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Settlement behaviour of embankment placed over wash pond sediment

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ABSTRACT
This paper presents the settlement behavior of an 18 m high embankment constructed over two decommissioned gravel quarry wash ponds in Cochrane, Alberta. Due to the time and cost constraints of the project, removal of the pond sediments accumulated from gravel washing was not a viable option and backfilling over the pond sediment was considered as an alternate approach to meet the project objectives.

RÉSUMÉ
Cet article présente le comportement de tassement d'un remblai de 18 m de haut construit sur deux bassins de lavage de carrière de gravier désaffectés à Cochrane, en Alberta. En raison des contraintes de temps et de coût du projet, l'élimination des sédiments de l'étang accumulés par le lavage du gravier n'était pas une option viable et le remblayage sur les sédiments de l'étang a été considéré comme une approche alternative pour atteindre les objectifs du projet.

1 INTRODUCTION

This paper presents the settlement and porewater monitoring data collected for an 18 m high embankment constructed over two decommissioned gravel wash ponds to support the construction of a new roadway in Cochrane, Alberta.

The two wash ponds, herein designated as the North and South Ponds, were located adjacent to each other and separated by a gravel berm. The North and South Ponds covered an approximate area of 2,100 m^2 and 6,800 m^2, respectively, and varied in depth up to approximately 8 m. The project site and proposed roadway alignment is presented on Figure 1.

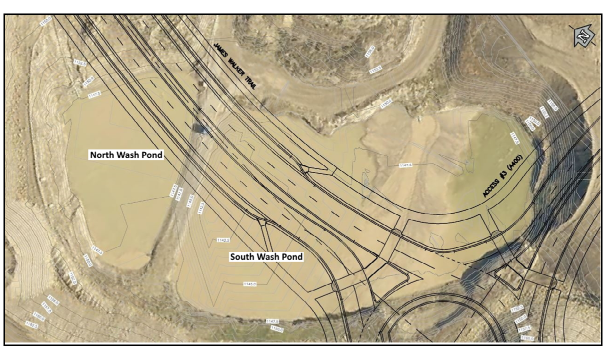

Figure 1. Project site photo (November 19, 2018)

Due to the time and cost constraints of the roadway project, removal of the pond sediment was not a viable option, and backfilling over the pond sediment was considered as an alternate approach to meet the project objectives.

2 SITE CONDITIONS

At the time of construction, the pond sediment varied up to 5 m thick in the South Pond, with the thickest layer located in the north portion of the South Pond. The pond sediment in the North Pond varied up to approximately 1 m to 2 m thick. A cross-section of the ponds and estimated sediment thickness is presented on Figure 2.

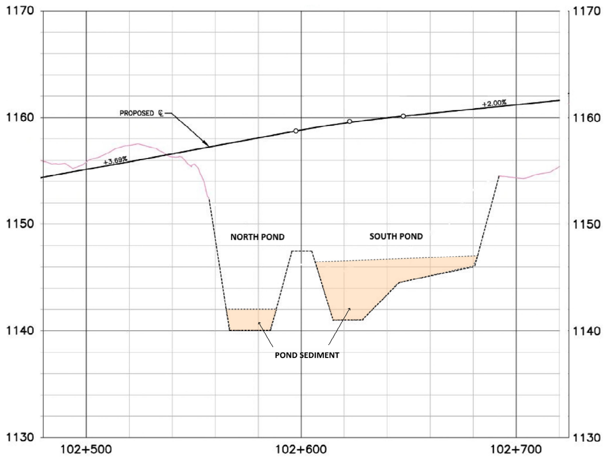

Figure 2. Cross-section of ponds

The pond sediment comprised silt and sand, with trace amounts of clay. The sediment was fully saturated and in a liquified state and behaved like quicksand. Two hydrometer tests were conducted on the sediment, and the results are presented in Table 1.

Table 1. Pond sediment hydrometer test results

Soil Characteristics	Sample 1 (%)	Sample 2 (%)
Clay	3	1
Silt	57	56
Sand	40	43
Cobbles/Boulders	0	0
Moisture Content	27	27

Based on the boreholes drilled at the project site, the native soils underlying and surrounding the ponds comprised stiff to very stiff clay till. The native clay till was moist and generally silty with some sand and some gravel. No groundwater was encountered in the boreholes.

