegetation and various kinds of biological activity which are adapted to a wet environment.*
> *(Warner & Rubec, 1997, p. 1).*

Under this definition, wetlands can vary in size, have areas of open water, or be temporarily dry, and can be treed, shrubby, or open, with mosses, sedges, or grasses. Depending on the location and time of year, it may be difficult to determine whether a location is in a wetland or in upland though there are general terrain, soil and vegetation species indicators that can aid in the determination (**FIGURES 1-4**).

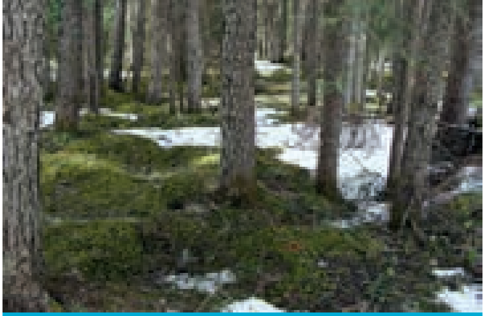


FIGURE 1B. *Hummocky terrain. (Photo courtesy of Ducks Unlimited Canada.)*

FIGURE 1C. *A mineral soil profile with a shallow organic layer (less than 40 cm deep) overlying a depleted mineral soil layer. (Photo courtesy of the Nova Scotia Department of Natural Resources.)*

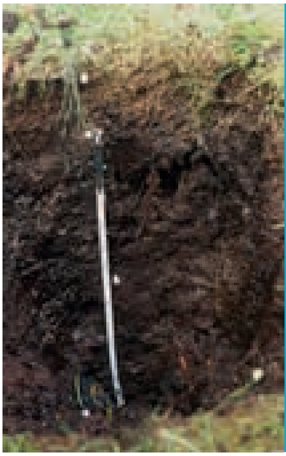


FIGURE 1D. *An organic soil profile, derived from peat, with an organic layer more than 40 cm deep. (Photo courtesy of the Nova Scotia Department of Natural Resources.)*

FIGURE 1A , B, C AND D. *General indicators of wetlands.*

FIGURE 2. *Selected tree species indicators of wetlands. *May also be associated with uplands.*

Black spruce* (Picea mariana)

Balsam poplar* (Populus balsamifera)

Tamarack (Larix laricina)

White birch* (Betula papyrifera)

FIGURE 3. *Selected shrub species indicators of wetlands.*

Bog laurel (Kalmia polifolia)

Labrador tea (Rhododendron spp.)

Speckled alder (Alnus incana)

Willow (Salix spp.)

FIGURE 4. *Selected groundcover species indicators of wetlands.*

Horsetail (Equisetum spp.)
(Photo courtesy of Louisiana-Pacific Canada Ltd.)

Rush (Juncus spp.)
(Photo courtesy of A. Morrison.)

Sedge (Carex spp.)

Sphagnum moss (Sphagnum spp.)
(Photo courtesy of Louisiana-Pacific Canada Ltd.)

CHALLENGES OF RESOURCE ROADS IN WETLAND ENVIRONMENTS

There are many planning, construction, and maintenance challenges associated with resource roads in wetland environments. These challenges result mainly from the organic soils and higher soil moisture levels that are associated with wetlands and include issues such as:

- Increased road settlement, which may lead to an uneven running surface and surface distress problems, such as rutting, or a road may require seasonally restricted use.
- Foundation settlement of water crossing and drainage structures. Uniform settlement can result in culvert sinkage, submerging the outlet and inlet, whereas differential settlement across the road profile results in the uplift of the ends of a culvert.
- Saturation of the road base through the increased amount of water, compromising the road's ability to support vehicle loads.

To ensure proper performance of resource roads, the presence of high soil moisture levels and possible surface and subsurface water movement must also be addressed.

The presence of organic and fine soil materials in wetlands, along with the lack of aggregates, can create conditions that increase road construction costs. The lack of suitable on-site materials results in increased costs, as the construction material needs to be sourced off site and hauled to the construction location. The amount of suitable road building material hauled to a site varies depending on the length of the wetland crossing, the category of road being constructed, and the alignment (both vertical and horizontal) of the transportation network. The sourced material may be as close as the approaches to the wetland crossing or may be transported from much greater distances.

IMPACTS OF RESOURCE ROADS ON WETLANDS

When a resource road is built through a wetland, the wetland's hydrologic functions may be compromised and result in various negative outcomes, such as:

- Compaction of the wetland soils under the weight of the road, which can impede surface and subsurface water movement. Long-term road settlement may further aggravate this issue.
- Inadequate water flow through the road, leading to ponding of water on the upgradient side as the wetland becomes saturated. Conversely, the downgradient side may not receive sufficient water to maintain the current wetland conditions. Both changes can result in an impact to the water-carrying capacity and filtration ability of the wetland, as well as to the movement of water through the wetland system.

On a local scale, there may be a change in the wetland in the abundance and composition of tree and other plant communities. A decrease in tree growth, reduced vigor, and damage to wetland plant communities are examples of poor environmental performance. Such changes can alter the value of these areas as wildlife habitat.

On a global scale, Canada's boreal forests and wetlands play a major role in carbon sequestration and storage. The hydrologic regime of a wetland is a key driver that determines its carbon balance, so altering the regime of the wetland can alter its carbon balance. Any resource management activity that disrupts a wetland's ability to sequester carbon may come under increased scrutiny as carbon reporting becomes more comprehensive.

04. KNOWING YOUR WETLANDS

WETLANDS ARE AN ESSENTIAL COMPONENT OF CANADIAN FOREST ECOSYSTEMS AND THEY PROVIDE VALUABLE ECOLOGICAL SERVICES, INCLUDING PLAYING A PIVOTAL ROLE IN REGULATING LOCAL AND REGIONAL FOREST HYDROLOGY, AND SERVING AS BOTH A SOURCE OF, AND A SINK FOR, WATER AND NUTRIENTS. WETLANDS ARE ABUNDANT FEATURES IN CANADA, COVERING OVER 14% (APPROXIMATELY 1.3 MILLION KM^2) OF CANADA'S LAND MASS (TARNOCAI, KETTLES, & LACELLE, 2001). MOST OF THESE WETLANDS (OVER 85%) ARE FOUND IN TEMPERATE AND BOREAL FORESTS. IT IS ESTIMATED THAT THE ANNUAL ECONOMIC BENEFIT OF WETLANDS TO CANADIANS, INCLUDING THEIR ROLE IN WATER STORAGE, WATER PURIFICATION, AND FLOOD AND CLIMATE CHANGE MITIGATION, IS OVER $512 BILLION (ANIELSKI & WILSON, 2005). THUS, MAINTAINING OR ENHANCING WETLAND QUANTITY AND QUALITY IN CANADA IS IMPORTANT FROM A LOCAL, NATIONAL, AND GLOBAL PERSPECTIVE.

BENEFITS OF WETLANDS

On a global scale, Canada's wetlands, especially peatlands, play a key role in regulating greenhouse gases, such as methane and carbon dioxide, and buffering the impacts of climate change. Approximately 1.14 million km^2 of peatlands (about 1/3 of the world's peatlands) are found in Canada (Tarnocai, Kettles, & Lacelle, 2002), storing an estimated 147 billion tonnes of carbon and sequestering between 25 and 37 million tonnes of atmospheric carbon per year (Bridgham, Megonigal, Keller, Bliss, & Trettin, 2006), the equivalent of the annual emissions of 19 to 28 million cars (United States Environmental Protection Agency, 2014).

Wetlands store water and release it when conditions warrant. Therefore, wetlands can help maintain water flow throughout droughts and floods, and can regulate flow during stormwater peaks, thereby reducing the risk of erosion. Since wetlands can slow water movement, they filter sediment, and excess nutrients and pollutants are either stored within these sediments or are taken up by plant roots and micro-organisms.

Wetlands also provide fresh surface water and replenish groundwater supply. In addition, some wetland plants, fungi, and animals serve as food (e.g., fish, waterfowl, wild rice, berries, fiddlehead ferns, moose, woodland caribou, and mushrooms) and are sources for timber, fuel, horticultural peat, and fur for domestic and commercial use. Wetlands also provide opportunities for recreational activities, including canoeing, hiking, hunting, and birdwatching.

Boreal and temperate wetlands are rich in biodiversity and provide important habitat for hundreds of species of plants and animals. Approximately 26 million waterfowl, representing 35 species, and about 7 million shorebirds, representing at least 19 species, are estimated to use boreal forest wetlands in Canada as a migratory stopover or as breeding habitat (Blancher & Wells, 2005).

Many species are considered wetland specialists (e.g., bog katydid) or require wetlands for part of their life cycle, and in Canada, some of these species are rare, threatened, or endangered (e.g., woodland caribou).

CLASSES OF WETLANDS

Land and wetland classification systems are developed so that areas that are ecologically different can be identified and distinguished from each other. In Canada, there is no single classification system that is used consistently across the country. Generally, most classification systems conform to the CWCS to at least the five major wetland classes, or types, based on properties such as soils (organic vs. mineral), water chemistry, water flow, water table, and vegetation community. As an example, MacKenzie and Moran (2004) divide the 5 major classes of wetlands found in British Columbia into over 50 subclasses, or "site associations," and Ducks Unlimited Canada has developed an ecologically based enhanced wetland classification system for the Boreal Plains ecozone, further categorizing the 5 major classes of wetlands into 19 minor classes (**FIGURE 5**).

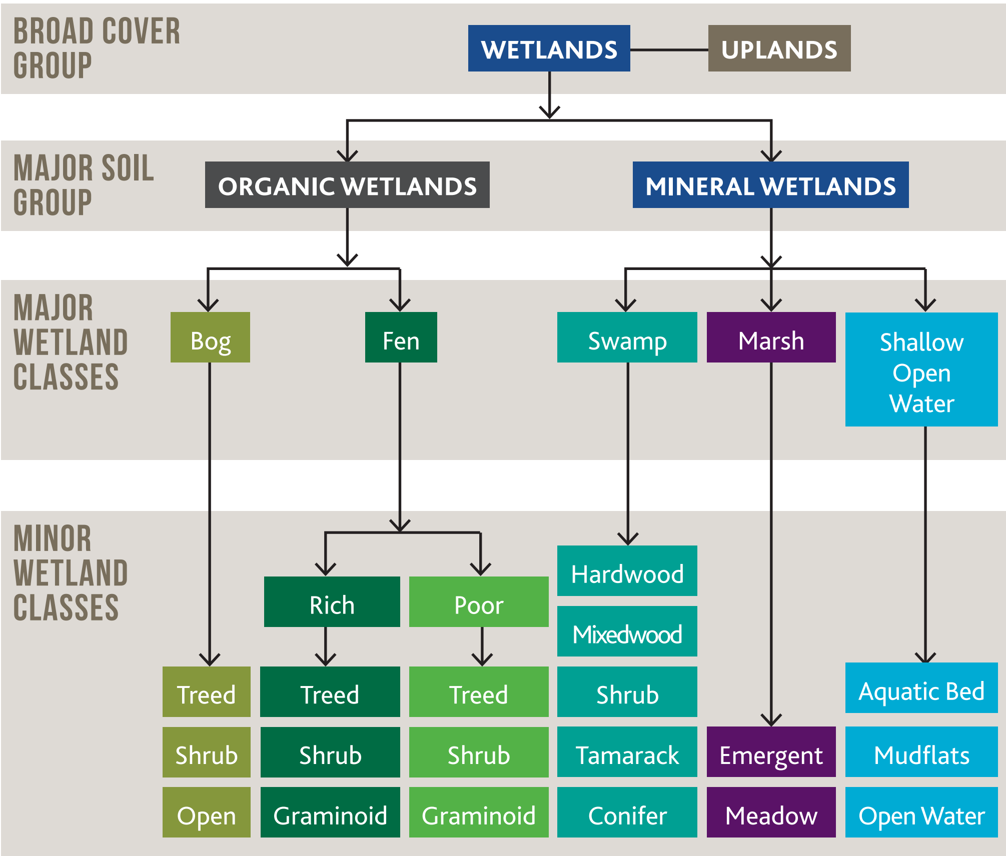


FIGURE 5.
Ducks Unlimited Canada's enhanced wetland classification system for the Boreal Plains ecozone.

ORGANIC WETLANDS

These have deep (more than 40 cm), poorly decomposed organic soil deposits that accumulate slowly over time due to cool and wet conditions. Organic wetlands are also referred to as peatlands (also commonly called muskeg), and are the most prevalent wetlands in Canada's temperate and boreal forests.

Bogs

- Bogs are peatlands with a poorly decomposed layer of peat made up primarily of decomposed Sphagnum spp. moss.
- They can be treed (e.g., lowland or stunted black spruce typically less than 10 m high), have low-lying shrubs (e.g., Labrador tea), or be open areas dominated by *Sphagnum* spp. moss. **FIGURE 6** shows a treed bog.
- They are raised or level with the surrounding land and are generally isolated from groundwater and runoff.
- They have no open water, but the peat below is saturated with water.
- They receive water and most nutrients from precipitation, so they are considered nutrient-poor.
- They may be important sources of water for adjacent forests, particularly during dry periods.
- They are considered stagnant because they have little to no vertical or lateral surface or subsurface flow.

FIGURE 6. *Treed bog.*
(Photo courtesy of Ducks Unlimited Canada.)

Fens

- Fens are peatlands with deep organic soil deposits of decomposed sedges and brown and sphagnum mosses.
- They can be treed (e.g., tamarack and stunted black spruce typically less than 10 m high), have shrubs (e.g., bog birch or willow species), or be open areas dominated by narrow-leaved sedges, grasses, and mosses. **FIGURE 7** shows a shrubby fen.
- They are highly connected to surrounding areas through groundwater and subsurface water flow.
- They receive water from a combination of precipitation, surface runoff, and groundwater, so they are more nutrient-rich and generally more productive and biologically diverse than bogs.
- They exchange water and nutrients with other wetlands and uplands, depending on certain conditions, such as the amount of precipitation and soil moisture level.
- They have a water table that fluctuates, but is generally within a few centimetres above or below the surface.
- They have slow lateral water flow at or below the surface, or through small and sometimes open channels or pools that can occur under normal climatic conditions (with the exception of treed nutrient-poor fens, which are considered stagnant and similar to bogs).

FIGURE 7. *Shrubby fen.*
(Photo courtesy of Ducks Unlimited Canada.)

MINERAL WETLANDS

These have shallow (less than 40 cm) organic deposits and are characterized by nutrient-rich soils and fluctuating water levels. The presence of shallow organic deposits is a result of periodic drying of the wetland, allowing for decomposition of the organic layer. Mineral wetlands are a diverse group that ranges from treed systems to shallow open waters, with dynamic water regimes. These wetlands usually form in bedrock depressions or on flat, poorly drained areas, and in water discharge zones at the base of long and sometimes steep slopes.

