Reusing Settlement Sensitive and Reclaimed Soils for Roadway Embankment Construction

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Paper prepared for presentation
at the 'Soils and Material Session' of the
2022 TAC Conference & Exhibition, Edmonton, AB

Acknowledgements:
Town of Cochrane
Urban Systems Ltd.
Lafarge Canada Inc.

Abstract

This paper documents the construction and settlement monitoring of an 18 m high roadway embankment that was constructed over two gravel quarry wash ponds for James Walker Trail located in Cochrane, Alberta.

The primary objective of the work was to ensure that embankment settlement would not adversely affect the performance of the future roadway/pavement structure. In addition, the project focused on reducing the amount of imported backfill and reusing available on-site soils.

The key challenge of the project was determining how to reuse the existing wash pond sediment to safely construct the embankment without adversely impacting the future roadway performance. The existing pond sediment consisted of wet, fully saturated, soft, sandy silt, varying between 2 m and 5 m thick with an estimated volume of up to 50,000 m^3.

The optimized simple design approach and proposed construction plan consisted of using a combination of geotextiles for soil stabilization and installing a drainage blanket connected to multiple drain outlets to drain the excess porewater out of the pond sediments during and after construction. The existing wash pond sediment material was able to be left in place and was reused as part of the embankment structure, thereby reducing the need to remove the pond sediment and import new fill.

The roadway embankment fill was subsequently placed in a staged approach to allow construction to continue safely while monitoring porewater pressure and settlement using a series of vibrating wire piezometers, vibrating wire settlement gauges, and settlement monuments. The embankment fills also reused reclaimed cobbles/boulders and on-site available soils including clay, silt, and sand to reduce the amount of import fill required.

The project was successful in reusing the estimated 40,000 m^3 of pond sediment, reusing available on-site soils, and minimizing the amount of import fill required. In addition to the cost savings related to these activities, several environmental benefits were also indirectly realized. Energy use and carbon emissions decreased due to reduced construction equipment operation and hauling activities associated with the pond sediments (i.e., up to 80,000 m^3 for the exporting of pond sediments and importing of new fill). Reusing on-site soil materials also reduced the environmental footprint of the project by minimizing the need to extract more fill from other sites, disposal of pond sediments, and reduced hauling activities along with any associated traffic congestion.

1.0 Introduction

This paper documents the construction of an 18 m high embankment that was placed over two decommissioned gravel wash ponds. The embankment was constructed in support of a new roadway (James Walker Trail) located in Cochrane, Alberta.

The primary objective of the work was to ensure that the embankment settlement would not adversely affect the performance of the roadway/pavement structure. In addition, the project was able to reduce the amount of hauled soft soil and imported backfill by reusing the available on-site soils.

The project site comprised two wash ponds, designated as the North and South Wash Ponds, which were previously used for gravel washing operations for Green Drop Quarry. The two ponds were located adjacent to each other and were separated by a gravel berm. The North and South Wash 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 below the surrounding grade. The project site and proposed roadway alignment is presented on Figure 1.

