Geotechnical Considerations in Design and Construction of North Commuter Parkway, Saskatoon SK

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Abstract

This case history reviews geotechnical conditions and design of the North Commuter Parkway (NCP) roadways and bridge crossing of the South Saskatchewan River at Saskatoon SK.

The geotechnical investigation of the NCP crossing identified complex geotechnical conditions in both the river valley and on the upland. The site was located within the ancestral Glacial Lake Saskatchewan, a proglacial lake that deposited variable depths of interbedded silt, sand and highly plastic clay. Development of the river channel had eroded much of the lacustrine sediments and underlying till leaving an eroded till landform with clay remnants on one side of the valley and lacustrine sediments on the other. This varying morphology presented highly variable geotechnical conditions with significant design challenges. Groundwater conditions were controlled by regional aquifers that underlay the entire project area in addition to local unconfined aquifers that were also addressed.

This paper presents the geotechnical design issues that were encountered in constructing the roadways and valley crossing. It addresses geotechnical conditions, foundation design, materials selection, groundwater control and construction issues that were addressed to successfully deliver this P3 project that is scheduled for completion in 2018.

1.0 Introduction and Project Overview

The North Commuter Parkway (NCP) comprises a new bridge and roadway system in north Saskatoon as shown in Figure 1. Graham Commuter Partners were the constructors of this P3 project and Clifton Associates Ltd. were the geotechnical engineers of record for the project and road designers for the valley section of the project. The work included a bridge crossing of the Saskatchewan River and approximately 8 km of new urban roadway, much of it across virgin terrain. Further, the length of bridge structure was minimized by placing the abutments on fills; the west approach fill extended into the river channel. This paper examines the geotechnical conditions for the project and design solutions employed to successfully complete this challenging project.

2.0 Site Characterization

2.1 Geomorphology

The Saskatoon landscape has been formed by multiple glaciations with each glacial cycle followed by de-glaciation and modification of the terrain by flowing meltwater. The last (Wisconsinan) de-glaciation occurred about 12,000 years BP (Christiansen 1979) creating glacial Lake Saskatchewan that covered the Saskatoon area for a sufficient period of time to deposit deep (up to 25 m) of glacio-lacustrine clay, often interbedded with silt and very fine sand.

The current landscape was formed as the glacial lake drained through the Saskatchewan River meltwater channel leaving lacustrine clay on the upland. As the river channel developed, previously deposited sediments were eroded, creating todays river valley. The river started to channelize by rapidly eroding through the lacustrine sediments; thus, the terrain traversed by the NCP roadways comprised a variety of landforms (see Figure 2), each with specific material types and geotechnical issues to be addressed.

The easterly and westerly limits of the NCP route traverses lacustrine clay deposited in glacial Lake Saskatchewan. The material is medium to highly plastic and is the least desirable construction on the project. Fortunately, the clay is underlain by till at a shallow depth.
As the river valley eroded, the channel migrated to the west, leaving a long “slip-off-slope”, or westerly dipping valley slope of eroded till on the east side of the river. This landform, an

ancestral riverbed, was a disordered, boulder-strewn plain of ridges and swales with local relief generally less than 10 m. Topsoil cover was thin, generally less than 150 mm. The ridges were abandoned point bars comprised of a boulder and gravel cap overlying a till core. Typical stratigraphy in the swales consisted of a thicker (up to 300 mm) organic topsoil horizon over a thin lag of boulders and sand over dense till.

Ancestral river erosion on the east valley slope created a series of current scars, two of which (Northeast Swale and Minor Swale) were sufficiently incised to create modern wetlands. These swales were infilled with sequences of alluvial and lacustrine sediments overlain with peat of varying thickness, creating valuable, sensitive habitat that required protection against disturbance during construction.

The westerly limit of the eroded till plain was bounded by a narrow depositional terrace that extended to the river. The terrace comprised thin sand and gravel over a boulder lag and hard Floral Formation till. The river channel has continued to migrate to the west in a channel that is eroded into hard dense till covered with a dense lag of gravel and boulders that generally varied from 1 to 6 m deep. The deeper boulder and gravel deposits occur on the west side of the river where the channel is more deeply eroded into the underlying till.

A steep 30 m high slope, created by ongoing erosion of the westward-migrating river, defined the west valley wall. Groundwater discharge (springs) were present about mid way up the slope. The groundwater discharge, coupled with surface runoff, created a series of shallow landslides on the slope. The generated colluvium and slope wash masked the face of the slope and deposited a depth of soft, unconsolidated sediments at the base of the slope.