Swamps

- Swamps are sometimes called forested wetlands, treed swamp forests, wooded swamps, or shrub swamps.
- Their soils are predominantly mineral-based, although deep (more than 40 cm), wood-rich peat deposits can occur (e.g., in swamps of black spruce or other conifers).
- They can be dominated by trees (more than 10 m high) or shrubs (more 2 m high), and can occur in various landscapes. They are common, but these wetlands are the least understood in forested environments. **FIGURE 8** shows a shrub swamp.
- They have a water table that fluctuates seasonally as a result of spring runoff and heavy rain events, with flooding (often when located adjacent to rivers or streams) and periodic drying, and typically have groundwater inputs, which add to their productivity.
- They are often transition areas between an upland forest and another type of wetland or a shoreline area, and typically have hummocky ground that may contain pools of water.
- Black spruce swamps that are isolated from flowing systems should be considered stagnant.

FIGURE 8. *Shrub swamp. (Photo courtesy of Ducks Unlimited Canada.)*

Marshes

- Marshes are sometimes called reed swamps or sedge meadows.
- They are dominated by non-woody aquatic vegetation, such as sedges, rushes, reeds, grasses, and cattails. In areas of open water, floating (e.g., pond lily) and submerged (e.g., pondweed) vegetation can be present. **FIGURE 9** shows a meadow marsh.
- They are considered inundated or flooded wetlands, as their water levels fluctuate yearly, seasonally, and even daily due to evapotranspiration, precipitation, surface runoff, stream or river inflow, springs, and groundwater seepage or discharge.
- They experience "drawdown" during periods of drought, which provides an opportunity for the regeneration of marsh vegetation from seeds stored in the soil.
- They are often transition areas between open water, swamps, and upland shorelines.
- They are the least common type of wetland in forested regions.

FIGURE 9. *Meadow marsh. (Photo courtesy of Ducks Unlimited Canada.)*

Shallow, open-water wetlands

- These wetlands are also often called ponds, shallow lakes, pools, oxbows, or sloughs.
- If there is vegetation, it is dominated by floating or submerged aquatic plants. **FIGURE 10** shows an open-water aquatic bed wetland.
- They are usually inundated or flooded, but they experience water level fluctuations seasonally or during periods of drought.
- They are predominantly open with standing water that is generally less than 2 m deep.

FIGURE 10. *Shallow, open-water wetland. (Photo courtesy of Ducks Unlimited Canada.)*

SEEPS, SPRINGS, EPHEMERAL DRAWS, AND VERNAL POOLS

Seeps, springs, and ephemeral draws are valuable hydrologic features that may be permanently or seasonally connected to wetlands and may influence where and how a resource road should be constructed. In some cases, these features may also be associated with wetlands (e.g., an ephemeral draw may be a shrub swamp). Seeps are wet areas where groundwater percolates up to the surface; springs are discrete areas where groundwater flows naturally from a rock or from the soil along the surface; and ephemeral draws (sometimes called swales) are small areas where the shallow layering of soil impedes water flow and promotes short-term surface saturation if there is sufficient precipitation and runoff.

Vernal pools, or woodland pools, develop in relatively small depressions that temporarily fill with water after a spring snowmelt, heavy rainfall, or as a result of a high water table. These pools are generally not hydrologically connected to other wetlands or streams, but they may be an important water source for surrounding vegetation. Vernal pools do not support breeding populations of fish, but they are important habitats for a variety of wildlife adapted to their conditions (e.g., frogs, salamanders, insects, and fairy shrimp).

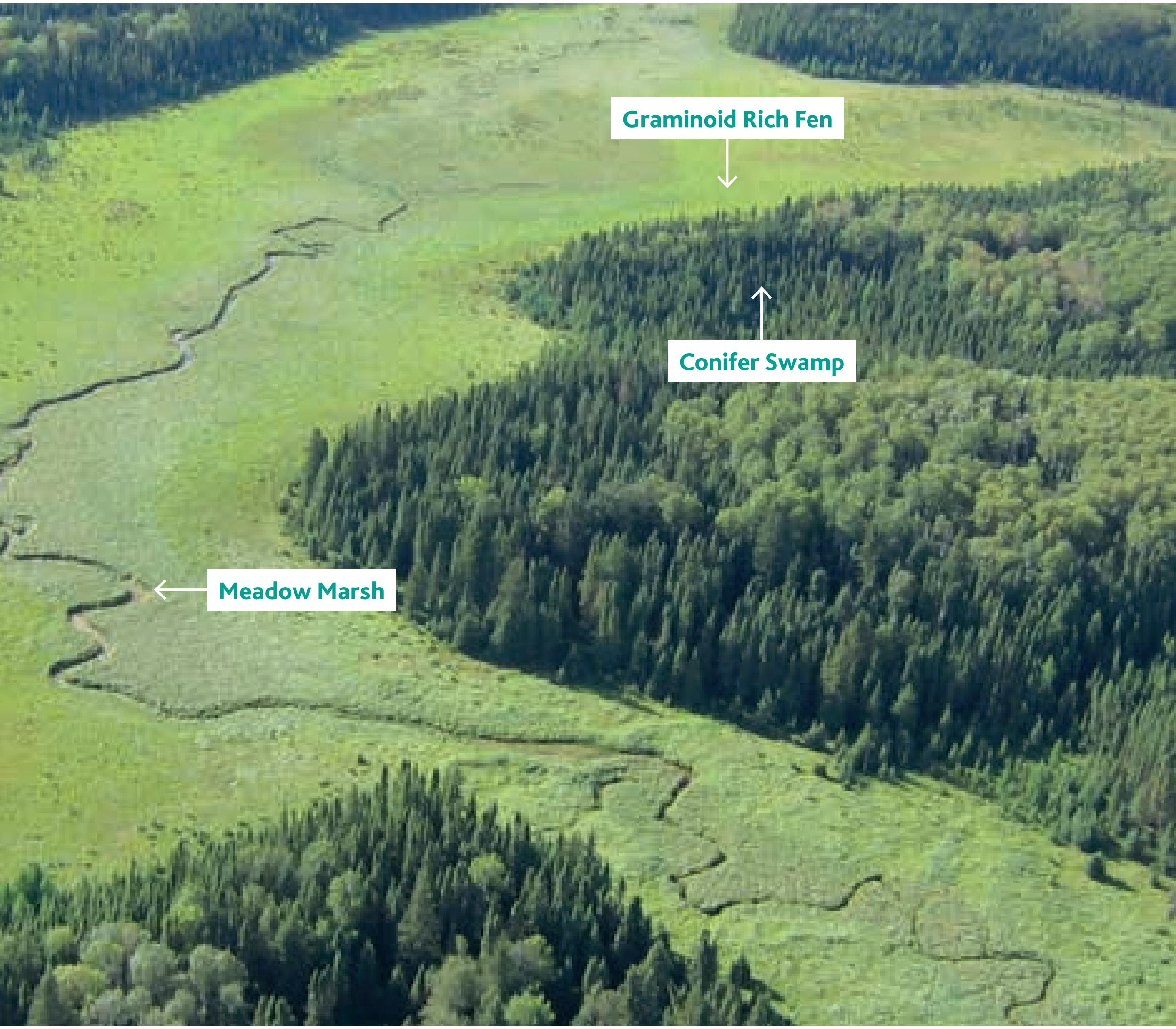
WETLAND COMPLEXES

Wetlands can occur as single, well-defined, and sometimes isolated features in areas of rolling terrain. In areas with low topographic relief, wetlands are often highly connected, resulting in a large expanse, or complex, of several wetlands transitioning from one type of wetland to another across the landscape (**FIGURE 11**). Several classes of wetlands can be associated with an open-water pond or stream, or they can be adjacent to an upland site. These wetland riparian areas are typically defined as areas of transition between open water and uplands, and as moisture and soil conditions change across that transition area, several types of wetlands may occur, such as emergent or meadow marshes, treed or open fens, shrub or conifer swamps, or any combination of these.

FIGURE 11. *When crossing a wetland complex (several wetlands connected together), design the crossing to accommodate the most dynamic flow conditions. (Photo courtesy of Ducks Unlimited Canada.)*

REGIONAL WETLAND ABUNDANCE AND DIVERSITY

Peatlands (bogs and fens) are the most abundant wetlands in Canadian forests (approximately 87% of all wetlands in Canada). In fact, peatlands comprise more than 30% of the land mass of Ontario and Manitoba. Peatlands are more commonly found in the cool and relatively flat northern forests of Alberta, Saskatchewan, Manitoba, Ontario, and Quebec, and are less common in mountainous areas of British Columbia and Yukon, where surface water moves quickly. Peatlands are also common throughout most of Newfoundland and Labrador, in eastern and southern New Brunswick, and in southwestern Nova Scotia (primarily bogs occur here, since the climate is cool and the land is generally flat and has poor drainage).



Swamps in northern forests commonly border streams or flowing water systems, but they can be more extensive in some locations. In middle-latitude forests, coniferous swamps may be common locally on gently sloping areas that are covered by shallow peat. In the more southern forests of Quebec and Ontario, coniferous or hardwood swamps commonly occur on the floodplains of lakes, rivers, and streams. In the eastern provinces, swamps are common near streams and shores, occurring primarily as conifer swamps or shrub swamps.

Compared to other wetland types, marshes are less abundant in forested regions, occurring mainly within inland deltas or along the shores of lakes and larger stream systems and sometimes as isolated marsh wetlands.

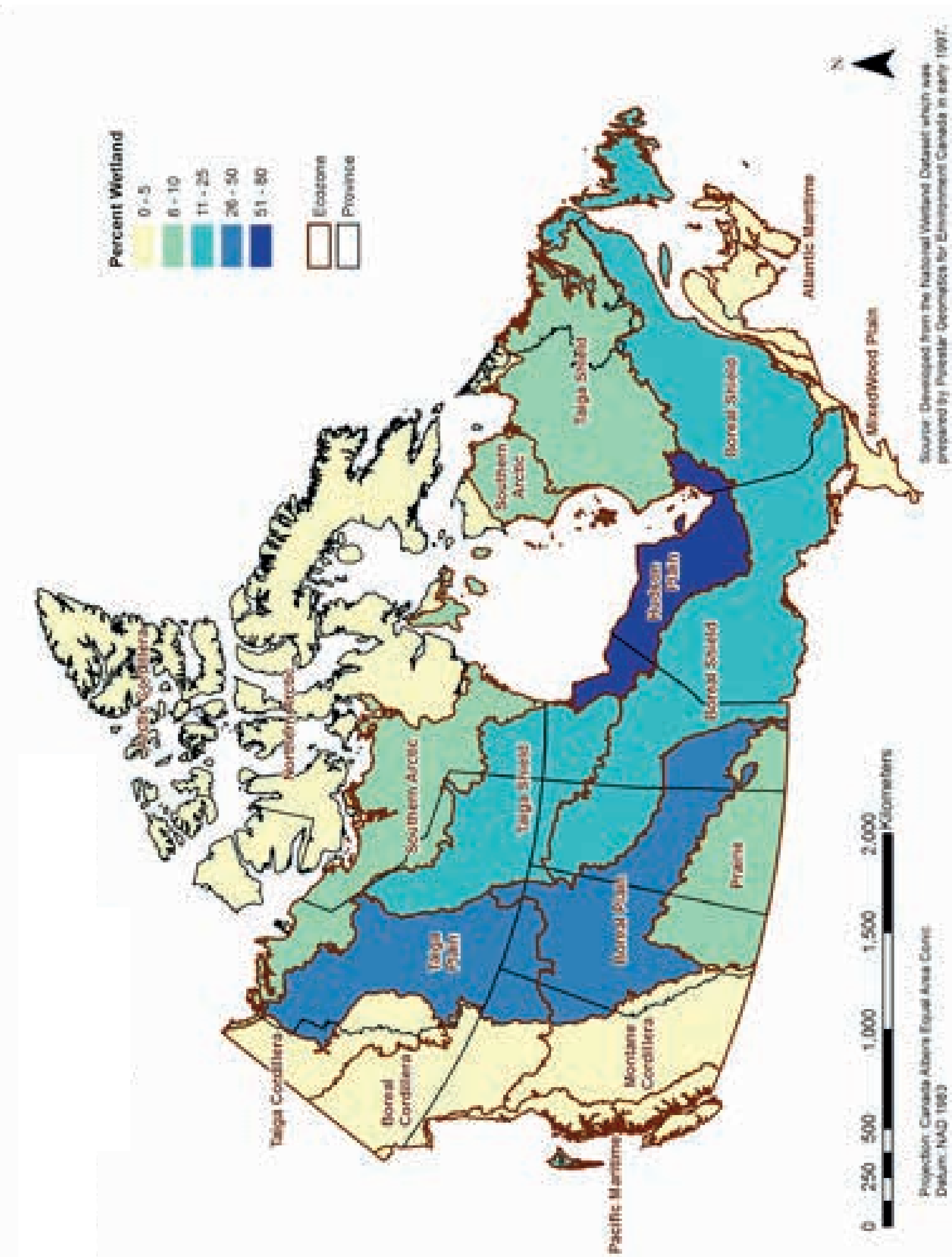
The local and regional distribution and diversity of wetlands in Canadian forests is a function of bedrock and surficial geology, topography, and climate (**FIGURE 12**).

For example:

- **Hudson Plains ecozone:** The flat terrain, impervious soil, poor drainage, and cool, moist climate promote the development of wetlands throughout much of this ecozone, resulting in the highest densities of wetlands and the largest wetland complexes in the world.
- **Boreal Plains ecozone:** The relatively dry climate, flat to gently rolling terrain, and varying amounts of surficial geology allow for a landscape rich with various types of wetlands.
- **Boreal Shield ecozone:** The humid climate, shallow soils, and millions of depressions among impermeable bedrock have resulted in the highest number of wetland hectares in Canada.
- **Atlantic Maritime ecozone:** This is one of the most diverse areas in Canada in terms of climate, topography, and ecology, resulting in the formation of various types of wetlands, from freshwater wetlands in undulating lowlands to peatlands in poorly drained areas. Wetlands are a major component of the Maritime landscape, but they are relatively less abundant here than in other areas of Canada.
- **Cordillera ecozones:** Wetlands here are found in the flat, poorly drained areas of the plateaus and valleys of the mountainous sedimentary bedrock terrain. Although there are areas with extensive wetland complexes, fewer wetlands occur in these ecozones than in other areas of Canada.

In addition to the biophysical aspects that govern the distribution and abundance of wetlands in Canada, the influence of beavers on wetland systems is significant in some locations. Beaver activity can block streams if dams are built or culverts are blocked. This typically results in the creation of new water bodies or wetlands on the upstream side of the road and the drying out of the downstream side, altering the amount of water that is present and the amount and type of associated vegetation.

