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1. PROJECT INFORMATION:

Project Title:	**Alternative Road Construction to Reduce Peatland Water Flow Obstruction: CNRL Pad TT Road**
Alberta Innovates Project Number:	G2019000341
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AI Project Advisor:	Dallas Johnson

2. APPLICANT INFORMATION:

Applicant (Organization):	Circle T Consulting, Inc.
Address:	P.O. Box 339, Vegreville, AB, T9C 1R3
Applicant Representative Name:	Terry Osko
Title:	Principal, Senior Environmental Scientist
Phone Number:	780-632-3387
Email:	terryosko@circletconsulting.ca

3. PROJECT PARTNERS

The financial, logistical, and technical contributions of project partners is gratefully acknowledged. The project is sponsored by iFROG, a group of nine collaborating in situ oil sands companies (Athabasca Oil Sands, Canadian Natural Resources Limited, Cenovus Energy, CNOOC Petroleum North America, ConocoPhillips Canada, Greenfire Energy, Harvest Energy, Imperial Oil, MEG Energy). The group's purpose is to develop, fund, and implement a balanced portfolio of wetlands research projects, based on the fundamental guiding principles of Land Stewardship, Research Intelligently, and Collaboration, that demonstrates iFROG members are meeting the intent of wetland research conditions within their respective AEPEA approvals. iFROG provides funding and an organizational umbrella for this project among other in situ reclamation and construction related research efforts.

As a member of iFROG and host of the research site, Canadian Natural Resources Limited (CNRL) is the primary champion of this project, contributing the study site, logistical support, and additional in-kind services.

Scott Ketcheson of Athabasca University graciously provided technical assistance.

A. EXECUTIVE SUMMARY

Alberta in situ oil sands operations occur in an environment where at least 50% of the land is wetland, primarily peatlands. Roads constructed on peatlands pose environmental and economic risks because damming of surface and subsurface water by roads cause flooding and drying of peatlands leading to undesirable ecological changes, increased greenhouse gas emissions, and increased road maintenance requirements. The primary objectives of this study were to 1) assess the effectiveness of increased drainage conduits of various types, as well as timber corduroy as a road foundation, in improving road drainage; and 2) compare the relative effectiveness of conduit types and corduroy in facilitating drainage. A recently constructed road that intersected several areas of deep fen peat was used as a study area. Road construction incorporated timber corduroy as road foundation in the peat sections, as well as multiple closely spaced (~ 13-19 m) conduits including culverts, log bundles, and HDPE pipe bundles. Although the road was still a barrier to water flow, particularly subsurface water, corduroy and conduits improved road permeability and achieved better water balance than typically observed with conventional construction. Corduroy alone was less effective in improving road permeability to water flow than it was with the addition of other conduits. Conduits performed similarly, but log bundles were less effective than culverts or pipe bundles. Nevertheless, all conduits could be useful depending on the specific hydrologic conditions, rod design, and conduit design. Improving preconstruction assessment of peatland hydrology to include water storage and subsurface flows would better inform choices of type, number, size, and depth of conduits to reduce water flow impediment, such as larger diameter culverts, stacked culverts or culvert pyramids, larger pipe and/or log bundles, additional log layers in the corduroy, or rock fill foundations. The project improved understanding of road, conduit, and hydrologic interactions to enable better-informed prescriptions for road construction. Industry will have a broader range of choices for selection and design of drainage systems for peatland roads resulting in reduced greenhouse gas emissions, reduced habitat fragmentation, and reduced habitat alteration or loss.

B. INTRODUCTION

Sector Introduction

Alberta in situ oil sands operations occur in an environment where at least 50% of the land is wetland, primarily peatlands. In situ oil sands infrastructure includes numerous roads required to develop drilling pads, haul equipment, and provide access for service and maintenance of operations. Soft peatland soils provide a poor and unstable foundation for roads. Excessive road settlement, peat displacement, and road failure are common risks. Furthermore, prescribed culvert placement often insufficiently accommodates water movement from one side of roads to the other. Together, these factors can lead to peatland damage, altered hydrologic environments, and ecological perturbations. These effects lead to greater habitat fragmentation than expected from the mere presence of roads. Alternate foundation materials or construction practices that can mitigate these factors are desirable. Additional or alternative conduits may be required to adequately move water across roads. Devon Canada (now CNRL) constructed a road (Pad TT Road) that intersects areas of soft peatland soils incorporating the following features to mitigate issues of poor road foundation and impeded drainage:

a) Timber-log corduroy as a road foundation in the soft peat sections.

b) Increased number of culverts through soft peat sections to increase drainage capacity.

c) Placement of two additional types of conduits (log bundles, HDPE pipe bundles) among the steel pipe culverts to enhance drainage. The corduroy foundation used within the soft peat sections may also afford additional drainage capacity.

Knowledge Gaps

None of the practices deployed in construction of the road is new technology, but the number and placement of drainage structures is unconventional and aimed at superior performance in terms of minimizing hydrologic disruption. Conventional culvert prescriptions are based on surface runoff models, which do not account for water storage within peatlands and the interaction between surface and subsurface volumes. Increasing the number, type, and frequency of drainage conduits within peat sections of the Pad TT Road was an attempt to improve drainage by addressing the unknowns of peatland storage and surface-subsurface interactions. While drainage across the road appears to be less impeded than conventionally constructed roads, how each of the conduit types and their placement depths contribute to improved flow was unknown. Specifically, the following knowledge gaps were addressed:

1) Does the road influence subsurface flow (i.e. cause upwelling of subsurface water), which can potentially affect greenhouse gas emissions?

2) What is the relative effectiveness of each of the conduit types and corduroy in moving water through the road?

It is not possible to generate meaningful future prescriptions for drainage structures in other peatland settings without addressing these questions. Characterizing vertical and horizontal flow patterns within the peat and through the drainage structures will better inform future prescriptions, thereby ensuring effective drainage is achieved at least cost.

C. PROJECT DESCRIPTION

This project was an incremental step to developing the understanding required for better road drainage prescriptions. The knowledge generated from this project is intended to serve energy, forestry, and any other industry that builds roads in boreal wetlands. There is no commercial market for the knowledge generated, but collectively, industry operators can potentially benefit from millions of dollars in reduced road maintenance costs and reduced environmental liabilities.

The outcomes of this project support the top two priorities within the “Wetland Mitigation Hierarchy” described in Alberta’s Wetland policy; namely, avoidance and minimization. The project examines alternative road construction practices aimed at minimizing, if not avoiding, negative hydrologic impacts associated with resource roads constructed within wetlands. The project will assess practices used on a specific road, providing information and recommendations for future road prescriptions, as well as setting the stage for future assessment of enhanced practices. Contributing to road construction practices that avoid or minimize the hydrologic impacts of resource roads constructed in wetlands, this project will help to prevent or minimize ecological perturbations and thereby maintain biodiversity within Alberta’s peatland ecosystems, reduce future reclamation liabilities, and reduce greenhouse gas emissions associated with raised water tables in peatlands.

Objectives:

a) Assess road performance in the corduroy sections as indicated by progressive road settlement over time and identify any problem areas.

b) Assess the effectiveness of the construction method in facilitating water movement from one side of the road to the other.

c) Understand how the road affects surface and subsurface flows, as well as how each conduit type contributes to mitigation, in order to refine future road prescriptions. For example, such knowledge can inform selection of culvert size, number, and placement depth to address specific hydrologic conditions of a given site, rather than applying blanket prescriptions.

D. METHODOLOGY

Site Description

The road is located at the CNRL Jackfish 2 in situ oil sands project located about 16 km southeast of Conklin, AB. The road was constructed during winter 2017/18 between an operational in situ well pad (Pad QQ) and a newly constructed pad (Pad TT). The road is approximately 1.5 km long, traversing three areas of deep fen peat extending approximately 180 m of road length (Figure 1). Corduroy, consisting of two layers of logs topped with mineral fill was used as the road foundation over the fen sections (Figure 2), within which drainage conduits were placed at short spacing. Three to four 600 mm diameter culverts were placed within each of the fen sections at spacing of 22 to 35 m (Figure 3). Additional conduits comprised of bundles of either corduroy log or surplus HDPE pipe liners (approx. 15 cm O.D, 10 cm I.D.), were placed at equal spacing among the culverts (Figure 4), although both bundle types were not installed at each corduroy section. Three log bundles were installed at one section, two pipe bundles and one log bundle were installed on the second section, and one pipe bundle was installed in the third section (Figure 3 caption).