3 PROJECT METHODOLOGY

3.1 Overview

The objective of this project was to develop a construction plan to safely backfill over the pond sediments without resulting in long-term instability and/or settlement issues of the embankment. The construction plan focused on porewater dissipation and tracking embankment settlement.

The ponds had freestanding water and the sediment was in a liquified state at the time of construction. The initial phase of work consisted of removing as much water from the ponds and pond sediment as possible using a series of vertical culverts and pumps.

In order to address any remaining porewater trapped in the pond sediment after backfilling, a drainage blanket overlying the pond sediment was proposed. The design concept was to use the weight of the embankment fill to squeeze porewater from the pond sediment into the drainage blanket, where the water could be transported off site using a series of horizontal French drain systems. Details regarding drainage blanket construction for the North and South Ponds are provided in Section 3.2 and Section 3.3, respectively. Details regarding the embankment backfill construction are discussed in Section 3.4.

In tandem with the drainage blanket construction and backfill placement, settlement plates and Vibrating Wire Piezometers (VWPs) were installed throughout the embankment and pond sediment to monitor settlement and porewater pressure behaviours, as discussed further in Section 4.0.

3.2 North Pond Drainage Blanket Construction

The North Pond was relatively deep, and constructing an outlet drain for the drainage blanket was not feasible. Alternatively, as the pond sediment was relatively shallow and on top of clay, it was proposed to stabilize the pond base using granular fill and remove the pond sediment.

Gravel fill, comprising cobbles and boulders, was end dumped into the pond and used to displace the sediment into the corner of the pond where it could be removed. The gravel fill created a stable ground surface for the embankment backfill.

As a precautionary measure to alleviate any potential porewater pressure buildup in the gravel fill, a drainage blanket was installed. The drainage blanket consisted of a 1.0 m thick layer of 25 mm crushed gravel with filter fabric below and above. Backfill construction started after the drainage blanket was installed.

3.3 South Pond Drainage Blanket Construction

The drainage blanket construction for the South Pond encountered additional challenges due to the larger footprint and thicker sediment. Dewatering of the pond was slow and ineffective leaving the sediment in a very soft and unstable state.

The drainage blanket was subsequently constructed in smaller segments, working from the pond edges towards the horizontal French drain system outlets. Combigrid (geotextile composed of geogrid reinforcement and filtration fabric) was used to create a stable surface for drainage gravel placement and to prevent drainage gravel from sinking into the sediment. The geotextile was rolled out in 5 m to 10 m segments followed by drainage gravel placement. The drainage gravel layer was 1.0 m thick and comprised 25 mm drainage gravel.

As anticipated, the sediment sank when loaded with drainage gravel and pushed/squeezed the sediment to the outer edges of the geotextile. To maintain positive drainage towards the horizontal drain outlets, excess and/or heaved sediment soils were removed as needed. Dewatering at the geotextile edges was continued in an effort to help improve stability as construction advanced.

The drainage blanket construction was dependent on the stability of the sediment and was only advanced when safe to do so. Embankment backfill was carried out in tandem with the drainage blanket construction where possible. Embankment backfill was limited to a maximum height of 5 m with a minimum setback of 30 m from the edge of the drainage blanket until the drainage blanket was complete. Figure 3 illustrates construction of the South Pond drainage blanket.

Figure 3. Drainage blanket construction on South Pond

3.4 Embankment Construction

As previously mentioned, embankment construction commenced after the drainage blanket was complete in the North Pond and in tandem with the drainage blanket construction in the South Pond.

Backfill material was imported from other areas of the roadway project and consisted of pit run and clay (silty, some sand, with trace to some gravel). Pit run was used to backfill the North Pond, and the clay fill was used to backfill the South Pond. Proctor tests were completed on imported material intended for backfill, and the average proctor test results are presented in Table 2.