The west uplands transitioned from the eroded crest of the valley wall to undisturbed lacustrine clay deposits extending to the westerly limits of the project.

2.2 Geology

More than 100 m of glacial sediments overlie the Cretaceous bedrock in the Saskatoon area. The glacial sediments comprise many unique stratigraphic units as illustrated in Figure 3; only the Saskatoon Group, comprising the surficial lacustrine sediments, Battleford Formation till, plus the till and inter-till sand units of the Floral Formation, along with recent sediments in the wetlands, were relevant to design and construction of the NCP.

Stratigraphy of the sector east of the Saskatchewan River is illustrated in Figure 4. The uppermost stratum on the east upland was glacio-lacustrine clay deposited in Lake Saskatchewan. This stratum was thickest near the east limits of McOrmond Drive, thinning to the west, and absent below elevation 505 masl. The clay was underlain by Battleford till, with the Floral Formation sediments (dense till and the intra-till sand of the current scar Forestry Farm Aquifer at depth). The Northeast Swale was an abandoned river channel eroded through the Forestry Farm aquifer that was the current scar subsequently backfilled with fluvial-lacustrine sediments (sand and clay) and peat.

Sand and gravel formed a depositional terrace that extended from the river shoreline to approximately elevation 480 masl. The sand and gravel was underlain a boulder lag that overlay the eroded dense Floral Formation till.

The arrangement of sediment in the river channel is illustrated in Figure 5. Since the river is actively eroding the toe of the west valley wall, a scour channel has developed there. The channel has been backfilled with more than 6 m of fluvial sand and gravel underlain by a lag concentrate of boulders that overlay unoxidized Floral Formation till. Elsewhere in the river channel, the sand and gravel varied from 1 to 4 m thick.

The west uplands display the full suite of sediments from lacustrine clay at surface to unoxidized Floral Formation till at depth. An intra-till sand unit forms the Dalmeny Aquifer that outcrops at depth on the valley wall. A similar sequence was observed on Central Avenue (Figure 6) except the Floral till has been eroded, leaving a thin veneer of silt, sand and gravel over the eroded till surface. The remaining till is thin, leaving the top of the Forestry Farm Aquifer sand very close to existing ground surface.

2.3 Groundwater Regime

The groundwater regime in the project area is a function of water levels in two types of aquifers:

- Two deep regional aquifers as shown in Figure 7:
  - the Forestry Farm Aquifer east of the river; and,
  - the Dalmeny Aquifer on the west side.
- Unconfined aquifers formed by the veneer of sand and gravel that overlies much of the area east of the river.

Water levels in the aquifers is a function of precipitation and runoff as illustrated in Figure 8, the hydrograph for the Saskatoon Observation Well in the Forestry Farm Aquifer in the project area (Saskatchewan Water Security Agency 2018). Water levels in the Forestry Farm Aquifer control the water levels in the Northeast Swale and, to a lesser extent, in the Minor Swale. The degree of variation in water levels in the aquifers means that the swales are intermittent wetlands but, at the time of NCP construction, water in the swales was near record high levels.

Intermittent unconfined aquifers form in the surficial sand and gravel, depending on precipitation and runoff conditions. Seepage was observed in several locations where excavation exposed the contact between the aquifer material and underlying low-permeability till.

3.0 Design Considerations

The principal design considerations related to materials selection; earthwork design; bridge foundation design; seepage control; and, ensuring environmental compliance. Each of these is discussed in the following paragraphs.

3.1 Materials Selection

A wide variety of natural soils, including highly plastic clay, low plasticity till, sand, boulders and abundant topsoil, were available within the construction corridor; project economies could be realized by judicious selection of materials since the choice of materials governs the design details for both earthworks and pavements.

The materials available were different on either side of the river. The east side had an abundance of high quality soils that included:

- Granular material from the ridges and point bars on the upland that was a select borrow source;
- Boulders from the eroded till terrain provided material for erosion control;
- Low plasticity till on the upland and as a subcrop under the surface sand deposits, used as a common excavation; and,
- Intra-till sand available at a shallow depth that was suitable both as a drainage material and select borrow.

Some less desirable soils were also encountered on the east side:

- An excess of topsoil that was used wherever possible to flatten slopes and for landscaping;
- Highly plastic lacustrine clay was encountered locally and, wherever possible, was excavated from under the roadway and replaced with higher quality material;
- Peat and soft organic sediments were encountered in the swales; and,
- A landfill of what appeared to be a mixture of construction debris and soil was encountered along the route and was wasted.