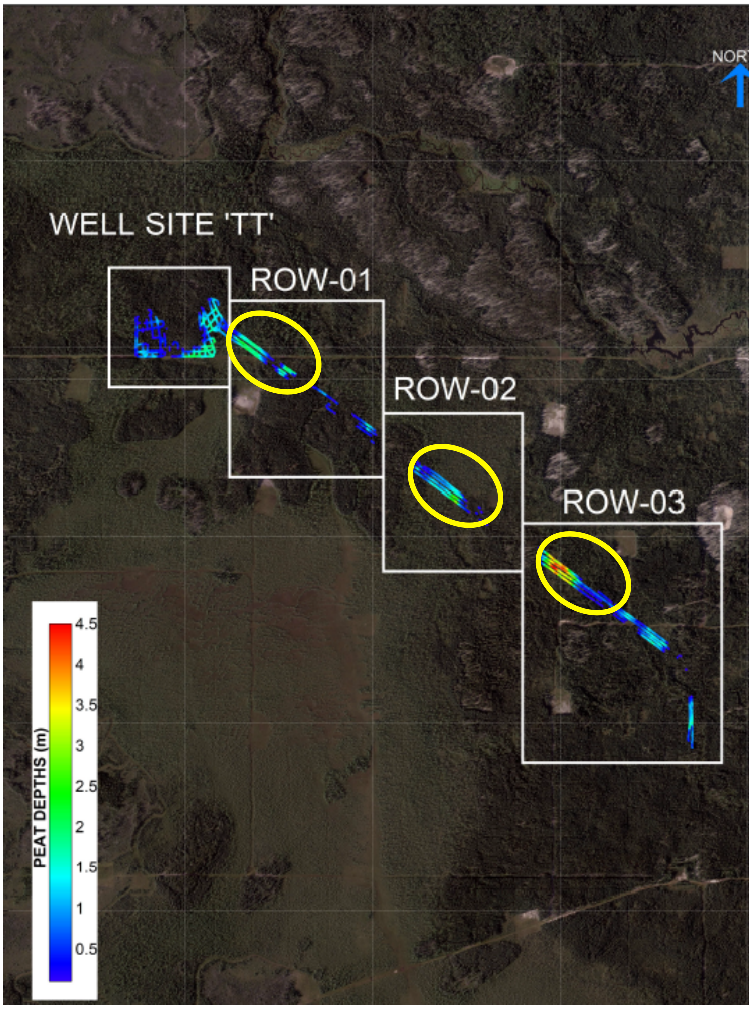


Figure 1. Peat depth map generated from ground penetrating radar survey of the road right-of-way prior to construction. The yellow ellipses indicate areas of deeper peat targeted for use of corduroy.

Figure 2. Left: Corduroy placed on fabric liner over deep peat section. Mineral fill was later placed over the logs. Right: Mineral fill placed on fabric liner over shallower peat.

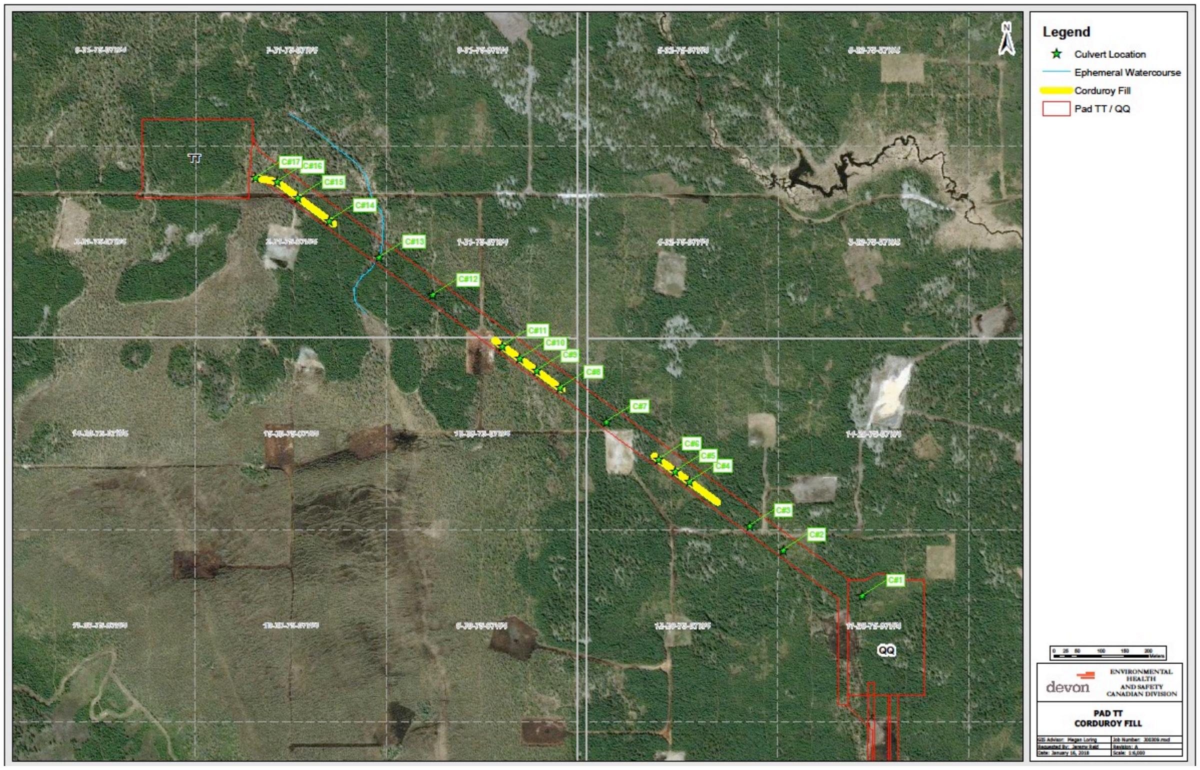


Figure 3. Overview of Pad TT. Corduroy placement locations are indicated in yellow. Culvert locations are numbered C#1 to C#17. Log bundles were placed before C#4 and between C#4 and C#5, C#5 and C#6, and C#10 and C#11. HDPE bundles were placed between C#8 and C#9, C#9 and C#10, and C#15 and C#16.

Figure 4. Left: Pre-embedded solid steel culvert covered with mineral fill and abutted with logs. Centre: HDPE pipe bundle being installed among corduroy logs. Right: Log bundle wrapped in a geotextile placed among corduroy logs.

Road and Drainage Conduit Survey

A Global Navigation Satellite System (GNSS), including base station and rover was used to survey sections of the road, right-of-way (ROW), and drainage conduits. The survey was referenced to an initial surveyed location or "field monument" with known geographic coordinates and elevation in meters above sea level (masl). The field monument is marked for use as a reference location for future surveys of road and conduit elevations.

Four different types of surveys were completed:

1) Drainage conduit end to end transects, completed from one end of the structure over the road to the other end.
2) Drainage conduit end point elevations, recording single point elevations at each end of the structure.
3) Corduroy section transects, with elevations recorded from one edge of the right-of-way (ROW) to the other across and over the road.
4) A survey along approximately three lengths or road, ranging from approximately 102 m to 180 m in length, down the centre line over the three corduroy sections.

All survey locations other than the three centre-line surveys were referenced to either a culvert number or to the nearest culvert number(s). Transect elevations were recorded at 2-m intervals using a 50-m appraiser's measuring tape to measure the distance between intervals, except for the road running surface survey, where elevations were recorded at a 2-pace interval, simulating the 2-m interval of the other surveys. Transects were oriented from the downstream side to upstream side.

General Water Table Observations

Five transects of water table elevation monitoring wells intersecting the road perpendicularly at key locations along its length were established in early August 2018. (Figure 5). Three transect locations coincided with locations where corduroy was used for road foundation, while two transects were located where peat was at least 1 m deep but no corduroy was used in road construction. Transects consisted of three wells on each side of the road (5 transects with 3 wells upstream and 3 wells downstream for a total of 30 wells – Figure 6). Wells were spaced 15 m, 30 m and 45 m from the road embankment edge (25 m, 40 m, and 55 m from road centre) within each transect. The ground elevation at each well was surveyed using the same GNSS as used for the road survey and length of well stand above the ground surface was measured at the same location. Water table depth measurements were completed in early August and late September in 2018. Measurements were completed in late May, June, July, and mid-October in 2019. COVID-19 restrictions limited measurements to a single event in early October of 2020. Water table depths were recorded once per month from June through October in 2021. Construction activity limited water table measurements to late June, July, and October in 2022. Water table elevations in meters above sea level (masl) were plotted with ground elevations at each well to compare water table elevations on either side of the road. Depths to water table from the ground surface were tabulated for comparisons between wells from each distance on each side of the road.