Table 2. Proctor test results for embankment fill

Backfill Characteristics	Pit Run North Pond[1]	Clay Fill South Pond[2]
Maximum Dry Density (kg/m^3)	2181.7	1896.7
Optimum Moisture (%)	7.6	12.7
Oversized Retained[3] (%)	33	12.0

[1]Average values of six proctor test results conduced on pit run.
[2]Average values of three proctor test results conducted on clay fill.
[3]19 mm oversized material was retained for Pit Run and 9.5 mm oversized material was retained for Clay Fill.

Backfill was placed in compacted 150 mm to 300 mm lifts at a minimum 98% standard proctor maximum dry density. Compaction testing was completed successfully with all testing passing compaction requirements.

4 INSTRUMENTATION

The following instruments were installed throughout the embankment and wash ponds to monitor porewater pressure and track settlement:

- Four VWPs, designated as VWPs #1 through #4, were installed in the South Pond approximately 1.0 m below the drainage blanket in the pond sediment. Refer to Figure 4 for approximate VWP locations.
- Five settlement plates equipped with vibrating wire sensors, designated as Plates #1 through #5, were installed throughout the embankment at various fill heights. Refer to Figure 4 for plate locations.
- Five settlement plates equipped with steel reference rods, designated as Rods #1 through #5, were installed throughout the embankment. Rod #1 was installed above the drainage blanket overlying approximately 3.0 m of pond sediment in the South Pond. Rods #2 through #5 were installed approximately 1.0 m to 2.0 m below the final embankment grade. Refer to Figure 5 for approximate settlement rod locations.

