SURFACE WATER MANAGEMENT CHALLENGES IN NORTHERN ALBERTA OILFIELD SITES

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Abstract: Northern Alberta is well known for its Steam Assisted Gravity Drainage (SAGD) sites. These are oilfield sites used for heavy oil production consisting of central processing facility, well pads and source water wells. In many cases the access roads to these facilities crosses water courses, wetlands and flowing fens (muskeg). In order to design and construct the roads for these sites, various permits from Alberta Environment including AER and ESRD must be obtained and many regulatory requirements shall be met. In addition, these sites usually require designing two separate systems for collecting clean and potentially contaminated surface water. Among other things, designing the surface water drainage system is another challenge that these SAGD projects are confronted with. Described herein are the design strategies that were invoked to meet the regulatory requirements faced by a real-life SAGD project in Northern Alberta.

Key Words: Roads and Drainage Systems, Surface Water, Stormwater, SAGD site drainage, Potentially Contaminated Water.

1 INTRODUCTION

Steam Assisted Gravity Drainage (SAGD) is an enhanced oil recovery technology for producing heavy crude oil and bitumen. These oilfield sites mainly consist of a central processing facility (CPF), well pads (WP), source water wells (SWW) and access roads. In order to design and construct the surface drainage system of SAGD sites various permits are needed which require adhering to provincial and regulatory requirements.

The fundamental objective of surface water management in these sites is to preserve and promote the general health and the environmental conditions of the area, which includes both the project area and adjacent lands that may potentially be impacted by the proposed development. It is important to recognize that surface water should be managed properly to meet the conditions and guidelines of Environmental Protection and Enhancement Act (EPEA).

In designing roads for crossing wetlands, two aspects have been taken into consideration. The road subgrade has sufficient bearing capacity and can safely support the anticipated vehicular traffic, and water management requirements to ensure properly passing surface and near-surface flows without negative impact on upstream and downstream. Water Act approval is required for road crossings on wetlands and water bodies with defined beds and banks or in areas with potential impact upstream or downstream flow patterns.

Wetland hydrology is complex due to the surface water, near-surface water and groundwater interactions. It would require intensive hydrologic modeling to accurately characterize these interactions. It is important to know that the presence of dead and/or dying trees is the most common visible sign that the hydrology of the site is altered. Another evidence that the hydrologic function of the site is altered is ponded water on one side of the road. Therefore it is crucial that the drainage patterns are properly defined and drainage areas are delineated for roads crossing the water bodies and wetlands and a comprehensive hydrotechnical study is implemented for the development area to support surface water management.

In summary the following objectives have been taken into consideration for surface water management of the site:

- Assess and characterize the watershed area.
- Estimate 1-in-25 year and 1-in-100 year storm runoff event and determine the potential impact on upstream and downstream flow patterns.
- Define design considerations for development of access roads over water bodies and wetlands in line with Water Act requirements.
- Recommendations.

2 PLANT LOCATION, SITE SPECIFIC DATA & DESIGN CONSIDERATIONS

The SAGD site plant in this study was located approximately 90 km south of the City of Fort McMurray and 35 km northwest of Conklin in Alberta (Figure 1). The Central Processing Facility (CPF) of the site is situated on relatively level to undulating terrain that is gently sloping and draining towards the northwest side of the area. The ground elevations ranged from 730 to 740 m at the northwest and southeast ends of the CPF area, respectively.