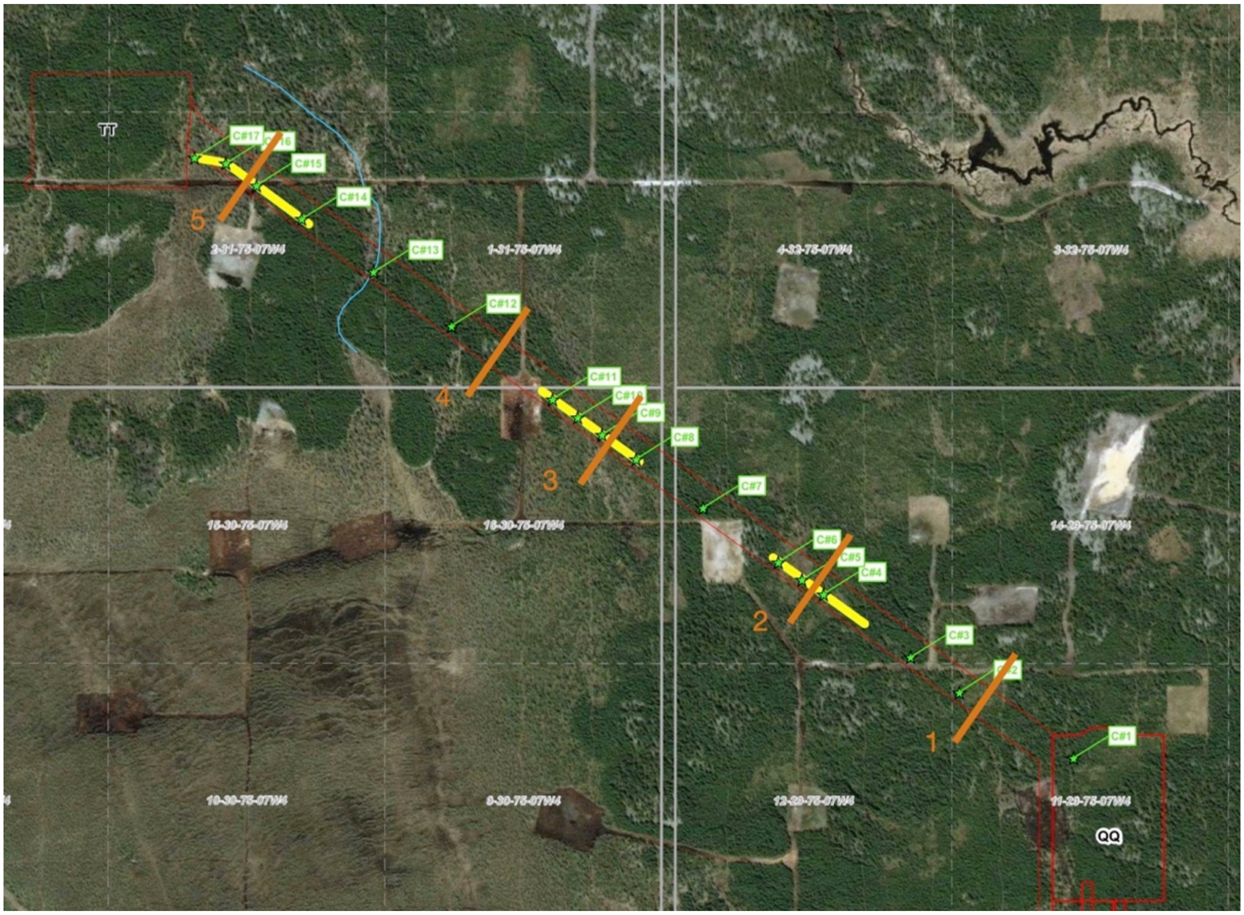


Figure 5. Approximate location of water well transects along Pad TT road.

Figure 6. Example of water well placement in original transects established in 2018. Wells were placed 15, 30, and 45 m from each edge of the road. Water flow is from southwest to northeast. Image is of Transect 3 area shown in Figure 5 above.

Assessment of Relative Conduit Performance

The middle corduroy section was selected as the test area to examine hydrologic responses associated with the specific drainage conduits because that section included both pipe and log bundles. Water well transects were installed directly in front of the inlet and outlet of each conduit type (culvert, pipe bundle, log bundle) at distances of 1 m, 5 m, and 15 m from the road edge on June 2, 2021 (Figure 7). One transect was also installed in the space between a culvert and pipe bundle with wells similarly spaced from the upstream and downstream road edges to measure hydrologic responses associated with corduroy only. This transect incorporated the 15 m well from the well transect installed in 2018. In addition, wells were installed at 1 m and 5 m distance from respective road edges along the transect within one of the sections one of the non-corduroy transect areas to establish a control. However, peat in this section was thinner near the road than it was more distant from the road where the initial wells were located. Therefore, the control was established at the other non-corduroy transect location, but not until July 13.

Two piezometers were also installed at the 5 m from road edge distance for each of the newly established transects, approximately 1 m on either side of the at that location (Figure 7). Slotting depths were selected to target the middle and near bottom of the peat profile. Since peat depth was generally 1.8 to 2 m, slotting depths were 85 cm for the middle and 155 cm for the bottom piezometer at each location. The water intake length of each piezometer was 20 cm, centred 10 cm above and below the target depth.

Water level loggers were installed in the 5 m wells to automatically record water levels every 30 minutes. Water levels were manually measured for each well and piezometer on the same dates as the other wells on site.

Water levels in all wells were used to calculate site average water table elevation for each manual measurement date. Water levels in 5 m wells were used to compare depth to water table (DTW) between sides of the road for conduits, corduroy, and control transects. Water levels at these wells and the piezometers were used to compare hydraulic gradients across the road among conduits, corduroy and control. Piezometer data were also used to calculate the vertical hydraulic gradient at each 5 m well location to assess vertical water movement (upwelling, discharge or recharge) on each side of the road. Slug tests were completed on October 21, 2022 to calculate hydraulic conductivity at each piezometer. Finally, daily average DTW was calculated from water level logger data to compare fluctuation patterns between sides of the road for conduits, corduroy, and control.

Figure 7. Layout of well and piezometer transects for conduit performance assessment. Wells were placed at 1, 5, and 15 m from each edge of the road immediately in front of a culvert, log bundle, and pipe bundle. Piezometers were installed approximately 1 m on either side of the well at 5 m from road edge. The southeast-most transect incorporated the original well transect established in 2018 and was situated between a pipe bundle and culvert.

E. PROJECT RESULTS

Water Flow and Vertical Movement Assessment Protocol

The use of chemical tracers was originally proposed for assessing vertical movement of water and comparing relative flows among conduits. However, an alternative protocol was used, relying on piezometers placed at specific depths, as well as continuous water level loggers to enable remote capture of hydrologic changes, thus reducing time and labour associated with chemical tracers. The alternate protocol produced good results, but equipment failures in 2021 and premature removal loggers due to construction activity in the road vicinity in 2022 limited water level logger data. Nonetheless, sufficient data was recorded to effectively assess water movements and relative conduit performance.

Supplemental Water Table Measurements

Supplemental water measurements recorded in 2020, 2021, and 2022 supported measurements recorded in years prior to this project, confirming observations of general effectiveness of the drainage design in moving water across the road, albeit imperfectly and variable among transect locations. Furthermore, the supplemental measurements were useful for calculating site average water table conditions to characterize general moisture patterns.

Road and Conduit Elevation Surveys

Road and conduit elevation surveys were successfully completed and compared to initial surveys completed during the late summer after initial construction. Most road settling had occurred during the first year, with little additional settling observed during the subsequent survey, indicating that settlement may be approaching equilibrium. However, there was additional movement of some culverts between the initial and subsequent surveys. While distortion of a number of culverts occurred due to road settling (Figure 8), as is common on roads constructed in peatland, they continued to move water from the upstream to downstream sides of the road.

Figure 8. Example of culvert distortion, causing upward deflection of the outlet. Such distortion is common with peatland roads. Corrugated steel culverts are more prone to distortion than steel pipe, like the one pictured.

Key Results

Vertical Water Movements

Hydraulic head was typically greater at the 85 cm piezometer slotting depth than the 155 cm depth on the upstream side of the road, indicating a downward gradient, or recharge (Table 1). Hydraulic head was typically greater at the 155 cm depth than the 85 cm depth on the downstream side of the road, indicating and upward gradient, or discharge. However, there was considerable variation among the conduits, corduroy, and control. The upstream piezometers of the control transect indicated a downward gradient on most measurement dates, but the gradient was not very steep. Gradients were downward on the downstream side of the road on average, but were mixed between upward and downward and were quite weak. Gradients were equally split upward and downward on the upstream side of the corduroy transect, with no real pattern in response to general water table conditions. On the other hand, the hydraulic gradient was upward during each measurement date on the downstream side of the corduroy transect and the gradients were generally steeper than the gradients on the upstream side, possibly indicating flow beneath the road from the upstream to downstream side via pore space among the corduroy logs. Gradients on the upstream side of the culvert transect were downward on half of the measurement dates and were weak. Gradients were stronger on the downstream side of the culvert transect and were predominantly upward. The hydraulic gradient was downward on all measurement dates on the upstream side of the pipe bundle transect. The gradients were generally weak, but were steeper during lower water table events. Gradients on the downstream side were generally upward and were somewhat stronger than on the upstream side. Gradients on the upstream side of the log bundle transect were predominantly upward, varied greatly in steepness, and had no distinct pattern in response to general water table. On the other hand, the gradients on the downstream side were very weak and almost evenly split between upward and downward. Somewhat shallower peat in the area of the log bundle transect compared to other transects may have had more influence on vertical water movements on the upstream side than occurred on the upstream side of other transects.

Table 1. Vertical hydraulic gradients between piezometers at 85 and 155 cm depths on each side of the road. Positive values indicate water recharge, or a downward gradient (more water pressure above than below). Negative values indicate water discharge, or a upward gradient (more water pressure below than above).