FIGURE 12. *Percentage of wetlands in Canada by ecozone.*



VEGETATION VARIATIONS

Given the differences in geology, topography, and climate across Canada, wetland vegetation indicators can vary regionally. Of the five classes of wetlands, swamps, often referred to as forested wetlands, are the most poorly quantified and perhaps vary the most in their tree and shrub indicator species (**FIGURE 13**).

West of the Rockies, swamps are dominated by black spruce, subalpine fir, red alder, western red cedar, western hemlock, yellow cedar, and mountain hemlock, or by various shrub species, including dwarf birch, speckled alder, pink spirea, and various willow species.

In the Boreal Plains, swamps are dominated by black spruce, balsam poplar, tamarack, white birch, Alaskan birch, and Manitoba maple, or by various shrubs, including speckled alder, red osier dogwood, and various willow species.

The Boreal Shield, including the Great Lakes–St. Lawrence region, has hardwood swamps dominated by black ash, red ash, white elm, red maple, silver maple, Manitoba maple, yellow birch, and white birch. Conifer swamps are dominated by black spruce, eastern white cedar, tamarack, and eastern hemlock, and shrub swamps are dominated by speckled alder and various willow species.

Across the eastern provinces, spruce swamps are common. Hardwood swamps are less frequent, but those that exist are primarily dominated by red maple, and black ash swamps occur regionally. Shrub swamps are common and dominated by speckled alder and willows.

FIGURE 13. *Selected swamp types commonly found in Canada.*

Shrub swamp. *(Photo courtesy of Marcel Darveau/Ducks Unlimited Canada)*

Silver maple hardwood swamp. *(Photo courtesy of Marcel Darveau/Ducks Unlimited Canada.)*

Mixed wood swamp. *(Photo courtesy of Ducks Unlimited Canada.)*

TABLE 1. *Wetland flow characteristics.*

TYPE OF FLOW	Stagnant	Slow lateral flow	Seasonally fluctuating	Inundated/flooded
CLASS OF WETLAND	Bogs	Fens [a]	Swamps [b]	Marshes and shallow, open-water wetlands

[a] *Where they can be identified, treed nutrient-poor fens should be considered stagnant.*
[b] *When conifer swamps are isolated and not part of flowing systems, they should be considered stagnant.*

HYDROLOGIC CHARACTERISTICS OF WETLANDS AND WATER FLOW CONSIDERATIONS

Understanding the flow characteristics of each type of wetland provides insight for resource road planning and construction. Depending on climate, geology, and topography, water within a wetland may move vertically (from changes to the water table), laterally (if flowing across the landscape), or a combination of both. Most wetlands function in a similar manner in this context, although there is variation. Further, wetlands that have similar flow characteristics can be grouped to more easily predict expected water flow (surface and subsurface) and fluctuations (**TABLE 1**). This information can then be used to help guide road planning and construction decisions, so that wetland hydrology is maintained.

When crossing stagnant wetlands, consider that these wetlands:

- receive water from rain or snow, usually resulting in minor seasonal fluctuation in water level;
- are often isolated from other wetland systems, with minimal subsurface water flow;
- often have water at or below the surface and the presence of a defined stream channel is unlikely; and
- have organic layers that may be very deep, with a minimum depth of 40 cm.

When crossing slow lateral-flow wetlands, consider that these wetlands:

- receive water from precipitation, runoff, and groundwater;
- are typically connected to adjacent wetlands and may demonstrate small flow channels;
- usually have slow water movement at and below the surface, including continuous seepage;
- may experience an increase in the volume and velocity of flow during peak rainfall or snowmelt events;
- are less likely to freeze because of surface and subsurface water movement year-round; and
- have organic layers that may be very deep, with a minimum depth of 40 cm.

When crossing seasonally fluctuating wetlands, consider that these wetlands:

- receive water from precipitation, runoff, and groundwater;
- are often part of a flowing water system;
- usually have slow water movement at or below the surface;
- may experience significant water flow in spring and after heavy rain that may flood above the root mat, but it can be dry in the middle of summer;
- often have small, defined channels of concentrated ephemeral surface flow or shallow subsurface flow; and
- have organic layers that are typically shallow (less than 40 cm), but conifer swamps may have organic layers of more than 40 cm in some locations.

When crossing inundated/flooded wetlands, consider that these wetlands:

- receive water from precipitation, runoff, and groundwater;
- experience water levels that fluctuate seasonally or annually, or may dry out completely;
- can sometimes be connected to flowing water systems (e.g., streams or creeks);
- may contain fish or be considered fish habitat; and
- should only be considered for crossing in the winter.

LOCAL AND REGIONAL HYDROLOGIC CONSIDERATIONS

Identification of wetland classes can be used as a decision-making tool and can provide clues into the permanency, amount, and type of water flow into and from a wetland. Thus, when making decisions about where and how to cross wetlands, it is critical to use maps of wetland distribution to recognize the potential crossing locations within a watershed and understand the connectivity of the system with other wetlands where a crossing is proposed. Given the range of conditions across the forested regions of Canada, it is also important to consider local and regional variations in how water moves across the landscape when planning and designing resource roads.

Regional differences in hydrology exist. Generally, local and regional hydrology is influenced by climate, bedrock geology, surficial geology, soil type and depth, topography, and drainage network. Examining these factors will assist planners and operators in making more accurate predictions related to the performance of different wetland crossings. To address the challenges in regional differences in hydrology, it is recommended that practitioners use locally available resources, including local or regional field guides, and the local knowledge and experience of resource professionals.

Climate

Regional and local climate influences the amount of runoff that can be expected, the water storage potential of an area, and the type of water flow. Locations in a wet or humid climate are likely to have greater runoff, less water storage potential, and therefore more lateral water flow across the landscape compared to dry or sub-humid areas. Climate can vary over time, so it is important to incorporate the climate cycle (e.g., wet period vs. dry period) into planning and decision-making. Planning and operating procedures that would perform well in both dry and wet climate periods may need to be implemented.

Bedrock, surficial geology, and soils

An understanding of climate becomes particularly useful when it is combined with an understanding of bedrock and surficial geology, as well as soils. For example, the potential for runoff is greater in areas with impermeable bedrock, such as in the Boreal Shield ecozone, compared to areas with more porous sedimentary bedrock, as is found in the Boreal Plains ecozone. In addition, areas with relatively shallow, fine-grained or clay surficial geology are more likely to be dominated by surface water flow than by groundwater or subsurface flow. Wetland soils, particularly peat soils, have higher organic content than upland soils, resulting in greater water-holding capacity. Thus, peatlands have the capacity to move much more water than uplands (albeit slowly). However, even shallow upland soils have the potential for higher runoff in areas that are humid and wet.

Topography and drainage network

In some areas, topography is an important driver of water movement. For example, where wetlands are located in significant topographical relief (i.e., steep slopes), significant runoff and fluctuating water flow can be expected and should be taken into consideration. On the other hand, wetlands are more likely to be connected (and share water flow) in areas of low relief (i.e., gentle slopes). Detailed maps of expected depth to water may be helpful in predicting the location of areas requiring special consideration where such information is available.

PUTTING IT ALL TOGETHER

In short, a number of factors influence the movement of water in forested environments. An understanding of these factors for the region where work will be undertaken will greatly enhance the ability of the practitioner to predict water movement in wetlands. To assist with understanding the factors that govern water movement, a table summarizing the primary controlling factors that govern water flow behaviour is included in **TABLE 2**.

TABLE 2. *The primary factors that influence water flow in forested environments* [a].

ORDER OF IMPORTANCE IN MAKING PREDICTIONS OF HYDROLOGY ↓	← RANGE TO CONSIDER	→
CLIMATE	**Dry, arid to sub humid** • Greater water storage potential • Vertical flow dominates • Runoff poorly coordinated with precipitation	**Wet, humid** • Less water storage potential • Lateral flow dominates • Runoff closely correlated with precipitation
BEDROCK GEOLOGY	**Permeable** • Vertical subsurface flow dominates **Bedrock slope perpendicular to surface** • Complex watershed boundaries	**Impermeable** • Lateral surface flow dominates **Bedrock slope parallel to surface** • Simple watershed boundaries
SURFICIAL GEOLOGY	**Deep substrate** • Intermediate to regional flows **Coarse grained** • Groundwater and subsurface flow **Spatially varied deposits** • Complex groundwater flow	**Shallow substrate** • Local flows most probable **Fine grained** • Surface/shallow subsurface flow and depression storage **Spatially uniform deposits** • Simple groundwater flow
SOIL TYPE AND DEPTH	**Upland mineral soils** • Subsurface flow dominates • Deeper soils • Large water storage potential • Little runoff generation • Deep rooted vegetation with access to stored water	**Lowland organic soils** • Surface flow dominates • Shallower soils • Small water storage potential • Greater runoff generation • Shallow rooted vegetation with limited access to stored water
TOPOGRAPHY AND DRAINAGE NETWORK	**Gentle slopes** • Disorganized drainage network • Small, variable runoff • Large groundwater recharge	**Steep slopes** • Organized drainage network • Large, uniform runoff • Less groundwater recharge

[a] *Adapted from DeVito et. al. (2005).*

05. PLANNING CONSIDERATIONS

WHEN DEVELOPING RESOURCE ROAD NETWORKS, ROAD PERFORMANCE CAN BE OPTIMIZED AND WETLAND FUNCTION CAN BE MAINTAINED IF ROAD PLANNERS AVOID WETLANDS WHEREVER POSSIBLE. PLANNING TO AVOID WETLANDS REDUCES THE CHALLENGES OF BUILDING ROADS IN WET SOIL CONDITIONS AND HELPS TO MAINTAIN THE NATURAL STATE OF WETLANDS BY PREVENTING POTENTIAL IMPACTS.

IN VARIOUS LOCATIONS IN CANADA, AVOIDING WETLANDS COMPLETELY IS NOT REALISTIC BECAUSE OF THE VASTNESS OF WETLANDS ACROSS THE LANDSCAPE. IF A RESOURCE ROAD MUST CROSS A WETLAND, THE ROAD SHOULD BE LOCATED TO MINIMIZE THE IMPACT ON THE WETLAND AND ITS ECOLOGICAL FUNCTION WHILE STILL MEETING OPERATIONAL, ECONOMIC, AND SAFETY REQUIREMENTS. WETLAND CROSSINGS SHOULD ALSO BE PLANNED TO BE DIRECT AND PREDOMINANTLY STRAIGHT TO MINIMIZE DISTURBANCE.

PLANNING FOR APPROPRIATE WATER MANAGEMENT IS INTRICATELY LINKED TO THE CHOICE OF CROSSING LOCATION AND THE CROSSING TECHNIQUE USED. WITH CAREFUL PLANNING, KNOWLEDGE OF THE TYPES OF WETLANDS AND THEIR ASSOCIATED FLOW CHARACTERISTICS, AND THE USE OF BMPS FOR WATER MANAGEMENT, IT IS PROBABLE THAT BOTH WETLANDS AND RESOURCE ROADS CAN FUNCTION AS ANTICIPATED. WHERE BMPS OR STANDARD OPERATING PROCEDURES EXIST, THEY MUST BE INCLUDED AS PART OF ROAD PLANNING AND BE COMMUNICATED TO FIELD STAFF TO ENSURE THAT THE INTENDED ROAD DESIGNS AND MITIGATION PRACTICES ARE USED.

WETLAND FLOW

Identifying the type of wetland flow (stagnant, slow lateral flow, seasonally fluctuating, inundated/flooded) can provide an initial risk assessment in terms of potential impacts on flow and where to locate road networks (e.g., which wetlands to consider avoiding). When a wetland must be crossed, identifying the type of wetland helps to predict the water flow (surface and subsurface) and the associated fluctuation by using the wetland flow groupings. This information can then be used to choose an appropriate type of road crossing that maintains the natural hydrologic connectivity (i.e., one that does not compromise this natural flow of water). This information is important for making decisions about the road and its crossing location, timing of construction, lifespan of the crossing (i.e., permanent vs. temporary roads), and in the selection of construction methods that best fit the conditions that occur at the site.

CROSSING LOCATION

Various planning tools and field survey techniques can be applied to ensure that requirements of both the road and the wetland are assessed and considered. A carefully chosen crossing location could mitigate potential impacts on the wetland and ensure ongoing road performance, thereby reducing maintenance and remediation and restoration costs.

Field reconnaissance is a critical component of any resource road planning initiative to determine the wetland type and the final crossing location. Regardless of the tools used during the planning phase, verifying site-level attributes in the field will aid with the final construction practice. The need to know the upland soil type and location of available borrow areas, as well as the presence and accumulation of deep organic sites, surface water and flow within the wetland are examples of why reconnaissance is needed.

If wetland characteristics cannot sufficiently be determined using the available resources, it is recommended that a wetland specialist be sought for helping to identify the wetland type and ensure that the road is planned to accommodate anticipated water flow and adequately meet all operational, environmental, and regulatory requirements.

TOOLS

During the initial phases of road location planning, GIS-based tools that include information such as photo and satellite imagery, wetland delineation, topography and vegetation maps, sensitive ecological features, surface geology, and applicable hydrology models should be referenced and used whenever possible (**FIGURE 14**). These tools are commonly used in forest management and should also be used to help locate resource roads to minimize impacts to wetlands. Determining whether a road will cross a single, isolated wetland or a larger, interconnected wetland complex is one aspect that can be aided with such planning tools.

The use of digital elevation maps and hydrology models, such as flow-channel assessments or wet areas mapping (Arp, 2009), can be useful to assess a landscape and assist in understanding wetland hydrology and flow patterns (**FIGURE 15**).

A particular challenge is that wetland inventory and landscape hydrology maps are often not available, resulting in a lack of regional or local information. This deficiency highlights the importance of using alternative datasets, such as existing forest inventory maps that may include a wetland feature and a stream layer, vegetation maps, or, at the field level, ecological land classification field guides to determine the presence and extent of wetland systems.

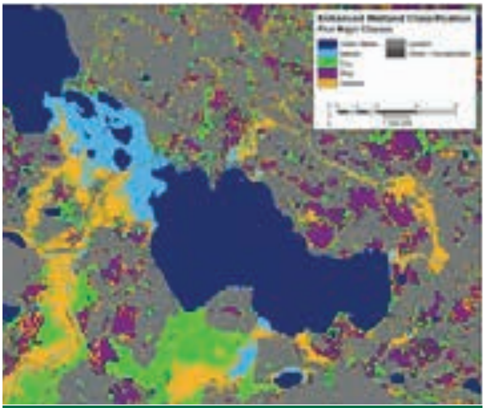


FIGURE 14.
GIS-based planning tools, such as a wetland inventory, can aid in road location planning. (Photo courtesy of Ducks Unlimited Canada.)