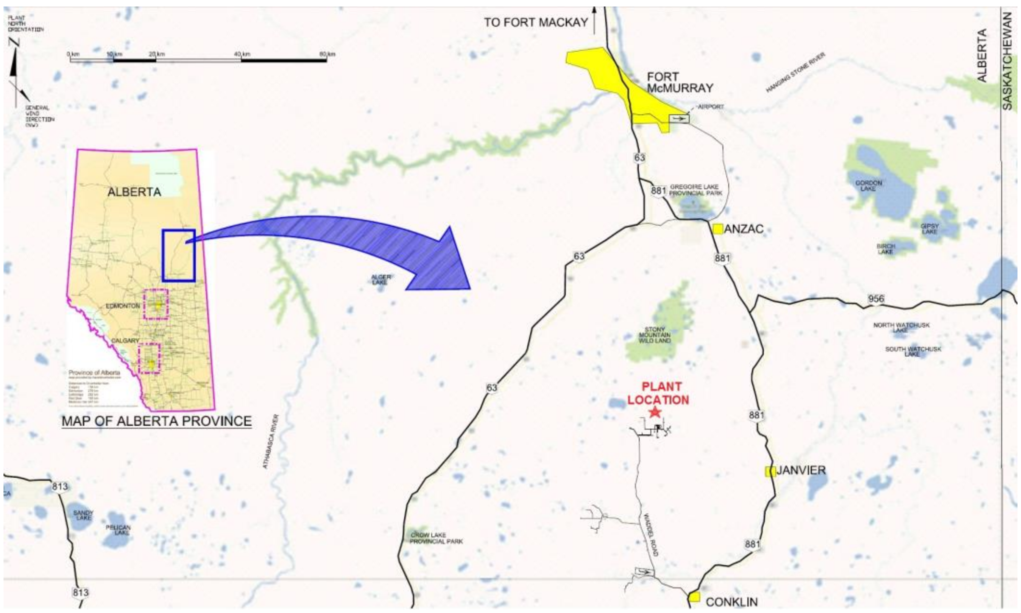


Figure 1: Site location

The site is located in an area of mixed forest, mainly spruce and pine. The soil stratigraphy for the site consists basically of Relative thin muskeg or organic, overlaying compact silty clay with some trace of sand and gravel, overlaying Compact dense clay till. For site preparation and in the initial phases of site preparation all the unsuitable soils from the CPF area will be replaced with a fill containing mainly clay material and then will be soil cemented to prepare the site for vehicle movement and to prevent erosion of bare soil.

The plant contains around 20km of primary and secondary gravel roads for connecting different areas of the plant. The roads will cross some watercourses, wetlands and muskeg areas.

Stormwater conveying system has been designed for 1-in-25 year storm event and was checked for 1-in-100 year storm to ensure headwater will remain within the 300mm from obvert of the culverts and will not flood the roadways. In order to estimate the storm runoff in Rational Method, the average rainfall data from Cold Lake and Fort McMurray Airports, as shown in Table 1, have been used.

Table 1: Cold Lake and Fort McMurray Airports stations rainfall data

Return Period (Years)	Coefficient & Exponent in IDF			
	Cold Lake		Fort McMurray	
	a	b	a	b
25	32.4	-0.701	26.3	-0.657
100	40.9	-0.705	32.8	-0.659

3 THEORETICAL BACKGROUND

Described below is the hydrotechnical design of the plant lease boundary.

3.1 Roads

Roads when crossing wetlands can act like dam on the hydrologic system because the weight of the road compresses the muskeg and the subsurface flow, bringing water to the surface. In designing of roads where crossing wetlands, two aspects have been taken into considerations. The road subgrade has sufficient bearing capacity and can safely support the anticipated vehicular traffic, and water management requirements to ensure properly passing surface and near-surface flows without negative impact on upstream and downstream. Therefore particular attentions were given to reinforcing the subgrade and ensure that the subgrade will not fail.

In this regard the primary and secondary roads were 8 and 6 m wide respectively and were designed for $0.6x10^6$ and $0.5x10^5$ Equivalent Single Axel Loads (ESAL's) and adjusted based on the Average Annual Daily Traffic (AADT), annual traffic growth and percentage of single unit trucks and tractor trailer units. The roads were considered to be gravel paved geogrid reinforced and SpectraPave4-PRO software was used for design. For more details on the software refer to Tensar website.

Minimum depth of fill was considered to be 1.2m over shallow muskeg and 1.5m over deep muskeg to provide bridging. Fill consolidation due to Primary and secondary of muskeg settlement also was taken into account for road footprint and culvert design.

3.2 Stormwater

Rational Method was used to calculate Stormwater generated from the sub-catchment area which is as follows (AEP 1999):

[1] $$Q = 0.00278 \times C_f \times C \times i \times A$$

where: $i = at_c^b$ = average rainfall intensity (mm/hr), t_c= time of concentration (hr), a, b= coefficient and exponent for the IDF curve (for details see Details in Table 1 or Alberta Environment Website) C_f= correction factor of runoff coefficient for different return periods (Table 2), C= weighted runoff coefficient expressing the ratio of rate of runoff to rate of rainfall (dimensionless), A= drainage area (ha) and Q= peak rate of runoff (m^3/s).