	Hydraulic Gradient (m/m)									
	T1 (Control)		T3 Corduroy		T3 Culvert		T3 HDPE Bundle		T3 Log Bundle	
Date	**Upstream**	**Downstream**	**Upstream**	**Downstream**	**Upstream**	**Downstream**	**Upstream**	**Downstream**	**Upstream**	**Downstream**
04-Jun-21	n/a	n/a	0.017	n/a	0.051	n/a	n/a	n/a	n/a	n/a
13-Jul-21	n/a	n/a	0.062	-0.158	0.037	0.028	0.020	n/a	n/a	0.017
16-Aug-21	0.015	0.007	-0.059	-0.018	-0.062	-0.030	0.020	0.073	0.029	0.017
13-Sep-21	-0.015	0.033	-0.029	-0.043	0.037	-0.248	0.033	-0.065	-0.123	0.059
14-Oct-21	0.015	0.033	0.047	-0.069	-0.020	-0.219	0.046	-0.092	-0.207	0.003
31-May-22	0.062	-0.007	-0.041	-0.107	-0.006	-0.219	0.033	-0.051	-0.054	-0.011
30-Jun-22	0.046	-0.007	-0.069	-0.145	-0.020	-0.190	0.033	-0.037	-0.040	-0.011
20-Oct-22	0.031	0.007	0.086	-0.069	0.008	-0.030	0.033	0.059	-0.207	-0.011
Average	0.026	0.011	0.002	-0.087	0.003	-0.130	0.031	-0.019	-0.100	0.009

Depth to Water Table (DTW)

DTW was almost always greater on the downstream side of the road than the upstream side for all conduit, corduroy, and control transects (Figures 9 to 13). The across road difference was always greatest at the control transect. The water table was above the ground surface on the upstream side of the control transect during the highest site average water table events from early to late June (Figure 9). DTW ranged from 18 to 20 cm deeper on the downstream side than upstream side at the control transect in 2021 and was generally 10 cm deeper in 2022. On the other hand, DTW was 1 to 4 cm deeper on the downstream side than upstream for corduroy, culvert, and pipe bundle transects in 2021 and 7 to 8 cm deeper in 2022 (Figures 10 to 12). DTW was 3-8 cm deeper on the downstream side than upstream for the log bundle transect in 2021 and 9 cm deeper in 2022 (Figure 13).

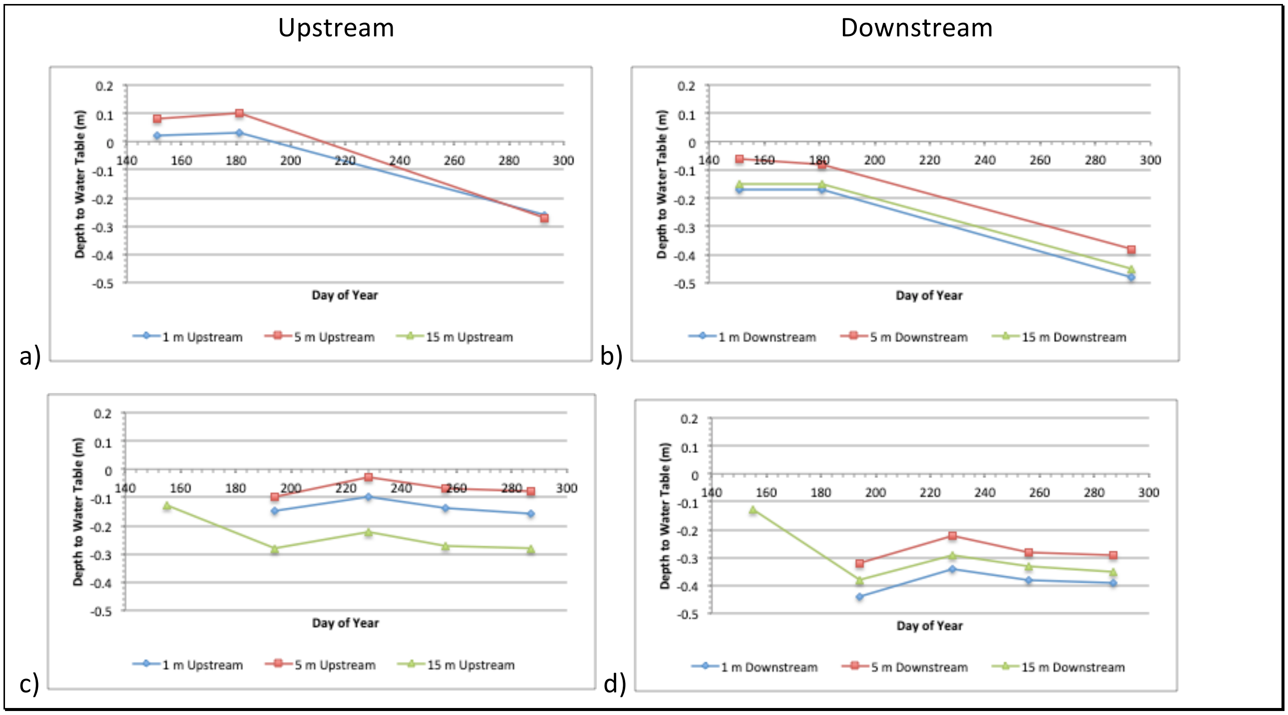


Figure 9. Control transect depth to water table recorded manually at wells 1 m, 5 m, and 15 m from road edge in 2022 ('a' and 'b') and 2021 ('c' and 'd').

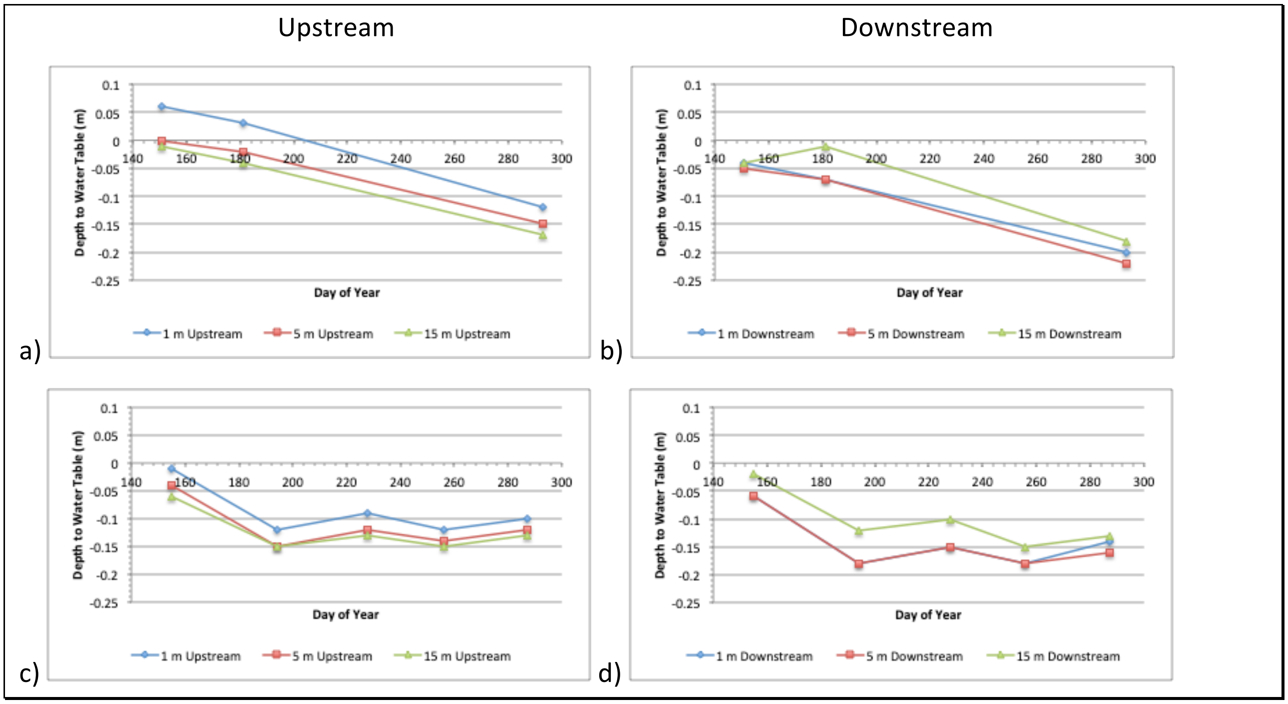


Figure 10. Corduroy transect depth to water table recorded manually at wells 1 m, 5 m, and 15 m from road edge in 2022 ('a' and 'b') and 2021 ('c' and 'd').