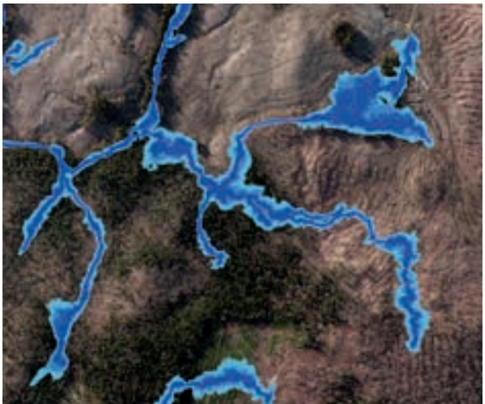


FIGURE 15.
Hydrology models, such as wet areas mapping, can predict areas on the landscape where soil moisture levels may be elevated. (Photo courtesy University of New Brunswick.)

LOCATING WETLAND CROSSINGS

When planning the construction of a resource road across a wetland, the characteristics of the wetland must be taken into consideration to determine the best road location and water management options. Of key importance is identifying the wetland type, which will provide an initial indication of water movement. Other field indicators that should be considered include the presence of wetland indicator species, the width of the crossing site, soil or peat depth, the presence of standing water and a defined watercourse, and whether the wetland is part of a larger complex.

Hydrologic features such as seeps, springs, ephemeral draws, vernal pools, and other features with concentrated seasonal surface flow or shallow groundwater flow will often be unmapped and may only be identified through field reconnaissance. When possible, hydrologic features should be avoided; if this is not possible, mitigation measures, such as those suggested for wetland crossings, should be implemented.

In larger connected wetland systems, the number of road crossings should be minimized while optimizing the operational needs of the road network. Multiple crossings can have a cumulative effect on the potential impacts on the wetland system and can increase short-term construction and long-term maintenance costs.

Narrow wetland crossings

Crossing a larger wetland at the narrowest location is often the most suitable choice with the following considerations:

- Since narrow crossing locations can be "pinch points," it is significantly more important to ensure optimal performance of a conduit at a narrow crossing location because it may be the only location that maintains flow.
- If a wetland that is part of a larger wetland complex must be crossed, the sections of the complex upgradient and downgradient of the crossing location need to be considered, as they may be more adversely impacted than the area of the crossing location.
- Since narrow crossing locations may have concentrated surface and subsurface flow, it is significantly more important to install conduits that are sized appropriately and located properly.
- The design of the wetland crossing should satisfy the maximum flow events anticipated for the type of wetland.
- Conduits may need to be installed at a higher density to accommodate the wetland flow.
- The road building material required may be sourced from adjacent upland locations.

FIGURE 16. *Numerous conduits may be needed to accommodate wetland flow.*

FIGURE 17. *Wide wetland crossings may span small upland areas (i.e., drier soils) that can be targeted to avoid saturated wetland soils, a technique sometimes called "island hopping."*

Wide wetland crossings

When a wetland cannot be crossed at its narrowest location, crossing it at the widest location may be a suitable choice with the following considerations:

- Installation of numerous conduits should be considered to allow multiple paths for flow across the entire width of the wetland area (**FIGURE 16**).
- If a wide wetland crossing spans several different types of wetlands, road construction practices should cater to the most dynamic water regime present.
- The road building material requirements within the wetland should be planned for in advance, as suitable material may not be available or may not be removed without affecting wetland conditions (**FIGURE 17**).

LOCATING CONDUITS

Determining where to position the required conduits can be challenging. Here are a few field and operational tools that can be used to aid in determining appropriate conduit locations:

- Obvious surface flow patterns can be identified through a field survey, which may help to determine where conduits should be placed.
- Vegetation that is representative of drier or wetter conditions can indicate differences in moisture levels. Wetland vegetation that is typical in areas of higher moisture levels (e.g., willows, grasses) may indicate areas of possible subsurface flow.
- Small changes in elevation, which can indicate possible flow channels, can be determined using digital elevation models derived from LiDAR. Field surveys can then be performed to verify the accuracy of this information.
- Small changes in elevation that are difficult to detect can be determined using elevation surveys (rod and laser level) across the wetland.
- Estimating soil or peat depth through the use of soil probes can aid in identifying potential conduit positions. A soil probe can be as simple as a long stick or narrow pole that is pushed by hand into the wetland soil (**FIGURE 18**). The depth of peat can be estimated, which can assist in determining road construction practices and conduit needs. Locations where the depth of peat is greater are often indicators, depending on the wetland type, of increased soil moisture or water levels.

FIGURE 18. *The use of a simple soil probe can aid in estimating soil depth and determining drainage structure placement.*

LOCATING FILL MATERIAL

Determining the need for fill material should be part of road location planning. Fill requirements should be sourced off site and beyond the slope toward the wetland, so as to not impact the integrity of the wetland (**FIGURE 19**). Borrow pits established close to the crossing can reduce the transportation cost of the borrowed material. If there are any concerns that exposed soils from the borrow pit may be transported into the wetland, erosion and sediment control practices should be implemented. Borrow pits are often strategically positioned to accommodate a short-haul distance and to prevent impact to a wetland's hydrology. Where borrow pits cannot be established near the crossing, material will need to be hauled to the site.

Where crossings are planned to intercept "islands" of higher ground (non-wetlands) before continuing across a wetland, there may be an opportunity to establish a borrow pit on the island. This step would provide additional fill material and alleviate the distance that the fill material is moved. Another planning consideration would be to position a road so that it crosses higher ground that contains a source of suitable road building material.

SEASONAL FACTORS

Water levels and soil conditions in wetlands can vary significantly throughout the year, depending on the type of wetland and the seasonal weather patterns, such as snow or rainfall and temperature. These seasonal changes, and in some cases, longer cycles of dry and wet conditions, can influence the timing and the methods of road construction that should be considered at the planning stage. The following factors are also important to consider:

FIGURE 19. *Schematic showing the strategic placement of borrow pits along higher ground.*

- The soils often found in wetlands can be highly erodible, so exposing soils during the times of year when precipitation is highest should be avoided.
- Water levels in wetlands may change both seasonally and annually, so it is important to understand the wetland type (especially for seasonally fluctuating wetlands) and plan for maximum water flows and levels, not just the flows and levels encountered at the time of construction. For example, a shrub swamp may be dry in the summer months, but may have significant water flow during spring runoff or a heavy rain event.
- Wetland conditions may be such that machine weight may only be supported in frozen conditions.
- If heavy precipitation events are forecasted, be prepared to stop ongoing road construction.

WINTER

In locations where soil moisture levels are usually high, such as in wetlands, it is common for roads to be constructed and used only during frozen winter conditions (**FIGURE 20**).

The construction of roads during winter, when water flow is minimal, presents operational benefits as well as environmental benefits in the form of reduced damage to forest and wetland soils (**FIGURE 21**). When the ground is frozen, it has a greater bearing capacity, and there is minimal water flow to consider in many types of wetlands. The improved bearing capacity greatly enhances the soil's ability to withstand the weight of heavy equipment. By preserving the integrity of the surface soils and the soils at depth, there is a direct benefit to the hydrologic connectivity of the wetland.

FIGURE 20. *Crossing wetlands during frozen winter conditions can offer operational and wetland protection benefits.*

FIGURE 21. *The site of a winter road where minimal disturbance to the wetland soils has occurred.*

When constructing a road over a wetland in winter conditions, it is important to know the type of wetland and its hydrology, and to consider the following:

- Slow lateral-flow wetlands, such as fens, can have water movement throughout the year, may be slow to freeze completely, and may be susceptible to flooding.
- Slow lateral-flow wetlands and seasonally fluctuating wetlands, such as fens and swamps, may not have significant ice formation, so the ice can be thin and weak, and in some cases, water can flow over the surface and possibly cause safety concerns.
- Promote greater frost depth by removing the insulating snow layer and track-walking the machines across the area. These techniques result in accelerated and deeper frost penetration.
- Use snow fill alone or snow and road fill material to form the road prism. This practice can reduce the need to establish borrow pits, which can possibly impact the landscape hydrology.
- Ensure that operations on winter roads are ceased when non-frozen conditions appear. Damage to the wetland can occur if the thawed soil becomes rutted or compacted to the degree that hydrologic conditions are affected.

EQUIPMENT

When constructing roads in conditions of low soil-bearing capacity (e.g., wetlands), equipment that exerts less ground pressure, such as excavators and bulldozers, should be used if possible. This consideration is particularly important during the initial phases of road construction, before the road base is built. Machines with lower ground pressure can reduce the potential impairment of wetland water flow by minimizing soil rutting and compaction. Using lower ground pressure equipment can also reduce machine sinkage, which can increase machine productivity and reduce fuel consumption.

When planning which equipment will be used to construct a road, consider the following:

- Using smaller and lighter equipment reduces machine ground pressure that is exerted compared to standard equipment, which may then be assigned to operate on upland sites.

DEFINED WATERCOURSES WITHIN A FORESTED WETLAND

Wetlands are often found near lakes, rivers, or streams, and may be connected to them. In addition, defined streams may flow through wetlands, such as fens, swamps, and marshes. These streams may contain fish and therefore have regulatory requirements related to near- and in-stream work, including road construction. It is important to identify these crossing locations and determine which regulatory and operational requirements must be met.

FIGURE 22. *Wide tires on gravel trucks reduce ground pressure and are suitable for working on sites with low bearing capacity.*

06. PRACTICAL APPLICATIONS

THE CONSTRUCTION OF RESOURCE ROADS ACROSS WETLANDS CAN OFFER MANY CHALLENGES, BUT THESE CAN BE GROUPED IN TWO PRINCIPAL CATEGORIES:

1. HOW TO DESIGN AND BUILD ROADS ACROSS WETLANDS THAT MEET ROAD PERFORMANCE EXPECTATIONS
2. HOW TO MAINTAIN THE INTEGRITY OF WETLANDS BY MANAGING THE SURFACE, SUBSURFACE, AND DEFINED CHANNEL FLOWS THAT ARE INHERENT IN WETLANDS

These two challenges are strongly linked, in that many road design, construction, and maintenance solutions and practices may be applied to meet both of these challenges.

Of the five major types of wetlands, it is predominantly bogs, fens, and swamps that are often crossed during non-frozen conditions. Inundated and flooded wetlands, such as shallow, open-water wetlands and marshes, are infrequently crossed during the non-frozen periods and are typically planned as winter crossings. For this reason, many of the road design considerations included in this guide are not applicable to inundated or flooded wetlands, other than what is presented for seasonal or winter operations.

FIGURE 23. *A recently cleared wetland crossing showing minimal disturbance to the root mat and peat layers (top) and a close-up of typical peat (bottom).*

ROAD CONSTRUCTION ON WETLAND SOILS

This section provides an overview of design and construction techniques for building a resource road across soils with low bearing capacity, which are common in wetlands. Each resource road that crosses a wetland must be uniquely designed to match the wetland's conditions, including the bearing capacity of the soil, the type of wetland, water flow characteristics, and the season. In addition, determining the water management techniques and construction methods to be used are important decisions that will affect the road design.

A critical component and common theme of the construction of roads on bogs, fens, and swamps is to clear the crossing area using high-flotation equipment and during frozen conditions to ensure that the ground is relatively undisturbed. Keeping the wetland soil, root mat, and stumps relatively intact will help maintain the limited amount of support on which the road can be built (**FIGURE 23**).

The most common material for roads constructed across wetlands is soil and granular material, either sourced locally or hauled to the site. The material is typically sourced from nearby borrow pits and is hauled to the site (for longer wetlands crossings) or from along the ditch line outside the wetland area. However, because sourcing fill material from along the ditch line has the potential to affect wetland hydrology, material should be sought from outside the wetland whenever possible (**FIGURE 24**).

Here are a few considerations for using local soil and granular material:

- Using soil and granular material can add significant static loads to the wetland crossing and may often need to be used in conjunction with alternative methods, lightweight materials, and conduits to create an effective wetland road crossing that does not result in the blockage of water movement.
- For longer wetland crossings, it can be difficult to source granular material for construction of the road. In these cases, the material may need to be sourced and hauled to the site.
- When difficulties are encountered in sourcing local or imported fill, other techniques and construction methods may be used to reduce the volume of fill required. For example, corduroy may be used to build the lower layers of the road prism, or geosynthetics may be installed to reduce fill requirements.
- An important component of road location planning is having knowledge of where appropriate fill material may be located. Knowledge of local geological land formations, such as eskers, can be useful in locating appropriate fill material.

FIGURE 24. *Sourcing fill material from along the ditch line may impede wetland hydrology. Consider sourcing the material from outside the wetland whenever possible.*

GEOSYNTHETICS

Geosynthetics, such as geotextiles, geogrids, and geocells, are proven technologies that enhance the structural performance of resource roads. Geosynthetics may also be used to mitigate any impacts that resource roads have on wetland hydrology.

There are five primary functions of geosynthetics: separation, reinforcement, filtration, drainage, and confinement. For resource roads across wetlands, the primary function of geosynthetics is to provide separation between two different types of soil. By working as a separator, a geosynthetic can increase the stability of weak subgrade soils and improve their performance. Using geotextiles on fine-grained soils can reduce the contamination of the aggregates that occurs when fine-grained soils mix with the subgrade materials. As a result, geotextiles reduce the risk of localized bearing failures, which typically occur when the aggregates are forced into the subgrade by dynamic wheel loads or when the subgrade soil migrates into the aggregate layer (**FIGURE 25**).

Geotextiles can also serve as a separation layer between the road construction material, road drainage structures, and other material, such as brush mats and corduroy. This can help prevent fine soil particles from filling the voids created by the corduroy or drainage structures, ensuring that water flow practices continue to function as designed, that water continues to move under the road, and that long-term maintenance costs are minimized.

Geosynthetics can also reinforce road subgrades on soils with very low bearing capacity. For a geosynthetic to provide adequate reinforcement, the fabric must be well-anchored, yet still capable of undergoing deformation (i.e., stretch). Once under tension, the fabric provides the required reinforcement (**FIGURE 26**).

Geosynthetics are available in many different forms, with woven geotextiles, geogrids, and geocells being applied to the construction of resource roads across wetlands. The decision about which type of geosynthetic will be used must be based on the desired function (separation or reinforcement). Regardless of the product used, it is important that it is installed in the manner recommended by the manufacturer and used for the function it was designed for.

GEOTEXTILES

Geotextiles are available in both woven and non-woven types, and offer different properties and applications (**FIGURE 27**).

- Woven geotextiles are manufactured by interlacing, usually at right angles, two or more sets of fibres. This process creates a relatively stiff fabric that stretches about 5 to 20% under tension. Woven geotextiles may be used to provide reinforcement or separation.
- Non-woven geotextiles are produced by bonding randomly oriented fibres. This process creates a fabric that stretches significantly under tension and is used primarily for separation.