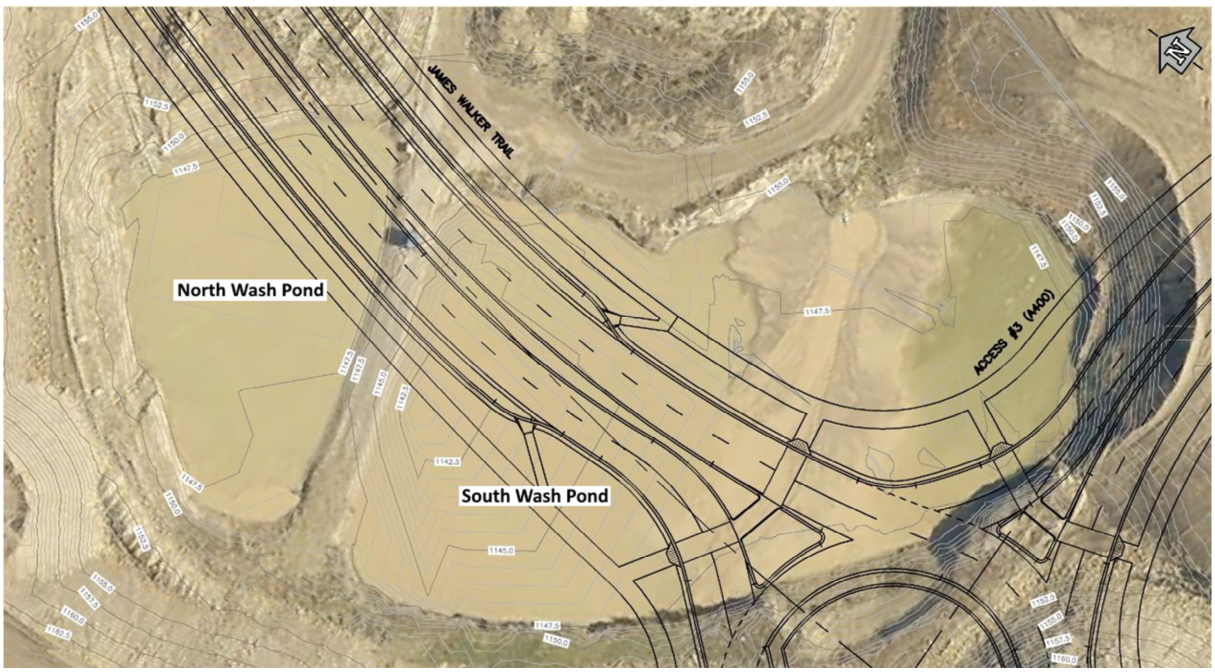

Figure 1: Project Site (November 19, 2018)

2.0 Site Conditions

At the time of construction, the pond sediment in the South Pond varied up to 5 m thick, with the thickest layer of pond sediment 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.

The pond sediment comprised silty sand with trace amounts of clay. At the time of construction, the sediments were in a fully saturated state and behaved like quicksand (liquified state). In addition, free-standing water was also present in certain portions of both ponds. Two hydrometer tests, along with moisture content tests, were conducted on the sediment, and the results are presented in Table 1.

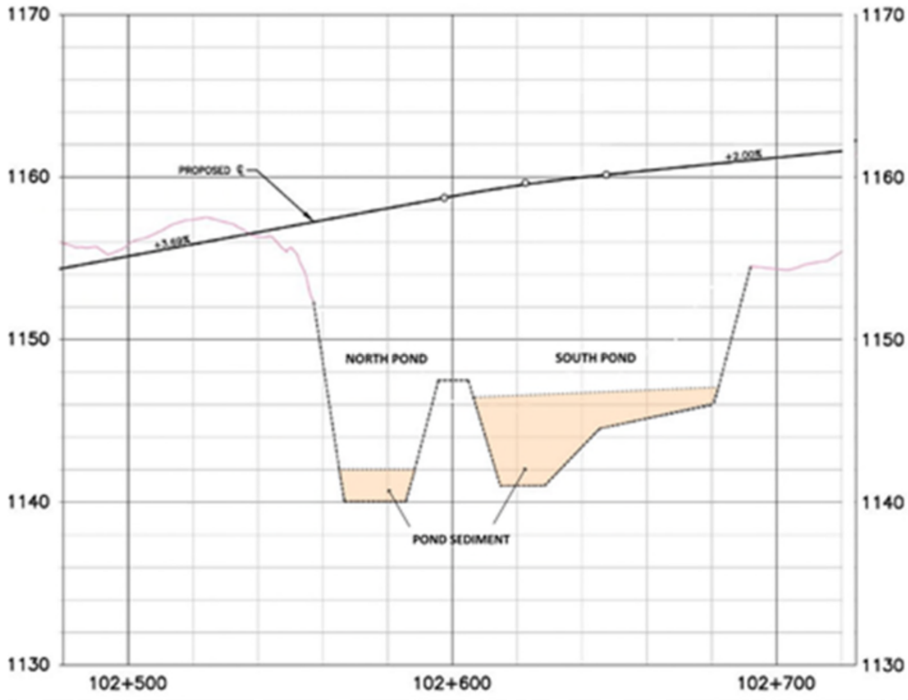

Figure 2: Cross-Section Profile – Estimated Sediment Thickness

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 around the ponds, the native soils comprised stiff to very stiff clay till. The native clay till was generally silty with some sand and some gravel. The native soils underlying the sediment were anticipated to be wet and soft due to the overlying sediment soils and repeated use by the gravel quarry.

3.0 Project Methodology

3.1 Overview

In the pond area, the total volume of soil removal was estimated to be up to 50,000 m^3, which included the existing volume of sediment and up to 2.0 m of underlying subgrade anticipated to be soft, wet, or loose soils due to gravel quarry operations.