Soils on the west side were less variable. Thin lacustrine sediments overlay till on the upland; these were excavated in the approach cut and replaced with till. The colluvial materials covering the valley wall and accumulated at the toe of the slope were excavated and wasted whereas the alluvial river sand was incorporated into the drainage blanket for the west approach fill.

There was insufficient excavation on the route of the west side of the river to construct the west approach fill so an off-site borrow source was located. The off-site borrow was till of similar characteristics as the local and proved to be an adequate material for construction of west-side earthworks.

3.2 Earthworks Design

Earthwork design was predicated on using the available natural materials to produce the highest quality embankments and earth structures. Routine design concerns regarding issues such as global stability and subgrade quality were addressed through application of applicable design standards and conventional geotechnical testing and analyses.

Optimizing subgrade strength with a view to minimizing pavement structure costs was a core consideration. Fill placement specifications for subgrades required a minimum density of 98% of Maximum Standard Proctor Density at a moisture content not to exceed the optimum to achieve maximum density. Further assurance of a quality subgrade was provided by specifying the top 600 mm of subgrade was to be constructed of select borrow comprised of either low-plasticity till or granular material.

Construction of the subgrade across the Minor Swale and Northeast Swale required ground improvement and surcharging to improve stability and achieve >90% consolidation of the foundation during the construction period. In both cases, the organic surficial deposits were removed and a clean sand drainage blanket placed over geotextile. After construction of the subgrade, a 1.5 m surcharge fill was placed over the entire roadway. Settlement was monitored using conventional raft-type settlement plates and vibrating wire piezometers; the surcharge fill was removed when the instrumentation indicated that the desired degree of consolidation had been achieved.

3.3 Bridge Foundations

The bridge general arrangement provided for both abutments on embankments and three river piers. The east approach fill, approximately 10 m high, was located approximately on the existing shoreline with only minor filling into the river required to construct the end slopes of the fill. The west approach fill, by contrast, was approximately 18 m high at abutment elevation and extended approximately 25 m into the river channel. Both abutments were supported on driven 610 mm pipe piles with 12.5 mm wall thickness with a nominal driven pile length of 18 m and 29 m on the east and west abutments, respectively. The ultimate design parameters were based on cohesion of 70 kPa and 175 kPa in the embankment and till foundation, respectively, and ultimate bearing capacity of 3500 kPa in the till. Final pile capacities were confirmed by PDA testing.

The river piers were supported on footing founded on hard, dense, unoxidized till below the depth of river scour. The ultimate bearing capacity of the soil at that elevation was determined to be 1850 kPa. Construction was accomplished by isolating each footing location with an earth cofferdam and excavating to foundation level in an open “glory-hole” excavation. Backfilling and placement of erosion protection (riprap) was completed after construction of the footing.

3.4 Hydrotechnical and Environmental Considerations

The South Saskatchewan River is a navigable river and an important aquatic habitat. The periods when construction was permitted in the river was regulated to protect aquatic life, as was the allowable degree of restriction of flow due to construction of the proposed earth cofferdams. Construction schedules revolved around the intervals when in-river construction was allowed, understanding that all conditions of the relevant permits must be met. A comprehensive Environmental Management Plan was prepared to document and implement the actions required to meet permit requirements.

The Canadian Navigable Waters Act governs the construction of any perceived or potential obstruction of a navigable river; hence, construction of the earth cofferdams for pier construction was a regulated activity. Hydrotechnical (HEC-RAS and Telemac) modeling of the river was carried out to demonstrate the cofferdam impact on river velocity through the constricted channel and the predicted backwater level increase that would accrue from each stage of cofferdam construction, assuming a 5-year runoff event would occur when the cofferdam was in place. The modeling indicated that the backwater effects would not precipitate local flooding along the river, and the increased velocities through the constricted channel were not deemed to be hazardous to river users.

Similar modeling was undertaken to demonstrate the velocities and backwater effects caused by construction of the bridge; a typical model output is illustrated in Figure 9. The work showed that the predicted backwater of 0.047 m was less than the allowable 0.10 m, and that the erosion potential of the maximum velocities predicted could be readily controlled using Saskatchewan Ministry of Highways and Infrastructure standard riprap specifications.