Table 2: Correction factor for runoff coefficient for different return periods

Return Period (Year)	Correction Factor for Discharge Coefficient (C_f)	Return Period (Year)	Correction Factor for Discharge Coefficient (C_f)
2-10	1	50	1.2
25	1.1	100	1.25

Note: Product of C_fxC shall not exceed 1.0.

For calculating time of concentration (t_c), the Hathaway equation (1945) has been used, which is as follows:

[2] $$t_c = 0.606 \frac{(n_s L)^{0.467}}{S_s^{0.234}}$$

where: t_c= time of concentration (hr), S_s= average subcatchment ground slope (m/m), L= flow length from the most remote part of the basin as extended from the stream source to the divide (km), n_s= subcatchment roughness coefficient. Table 3 shows the roughness coefficient for different ground cover for use in Hathaway formula.

Table 3: Roughness coefficients for Hathaway formula for overland flow

Ground Cover	Roughness Coefficient (n)	Ground Cover	Roughness Coefficient (n)
Smooth, impervious	0.02	Deciduous timber land	0.60
Smooth, bare packed soil	0.10	Coniferous timber land	0.70
Poor grass, row crops, rough bare soil	0.20	Timber land with deep litter	0.80
Pasture, range land	0.40		

The minimum time of concentration was considered to be 10 minutes. The carrying capacity design of open channels and culverts was calculated using the Manning's Equation as follows (Chow 1959, Chow *et al.* 1988 and Jaska 2000):

[3] $$Q = \frac{A_p}{n} \times R^{2/3} \times S^{1/2}$$

where: A_p= cross-sectional area of flow, at right angles to the direction of the flow (m^2), n= Manning's roughness coefficient (unitless), R= hydraulic radius (m) and S= slope (m/m).

If there is no available vendor data for Manning's roughness coefficients, the Manning's n value from "AISI and CSPI 1996" can be used. It should be noted that the rational method has limitations on drainage areas and while designing, the limitations should be carefully considered.

3.3 Wetland

The criteria described herein is designed to maintain the hydrologic and ecologic function of wetlands and ensure that surface and subsurface water move as if no road was present. The drainage design presented in this section consists of surface culverts and subsurface drainage options.

In all cases, geotextile fabric and geogrid should be placed directly on the wetland surface, prior to construction, to preserve the vegetation layer (muskeg). It is recommended that construction should ideally occur during frozen ground conditions.

General Consideration

- Wetland boundary was determined from aerial photo, LiDAR data and field study.
- Site investigation and classification including aquatic and hydrologic assessment were performed for each wetland prior to crossing design.
- Drainage patterns and flow directions were computed for the wetland areas for the identified crossing sites.

Surface Drainage over Wetlands

The following issues have been considered for surface culverts in wetlands:

- Culverts were over-sized to account for partial blockage by vegetation, beaver activity, sediment or ice.
- The capacity of culverts designed to be sufficient to prevent water to be impounded upstream of the crossings causing wetlands and fens to become oversaturated and also dry out downstream of the road due to reduced subsurface or near-surface flow.
- Corrugated steel pipe with minimum size of 800mm was used.
- The designed culverts can act as surface drainage culvert and as well as equalizer culvert.
- A maximum typical culvert spacing of 100m was considered. However distance between culverts can be calculated based on the wetland drainage area and near surface flow and should not be more than 200 m.
- Culverts should be field fit to maintain the natural dispersed flow patterns within the wetland.
- It is recommended culverts to be installed after initial fill placement over muskeg to allow muskeg primary consolidation happens prior to culvert installation. If the culverts become fully buried after construction due to muskeg settlement, the inlet and outlet of the culverts should be excavated and filled with rock drain to restore conveyance.
- Well vegetated side slopes around the culvert inlets and outlets has been considered to provide adequate erosion protection because of the low flow velocities.
- Culverts may be screened with anti-beaver structures to reduce the potential for blockage due to icing and/or debris.