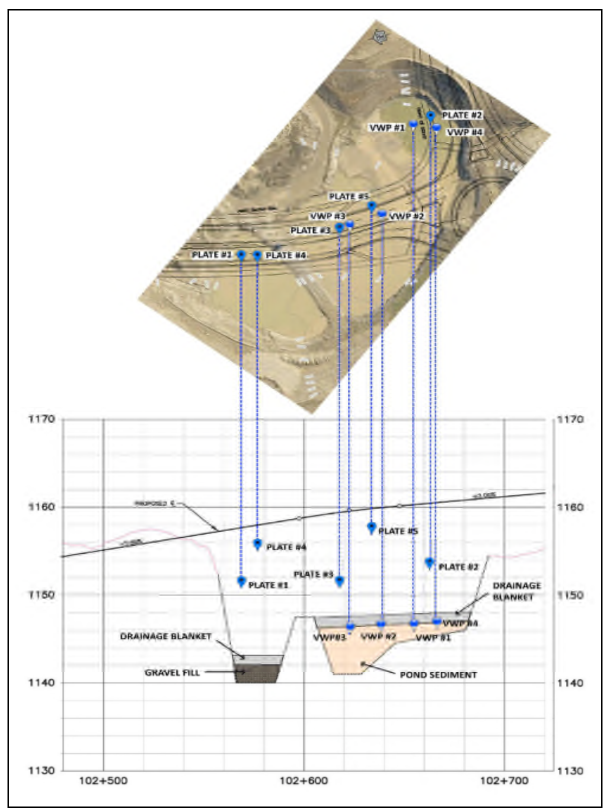

Figure 4. VWP and settlement plate locations

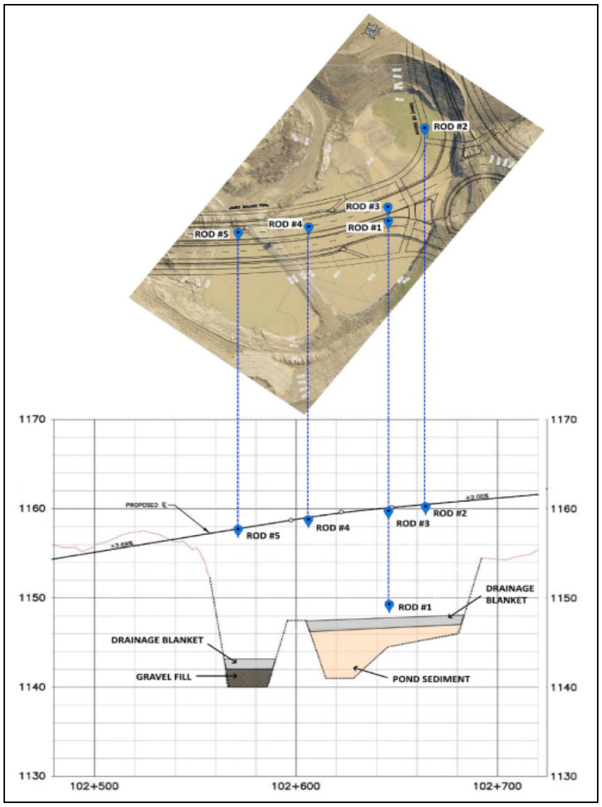

Figure 5. Settlement rod locations

VWPs #1 and #2 were installed during construction of the drainage blanket on June 25, 2019, and July 12, 2019, respectively; however, these VWPs were damaged shortly after installation. As a result, VWPs #3 and #4 were installed as replacements on September 23, 2019, when the embankment was approximately 8.5 m to 11.5 m high.

All the settlement plates were installed in tandem with embankment construction. Plates #1 and #2 were installed on August 22, 2019, Plate #3 was installed on September 21, 2019, and Plates #4 and #5 were installed on October 9, 2019.

Readout cables from the VWPs and settlement plates were trenched through the embankment to readout boxes located along the embankment slopes.

Rod #1 was installed on June 28, 2019, in tandem with drainage blanket construction. Rods #2 through #5 were installed on November 22, 2019, after the final grade of the embankment was reached.

The settlement plates and rods were installed at various heights throughout the embankment and on top of varied fill types, fill thicknesses, and thicknesses of pond sediment. A summary of the underlying fill/pond sediment at each settlement plate and settlement rod are presented in Tables 3 and 4.

Table 3. North Pond – soil underlying settlement plates

Settlement Instrument ID.	Soil Type and Approximate Thickness (m)		Total Fill Thickness (m)
	Pit Run[1]	Gravel Fill[2]	
Plate #1	9.0	2.0	11.0
Plate #4	13.0	2.0	15.0
Rod #5	15.0	2.0	17.0

[1]Thickness of fill includes 1.0 m thick layer drainage blanket.
[2]Gravel fill comprised cobbles and boulders placed along the pond base.

Table 4. South Pond – soil underlying settlement plates

Settlement Plate No.	Soil Type and Approximate Thickness (m)		Total Fill Thickness (m)
	Clay Fill[1]	Pond Sediment[2]	
Plate #2	5.0	2.0	7.0
Plate #3	4.0	5.0	9.0
Plate #5	9.0	4.0	13.0
Rod #1	1.0	3.0	4.0
Rod #2	12.0	1.0	13.0
Rod #3	12.0	1.0	13.0
Rod #4	11.0	5.0	16.0

[1]Thickness of fill includes 1.0 m thick layer drainage blanket.
[2]Pond sediments in the South Pond consisted of saturated silty sandy soils.

5 MONITORING DATA

The following subsections present the raw data collected from the VWPs, settlement plates, and settlement rods. A summary and discussion of the data are presented in Section 6.0.

5.1 VWP Data

As previously mentioned, VWPs #1 and #2 were damaged during drainage blanket construction (i.e., no data was collected for these VWPs). Data was collected from VWPs #3 and #4 between September 23, 2019, and April 23, 2020.

The porewater pressure data readings from VWPs #3 and #4 are presented graphically on Figures 6 and 7, respectively. The porewater pressure is also plotted against the approximate fill height overlying the VWP tip.