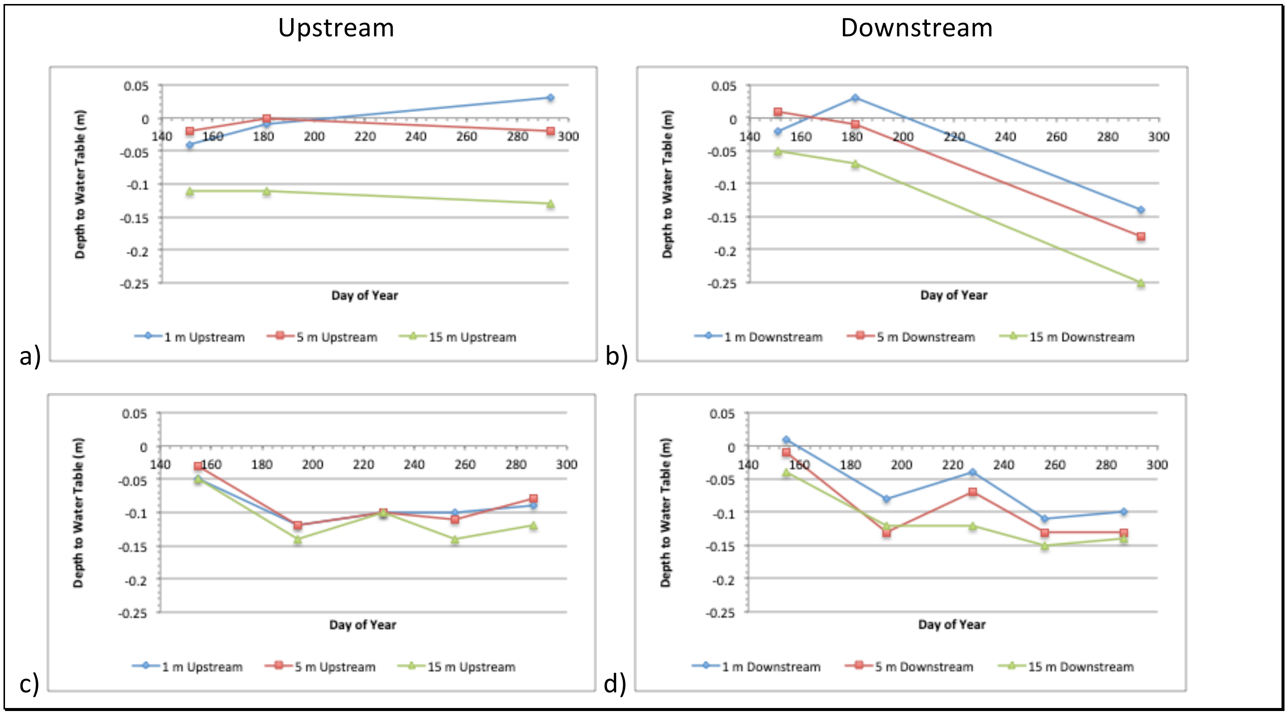


Figure 11. Culvert transect depth to water table recorded manually at wells 1 m, 5 m, and 15 m from road edge in 2022 ('a' and 'b') and 2021 ('c' and 'd').

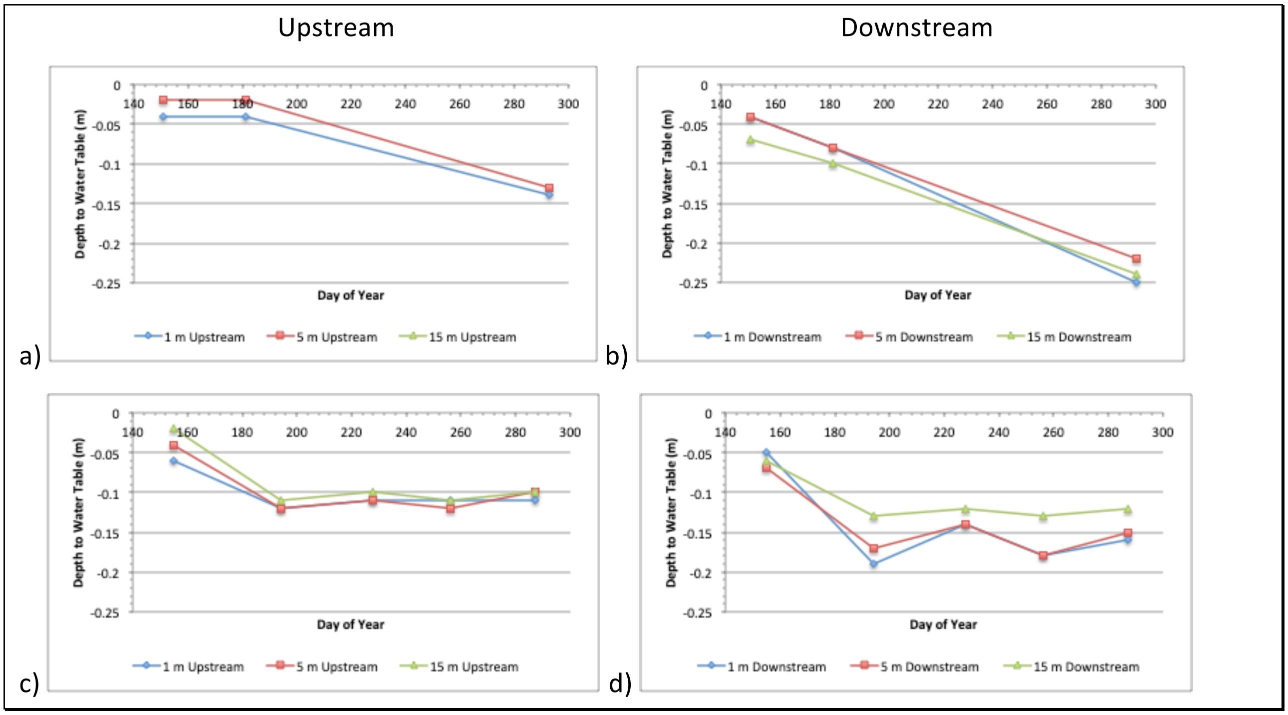


Figure 12. HDPE Pipe Bundle transect depth to water table recorded manually at wells 1 m, 5 m, and 15 m from road edge in 2022 ('a' and 'b') and 2021 ('c' and 'd').

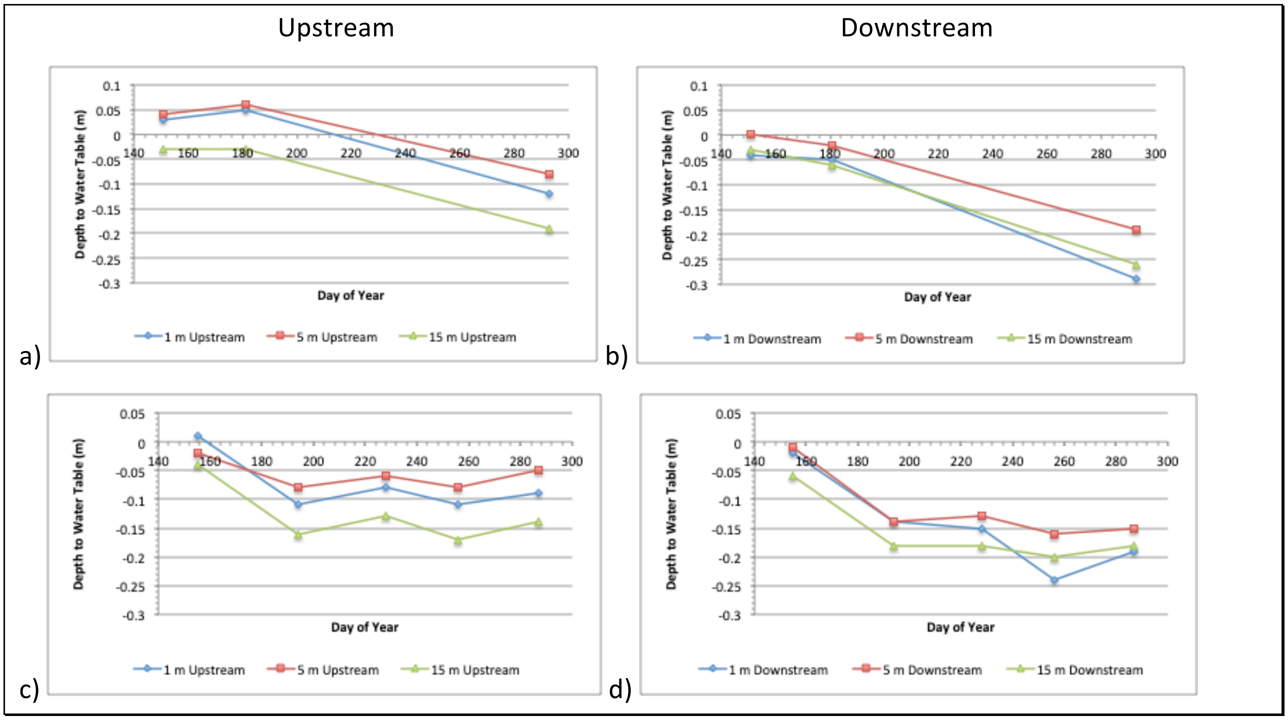


Figure 13. Log Pipe Bundle transect depth to water table recorded manually at wells 1 m, 5 m, and 15 m from road edge in 2022 ('a' and 'b') and 2021 ('c' and 'd').

Differences in DTW sides of the road generally increased as the water table elevation decreased, but distinct patterns in the continuous water level logger data were observed among conduits and corduroy between mid-June and mid July 2021 when the site average water table elevation decreased by 10 cm (Figure 14). DTW was greater on the downstream side of the corduroy transect than the upstream side during the beginning of this period when the overall water table was highest, but DTW began to converge between sides over time as the water table elevation fell. The opposite pattern was observed for the pipe bundle transect, where DTW was similar between sides of the road at the beginning of the period and then became deeper on the downstream side as the water table dropped. The log bundle transect pattern was somewhat similar to the pipe bundle, but with greater differences between road sides over the entire period. DTW was least different between road sides for the culvert transect. DTW was slightly greater on the downstream than upstream side for most of the period, with similar depths between sides for the last 7 days.