Subsurface Drainage over Wetlands

- The following issues have been considered for subsurface drainage in wetlands: Rock drain and multiflow pipe were used for subsurface drainage.
- The capacity of the near surface drainage system designed to be sufficient to prevent water to be impounded upstream of the crossing causing wetlands and fens to become oversaturated and also dry out downstream of the road due to reduced subsurface or near-surface flow.
- The average subsurface flow rate can be estimated by applying a mean hydraulic conductivity of 10^{-5} m/s multiplied by the cross-sectional size of the fen.

- Multi-flow piping with the capability of conveying up to 1L/s of flow was used for muskeg depths of up to 1m at a typical spacing of 25m. Horizontal T's, at least 3m wide, was considered to be installed on the upstream side to increase the collection of the subsurface flow.
- Rock drain wrapped in woven geotextile was used for muskeg depths greater than 1m. A spacing of 100/D, where D is equal to the muskeg depth, was considered. To improve flow capacity of rock drain a 150mm perforated drain pipe wrapped in non-woven geotextile was inserted into the rock drain. The pipe was extended out beyond the road fill to maintain a hydraulic connection. The flexibility of the pipe will allow for movement to remain effective during settlement.
- The gradation of the rock drain designed to be between 50mm to 400mm and with the minimum size of the conveying system 700mm wide and 500mm high to facilitate drainage.

4 RESULTS

Typical road cross-section for primary roads to meet above design considerations is shown in Figure 2.

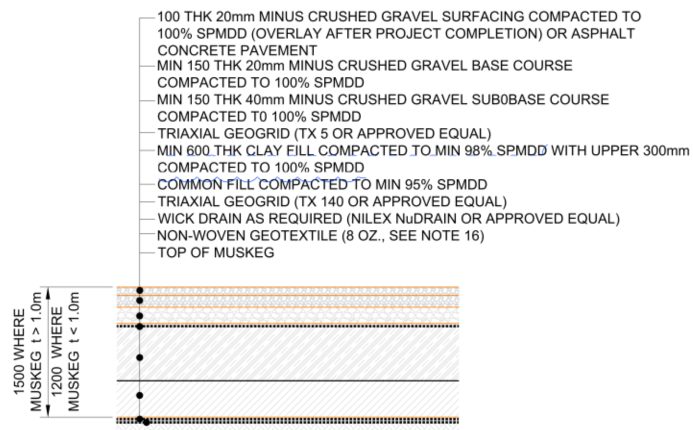


Figure 2: Typical primary road structure design for roads passing a wetland / muskeg area

As mentioned above, rainfall was estimated using long term averages from the Fort McMurray Airport and Cold Lake Airport climate stations. In total 34 sub-catchments were delineated (Figure 3) and the surface flows were estimated using the Rational Method. For sub-catchments greater than 100ha the Soil Conservation Service (SCS) method with the curve number of 80 was also used to compare the results to the Rational Method and to ensure the culverts were properly sized. Table 4 shows the summary of the watershed size and selected culvert size for the study area including the wetlands crossings.