The initial plan considered removing the sediment and underlying soils, stockpiling the material to dry, then re-using the material for backfill. The process to remove the sediment was estimated to take up to 10 weeks, which included excavation and hauling. The estimated timeframe, however, could not account for the time needed for the material to dry and would have potentially delayed the project. Furthermore, another 10 weeks to haul the sediment back to site and compact it would have been required. Due to the time constraints of the project and the uncertainty associated with the time needed to dry the removed soils, an alternative methodology was developed.

Based on the preliminary fieldwork, the sediment was able to create a dense to very dense subgrade suitable for embankment construction when dried. The design approach then shifted to developing a method to drain the sediment in place, which would eliminate the need to double handle the soils and would maintain the project schedule. As part of the revised methodology, the long-term stability and performance of the embankment subgrade (i.e., pond sediment) also became one the focuses of the project design, as stability and performance were concerns.

The initial phase of work consisted of removing as much water from the ponds and pond sediment as possible using a series of vertical perforated 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 installed. The design concept was to use the weight of the embankment fill to squeeze excess 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 the 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.

A series of settlement plates and Vibrating Wire Piezometers (VWPs) were installed throughout the embankment and sediment to monitor settlement and porewater pressure to assess performance of the drainage system and embankment during and after construction. Details regarding the instrumentation are discussed further in Section 4.0.

Utilizing this methodology saved a significant amount of time and resources that would have been otherwise spent rehandling material or sourcing new material. The environmental benefits are discussed further in Section 5.0.

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 geogrid-reinforced 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, particularly where the thicker sediment was located. As a result, dewatering of the pond was slow and ineffective leaving the sediment in a very soft and unstable state when construction was schedule to start.

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 the 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 gravel and clay (silty, some sand, with trace to some gravel). Pit run was used to backfill the North Pond, and 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)	2182	1897
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.

4.0 Instrumentation

The following instruments were installed throughout the embankment and wash ponds to monitor porewater pressure and to track the amount of 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 4 for approximate settlement rod locations.

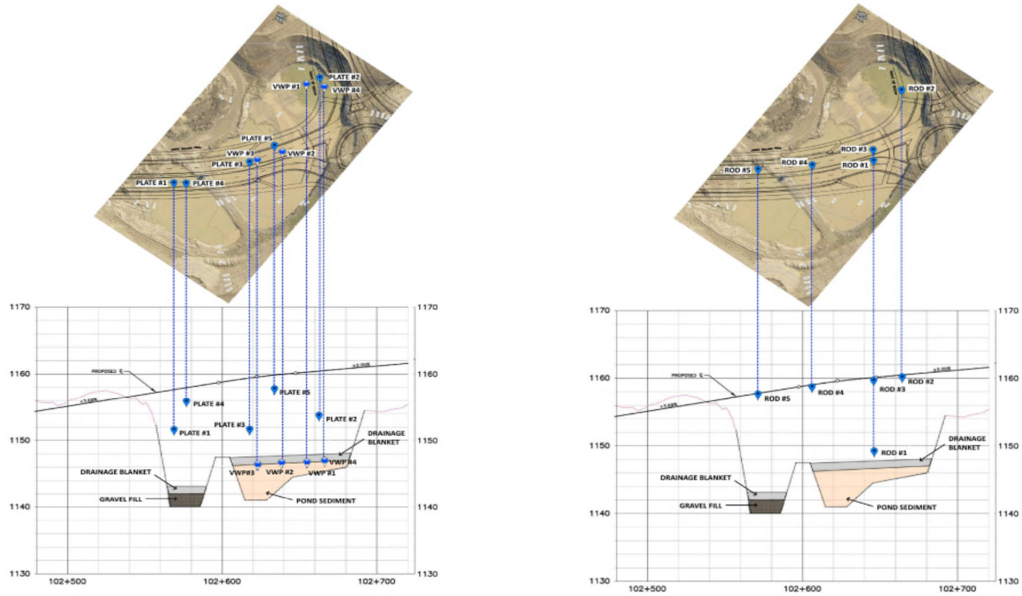

Figure 4: VWP and Settlement Plate Locations and Settlement Rod Locations

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.

4.1 Summary of Instrumentation Data

4.1.1 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.

4.1.2 Settlement Readings

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 was 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 thicknesses include a 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.

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 thicknesses include a 1.0 m thick drainage blanket, fill, and pond sediment thickness.