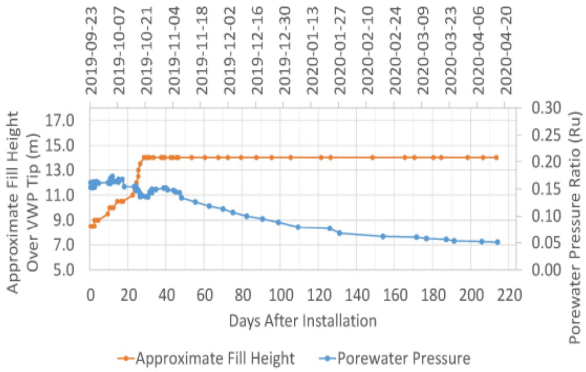

Figure 6. VWP #3 porewater pressure vs. approximate fill height overlying VWP tip

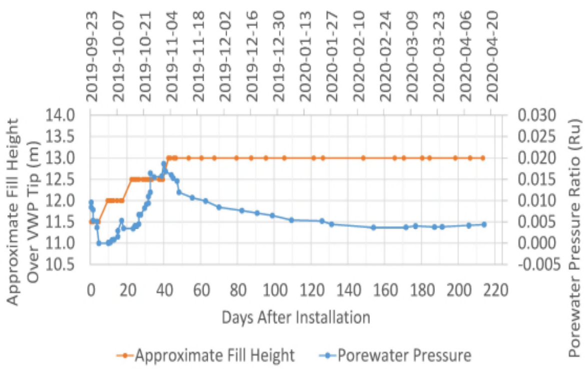

Figure 7. VWP #4 porewater pressure vs. approximate fill height overlying VWP tip

5.2 Settlement Plate Data

Data was collected for the settlement plates between August 22, 2019, and April 23, 2020. The settlement data for Plates #1 through #5 are presented graphically on Figures 8 through 12. At the time of this report, settlement monitoring is still ongoing.

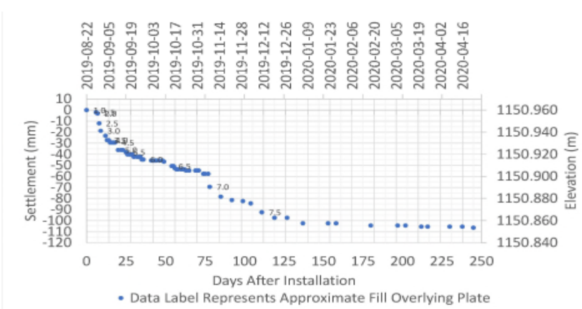

Figure 8. Settlement Plate #1 data vs. time overlying 9.0 m of pit run and 2.0 m of gravel fill

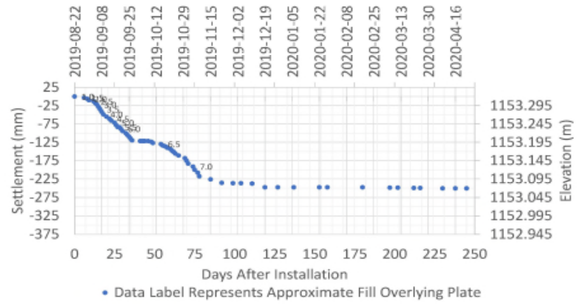

Figure 9. Settlement Plate #2 data vs. time overlying 5.0 m of clay fill and 2.0 m of pond sediment

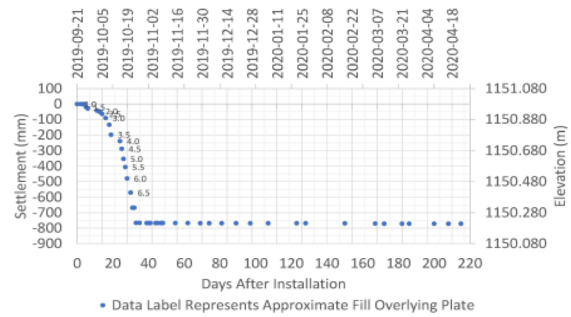

Figure 10. Settlement Plate #3 data vs. time overlying 4.0 m of clay fill and 5.0 m of pond sediment

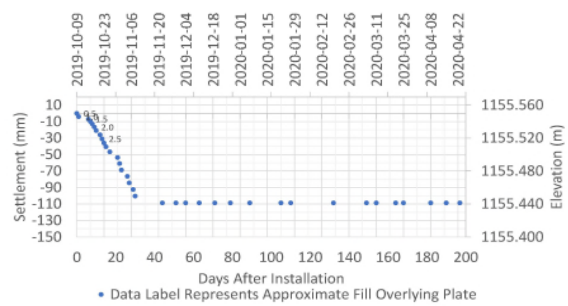

Figure 11. Settlement Plate #4 data vs. time overlying 13.0 m of pit run and 2.0 m of gravel fill