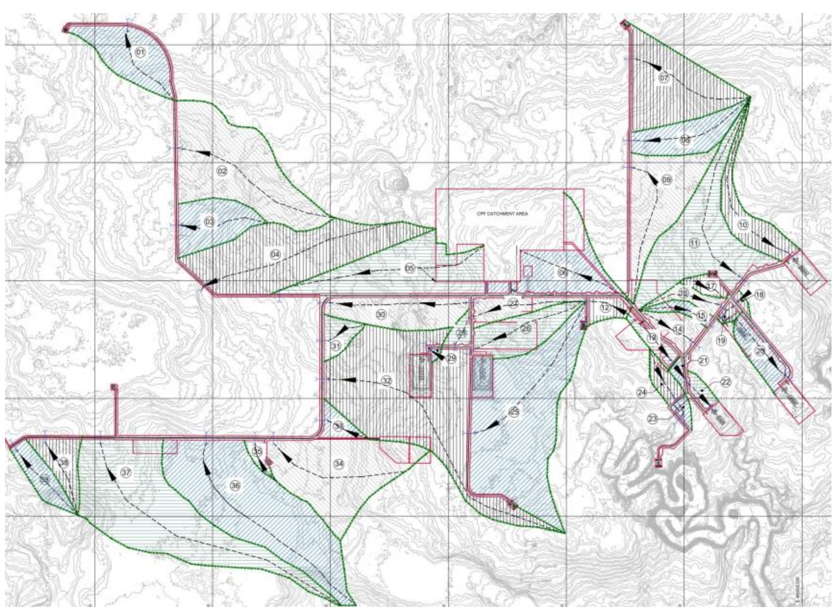


Figure 3: Sub-catchment delineation for the study area

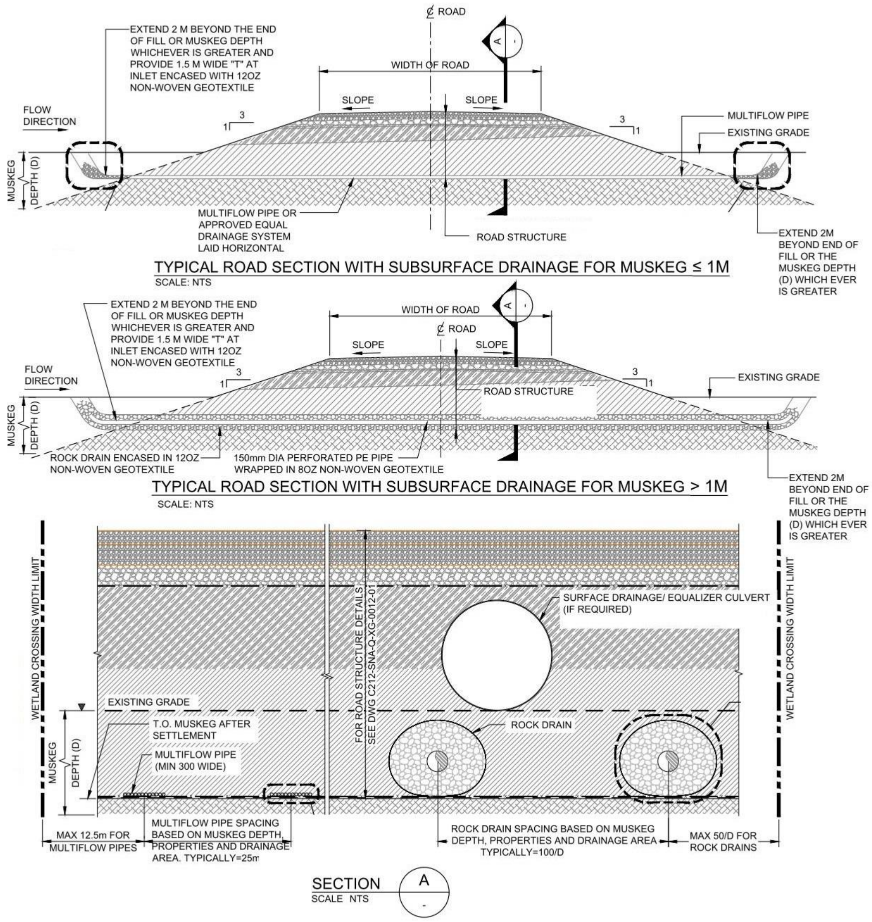
Table 4: Surface water culvert sizes for the study area including the wetland crossings

Watershed #	Indirect Cat. Area	Calc. Culv Size	Number of Culverts	SELECTED CULV SIZE
	ha	m		
1	44.3	0.97	1	1.2
2	127.4	1.03	2	1.2
3	30.2	0.87	1	1.0
4	13.5	0.64	1	0.8
5	85.8	0.90	2	1.0
6	96.6	0.87	2	1.0
7	58.5	0.95	1	1.2
8	10	0.63	1	0.9
9	17.2	0.74	1	0.9
10	14.3	0.68	1	0.8
11	128.3	0.97	2	1.2
12	121.3	1.02	2	1.2
13	79.7	0.87	2	1.0
14	20.4	0.72	1	0.9
15	333.4	1.29	2	1.4
16	37.2	0.86	1	1.0
17	38.9	0.89	1	1.0
18	21.2	0.71	1	0.8
19	28	0.83	1	1.0
20	130.1	1.05	2	1.2
21	11.8	0.60	1	0.8
22	24.8	0.91	1	1.0
23	16.8	0.68	1	0.8
24	8.2	0.59	1	0.8
25	14.4	0.69	1	0.8
26	7.4	0.53	1	0.8
27	9.3	0.56	1	0.8
28	5.9	0.53	1	0.8
29	29.1	0.78	1	0.9
30	3.9	0.44	1	0.8
31	100.4	0.95	2	1.2
32	51.3	0.96	1	1.2
33	28.8	0.81	1	0.9
34	60.8	0.85	2	1.0