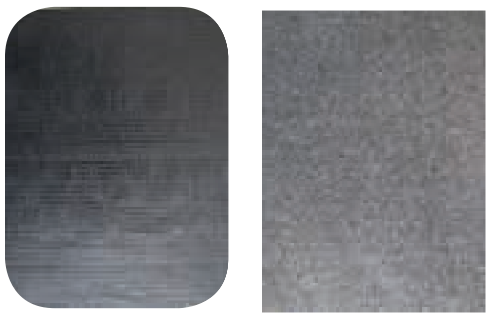


FIGURE 27. *Woven (left) and non-woven (right) geotextiles offer different properties.*

FIGURE 25. *Geotextiles can act as a separation layer to minimize bearing failures and reduce aggregate thickness.*

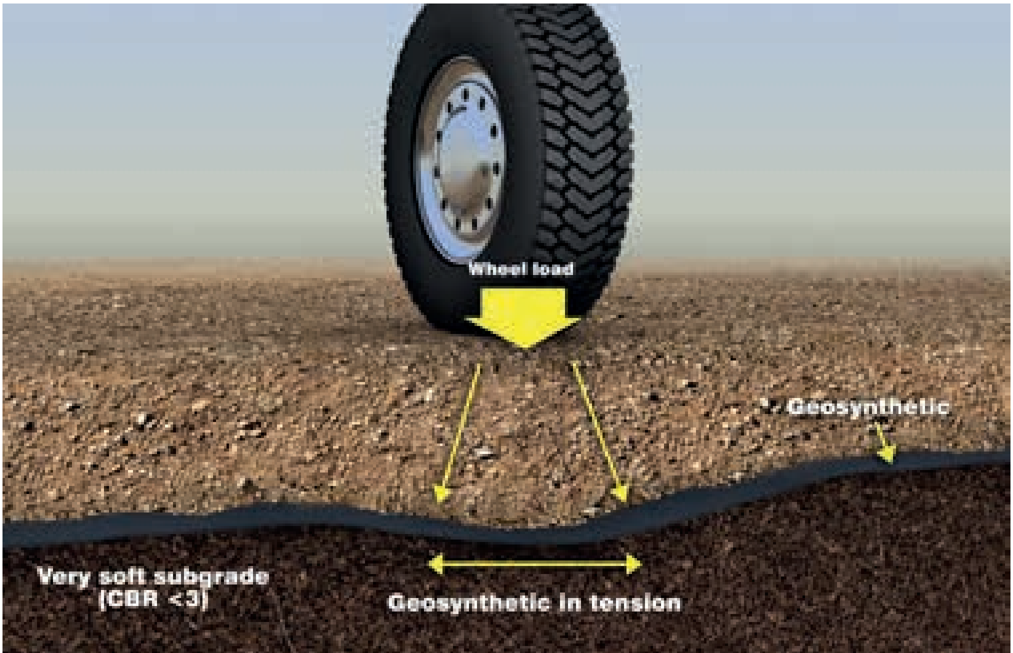


FIGURE 26. *A geosynthetic under tension can offer reinforcement.*

GEOGRIDS

Geogrids are manufactured from high-strength polypropylene (**FIGURE 28**). Geogrids offer very high tensile strength values and are designed to provide reinforcement and confinement, and may be used in conjunction with a geotextile if separation is also required. When a geogrid is used with the appropriate aggregate material, the aggregate becomes interlocked in the geogrid cell openings (**FIGURE 29**).

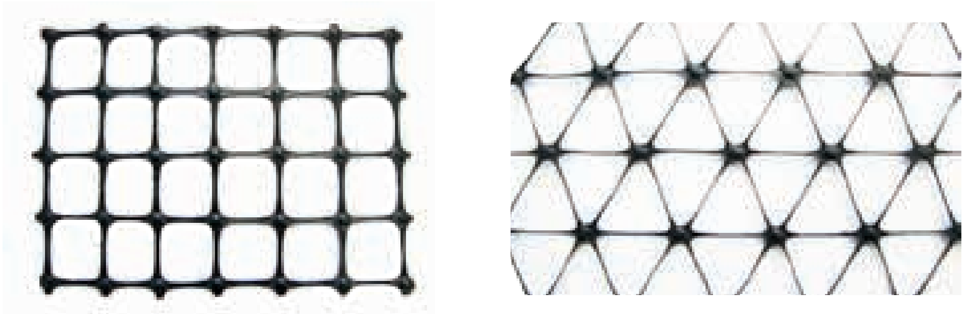


FIGURE 28. *Geogrids are available in bi-axial (square-shaped openings) or tri-axial (triangle-shaped openings) configurations.*

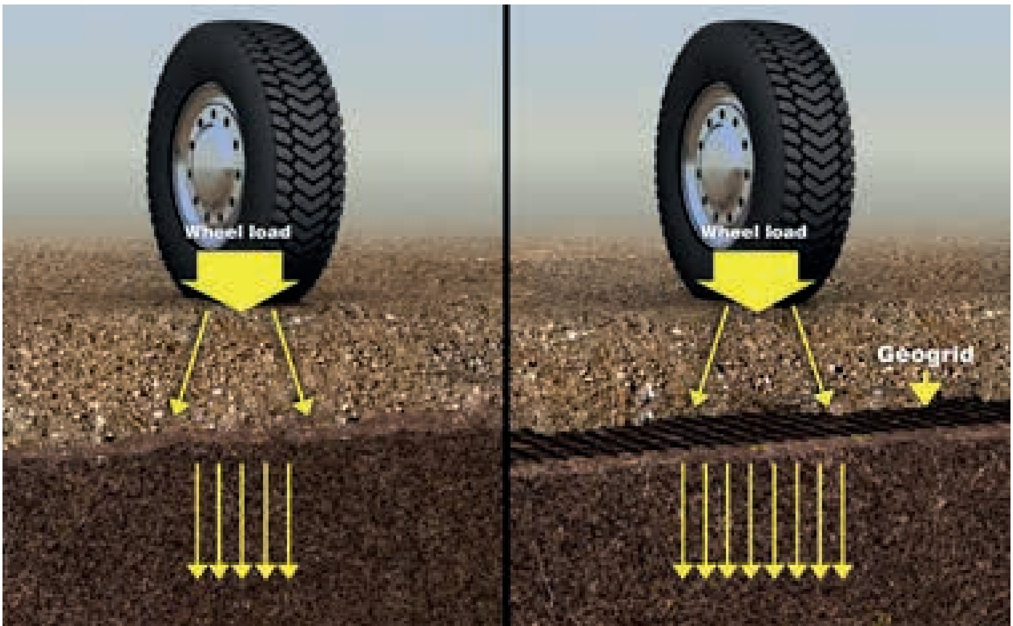


FIGURE 29. *Geogrids function as a reinforcement layer for road subgrades, preventing the aggregate material from being pushed into the underlying soils. They also allow a wider distribution of vertical pressure (snowshoe effect).*

GEOCELLS

Perforated geocells (also called cellular confinement) are manufactured from high-density polyethylene (HDPE) to form honeycomb-shaped structures (**FIGURE 30**). The geocells confine the infill material, which increases the material's resistance to deformation from loading, allowing the geocell and the infill material to act as a platform that distributes loads over the subgrade area. Fine-grained material, such as sand, can be used with a geocell, and the perforations in the cell walls provide for lateral drainage.

FIGURE 30. *Perforated geocells stabilize and confine fill material. They are often applied when high loading is expected and where granular material is unavailable. (Photo courtesy of Presto Geosystems.)*

CHOOSING A GEOSYNTHETIC

Because there is such a wide range of geosynthetics and manufacturer product names, and because it is difficult to identify the differences between similar products, knowing which geosynthetic to use in a given situation can be a challenge. It is important to work with a geosynthetic supplier or road design expert to identify the most appropriate product, installation procedures, and application for the given design functions of the product and the use of the resource road **(TABLE 3)**.

TABLE 3. *General guidelines for the application of geotextiles, geogrids, and geocells*

GEOSYNTHETIC	COST	SEPARATION	REINFORCEMENT	FILTRATION
WOVEN GEOTEXTILE	✓	✓✓✓	✓✓	✓
NON-WOVEN GEOTEXTILE	✓	✓✓✓		✓✓✓
GEOGRID	✓✓	✓	✓✓✓	
GEOCELL	✓✓✓		✓✓✓	

FIGURE 31. *Example of a corduroy structure.*

CORDUROY

It is a common practice to cross wetlands by laying tree-length logs parallel to each other and perpendicular to the direction of intended travel. The use of logs in this manner is referred to as a corduroy structure (**FIGURE 31**). The logs allow the road base to be more widely built, thus distributing the downward forces from the road fill and the passing vehicles over a greater area, which improves the bearing capacity of the site. The voids between the logs also help facilitate the movement of water below the running surface of the road.

Here are a few considerations for using corduroy:

- Corduroy structures are often built at the time of right-of-way clearing, when areas of soft soil are identified.
- Logs can also be delivered to the construction site with a skidder or forwarder and can be placed by an excavator, feller buncher, or harvester. Once the logs have been placed, the area has a higher bearing capacity for the heavy equipment (e.g., bulldozer) used to complete the construction of the crossing (**FIGURE 32**).
- Geotextile material can be placed along the ground surface, before logs are placed, and on top of the corduroy to act as a separation layer between the corduroy, the wetland soil, and the road fill material. This practice helps prevent soil and road fill material from the filling the log voids and facilitates water passage.
- The size, length, and species of logs used to build a corduroy crossing are dictated by log availability, log market conditions, and utilization standards, among other factors. Using low-value logs is often considered before using high-value logs.

FIGURE 32. *Bulldozer working on top of a positioned corduroy structure as it delivers a layer of fill.*

- The diameter of a log needs to be large enough so that it does not break under a load; the smallest diameter may range from 10 to 25 cm.
- To extend the width of the road base and spread a load over a wide area, tree-length logs should be used. Both conifer and deciduous species may be used for corduroy crossings.
- Logs that extend past the road embankment and are left exposed can degrade due to accelerated rot and they will be unable to perform as intended. Corduroy, especially for permanent roads, must be fully covered to help prevent rot.
- The height of a corduroy crossing will be site-specific. Structures are typically built as a single-log layer, but may be built with two or three layers, depending on the diameter of the logs and whether the road is permanent or temporary. The second corduroy row is less likely to become pressed into the soil (**FIGURE 33**). The orientation of the logs to each other will likely be more of a concern with larger-diameter stems. The row of logs should be fairly level, which may require aligning the butts of second-row logs with the tops of the first-row logs.
- Corduroy crossings are often constructed during the winter. The frozen ground gives the soil additional strength, which helps prevent the sinking of heavy equipment and any damage the equipment may cause to the wetland. Once the section of corduroy road has been built, the road can be travelled on in all seasons (**FIGURE 34**).
- Tops and limbs may be added on top of logs to produce a layer of brush. The brush mat functions as a separation layer between the road construction material and the logs. This technique assists in preventing the running surface material from being transported into the voids between the logs.

FIGURE 33. *A section of corduroy being built with larger-diameter, tree-length logs more than one log high. Notice the alternating directions of butts and tops to make the structure level, as well as the use of geotextile below the logs.*

FIGURE 34. *Construction of a corduroy section of road during the winter, with geo-textile being placed along the ground surface (top). The completed road crossing, which was built with delivered aggregate (bottom).*

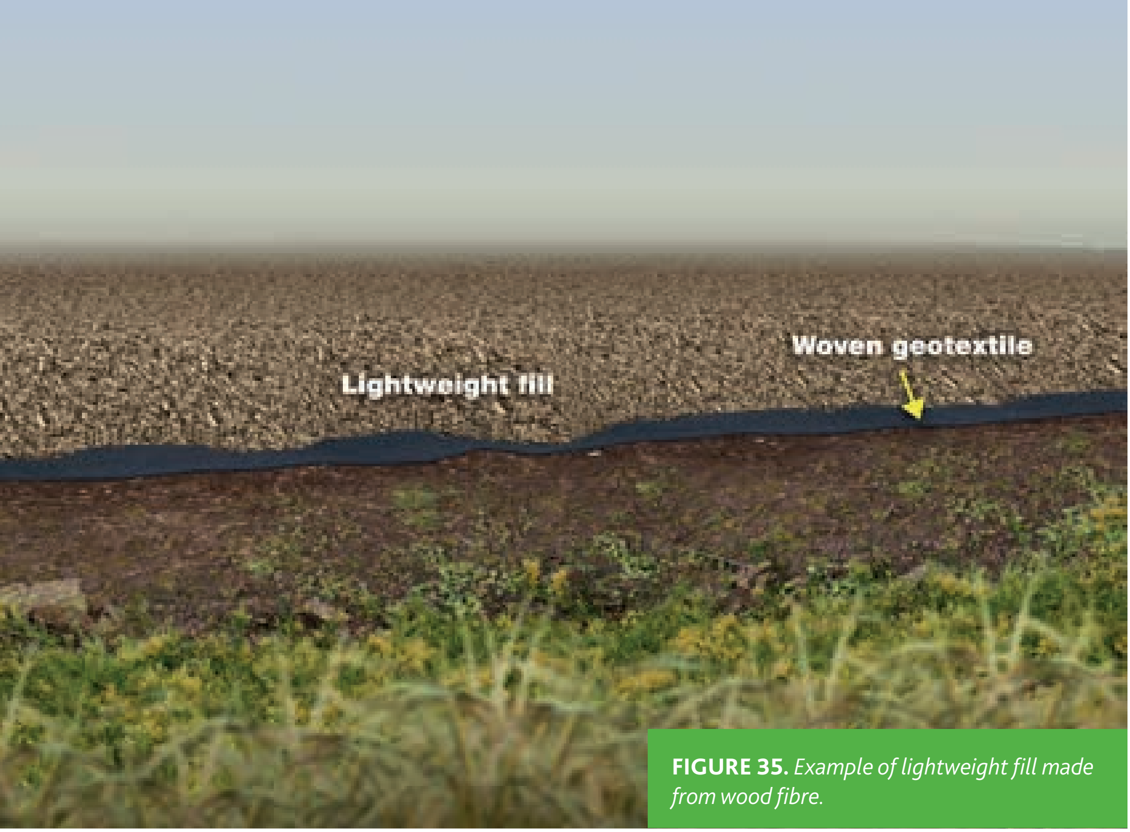


FIGURE 35. *Example of lightweight fill made from wood fibre.*

ALTERNATIVE FILL MATERIALS

Lightweight fill, such as expanded polystyrene (EPS) or wood fibre, has been used during the construction of roads to reduce the bearing pressure on weak soils compared to heavier, traditional soil and aggregate fill (**FIGURE 35 AND 36**). Using lightweight fill across an intact wetland surface will help to reduce the compressive forces acting on the peat column and will reduce road settlement. Lightweight fill is not intended for placement on stable or firm soils, which are not likely to compress or settle over time, such as the parent material below the peat.

Here are a few considerations for using lightweight fill:

- If wood fibre will be used during road construction, a separation layer of geotextile beneath the fibre can prevent the wood from entering the wetland and may aid with the decommissioning and reclamation of the crossing.
- If aspen wood fibre will be used near aquatic environments, government standards and regulations should be considered, as management of leachates may be required.
- EPS blocks are commonly used as a lightweight fill for municipal and highway projects. The transportation of EPS blocks to a remote wetland location may make their use less cost-effective than for traditional road construction projects (**FIGURE 37**).