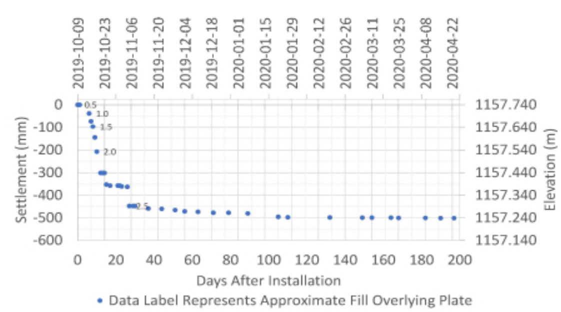

Figure 12. Settlement Plate #5 data vs. time overlying 9.0 m of clay fill and 4.0 m of pond sediment

5.3 Settlement Rod Data

Settlement rods were surveyed after initial installation and approximately every two to four weeks after installation between June 28, 2019, and April 17, 2020, for Rod #1 and between November 22, 2019, and April 17, 2020, for Rods #2 though #5. The amount of settlement at each rod is presented graphically on Figure 13.

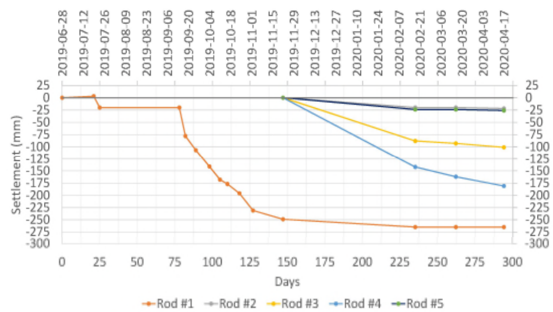

Figure 13. Settlement rod data vs. time

6 SUMMARY AND DISCUSSION

A summary and discussion of the data collected are presented in the following subsections.

6.1 Porewater Dissipation and VWPs

Visual inspection of the vertical culverts off site, where the drainage blanket drainage system outlets connected to, showed an influx of water during the initial embankment construction indicating that the drainage blanket and outlet drains were operating as designed. Less and less water was observed as the embankment construction continued.

The VWPs were important in providing confirmation that porewater pressure in the pond sediment was dissipating. Based on the data, the porewater pressure in the pond sediment behaved as anticipated, increasing with additional fill placement and dissipating over time.

The porewater pressure in VWP#3 appeared mostly dissipated by the time of installation with a peak value of 0.02, which slowly decreased to 0.005 after approximately 100 days.

The porewater pressure in VWP #4 peaked at 0.17. The porewater pressure slowly decreased and stabilized at 0.05 after approximately 190 days. VWP #4 was installed in the thickest portion of the pond sediment where the highest porewater pressure was anticipated, which corresponded to the data collected.

6.2 Settlement Data

6.2.1 Summary of Settlement Data

The settlement data was important in determining when the embankment settlement had stabilized and construction of the roadway could commence.

Note that Rods #2 through #5 were installed after embankment construction was complete to monitor the long-term settlement of the embankment. The settlement observed in these rods is not representative of the overall embankment settlement.

The settlement plates, Plates #1 through #5, were installed throughout the embankment to monitor settlement behaviour of different thicknesses of underlying fill and pond sediment.

Based on the data, the majority of the settlement in the plates and rods appeared to have stabilized by the time of the last reading. The total amount of settlement encountered at each settlement plate and rod is presented in Tables 5 and 6.

Table 5. North Pond – total amount of settlement

Instrument ID.	Total Fill Thickness Underlying Instrument[1] (m)	Total Settlement (mm)	Total Settlement / Total Fill Thickness (%)
Plate #1	11.0	106	1.0
Plate #4	15.0	109	0.7
Rod #5	17.0	26*	0.2*

[1]Refer to Table 4 for detailed fill type and thicknesses. All thickness includes 1.0 m thick drainage blanket, fill, and gravel fill (cobbles and boulders).