* Rods were installed after embankment construction was complete and are not representative of the total embankment settlement.

5.0 Environmental Benefits

A number of environmental benefits were realized by reusing the pond sediment and are discussed in the following section. The numbers provided are estimates only and are based on the construction methodology and information available at the time of preparation of this paper.

The project was able to effectively save on not having to remove and haul an estimated total of 40,000 m^3 of pond sediment and unsuitable underlying soils from the South Pond. This represented a significant environmental benefit as this material was able to be reused and alternative suitable material sourcing elsewhere was not required.

In total, an estimated 80,000 m^3 of earthworks were saved on the project as a result of not having to remove pond sediment/unsuitable underlying soils and replace with suitable backfill. This reduction in earthworks also meant a significant reduction in the carbon emission footprint of the overall project.

Based on the estimated volume of soil removal (i.e., 40,000 m^3 of pond sediment and unsuitable underlying soil removal), the soil removal was estimated to take up to 8 weeks to complete, which assumed 2 excavators and 10 loaders operating 10 hours per day on a 6-day work schedule. An equivalent amount of time was also estimated for hauling back suitable fill soil.

Based on the anticipated schedule, average fuel consumption rates (Volvo Construction Equipment), and the United States Environmental Protection Agency (EPA) carbon dioxide emission values per gallons of diesel fuel consumed, an estimated total of 566.8 metric tons of carbon dioxide emissions savings were realized by reusing the pond sediment which comprised not removing pond sediment/unsuitable underlying soils and replacing with suitable backfill (i.e., 80,000 m^3 of earthworks).

The estimated fuel consumption and carbon emission savings, based on the earthworks schedule, is presented in Table 7.

Table 7: Estimated Fuel Consumption and Carbon Emissions Saved

Construction Equipment	Pieces of Equipment	Estimated Hours[1]	Fuel Consumption Rate[2]	Total Estimated Fuel Consumption	Carbon Dioxide Emissions Equivalent[3]
Excavator (EC200E)	2	960 hours	15.1 L/hour (4 gallons/hour)	28,992 L (7,659 gallons)	78.2 metric tons
Loader (A25G)	10	960 hours	18.9 L/hour (5 gallons/hour)	181,440 L (47,931 gallons)	488.6 metric tons

1. Number of hours based on a 16-week schedule for excavating/hauling a total of 80,000 m^3 of earthworks.

2. Estimated fuel consumption rate based on Volvo Construction Equipment (https://www.volvoce.com/united-states/en-us/services/volvo-services/fuel-efficiency-services/fuel-efficiency-guarantee/).

3. Estimated equivalent carbon dioxide emissions calculated based on conversion rate of 10.180 $x10^{-3}$ metric tons CO_2/gallon of diesel fuel (EPA – https://www.epa.gov/energy/greenhouse-gases-equivalencies-calculator-calculations-and-references).

6.0 Conclusion

The staged construction approach, along with the drainage blanket, was able to create a stable subgrade structure out of the pond sediment. By reusing the soil, the project was able to benefit from a financial and environmental perspective by reducing the need for removal, rehandling, or sourcing and hauling of new material.

An estimated 40,000 m^3 of sediment and soft soils did not have to be removed from the ponds or to be processed (i.e., dry or mix with other soils) prior to reuse. The estimated carbon footprint saved as a result of not handling a total of 80,000 m^3 of earthworks (a combination of not removing and hauling back the soils) was estimated to be 566.8 metric tons of carbon dioxide.

The initial embankment settlement estimate varied between 200 mm and 450 mm based on sediment thickness varying between 2.0 m and 5.0 m. Based on the monitoring program, the settlement plates settled between 106 mm and 771 mm, with the largest amount of settlement observed where the sediment was the thickest. The estimates were generally consistent with the predicted behaviour; however, more settlement than predicted was observed at the thickest layer of pond sediment.

The monitoring program was important in tracking and determining when settlement had effectively stopped and how much settlement had occurred to assist in the roadway construction in terms of grading and when construction was able to start. In addition, tracking the porewater pressure within the pond sediment allowed confirmation that the drainage system was working as porewater pressure values continually dropped over the course of construction and tapered off to nearly zero.

The project methodology was able to effectively reuse the poor subgrade soils (i.e., pond sediments) by not conforming to conventional construction methodology. The monitoring and instrumentation also played a very important role as it provided empirical data showing the performance of the embankment was not adversely affected by the pond sediments.

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