FIGURE 36. *A road made from wood fibre.*

FIGURE 37. *EPS blocks as lightweight fill used for a bridge approach. (Photo courtesy of Tembec.)*

FIGURE 38. *Example of a temporary access mat.*

TEMPORARY ACCESS MATS

Temporary access mats, or rig mats, are made from various materials, including softwood or hardwood, composite laminate wood, bamboo, composite HDPE, composite polypropylene with fibreglass casing, and rubber (**FIGURE 38 AND 39**). One of the main uses of mats is for temporary access roads to mine sites, well pads, or pipeline routes, and for installation of transmission lines.

Temporary mats are constructed square or rectangular in shape and are available in various dimensions, but the typical dimensions are 2.4 m wide (8 feet) by 4.3 m long (14 feet).

When used for temporary access, these mats act as a system to provide a travel surface across areas of poor bearing capacity, such as wetlands. The mats are modular, reusable, easily rented (rather than purchased), and have a wide load distribution, thereby providing flotation for passing heavy equipment.

FIGURE 39. *Temporary mats made of wood and metal (top) and all wood (bottom). Note that the two all-wood mats stored on top of each other have a three-finger interlock design for joining with adjacent mats when positioned end-to-end.*

Here are a few considerations for using temporary access mats:

- Mats should be used only for temporary access and should be removed after use.
- Wood mats tend to be heavy and can become heavier when they are saturated and dirty.
- Heavy equipment is needed to load and unload the mats, and because of their weight, the delivery of mats to a site may require more than one truck.
- Mats can become embedded or frozen into the soil, thus hindering shallow subsurface flows and becoming difficult to remove.
- Mats may sink or settle into the soil, so some sections may need to be double-matted.
- Mats can break and deform during the construction, use, and removal phases, which may result in losses and necessary replacement.
- Mats typically need to be cleaned before reuse at a new site. Cleaning the mats helps to remove any pollutants or potentially harmful bacteria, fungi, or seeds, and helps prevent the introduction of invasive species.
- Wood mats have openings that may allow contaminants from the site to seep through, whereas some composite mats have a unique twist-and-lock system and an overlapping lip to provide a continuous barrier.
- The benefits of using mats in maintaining flow in different types of wetlands have not been fully evaluated, so this should be considered if this technique is chosen.
- Caution should be used when using mats on slow lateral-flow or seasonally fluctuating wetlands, as changes in water level after snowmelt or rain events may result in water flowing over the mats.
- Where additional flow capacity is needed below a mat, the use of additional conduits should be considered to allow for lateral water movement.

Rubberized and composite mats are also available for use on weak soils (**FIGURE 40**). Rubber mats are heavier than wood mats, and as a result, they are expensive to ship, and since they tend to sink on soft, wet soils, they need to be layered to compensate. Rubber mats are more costly than wood mats, but they are more resilient to weathering and damage, they do not freeze in place, and they have a relatively long lifespan.

Bamboo and composite mats are relatively light compared to traditional wood and rubber mats, and thus, they are less expensive to transport. Bamboo mats are less expensive than composite mats, but more expensive than wood mats. Because composite mats are engineered, their strength is more uniform than that of wood mats, and they are more durable.

FIGURE 40. *Rubberized mat made of recycled rubber tires (top) and a composite plastic mat (bottom). (Photo courtesy of Alberta Environment and Parks.)*

TEMPORARY WINTER ROAD WETLAND CROSSINGS

When a winter road that crosses a wetland is nearing the end of its use in spring, when temperatures rise and the snow melts, water management is of primary concern. Careful attention needs to be given to halting travel on the road when temperatures start to warm and the ground begins to thaw. Serious damage to a wetland can occur if the thawed ground becomes rutted or compacted in such a way as to alter the summer hydrologic conditions (**FIGURE 41**).

Here are a few considerations for constructing temporary winter roads across a wetland:

- When the road is in use during frozen conditions, there is usually no flowing water along the surface, and the subsurface flow (if any) is likely maintained within the undisturbed ground.
- Water movement can occur throughout the winter in slow lateral-flow wetlands, so these types of wetlands may require additional freezing techniques to promote frost depth. These locations may require road conduits or alternative winter road practices. Understanding the flow characteristics of the wetlands that will be crossed can assist planners and operations staff determine the most appropriate location and water management options.
- Before the snowmelt occurs and after vehicle traffic has halted for the season, it is common to promote drainage flow paths through the road. This can be accomplished by ripping or digging a trench through the snow and gravel fill to permit surface and subsurface flow. This technique helps prevent flow from spreading over the entire road, which can cause erosion and other damage.

FIGURE 41. *Winter roads across frozen wetlands can have a much lighter impact on the surface vegetation and soil if constructed and used appropriately, resulting in less rutting and compaction.*

WATER MANAGEMENT: SURFACE AND SUBSURFACE FLOW

Well-planned and executed road construction practices should include adequate provisions for water movement and drainage. Water management is an important aspect of any road construction project, but it is especially important when building wetland crossings. Planning for the appropriate wetland crossing location and conduit placement is no simple task. Identifying a wetland's flow characteristics can assist with these planning decisions and help identify the flow requirements for a given wetland crossing. Putting these wetland flow considerations into practice is likely new and challenging for many natural resource managers, but the practices can greatly assist in reducing construction and maintenance costs and the impacts on wetland water flow.

CULVERTS

Culverts are the main water management technique used to allow water to flow from one side of the road to the other. Common culvert materials include corrugated, galvanized metal and HDPE. Where culverts are used to maintain water flow through a wetland, they must be placed in locations that will allow water to move freely to downgradient locations.

Advantages

Culverts can provide for both surface and shallow subsurface flow if they are embedded (i.e., partially buried) during installation. By doing so, the above-ground portion will enable all surface flow events (including storm or seasonal effects), and the below-ground portion will allow passage of shallow, subsurface flow. A common embedment depth is 40% of the diameter for round culverts or 20% of the rise for pipe arches, which allows for the widest part of the culvert to be near the ground surface. Considering the root mat and ground surface will be disturbed while a culvert is being embedded, reinforcement will be required to improve the bearing capacity of the disturbed ground. Culverts can also be manufactured with a step-bevel; both embedment and bevelled ends are good practices for promoting flow through a culvert (**FIGURE 42**).

FIGURE 42. *A partially embedded culvert (left) and a culvert prepared with a step-bevel (right).*

Limitations

Due to the low bearing capacity of wetland soils, culverts can settle over time (**FIGURE 43**). The settlement can be uniform, resulting in the culvert ends being entirely under the ground or water surface, or non-uniform, resulting in the ends pointing upward. A common technique for preparing for the settlement of the centre of a culvert is constructing a cambered culvert. Culverts that sink over time in some wetlands and become submerged may not necessarily be considered non-functioning with respect to providing an open conduit for hydraulic connectivity. Culverts have been installed completely subsurface and buried over during the construction of wetland crossings as a planned method of subsurface water management.

In some cases, multiple culverts may be needed to maintain wetland flow. A single culvert may become a pinch point that increases the velocity of water movement and can easily be blocked by floating debris and beaver activity.

FIGURE 43. *Culverts that have sunk below the water surface.*

Application

Culverts need to be sized and spaced appropriately across a wetland to provide a flow capacity to match the predicted water movement of the wetland and the length of the crossing. Generally, steel culverts used for wetland crossings range in diameter from 250 to 800 mm. Where smaller-diameter culverts are used, they tend to be made of HDPE.

The appropriate spacing of culverts through a wetland crossing can be difficult to determine. Depending on the flow requirements of the wetland, the spacing may vary. Placing a culvert at each end of a wetland crossing allows for easy access and use of the upland soils to aid with the construction and bedding for the culvert; this would also apply to any islands of high ground traversed within a wetland crossing. Depending on the length of the wetland crossings, observed spacing ranges from 2 to 3 culverts 15 m apart, in areas of concentrated flow, to evenly spaced culverts at up to 250 m intervals (**FIGURE 44**).

In general, the diameter of spaced culverts is not as critical as the spacing itself, considering the slow movement of water; the culverts tend to "balance" the amounts of water on either side of the road and often do not flow at capacity. For seasonally fluctuating wetland systems that can move a considerable amount of water at certain times of the year (e.g., rain event, snowmelt), larger-sized culverts may be required to accommodate the increased flow volume. Any flow that reaches the midpoint between culverts at a road would have to travel parallel to the road until it reaches a culvert to pass through the road. There are techniques to help promote and direct the flow toward the spaced culverts, such as using a perforated and flexible HDPE culvert with a small diameter. Suggested maximum intervals for spacing of culverts are provided in **Table 4**.

FIGURE 44. *Newly constructed road across a treed bog showing evenly spaced culverts.*

TABLE 4. *Culvert usage recommendations that accommodate wetland flow characteristics* [a, b]

CULVERT SPACING	Stagnant	Slow lateral flow	Seasonally fluctuating
	Widely spaced	Mid to widely spaced	Closely spaced
MAXIMUM CULVERT SPACING, PERMANENT ROAD	200 m	150 m	100 m
MAXIMUM CULVERT SPACING, TEMPORARY ROAD	250 m	200 m	150 m
CULVERT DIAMETER	250–500 mm	500–800 mm	> 800 mm

[a] *Where culverts are the chosen conduit, the length of the wetland crossing will help determine the ideal number of culverts used. A minimum of one culvert should be placed regardless of the length of the crossing.*

[b] *The suggested range in spacing may be further influenced by site-specific wetland characteristics. For example, where a crossing is located at a narrow area of the wetland, closer spacing of culverts may be required to accommodate the funnelled flow through this area. Edges of wetland crossings adjacent to drier upland soils could provide better bearing with respect to culvert installation and potential settlement over time.*

For crossings of longer distances requiring many culverts, a set spacing of the culverts is likely the best option to accommodate flow, as detailed field surveys may not be able to identify culvert locations accurately. Installing culverts at aggressive spacing (e.g., 25 to 50 m) can provide a higher level of certainty that hydrologic connectivity is maintained, resulting in improved environmental performance (**FIGURE 45**). This should be considered in remote locations, where heavy equipment is not likely to return if additional work is required.

Where it is possible to monitor a crossing to determine its performance, additional culverts can be installed at a later time if field indicators (e.g., ponded water) suggest the need for them. This technique is labour-intensive and costly, as the remobilization of equipment to the site and the installation of new culverts are additional costs. This emphasizes the importance of considering adequate culvert placement when the crossing is initially being built.

FIGURE 45. *Closely spaced culverts that balance flow on either side of the road at a wetland location where sections of open water are present. (Photo courtesy of Tembec.)*

On temporary or winter roads, corduroy may be placed around a culvert to provide for additional flow capacity. This technique is more appropriate for temporary roads because it is not possible to compact backfill next to and over the culvert (**FIGURE 46**). It is the compacted backfill that can build a soil arch that is more appropriate for long-term engineered crossing structures.

Wetland flow considerations

Culverts are appropriate for use in all wetland flow groupings, including stagnant, slow lateral flow, and seasonally fluctuating.

Additional considerations include:

- Culverts may be used along with other practices, such as corduroy, log bundles, or aggregate mattress, to allow the required wetland flow through the road.
- In stagnant wetlands, small, widely spaced culverts should be considered (**FIGURE 47**).
- In slow lateral-flow systems, medium-sized culverts should be considered (**FIGURE 48**).
- In seasonally fluctuating wetlands, larger, closely spaced culverts should be considered (**FIGURE 49**).
- In seasonally fluctuating wetlands, where flows and water levels tend to increase during the wet season and decrease during the dry season, culverts may be needed at various heights (i.e., embedment depths) to account for changes in the depth and flow of the water.

FIGURE 46. *Logs placed on either side and over the top of a culvert. Notice the placement of the geotextile separation layer over the parts of the logs that are exposed, which prevents road material from eroding into the watercourse.*

FIGURE 47. *To provide for wetland flow in stagnant wetlands, use widely spaced, small-diameter culverts.*

FIGURE 48. *To provide for wetland flow in slow lateral-flow wetlands, use mid-sized-diameter culverts.*

FIGURE 49. *To provide for wetland flow in seasonally fluctuating wetlands, use closely spaced, large-diameter culverts.*

FIGURE 50. *Example of a log bundle.*

LOG BUNDLES

Log bundles can be used to allow water to flow and to balance the water on either side of a wetland crossing. A log bundle is built by laying logs through the road, similar to a corduroy structure (**FIGURE 50**).

Advantages

The linear voids created by laying logs next to each other allow water to pass through the structure. The use of logs sourced near the construction site provides a cost-effective choice for a conduit. Log bundles may be less easily blocked by beaver dams compared to culverts, since the slow and continuous seepage through the structure does not produce an obvious sound of running water, which often attracts beavers.

Limitations

Temporary roads are more suited for smaller and single-row log bundles. Because of the temporary nature of the crossing, the log bundle may be built to a lower standard (e.g., not cut to length or deeply covered) (**FIGURE 51**), since these structures will be removed during road decommissioning.

FIGURE 51. *Log bundle installed through a temporary road across a shrub swamp. The structure is built one log high, with a separation layer above the logs and the road material. Note that culverts are easily incorporated into this style of structure.*

Application

The spacing of log bundles should be similar to what would be appropriate for culverts. A geotextile separation layer should be placed above the structure to prevent the road fill from migrating into the voids; separation is also recommended below the log bundle or around the entire log bundle. Building the structure with multiple layers (i.e., more than one log high) provides additional flow capacity (**FIGURE 52**).

Wetland flow considerations

Log bundles are appropriate for use in all wetland flow groupings, including stagnant, slow lateral flow, and seasonally fluctuating.

Additional considerations include:

- Log bundles should be used as part of a system of practices rather than as a practice used independently.
- Log bundles should be considered as a practice for addressing water movement concerns on an existing road or a temporary road rather than as a practice on a newly built, permanent road.
- In slow lateral-flow and seasonally fluctuating systems, the number of logs in a log bundle should be increased to allow the required water passage.

FIGURE 52. *First row of a log bundle in an excavated trench (left); second row of the log bundle before the tops of the logs were trimmed (middle); final road grade showing the log bundle with geotextile placed over it (right). Note that this log bundle was installed through an existing road to provide additional water passage.*

FIGURE 53. *Example of an aggregate mattress.*

AGGREGATE MATTRESS

Sections of resource roads, including causeways and bridge approaches, can be built from angular aggregate, which allows water to pass through the voids between individual pieces. The technique is commonly called an aggregate mattress, or aggregate seam, and is appropriate for both temporary and permanent roads (**FIGURE 53**).

Advantages

A road built with an aggregate mattress allows water passage through the entire length of the constructed section. Aggregate mattresses have been used for water passage at wetland crossings.