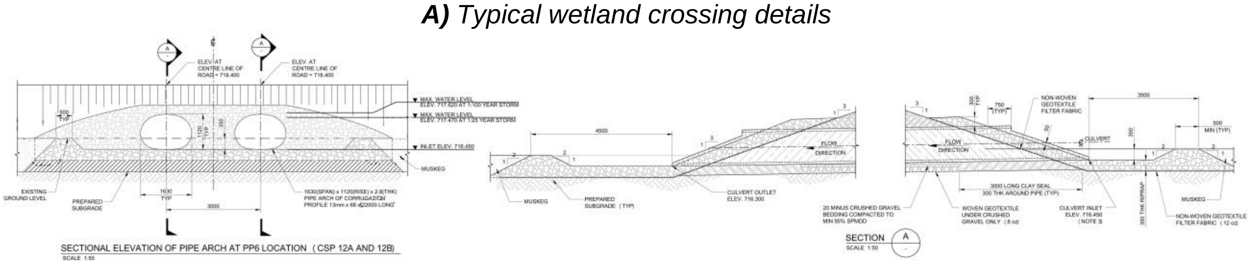
A total of 15 wetland road crossing areas were identified, as described in Section 2 and summarized in Table 4. It was concluded that two (2) locations with the defined bed and banks (PP6 and PP20) require Water Act Approval prior to construction. The remaining undisturbed wetlands do not have defined open water bodies and therefore no regulatory triggers. Table 5 below shows a wetland crossing schedule and the subsurface crossing options. Also Figure 4 shows the typical wetland crossing details for the study area.

Table 5: Wetland crossing schedule

WETLAND CROSSING NUMBER	AVERAGE MUSKEG DEPTH	WETLAND CROSSIGN WIDTH AND STATION ALONG ROAD ON WETLAND		MULTIFLOW PIPES		ROCK DRAINS	
	(mm)	FROM	TO	MAXIMUM SPACING (m)	MINIMUM NUMBER IN WETLAND CROSSING WIDTH (#)	MAXIMUM SPACING (m)	MINIMUM NUMBER IN WETLAND CROSSING WIDTH (#)
PP3	820	0+750.00	0+900.00	25	6	N/A	N/A
PP4	640	2+320.00	2+405.00	25	4	N/A	N/A
	1200	2+405.00	2+475.00	N/A	N/A	83	1
	800	2+475.00	2+550.00	25	3	N/A	N/A
PP6	1640	2+865.99	3+029.00	N/A	N/A	60	3
	1640	3+029.00	3+090.00	N/A	N/A	60	2
	750	3+090.00	3+567.00	25	20	N/A	N/A
PP7	1360	4+186.65	4+446.47	N/A	N/A	73	4
	1360	4+446.47	4+967.00	N/A	N/A	73	8
PP11	780	1+030.00	1+180.00	25	6	N/A	N/A
PP8	3200	0+400.00	0+760.00	N/A	N/A	31	12
PP9	3200	0+760.00	0+850.00	N/A	N/A	31	3
	2450	0+850.00	1+000.00	N/A	N/A	40	4
PP10	1050	1+000.00	1+225.00	N/A	N/A	95	3
	1800	1+440.00	1+470.00	N/A	N/A	55	1
PP5	800	0+000.00	0+120.00	25	5	N/A	N/A
PP2	650	0+480.00	0+600.00	25	5	N/A	N/A
PP1	650	1+300.00	1+410.00	25	5	N/A	N/A
PP18	650	1+720.00	1+960.00	25	10	N/A	N/A
PP19	2200	2+640.00	2+960.00	N/A	N/A	45	8
PP20	No Data*	4+050.00	4+485.00	25	18	N/A	N/A
PP14	480	1+075.00	1+180.00	25	5	N/A	N/A



A) *Typical wetland crossing details*



B) *Wetland crossing details at PP6*

Figure 4: Typical wetland crossing details for the study area

5 RECOMMENDATION

The challenges involved in the design for this particular SAGD site, are presented here continued with some recommendations to help overcome these challenges:

5.1 Road

Good road construction practices should include adequate provisions for drainage and well-designed road will not interfere with the hydrology of a site; roads should be designed to allow water to move as if no road was present (South Carolina Forestry Commission 2011).