*Rods were installed after embankment construction was complete and are not representative of the total embankment settlement. Discussed further in Section 6.2.3.

Table 6. South Pond – total amount of settlement

Instrument ID.	Total Fill Thickness Underlying Instrument[1] (m)	Total Settlement (mm)	Total Settlement / Total Fill Thickness (%)
Plate #2	7.0	251	3.6
Plate #3	9.0	771	8.6
Plate #5	13.0	502	3.9
Rod #1	4.0	262*	6.6*
Rod #2	13.0	52*	0.4*
Rod #3	13.0	128*	1.0*
Rod #4	16.0	227*	1.4*

[1]Refer to Table 4 for detailed fill type and thicknesses. All thickness includes 1.0 m thick drainage blanket, fill, and pond sediment thickness.

*Rods were installed after embankment construction was complete and are not representative of total embankment settlement. Discussed further in Section 6.2.3.

6.2.2 Settlement Plates

The settlement observed in Plates #1 and #4 was similar at 106 mm and 109 mm, respectively. The settlement observed in these plates was much lower with respect to fill heights, ranging between 0.7% and 1.0%, when compared to the plates installed in the South Pond, which ranged between 3.6% and 8.6%. The overall settlement in the North Pond appeared to have stabilized after approximately 150 days. The relatively small percentage of fill settlement was likely attributed to the pond sediment removal, gravel-filled pond base, and pit run used in the embankment.

The largest amount of settlement was encountered in Plate #3 at 771 mm in the South Pond. The largest amount of settlement was anticipated at this location as it was overlying the thickest layer of pond sediment. The settlement appeared to have occurred rapidly and stabilized after approximately 30 days. Relative to the fill height and pond sediment thickness underlying the plate, the settlement was equivalent to approximately 8.6% of the total underlying fill thickness.

Plates #2 and #5 encountered settlement of 251 mm with 7.0 m of fill underneath the plate and 502 mm with 13.0 m of fill underneath the plate, respectively. Between the two plates, the amount of settlement doubled when the fill and pond sediment thickness nearly doubled, suggesting a possible linear relationship between fill height and settlement, as discussed further in Section 6.2.4. The overall settlement appeared to stabilize after approximately 120 days for both plates.

6.2.3 Settlement Rods

Rod #1 was installed over the 1.0 m thick drainage blanket and approximately 3.0 m of pond sediment and settled 262 mm. In comparison to Plate #2, which had a settlement of 251 mm overlying a pond sediment thickness of 2.0 m and 5.0 m of fill, the settlement values were relatively similar, suggesting that pond sediment thickness had a much larger influence on settlement than fill thickness. The settlement in this rod appeared to stabilize after 235 days.

When comparing the settlement data from the plates and Rods #2 through #5, the majority of the embankment settlement (short term) had already occurred before the rods were installed. As such, this settlement data was only used to establish if settlement of the overall embankment was still occurring and when that settlement would stabilize. At the time of the last reading, the settlement in Rods #2 and #5 appeared to have stabilized at approximately 150 days after installation (i.e., 150 days after embankment construction was complete). Settlement in Rods #3 and #4 appeared to be tapering off; however, additional settlement at these two locations is anticipated to continue and will continue to be monitored.

6.2.4 Settlement and Pond Sediment Thickness

Based on the settlement data collected over the pond sediment (i.e., instruments installed over the South Pond), the total settlement appeared to be significantly influenced by the sediment thickness and to a lesser extent the total fill thickness.

Comparisons of total embankment settlement versus the pond sediment thickness and total fill thickness are presented in Table 7. The comparisons are also presented graphically on Figures 14 and 15.

Table 7. Pond sediment thickness and total settlement

Pond Sediment Thickness (m)	Total Embankment Settlement (mm)	Total Fill Thickness Underlying Instrument[1] (m)	Instrument ID.
2.0	251	7.0	Plate #2 – South Pond
3.0	262	4.0	Rod #1 – South Pond
4.0	502	13.0	Plate #5 – South Pond
5.0	771	9.0	Plate #3 – South Pond

[1]Refer to Table 4 for detailed fill type and thicknesses. All thickness includes 1.0 m thick drainage blanket, fill, and pond sediment thickness.