Limitations

Careful attention to the management of fine soil particles is required to prevent these particles from filling the voids within the aggregate and blocking water movement. A geotextile is often used to separate the road running surface material and the underlying soils from the base course aggregate to help prevent fine soil particles from migrating into the voids and blocking flow. It is essential to prevent the base course from infilling to allow for water passage. The removal of an aggregate mattress can be difficult if the road will eventually be decommissioned, so for this reason, it is best for permanent roads. An aggregate mattress is best applied on wetlands with shallow peat and organic soils. On sites with deeper peat, the aggregate fill may sink further. If structure sinkage is a concern, a geosynthetic can be installed under the aggregate to provide foundation reinforcement.

FIGURE 54. *Newly built resource road across a wetland showing the size and depth of rocks used for the aggregate mattress.*

Application

The length of the aggregate mattress section can vary from the width of the entire wetland to short sections or seams at strategic or set spacing, depending on the anticipated flow and associated dynamics. However, as with the use of corduroy, additional conduits can be incorporated and the decision to do so is often site-specific.

Angular aggregate is the most common material used during the construction of an aggregate mattress, and the angularity of the aggregate is key to providing a stable, interlocked base.

A geotextile should be considered for placement below the aggregate, not only as a separation layer, but also to increase the bearing capacity, provided it is well-anchored to the remaining sheared stumps. The increased bearing may also allow for the construction of a thinner base course and result in less road maintenance because road settlement will be minimized.

It is important to keep the source aggregate clear of fines to help promote flow through the interior voids. Fines can be separated from the larger aggregate by hosing the aggregate with water once it is in place, screening at the loading site, or not using the last portion from the box of the rock truck, as that is where many of the fines accumulate. Once the aggregate has been delivered, the material can be pushed and rolled into place by on-site equipment. The rolling of the material promotes the segregation of fines to the lower parts of the layer, where the fines typically have less potential to restrict drainage.

As an example, the aggregate base layer can be constructed from 60 cm minus (24 inch minus) rock to a depth of 1 m, and be made as wide as is specified for the class of road (**FIGURE 54**). A separation layer is needed on top of the base course before the running surface material is delivered to prevent fines from migrating into the voids in the base course.

Wetland flow considerations

An aggregate mattress is appropriate for use in all wetland flow groupings, including stagnant, slow lateral flow, and seasonally fluctuating.

Additional considerations include:

- An aggregate mattress should be used as part of a system of practices rather than as a practice used independently.
- In stagnant and slow lateral-flow wetlands, an aggregate mattress can reduce the need for additional conduits.

FIGURE 55. *Example of a corduroy structure to provide water flow through a road.*

CORDUROY

In addition to being used as a method to improve the bearing capacity of the road foundation, corduroy logs may also be considered as a method to provide for shallow surface or subsurface flow in a wetland (**FIGURE 55**).

Advantages

A road built with corduroy allows water passage through the entire length of the constructed section. The voids between the logs provide numerous openings for the movement of both surface and shallow subsurface water (**FIGURE 56**).

FIGURE 56. *Two corduroy roads showing the use of logs, a separation layer, and road fill as part of a road across a wetland.*

FIGURE 57. *Corduroy crossing showing logs placed two or three high, and the use of a culvert to provide for additional flow. Arrow indicates the geotextile separation layer between the top of the logs and the bottom of the road base. The depth of road fill shown is similar to that of the corduroy (1:1).*

Limitations

For brush that is installed over the corduroy, any needles or leaves that are attached to the tops and limbs may become loose and hinder water passage over time. For temporary roads, the needles and leaves may still be intact or near the original position and may not hinder flow through the lineal voids. For permanent roads, a separation layer should be used between the logs and the brush mat.

Application

To promote flow and keep the voids clear, an upper layer of geotextile can be used as a separation layer between the logs and road fill material. Alternatively, a layer of brush (i.e., branches, stems, and tops) can be placed on top of the corduroy logs to act as the separation layer between the road base and the logs. Water will pass more easily if a crossing is built two logs high, as there is more opportunity for seasonally high flow to exploit the lineal voids among the logs in the second row. Consideration should be given to installing a geotextile over the root mat to separate the logs from the wetland soils to prevent the log voids from infilling.

Culverts can be incorporated into the corduroy for additional flow capacity (**FIGURE 57**). When using logs as fill around a culvert, caution must be taken to ensure that the logs do not puncture the pipe wall.

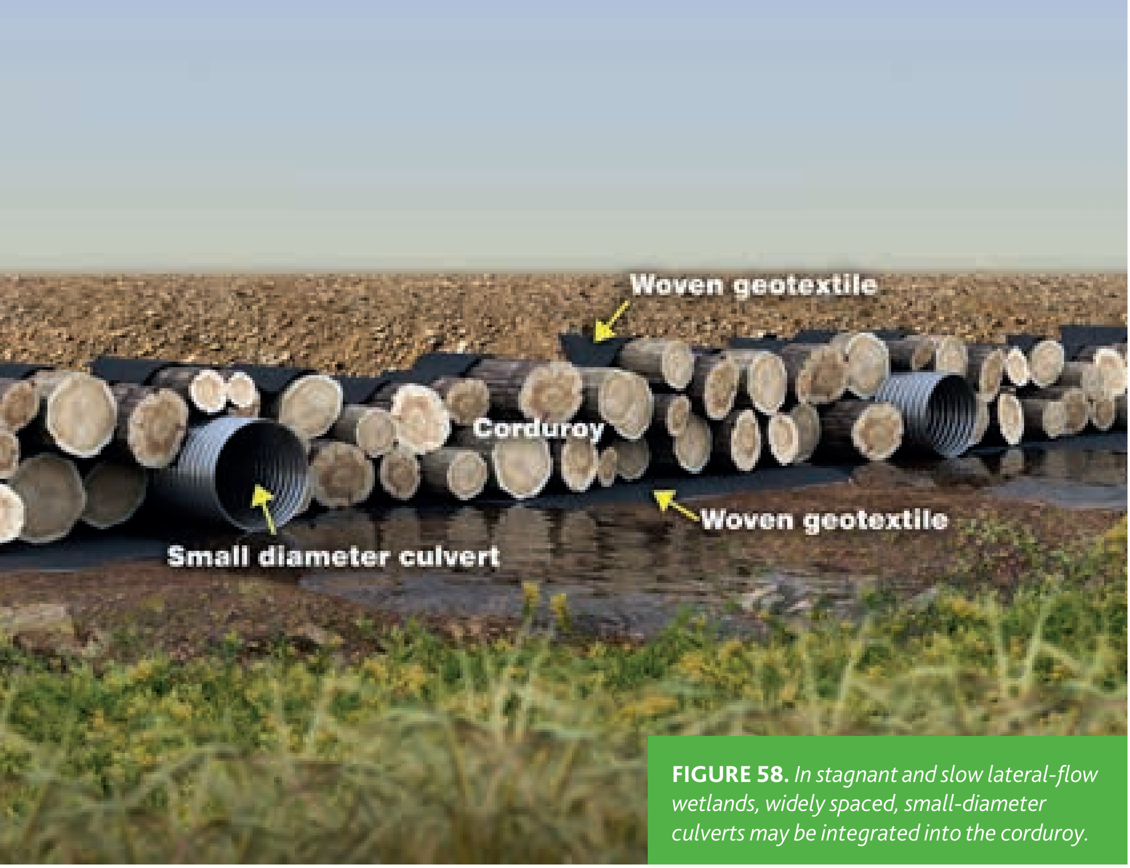


FIGURE 58. *In stagnant and slow lateral-flow wetlands, widely spaced, small-diameter culverts may be integrated into the corduroy.*

Wetland flow considerations

Corduroy is appropriate for use in all wetland flow groupings, including stagnant, slow lateral flow, and seasonally fluctuating.

Additional considerations include:

- Corduroy should be used as part of a system of practices rather than as a practice used independently.
- Corduroy should be installed along the entire length of a crossing to allow for the required water passage.
- The number and size of culverts to be used among corduroy logs will depend on the type of wetland being crossed.
- For stagnant and slow lateral-flow wetlands, smaller and fewer culverts may be incorporated into the corduroy (**FIGURE 58**).
- Where more dynamic water flow characteristics are predicted, such as in seasonally fluctuating wetlands, larger and more frequent culverts may be used (**FIGURE 59**).
- Additional culverts are often used in a low area of a crossing or where there is a defined seep or ephemeral draw (**FIGURE 60**).

As knowledge and awareness of wetland systems and the interaction of resource roads and wetlands increases, additional ideas and innovative wetland crossings may develop (**FIGURE 61**).

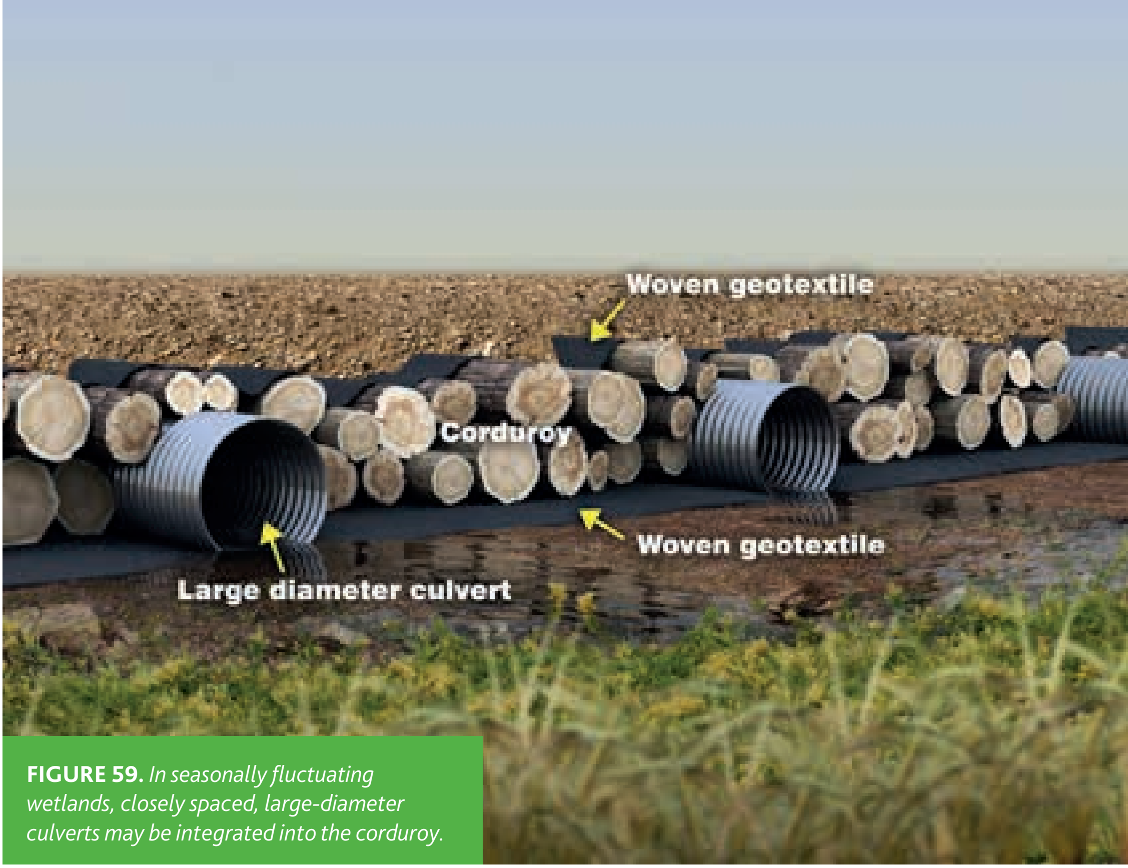


FIGURE 59. *In seasonally fluctuating wetlands, closely spaced, large-diameter culverts may be integrated into the corduroy.*

FIGURE 60. *A culvert was incorporated into this corduroy crossing to provide for additional flow capacity. The culvert was positioned at a low area, where greater flow was anticipated. Note that the geotextile used for separation has been secured by wrapping it around a curb log.*

FIGURE 61. *A pile-supported jump span bridge allows the road to span open water and sensitive wetland sites. (Photo courtesy of Landmark Solutions.)*

WATER MANAGEMENT: WATERCOURSE CROSSINGS

The installation of water-crossing structures in defined channels across wetlands presents unique challenges. Low soil-bearing capacity is common in wetlands, and can result in performance issues with the road and compromise the ability of watercourse-crossing structures to meet the requirements for fish passage or aquatic habitat protection. To ensure the required performance, innovative foundation improvement practices may need to be implemented. Watercourses found in wetlands are often wide and shallow, with slow water flow, and are prone to overtopping their banks with frequent flood conditions.

A defined stream channel should be managed appropriately regardless of whether it is upland or within a wetland. Provincial and federal regulations that refer to the management of fish streams, community watersheds, water intakes, and stream connectivity should be followed. The sizing of crossing structures to meet specific return intervals varies by province; 50- to 100-year return intervals are common.

CULVERTS

Culverts are the most commonly used structures in roads across wetlands and a common problem is that a culvert may partially or completely sink into the soil under the weight of the overlying fill. This is often evident at the centre of a culvert and can result in a banana-shaped culvert, with its ends higher than its centre. This can affect the structure's ability to provide adequate passage for water, fish, and other aquatic species.

Designing and building a strong foundation for water-crossing structures on wetland soils can be a challenge due to the deep soils and high water table often present. When there is an opportunity, the first step in achieving a strong foundation is to evaluate where a culvert should be installed and whether it is suitable to excavate the overlying organic soils until a more stable underlying soil material is reached. If it can be reached, then after the excavation is complete, the foundation for the structure can be built back up to the required elevation.

Where this cannot be undertaken, other foundation improvement options may be considered.

The use of geosynthetics (i.e., geotextiles, geogrids, or geocells) may help improve the culvert foundation, as geosynthetics can provide separation and reinforcement. Depending on the site characteristics, design, and operating requirements, a variety of geosynthetic configurations may be applied.

FIGURES 62 to **64** present examples of foundation improvement techniques that have been implemented for smaller water-crossing structures. Many modifications to these techniques may be made based on local knowledge and field experience, including the use of bearing improvements for culverts installed within wetlands and for watercourse crossings.

FIGURE 62.
A trench is excavated down to stable material, lined with a woven geotextile, and backfilled with compacted aggregate.

FIGURE 63.
If stable soil material cannot be found, a shallow trench may be excavated to achieve the desired structure elevation, lined with a woven geotextile and a geogrid, and then backfilled with compacted aggregate.