3.5 Groundwater Regime and Seepage Control

Two separate groundwater regimes were observed within the project area. The deepest system was an intra-till aquifer within the Floral Formation sediments. This stratum is known as the Forestry Farm Aquifer on the east side of the river and the Dalmeny Aquifer on the west side (see Figure 7). These are water-table aquifers with the piezometric levels well below the overlying Floral till aquitard. Water levels have been relatively stable until the wet cycle of the last decade that have caused water levels to rise more than 6 m, including 4.6 m since 2010 as shown in Figure 8. The Forestry Farm Aquifer outcrops on the lower eastern slope and in the current scar that form the Northeast Swale. The water levels in the swale were near historic highs at the time of investigation, due to similarly high water table in the Forestry Farm Aquifer. The upper part of the aquifer was, however, unsaturated, allowing the clean aquifer sand to be harvested for drainage blanket and select borrow.

The second series of aquifers are local shallow, unconfined aquifers that are recharged from the surface, resulting in intermittent seeps at the aquifer-aquitard contact at the base of the aquifer. The severity and duration of the seeps is a function of aquifer geometry and the efficiency of recharge from precipitation and runoff. One such aquifer was encountered on the valley slope east of the bridge; a perforated subdrainage system was installed to control groundwater levels under the roadway.

The Dalmeny Aquifer outcropped as a series of springs and minor seeps about mid-height of the west valley wall at a location that would be covered by approximately 10 m of approach embankment. Positive control measures were required to collect and positively drain seepage water to maintain natural drainage from the aquifer and prevent seepage from softening the fill and adjoining slopes. A perforated drain system, as illustrated in Figures 10, 11 and 12, was installed to collect the seepage and conduct it to the storm water drainage system for discharge to the river.

3.6 Summary

Investigations for the North Commuter Parkway began in the fall of 2016 with construction beginning soon thereafter. The challenging geotechnical conditions discussed have been successfully addressed through close cooperation among the owner, constructors, designers and public stakeholders. Completion of the project is scheduled for the fall of 2018 when it will be turned to the concessionaire to operate for 30 years before it reverts to the City of Saskatoon.

References

Christiansen, E. A. 1979. The Wisconsinan deglaciation of southern Saskatchewan and adjacent areas. Can. J. Earth Sci. Vol 16 p 913-398.

Christiansen, E.A. 1992. Pleistocene stratigraphy of the Saskatoon Area, Saskatchewan, Canada; an update. Can. J. Earth Sci. Vol. 29, p. 1767-1778.

Saskatchewan Water Security Agency, 2018. Observation Well Network. WSA Well Saskatoon (NW16-08-37-04 W3) Hydrograph.

Figures

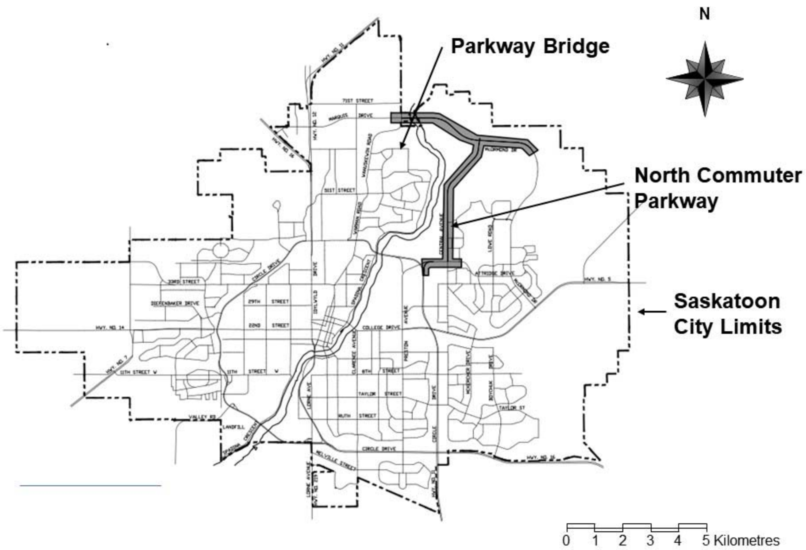

Figure 1 – Location of North Commuter Parkway, Saskatoon, Canada.