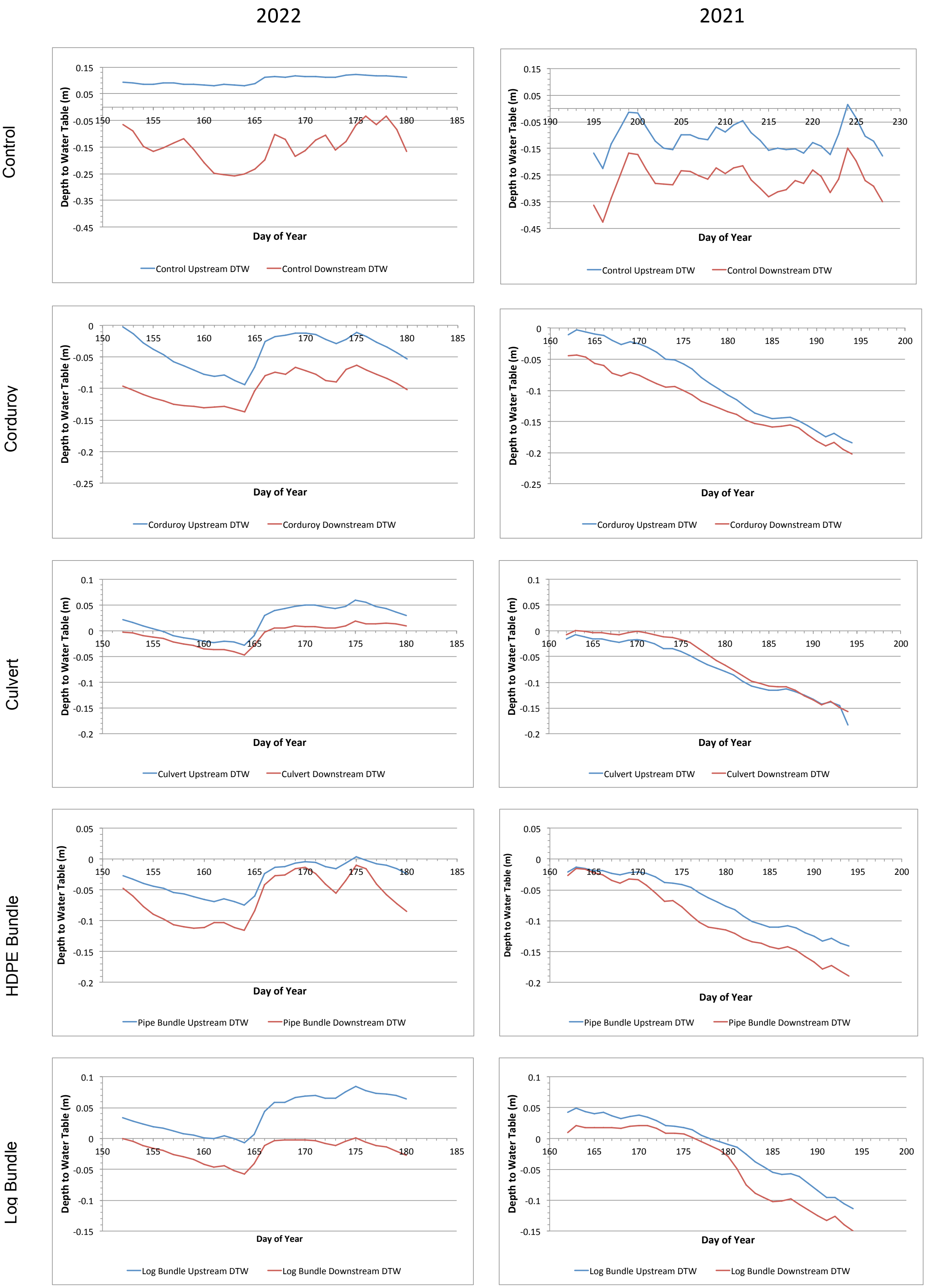
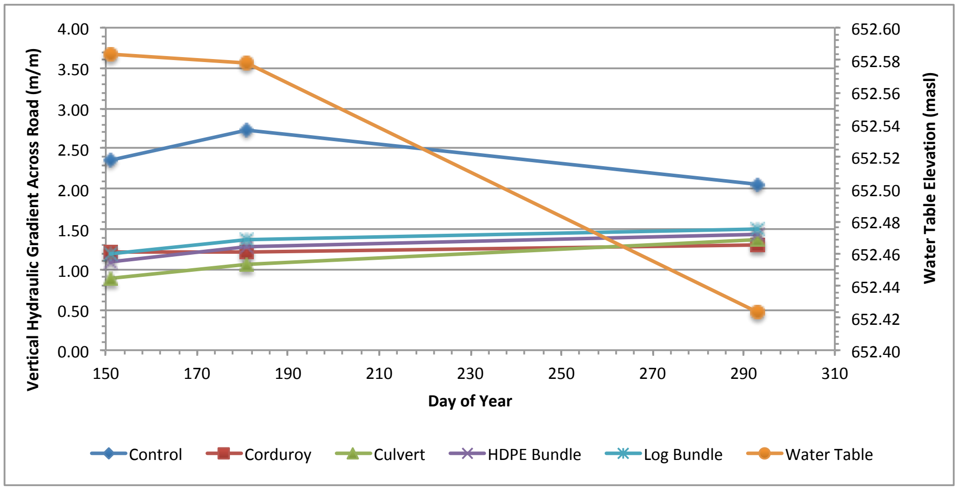


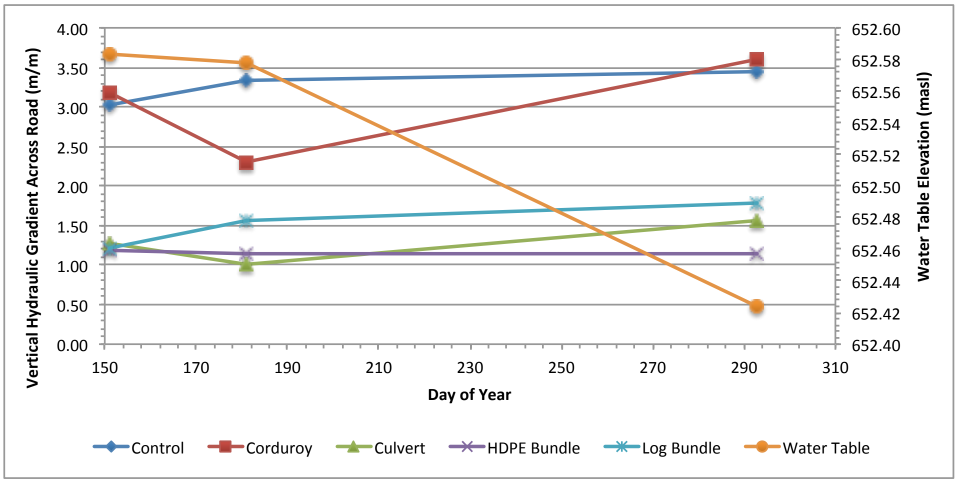
Figure 14. Average daily depth to water table (m) recorded by data loggers in wells 5 m from upstream and downstream sides of road during spring and early summer of 2022 and 2021.

Vertical Gradients Across Road

There was a topographical gradient sloping from the upstream to downstream side of the road. Therefore, if the water table was parallel with the ground surface, a hydraulic gradient would also be observed, which would normally be expected in absence of the road. However, since DTW was generally deeper on the downstream side than the upstream side, the inference is that the hydraulic gradient was steeper than the topographic gradient and the road has impeded flow. The steepness of hydraulic gradients varied among conduits, corduroy, and control, as well as with peat depth (Figures 15 and 16). Hydraulic gradients measured between wells at 5 m from the road edge on either side of the road represent water intake from the top 1.15 m of the peat surface, whereas, gradients measured between piezometers on either side of the road represented conditions at specific depths within the peat profile. The hydraulic gradient between upstream and downstream sides of the road at the control transect was on average 173% steeper than the topographic gradient for wells, whereas the gradients were closer to parallel with the topographic gradient, though still steeper for the corduroy and conduit transects. The average hydraulic gradients for all measurement dates were 18%, 6%, 23%, and 31% steeper than the topographic gradient for corduroy, culvert, pipe bundle, and log bundle transects, respectively. The average hydraulic gradient between 85 cm piezometers on either side of the road were 218%, 174%, 23%, 4%, and 40% steeper that the topographic gradient for control, corduroy, culvert, pipe bundle, and log bundle transects, respectively. The hydraulic gradient between road sides at 155 cm piezometer depth was 68% steeper than the topographic gradient at the control transect, 13% less steep at the corduroy and culvert transects, and 38% and 63% steeper at the pipe and log bundle transects.



a)



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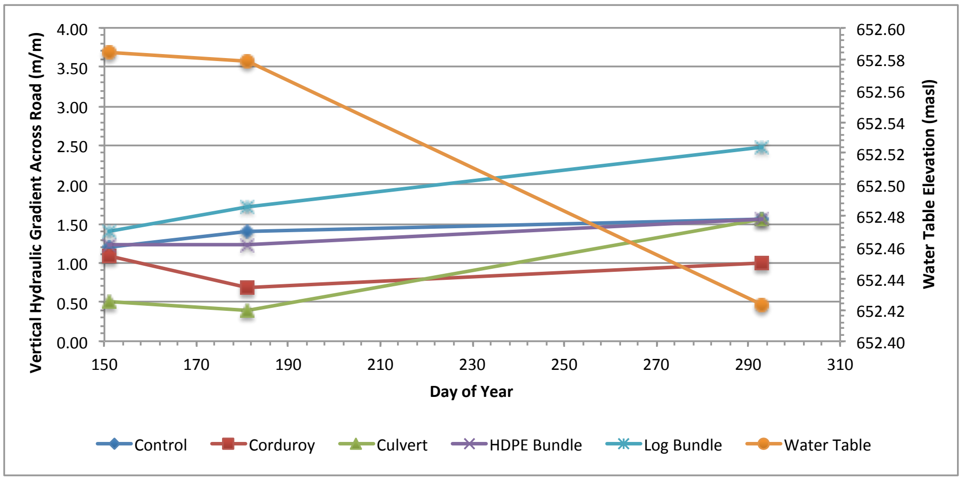

c)

Figure 15. Hydraulic gradients between upstream and downstream sides of road at wells (a), 85 cm slotted piezometers (b), and 155 cm slotted piezometers (c) in 2022. Gradients greater than 1 are steeper than the topographic gradient between the upstream and downstream sides of the road.