Location tools

During the initial planning stages the use of tools such as the following can help minimize the number of stream or wetland crossings (Decker 2003): wetland maps (where available), topographic maps, forest cover maps, aerial photographs, digital photography, bedrock and surficial geology maps, LiDAR (light detection and ranging is an optical remote sensing technology), flow predictions using a road engineering software package, channel assessments, Google Earth, and fish inventory information. These tools can also be used to avoid wetland crossing or locate the shortest route across a wetland. Other factors are: (1) realizing the position of the proposed road within a catchment, and (2) understanding whether the road is located in a localized wetland basin/complex or in an interconnected wetland complex.

It is widely suggested to construct fill roads (where fill is delivered and built up) in forested wetlands only when alternative access routes do not exist. This is especially important in wetlands with flowing water (i.e., fens) because fill roads have the potential to hinder or restrict natural flow patterns; roads constructed at natural ground level have less potential to restrict flowing water (Mississippi Forestry Commission 2008). Culverts, bridges, or other means of conveying water through the road must be used to prevent any restriction of water movement. The sizing and spacing of culverts and bridges need to be planned with high-flow events in mind, which may happen only periodically. Properly planned and constructed temporary roads will have fewer effects on the hydrology of forested wetlands than permanent roads (Baker 1991).

Avoiding wetlands
Avoiding the construction of resource roads in boreal wetlands wherever possible is something that was well supported by the literature too. Cox and Cullington (2009) suggest that the construction of roads through wetlands should be avoided unless there is no reasonable alternative; building roads in or near wetlands is difficult and expensive. Road managers often avoid wetlands by planning longer roads that circumvent these sites (Légère and Blond 2002). Special attention should be paid to identifying wetland locations, types, and sensitivities prior to beginning road construction operations. The incentive to build resource a road across a wetland arises when the distance associated with avoiding the wetland becomes too great. In various locations in Canada, avoiding wetlands all together is not a realistic option due to the vastness of the wetlands on the landscape. Given that resource roads are necessary, negative impacts can be minimized through the use of properly utilized BMPs (Graf 2009).

Winter construction
If a wetland is planned to be crossed it is beneficial to construct the road during frozen conditions (Illinois Department of Forest Resources 2000). Frozen ground offers a greater bearing capacity, and there are well-known techniques for promoting early and deep freezing of the soils. Snow will often be cleared away to remove any insulating effect, and tracked machines will be walked along the road to help drive in the frost. Many road-building practitioners believe that during frozen conditions the wetland is not overly affected and that during non-frozen periods the subsurface flows should function as intended. Although this is a common prediction, road builders have some uncertainties and questions regarding the actual effects of building frozen roads on surface and subsurface flows during non-frozen periods.

5.2 Surface Water Management Planning
Water management can have a range of effects depending on the extent and intensity of the works; widespread drainage measures are likely to have less significant effects than concentrated systems (Sheehy 1993). Development of access roads in boreal wetlands has taken on a dual focus such that the need to establish a road must be fulfilled, but only while addressing water management requirements, and thus the characteristics of a wetland require careful attention which may result in modifications to traditional forestry operational approaches.

Surface drainage considerations
It is unclear if many corduroyed sections of road are attempting to also promote water flow or if they are attempting to address only the traditional bearing capacity improvements. The opportunities to use this technique to promote water flow need to be explored further. Because of voids left between logs and the lineal nature of a log, this construction technique could be the starting point for an improved method of addressing both bearing and hydrologic function of a wetland. Given that corduroy should be laid parallel to the direction of flow to promote drainage, understanding wetland function and the direction of flow is critical to the success of the design (Forestry Corp 2004).