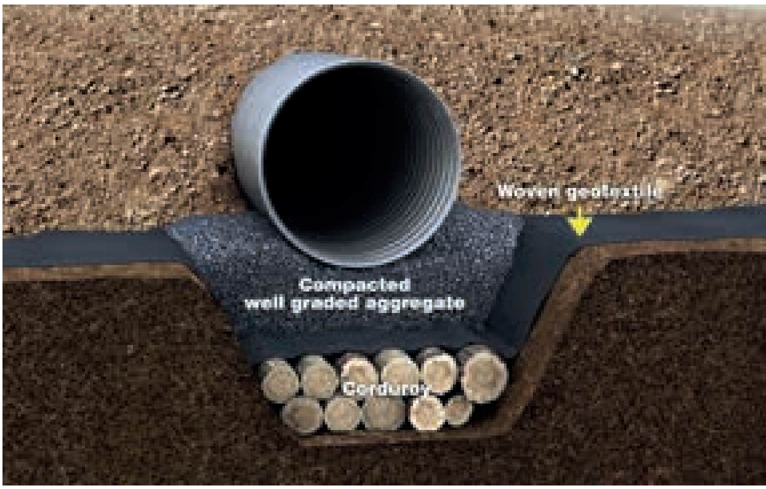


FIGURE 64.
If stable soil material cannot be found, a shallow trench may be excavated and then filled with multiple or alternating layers of corduroy. A woven geotextile is then added for separation before preparing the bed for the culvert.

FIGURE 65. *Typical footings for an open-bottom arch: a corrugated pad footing (left) and a precast concrete footing (right).*

ARCHES

Open-bottom arches can provide an alternative water-crossing structure, but they require proper footing designs that may pose a challenge on wetlands. Two common footing designs are corrugated pad footing and precast concrete footing (**FIGURE 65**). The arch should be sized to allow the footings to be positioned outside the natural high-water mark for the stream. It is important to keep the footings from being scoured or undermined by the forces of the flowing water. Regardless of footing design, aggressive armouring of the footings with large aggregate provides protection from scouring.

When installing open-bottom arches in areas where the bearing capacity of the soil is lower than the specified minimum, the foundation will need to be improved (**FIGURE 66**).

FIGURE 66. *A sequence of events for improving the bearing capacity of a site in preparation for installing an open-bottom arch. The weak soil was identified as not meeting the design requirements for corrugated pad footings (left); large aggregate was placed after excavation of weak soil (middle); coarse sand was used to level the site in preparation for the placement of the open-bottom arch (right). The stream was then diverted back through the arch.*

FIGURE 67. *A pile-supported abutment (left) and a pile-supported wingwall (right).*

BRIDGES

Bridges are often preferred for spanning wide streams, where increased site or environmental protection objectives must be met, or where a watercourse is defined as a navigable watercourse or route. Bridges are a more expensive option than culverts, so they are not often used to cross small streams. The opening below a bridge allows for debris to flow freely through the channel, so blockage is not a concern.

The bridge abutments require adequate bearing capacity; lightweight fill, such as EPS blocks, may be especially useful as a backfill material in these locations. Pile-driven abutments are common in various locations; **FIGURE 67** shows the use of pile-supported abutments. Aggregate is often used for armouring abutments and channel banks, but it may be too heavy for use in a wetland. Using a geotextile or geogrid can improve the bearing conditions of the site.

FIGURE 68. *A floating bridge alleviates some of the load-bearing requirements associated with typical abutments. Here, a floating bridge was chosen to cross a defined channel through a wetland as the channel did not freeze to the bottom during winter access, and seasonal timing was not always conducive to the construction of an ice bridge.*

FIGURE 69. *A bridge is used to cross a channel where a culvert is not well-suited.*

When a bridge is used to span a defined stream channel within a wetland, the approaches are usually built up on either side (**FIGURE 69**). Practitioners should consider culverts or other water-passing options within the approaches to address lateral flow and flood conditions that can occur in these areas (**FIGURE 70**).

FIGURE 70. *Culverts may be installed in the approaches to defined water crossings to enable hydrologic connectivity of the wetland. A permeable fill, designed and built to allow for water passage, may be considered as well.*

TEMPORARY WINTER CROSSINGS

Temporary winter stream crossings can be built using a range of construction techniques. Snow and ice fills are commonly used as an economical crossing that can have favourable environmental performance (**FIGURE 71**). Other common winter crossings include portable bridges, log bundles with snow cover, and culverts with snow cover (**FIGURE 72**). With a portable bridge, there is a need for abutments. Abutments can be heavy and may pose a settlement issue during non-frozen periods. In-stream structures, such as log bundles and culverts, need to be removed before the spring freshet, so as to not impede stream flow. A log bundle allows for some slow flow, but not the flow often seen in a defined channel during non-frozen periods. A culvert used for a winter crossing can be undersized for the flow during non-frozen periods. For both culverts and log bundles, careful removal is required to prevent damage to the stream bank and channel. These types of in-stream structures tend to adhere to the stream banks after their use all winter. Depending on the amount of snow that is on site during construction, natural or artificial snow can be used.

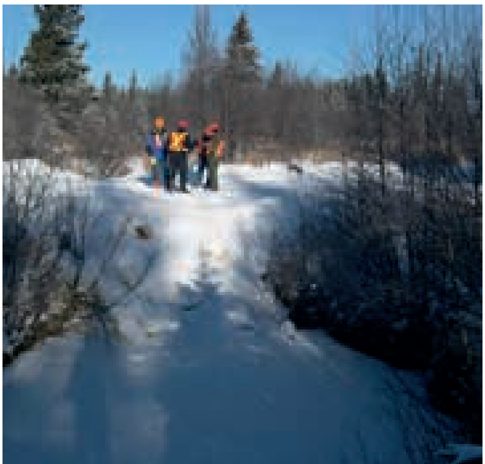


FIGURE 71. *Winter crossing made of snow and ice.*

FIGURE 72. *Three common winter stream-crossing techniques.*

FIGURE 73. *The use of stakes to mark culvert locations helps prevent damage to the culvert during road maintenance and snow removal, and aids in infrastructure inventory.*

MONITORING ROAD PERFORMANCE

Implementing a road performance monitoring and inspection plan is an important part of road management, for both permanent and temporary roads. The challenges of maintaining wetland-crossing resource roads to the required design and performance levels heighten the need for ongoing monitoring and continuous maintenance.

It can be difficult to determine whether a crossing is maintaining wetland flow, considering that indicators of flow impairment (e.g., changes to vegetation on either side of the crossing) might not be apparent for many years after construction. For this reason, the road and wetland conditions must be monitored to evaluate if current structures need repair or replacement, if new conduits need to be installed, or if a road must be repaired or upgraded. With culverts, it can be difficult to determine the number required and the exact placement during initial construction across a wetland; however, an effective monitoring program will identify future road drainage needs and the placement of additional culverts.

An important consideration for monitoring road performance is to ensure that an accurate inventory and database of the road and related infrastructure is maintained. This includes using roadside stakes or flags and maintaining a GIS inventory to identify critical infrastructure, such as conduits (**FIGURE 73**). Implementing regularly scheduled inspections can provide data that can be used to identify common wetland crossing challenges and to aid in identifying practices that meet road performance objectives.

There are many indicators that can help determine whether a resource road is negatively affecting a wetland's hydrology and whether road maintenance is required.

Road indicators:

- Road surface distress, such as rutting, indicating increased moisture levels from water entering the road material from beside or below the road (**FIGURE 74**).
- Perched or sunken culverts that may no longer be able to meet water passage needs (**FIGURE 75**).
- Excessive erosion on road embankments that blocks flow into installed conduits and erodes the road surface (**FIGURE 76**).
- Uneven vertical alignment of the road resulting from sinkage of the road foundation and blockage of subsurface flow (**FIGURE 77**).

FIGURE 74. *Rutting of the road surface can be an indicator of problems with the underlying road layers.*

FIGURE 75. *Culverts that have settled from their original position may no longer be able to meet design needs.*

FIGURE 76. *Erosion from road embankments can block culverts and impede water movement.*

FIGURE 77. *Uneven road surfaces can be an indicator of road settlement.*

FIGURE 78. *Tree dieback (on right side of photo) can be an indicator of changing soil moisture levels.*

Site indicators:

- Reduced tree and vegetation vigor or dieback as a result of increased soil moisture levels on one side of the road (**FIGURE 78**).
- A change in tree species or vegetation composition in response to increased or decreased soil moisture levels.
- Increased surface water levels and water ponding on one side of the road (**FIGURE 79**).
- Permanently water-filled ditches on both sides of the road indicating a high water table and blockage of lateral water movement in the wetland (**FIGURE 80**).

FIGURE 79. *Blockage of wetland flow can result in water ponding and negative impacts to the road base.*

FIGURE 80. *Permanently filled ditches can be a consequence in certain wetland types and can negatively impact road performance. (Photo courtesy of Tembec.)*

DECOMMISSIONING AND RESTORATION

The decommissioning and rehabilitation of resource roads is frequently performed for many reasons, including meeting forest management objectives, fulfilling wildlife habitat requirements, and restricting public access. A resource road wetland crossing may be partially or completely decommissioned and the site restored, depending on future operational requirements and applicable regulations. For wetland crossings, the focus is to maintain or restore wetland vegetation and water movement.

The decision to remove water-crossing structures to facilitate road decommissioning needs to acknowledge many operational and environmental factors, some of which are unique to resource roads that cross wetlands. For a road that must be decommissioned, the process of doing so should be considered during the planning and construction phases, so that the materials and techniques used can facilitate the removal and retrieval of material and improve the likelihood of successful and timely restoration.

The restoration of wetlands to pre-disturbance conditions may be more challenging than that for sites located in upland forests. Increased awareness of these needs in the planning, constructing, and operating phases can reduce the costs of restoration and can help ensure that the restoration meets the required objectives. Decommissioning and restoring a wetland crossing can be more effective when minimal damage has occurred to the soil, vegetation, and hydrology, which is made possible by thorough planning and careful construction of the wetland crossing.

Here are a few key considerations for the decommissioning of resource roads across wetlands:

- To facilitate removal of conduits, the installation methods that were used should be considered. For example, if a log bundle will be installed, the logs can be cabled together so that the bundle could be removed as one piece.
- Choosing a geosynthetic with high tear strength can help the product from being ripped during removal. The geosynthetic can also be installed in a way that will facilitate its removal, such as wrapping the end of the product around a log or attaching it to a piece of dimensioned lumber, which can be more easily retrieved and grasped by the bucket and thumb of an excavator (**FIGURE 81**).
- If erosion control products are needed for a road, such as in the ditch or on the road fill slope, the use of biodegradable or photodegradable products should be considered. These products, designed to degrade slowly, are more suitable for leaving on site and not retrieved. This provides operational savings, and the degrading product will not necessarily impede the restoration of the site.
- To facilitate the decommissioning tasks, plan and assign the appropriate equipment. For example, an excavator equipped with a hydraulic thumb can aid in the removal of conduits.

FIGURE 81. *A woven geotextile is attached to dimensioned lumber to aid in removal during road decommissioning.*

When the partial decommissioning of a wetland crossing is being considered, the drainage structures and sections of the road may be removed down to the natural level of the wetland soils (**FIGURE 82**). In this case, the removed drainage structures and subsequent trenching across the road offers opportunities to retain the surface and subsurface wetland flow connectivity.

When performing partial decommissioning, any excavated material, such as corduroy or log bundles, should be removed from the wetland and stockpiled or spread outside the wetland crossing. The excavated material may be considered for use in the partial restoration of local borrow pits. Structures such as culverts should also be removed from the site and properly disposed of or reused at another location.

The full decommissioning of a road may be considered where operationally feasible, such as in short wetland crossings, or where full site reclamation is needed to meet regulatory requirements, or wildlife or other ecological needs. For a full decommissioning, all or part of the work of heavy equipment may need to be performed during frozen conditions, so that the wetland soils are not disturbed. All material and structures should be removed and disposed of, reused, or applied for the rehabilitation of borrow pits.

Even though a road may no longer be required for industrial use, light public traffic may still occur and will require consideration. The use of armoured fords is a common practice when structures are removed, but consideration for public traffic is still required. However, the soft soil conditions typical of wetlands (particularly deep organic wetlands) make it difficult to construct and maintain fords that allow vehicle passage while still meeting ecological objectives. For this reason, if public traffic is still required on a resource road across a wetland, leaving the structure in place and implementing a maintenance and inspection plan may be the most suitable long-term action.

FIGURE 82. *The removal of conduits and trenching across the road can aid in restoring natural surface and subsurface wetland flow.*

EROSION AND SEDIMENT CONTROL

Preventing sediment delivery into a watercourse is the primary goal of erosion and sediment control. Exposed soils are vulnerable to the forces of erosion. When sediment enters a wetland, it can degrade water quality and habitat quality. Surface flow in wetlands is often low-velocity, with minimal erosive forces (an exception may be for seasonally fluctuating wetlands). Exposed soils are more easily eroded by the energy of rainfall and surface flow (e.g., sheet, rill, and gully erosion) than soils that have been protected and armoured. When planning erosion and sediment control measures for resource roads across wetlands, there are fundamental features that are unique to the wetland environment that need to be considered, such as its proximity to water and its high water table.

Many techniques for containing sediment require length, depth, and space on a landscape to allow for the deposition of sediment-laden water. For example, the construction of a detention pond to capture sediment or an off-take ditch is not possible in a wetland due to the high water table. Because many sediment control techniques are not easily accomplished in a wetland environment, preventing erosion in the first place should be the primary goal.

Providing an aggregate running surface not only addresses an engineering component of a resource road, but it also provides protection against erosion. Surfacing material can be provided in various sizes and thicknesses (**FIGURE 83**).

Water that runs any distance along a road surface has the potential to cause erosion. A well-crowned road will shed water and prevent it from accumulating and travelling along the road surface. Crowning a road aids in the removal of water by promoting positive drainage off the road along a relatively short distance, which in turn reduces the likelihood of road surface erosion. A 4 to 6% crown (cross slope) is typically sufficient to provide positive drainage. Maintaining a crowned surface will be accomplished by periodic grading using appropriate techniques; the ditch line or absence of a ditch line (common in wetlands) should be carefully considered so as to not remove established wetland vegetation (**FIGURE 84**).

Erosion and sediment controls should be in place during the decommissioning of a crossing to help reduce the introduction of sediment to a wetland. For example, with a corduroy structure, the majority of the logs may be left in place once the road fill material and separation layer are removed. The logs that make up a corduroy crossing can become fully or partially embedded in the wetland soil and their removal can introduce sediment into the wetland, resulting in more damage than if the logs remained. A solution would be to remove only some of the corduroy logs to provide an area for additional flow (through the depressed ground left behind after logs have been removed). This corduroy opening could be planned at set spacing or for targeted low areas. A high-strength geotextile separation layer can help contain more soil material as the road is being decommissioned, compared to a weak geotextile, which would likely rip or shred as it is being removed.

FIGURE 83. *The use of an aggregate running surface protects the underlying soil from erosion.*

FIGURE 84. *Berm of material near the shoulder of the road developed by a grader will be worked back across the road to build a crown. Careful attention must be given to the protection of roadside vegetation.*

07.
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APPENDIX III. SUGGESTED READING

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