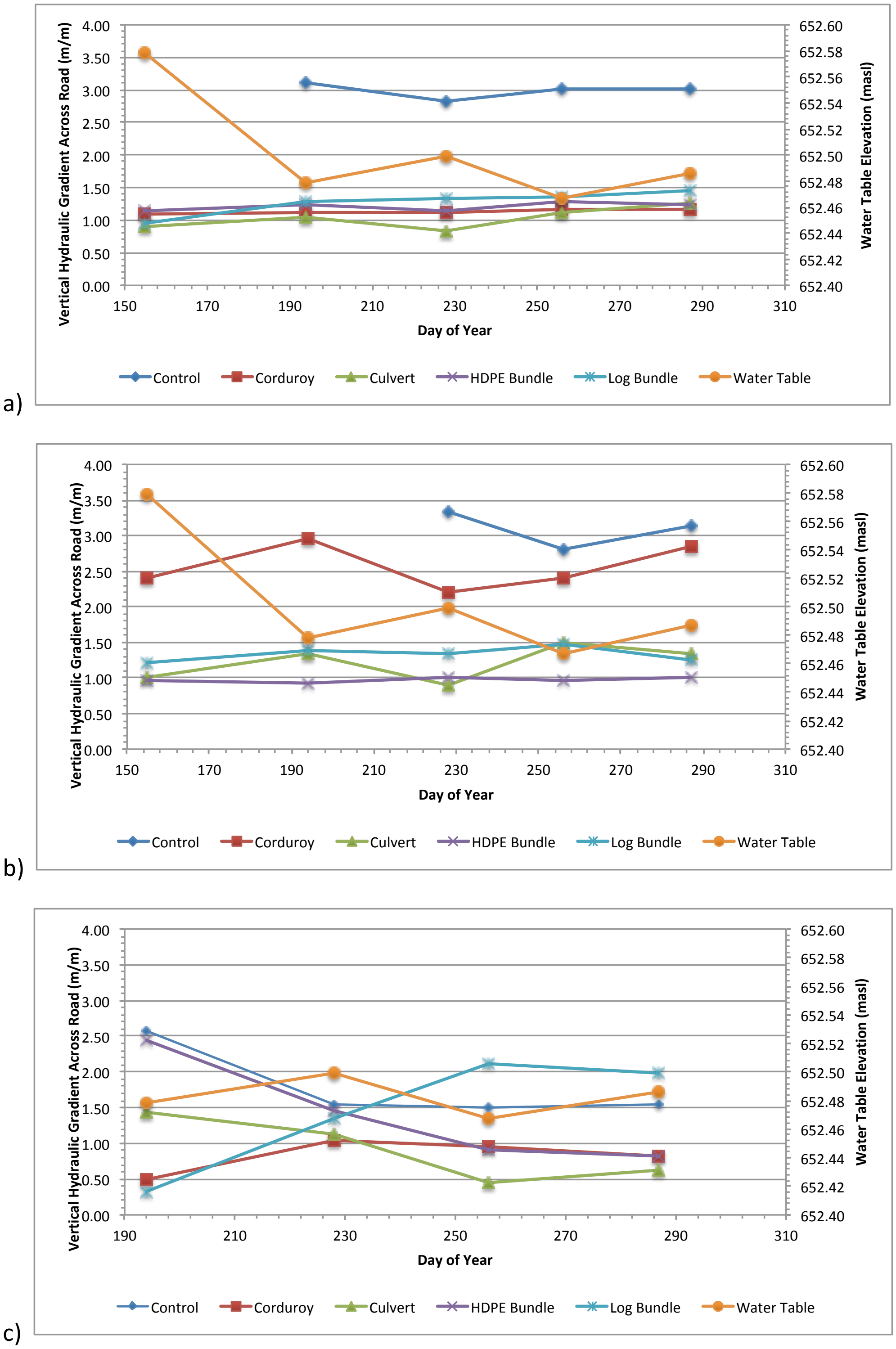

Figure 16. Hydraulic gradients between upstream and downstream sides of road at wells (a), 85 cm slotted piezometers (b), and 155 cm slotted piezometers (c) in 2021. Gradients greater than 1 are steeper than the topographic gradient between the upstream and downstream sides of the road.

F. KEY LEARNINGS

All conduits, as well as corduroy contributed to increasing permeability of the road to water flow. However, corduroy alone was less effective than corduroy with the addition of a conduit closer to the ground surface. While conduits were somewhat similar in effectiveness, log bundles seemed less effective than culverts or pipe bundles. Reduced effectiveness of log bundles is likely because flow is limited to the spaces between longs, whereas pipe bundles have to the spaces between pipes as well as the open tubular space to accommodate flow. Culverts of course are completely open with very little resistance to flow.

Conduits were most effective at higher water table conditions, where the water table could actually reach the elevation of the conduit to access the openings and flow through. This limitation impeded subsurface water flow, causing it to build up on the upstream side of the road. Therefore additional subsurface drainage capacity needs to be integrated into road designs to address subsurface flow. Such designs could include larger diameter culverts, stacked culverts or culvert pyramids, larger pipe and/or log bundles, additional log layers in the corduroy, or rock fill foundations.

Properly installed, culverts are the most free-flowing conduits, however, both pipe and log bundles also move water fairly well (Figures 17 and 18). Therefore, all of the conduits examined are useful in promoting road permeability, but choice of conduit type and placement should be made based on enhanced assessment of peatland hydrologic conditions prior to road construction. Since most road drainage designs rely primarily on models of surface flow, assessment of subsurface flows should be integrated into drainage designs. Conduit type, size, depth, and spacing could then be selected based on a better estimate of water volumes required to be moved in conjunction with cost and availability of conduit materials. All of the conduits used here are relatively low cost as they were salvage materials from other operations. Salvage steel pipe of various diameters is often available in association with in situ oil sands developments. The HDPE pipe for the pipe bundles were surplus pipe liners, and the logs for corduroy and bundles were salvaged material from clearing for local development. Continuous steel pipe performs better than corrugated steel culverts and is much more economical if it is acquired as salvage from associated in situ operations. The HDPE pipe liners may not always be available but are a good option when they are. Similarly, the only cost associated with salvage logs is transportation to site, but this can be minimal if the salvage coincides with the development that a road is supporting. Conduit type, size, depth, and spacing should be optimized by the relative availability of each, as well as alternatives, and the drainage requirements of the specific peatland in which the road is built.

Figure 17. Water along road edge draining into a log bundle during second season post road construction.

Figure 18. Water flowing out of pipe bundle outlet in late May 2022.

Corduroy used as a road foundation can also reduce construction costs by reducing the amount of earthen fill required to build the road. If salvage logs are readily available and can be substituted for earthen fill, less borrow material is required, thereby reducing the overall disturbance footprint and costs of borrow pit reclamation. Some operators have reported up to 50% less fill has been required when using corduroy as a road foundation (Osko et al. 2018). Furthermore, companies using corduroy report reduced annual road maintenance costs. Reclamation costs of corduroy roads should be similar to conventional roads. Where deep fill is required for peatland roads, common practice presently is to lower the road surface to near the average elevation of hummocks and hollows on the adjacent peatland and then revegetate with suitable peatland species. In such cases, earthen fill still remain above the corduroy, in which case it would not be removed and reclamation costs would remain the same as a conventional road. However, drainage would be improved because of the increased porosity of the corduroy foundation. Reclamation may be somewhat more challenging logistically in cases where shallower fill was used and all materials are removed because of the need to switch between dump trucks and log trucks as materials are removed. However, since buried logs do not readily decompose, they would be reusable for foundation on other nearby construction, as would the removed earthen fill. Alternatively, the logs could be left in place and integrated into the natural progression of peatland restoration. Corduroy has more commonly been used in forestry than in the energy sector, but energy operators are giving more consideration to corduroy use. At least one company uses corduroy on all of its peatland roads constructed for projects in northeast Alberta (Osko et al. 2018).

While it is common for culverts to bow as peatland roads settle, culverts used in this road were placed on four piles to prevent settling (Figure 19.). However, depth of fill in the middle of the road would have exerted more pressure on the under-road piles than shoulder piles. Redistribution of piles under the road focusing on the deepest fill and minimizing support under road shoulders may have reduced bowing of culverts observed in this study.