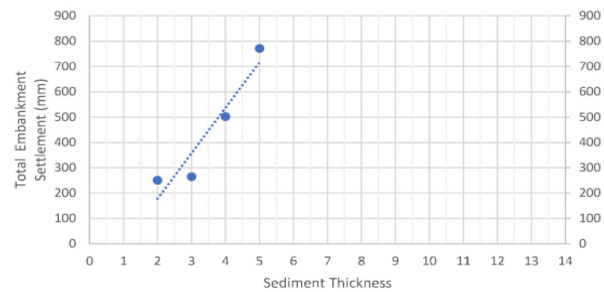

Figure 14. Sediment thickness versus total settlement

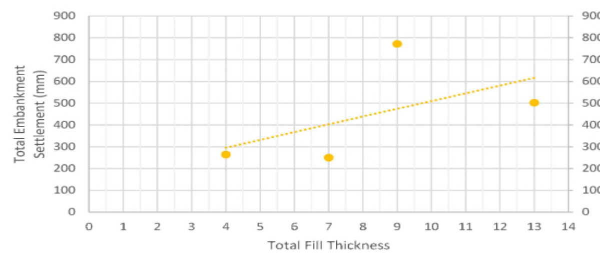

Figure 15. Total fill thickness versus total settlement

Based on the best fit lines presented in Figures 14 and 15, the total embankment settlement appears to have a stronger correlation between sediment thickness than total fill thickness, suggesting that pond sediment thickness has a greater influence on the overall settlement.

Typical fill embankments comprising similar cohesive silty clay material generally settle between 1.0% and 2.0% of the total fill height (Rivard and Goodwin 1977). Under this assumption for the fill underlying the plates (i.e., between the plate and drainage blanket), the pond sediment would account for approximately 70% to 95% of the total settlement.

6.2.5 Settlement Versus Time

Based on the settlement plate data collected (Plates #1 through #5), 94% to 100% of the total settlement occurred during and/or shortly after construction. The total amount of settlement observed upon completion and 30 days after embankment construction is presented in Table 8.

Table 8. South Pond – total amount of settlement

Instrument ID.	Total Settlement[1] (mm)	Settlement mm (% of Total)	
		Upon Completion	30 Days After Construction
Plate #1	106	92 (87%)	102 (96%)
Plate #2	251	191 (76%)	237 (94%)
Plate #3	771	570 (73%)	767 (99%)
Plate #4	109	31 (28%)	109 (100%)
Plate #5	502	448 (89%)	472 (94%)

[1]Total settlement at the time of last reading (April 23, 2020). Settlement is anticipated to have stabilized at the time of the last reading.

7 CONCLUSION

The findings of this study were able to demonstrate that the embankment settlement had stabilized and construction of the roadway was able to commence.

The drainage blanket and horizontal French drain system functioned as designed to remove water off the site and was a suitable alternative to conventional vertical drains.

The settlement data suggest that pond sediment may account for 70% to 95% of the total settlement. The total amount of settlement ranged between 3.6% to 8.6% of the total underlying fill height and for pond sediment thicknesses varying between 2.0 m to 5.0 m, respectively.

Based on the settlement data, 94% to 100% of the total settlement occurred approximately 30 days after the embankment was constructed.

The details and findings of this study are presented for general information purposes. The construction methodology and monitoring were developed specifically for this project and proved effective for backfilling over the pond sediment.

Following the results of this report, the settlement and long-term performance of the embankment will continue to be monitored.

8 ACKNOWLEDGEMENT

The authors would like to thank The Town of Cochrane for their permission to use the data presented in this paper. The authors would also like express their thanks to Urban Systems Limited and Lafarge Canada Inc. for contributions during the construction and data collection.

9 REFERENCE

Rivard, P.J. and Goodwin, T.E. 1977. Geotechnical characteristics of compacted clays for earth embankments in the Prairie provinces, *Canadian Geotechnical Conference '77*, Saskatoon, Saskatchewan, Canada.