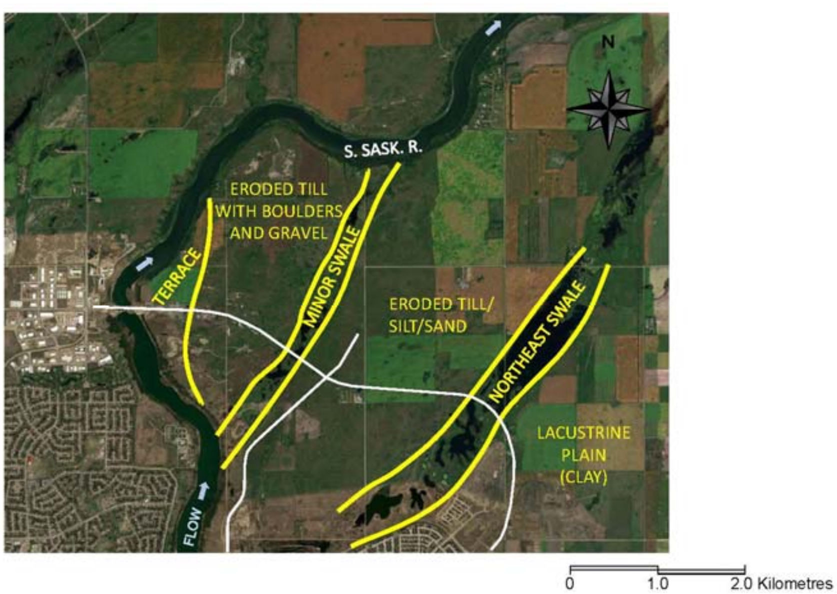

Figure 2 – Landforms along the route of North Commuter Parkway, Saskatoon, Canada.

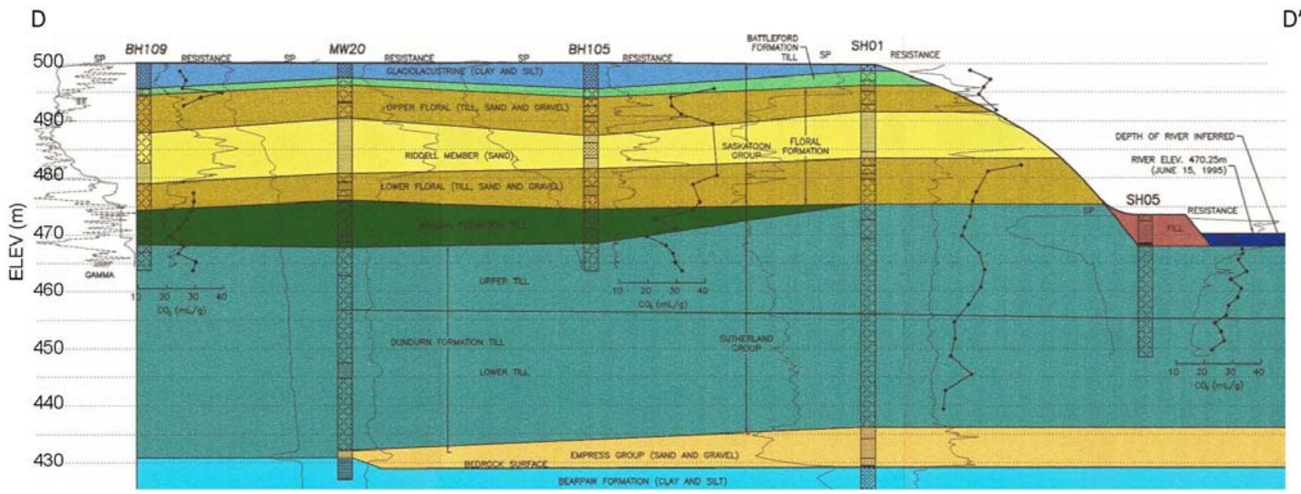

Figure 3 – Regional stratigraphic cross section west of South Saskatchewan River, Saskatoon, Canada (After Christiansen 1992).