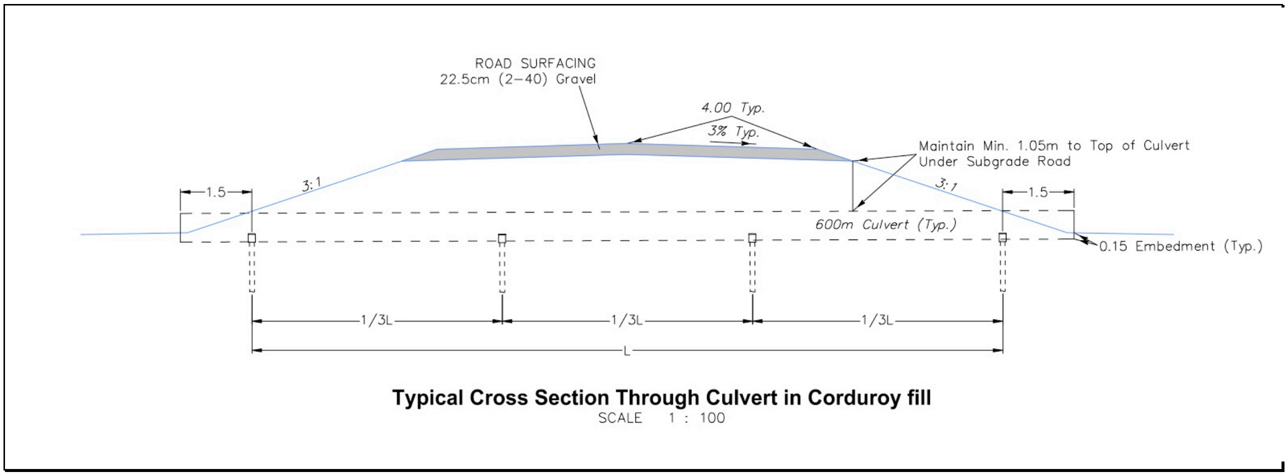

Figure 19. Design drawing of pile placement under culverts. Eliminating the two outside piles may allow culverts to settle more evenly and reduce bowing (Drawing produced by All-Can Engineering & Surveys (1976) Ltd.).

G. OUTCOMES AND IMPACTS

Project Outcomes and Impacts

The project provided important information regarding effectiveness of using corduroy as a peatland road foundation, as well as corduroy and various conduits for improving road permeability to water flow. This information can be used immediately by industry to better design roads with fewer undesired hydrologic, ecologic, and ultimately economic consequences. The information resulting from the project, combined with enhanced pre-construction hydrologic assessments will provide industry with a broader range of choices for selection and design of drainage systems for peatland roads. Some companies already use corduroy for road construction and have been experimenting with alternative drainage conduits. Exposure to more information such as that generated by this project will increase adoption of these practices by industry.

Performance Measures

Inundation of peatlands is known to increase methane emissions, while drying peatlands emit more carbon dioxide. Water balance across newly constructed roads adopting construction practices arising from the study will result in reduced methane emissions from inundated peatlands on upstream sides of future roads and reduced carbon dioxide emissions from drying peatlands on the downstream side of roads.

The project improved understanding of road and conduit effects on vertical water movement through the peat column, the role and effectiveness of drainage conduits in moving water through road, and the relationships between conduit types and depth of placement, such that better informed prescriptions can be developed for road construction.

The project included twelve collaborators, including nine industry funders, a non-for-profit forestry research organization, a university researcher, and Alberta Innovates. The broad collaboration will enhance exposure of project results and encourage wider adoption of the studied practices.

The project was described in an oral presentation in February 2020 at the Annual General Meeting and Conference of the Canadian Land Reclamation Association (CLRA) held in Red Deer, AB. A presentation featuring the project was made during a virtual conference hosted by the Society for Ecological Restoration (SER) in June 2021.

The project will be presented at a World Wetlands Day event hosted by Mount Royal University in Calgary in February 2023, as well as a joint conference of CLRA, the Society for Wetland Scientists, and SER called RE3 in Quebec City in June 2023.

H. BENEFITS

Economic

While this project was ecologic, rather than economic, the project may have economic benefit to industry by showcasing a positive example of environmental stewardship and responsible resource development. In addition, industry operators can potentially collectively benefit from millions of dollars in reduced road maintenance costs and reduced environmental liabilities.

Environmental

Inundation of peatlands is known to increase methane emissions, while drying peatlands emit more carbon dioxide. Water balance across newly constructed roads adopting construction practices arising from the study will result in reduced methane emissions from inundated peatlands on upstream sides of future roads and reduced carbon dioxide emissions from drying peatlands on the downstream side of roads. More directly, adoption of knowledge from the project will also lead to reduced ecological perturbations and habitat fragmentation resulting from alternate flooding and drying of peatlands on upstream and downstream sides of roads, followed by additional perturbations when roads are decommissioned and original hydrologic conditions restored. Adoption of knowledge from the project will prevent disruption of hydrologic conditions resulting from roads such that decommissioning roads would otherwise reverse.

I. RECOMMENDATIONS AND NEXT STEPS

A working group consisting of nine in situ oil sands companies supported the project. Furthermore, the working group operates within Canada's Oil Sands Innovation Alliance (COSIA) structure. As such, the project has excellent exposure to numerous in situ oil sands operators through networks developed via COSIA, its member companies, and the non-COSIA members of the working group. Project information will be provided directly to the member companies for immediate adoption, as well as disseminated via COSIA's communications networks to other companies. The working group also has also fostered relationships with regulators, inviting them to working group information and planning meetings, as well as field visits to showcase projects. This relationship will promote project results to regulators and foster discussions for further improvements to practices and regulatory guidelines.

A next step will be to address enhanced hydrologic assessment that includes subsurface water storage and flows to be included in road planning and design to properly estimate the drainage requirements of new roads and drive drainage design. This may be accomplished by completing a pilot study to demonstrate the potential volumes of water unaccounted for when designing road drainage based solely on surface runoff.

J. KNOWLEDGE DISSEMINATION

As indicated above, project results will be presented to at least two conferences in 2023. Further dissemination will be accomplished through the partner companies, COSIA networks, and regulatory relationships described above. Dissemination activities will include direct presentations to partner companies, field visits to the site, and circulation of the technical report and presentation copies via the COSIA reporting network.

K. CONCLUSIONS

Alberta in situ oil sands operations occur in an environment where at least 50% of the land is wetland, primarily peatlands. Roads constructed on peatlands pose environmental and economic risks because damming of surface and subsurface water by roads cause flooding and drying of peatlands leading to undesirable ecological changes, increased greenhouse gas emissions, and increased road maintenance requirements. The primary objectives of this study were to 1) assess the effectiveness of increased drainage conduits of various types, as well as timber corduroy as a road foundation, in improving road drainage; and 2) compare the relative effectiveness of conduit types and corduroy in facilitating drainage. A recently constructed road that intersected several areas of deep fen peat was used as a study area. Road construction incorporated timber corduroy as road foundation in the peat sections, as well as multiple closely spaced (~ 13-19 m) conduits including culverts, log bundles, and HDPE pipe bundles. A series of water well transects were established to measure water table levels in locations where corduroy and conduits were placed, as well as in two narrower sections of peat where no corduroy was used. Piezometers and continuous water level loggers were also installed in select locations to compare hydrologic responses to the installed conduits and corduroy. Corduroy and conduits improved road permeability and the road achieved better water balance than typically observed with conventional construction. However, the road was still a barrier to water flow, particularly subsurface water. Water balance across the road was most closely achieved when the general water table was high, such that water could access the conduits and flow through. Corduroy alone was less effective in improving road permeability to water flow than it was with the addition of conduits. Conduits performed similarly, but log bundles were less effective than culverts or pipe bundles. Nevertheless, all conduits could be useful depending on the specific hydrologic conditions. Current practice for designing road drainage relies primarily on surface runoff estimates. Enhanced preconstruction assessment of peatland hydrology that includes water storage and subsurface flows is required to direct choices of proper type, number, size, and depth of conduits used for future road construction. Future peatland road design should consider larger diameter culverts, stacked culverts or culvert pyramids, larger pipe and/or log bundles, additional log layers in the corduroy, or rock fill foundations as means to reduce impediment to water flow based on enhanced hydrologic assessments. The project improved understanding of road and conduit effects on vertical water movement through the peat column, the role and effectiveness of drainage conduits in moving water through road, and the relationships between conduit types and depth of placement, such that better informed prescriptions can be developed for road construction. Better prescriptions will lead to fewer undesired hydrologic, ecologic, and ultimately economic consequences. Industry will have a broader range of choices for selection and design of drainage systems for peatland roads resulting in reduced greenhouse gas emissions, reduced habitat fragmentation, and reduced habitat alteration or loss. Project results were presented at two conferences during 2020 and 2021 and will be presented at least 2 more during 2023. Project results will also be disseminated via industry networks through the nine project partner companies, Canada's Oil Sands Innovation Alliance, and relationships of these entities with provincial regulators. Dissemination activities will include presentations, technical reports, and site visits. Future work to facilitate adoption of project knowledge may include a pilot study to demonstrate the potential volumes of water unaccounted for when designing road drainage based solely on surface runoff rather than including subsurface flows.

L. LITERATURE CITED

Osko, T., C. Gillies, and M. Pyper. 2018. COSIA In-Situ Oil Sands Shared Practices for Working in and Around Wetlands. Prepared for: Canada's Oil Sands Innovation Alliance, Calgary, 69 pp.