Subsurface drainage considerations
In areas of low topographic relief, it can be difficult to know which way the water flows; however, it is imperative to plan for water movement and not impede flows in order to prevent negative impacts to the wetland function (Ducks Unlimited Canada and University of Alberta 2006). The planning of a crossing should also take into account that wetland hydrology can occur laterally and/or vertically.

Cox and Cullington (2009) in British Columbia have suggested that subsurface drainage structures be built with large, clean gravel or crushed rock placed on top of geotextile fabric to allow unrestricted water movement from one side of the road to the other. The use of geotextile may provide additional bearing capacity to help support the gravel and keep it from sinking. The design of this technique can also include a second layer of geotextile at the top of the aggregate mattress to act as a separation layer and to prevent road surface material from migrating into the seam designed for water movement. The lower level of geotextile can be positioned on undisturbed vegetation.

5.3 Monitoring & Maintenance

Drainage patterns disturbed during construction should be inspected to confirm that riparian vegetation and stable drainage conditions have been re-established. Regraded areas should be inspected for evidence of erosion or instability, and repaired or stabilized as required. Revegetation efforts should be monitored and maintained to ensure growth and survival.

Replanting will be required if survival of vegetation is inadequate. Monitoring and maintenance will be an integral part of the Corner's operations.

6 SUMMARY AND CONCLUSIONS

The construction of access roads through wetlands can create numerous environmental and operational challenges for road owners. Understanding and promoting good water management techniques for access roads in wetlands may help address many of these challenges.

The design strategies invoked to meet the regulatory requirements faced by a SAGD project in northern Alberta were described. It is recommended that that a well-designed road and a good road construction practices should include adequate provisions for drainage to prevent or minimize interfere with the hydrology of a site and the potential effects on wetland ecosystems. A good practice when crossing a wetland and/or water course can be summarized as follows:

Watercourse

Culverts for wetland and watercourse crossings shall meet the requirement of Alberta Government Water Act - Code of Practice for Watercourse Crossing.

If watercourse crossing is over a water body with fisheries potential, design considerations to promote fish passage and reduce impacts to fish during construction (bridge or culvert) shall be included. Design considerations may include slope, depth, minimum embedment and velocity mitigation (e.g., baffles, widths) to promote fish passage.

Detail survey shall be provided for all watercourses to determine bottom and banks at least 50m upstream and downstream of the crossing. Watercourse natural slope shall be specified on survey drawings. Wetland boundary shall be determined from aerial photo, LiDAR data and field study.

Minimum gradient of culverts for watercourse crossings shall meet existing slope of the watercourse.

In case of realignment of a water course to suit crossing, the length of channel should be less than 20m unless authorization is provided under Water Act. The slope of channel realignment shall be less than or equal to watercourse slope at the crossing. The channel realignment shall be protected with erosion and sediment control measures.

Construction of watercourse crossings subject to Water Act approval or Code of Practice notification shall be done outside of the restricted activity period.

During construction of watercourse crossing, monitoring with a qualified wetland aquatic environmental specialist (QWAES) and/or fisheries monitor will be required.

Wetland

Site investigation and classification including aquatic and hydrologic assessment shall be performed for each wetland prior to crossing design.

Drainage patterns and flow directions shall be computed for the wetland areas for the identified crossing sites. Subsurface and near-surface drainage system shall be adequately designed for each wetland to keep the hydrologic regime of the wetland and fens systems.

The capacity of the culvert and near surface drainage system shall be sufficient to prevent water to be impounded upstream of the crossing causing wetlands and fens to become oversaturated and also dry out downstream of the road due to reduced subsurface or near-surface flow.

Due to subsurface and near surface flow in wetland area, culvert and/or subsurface drainage system shall be provided when roads crossing wetlands. Distance between equalizer culverts shall be calculated based on the wetland drainage area and near surface flow and shall not be more than 200m.

Rock drain and multiflow pipe can be used for subsurface drainage. The average subsurface flow rate can be estimated by applying a mean hydraulic conductivity of 10^{-5} m/s multiplied by the cross-sectional size of the fen. Distance between subsurface drains shall be calculated based on the wetland drainage area and depth of muskeg and shall not be more than 100m.

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