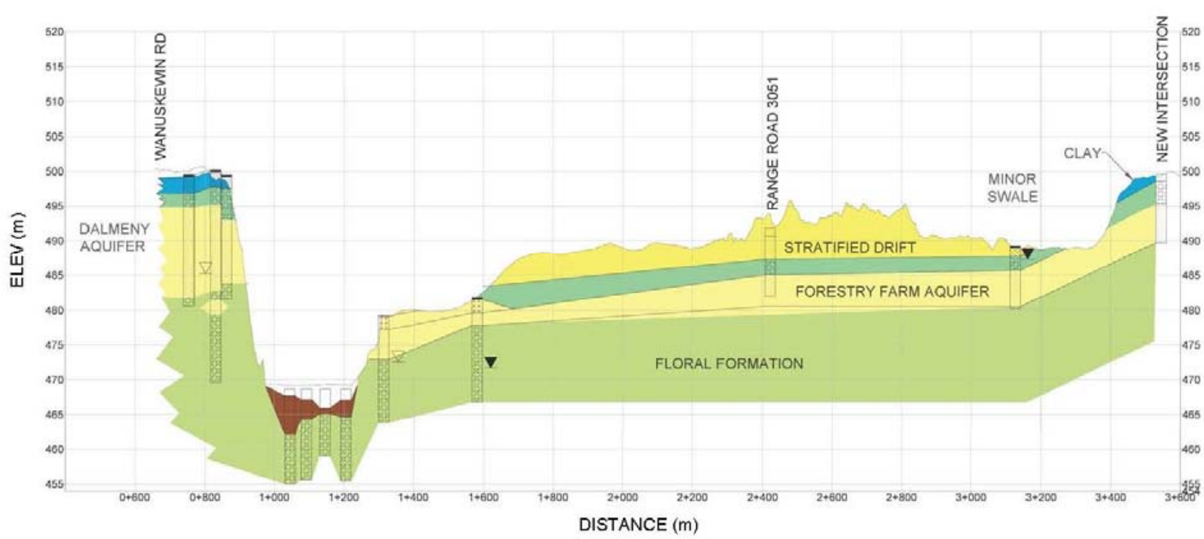

Figure 4 – Stratigraphy along North Commuter Parkway in vicinity of South Saskatchewan River, Saskatoon, Canada.

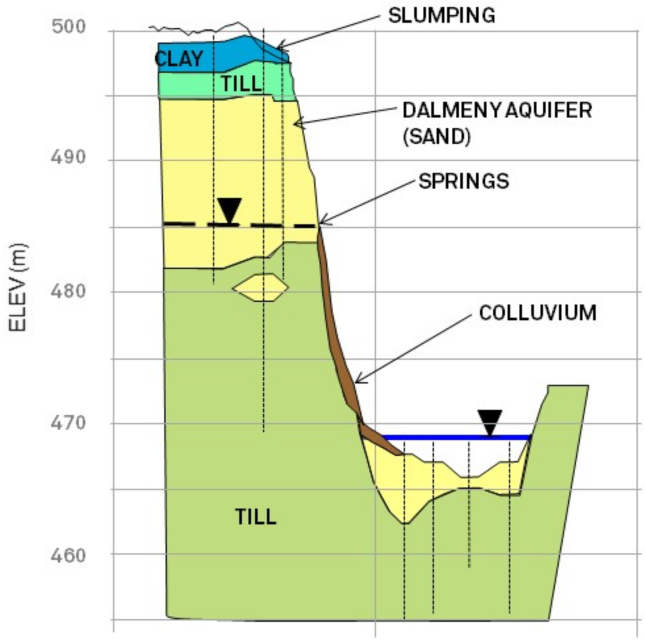

Figure 5 – Stratigraphy and piezometric levels, west wall of South Saskatchewan River Valley, Saskatoon, Canada.

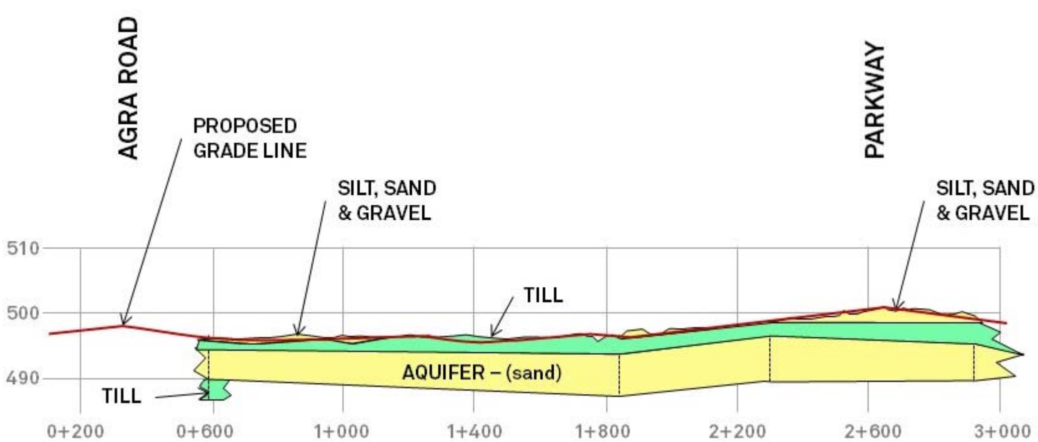

Figure 6 – Stratigraphy along Central Avenue, North Commuter Parkway project, Saskatoon, Canada.

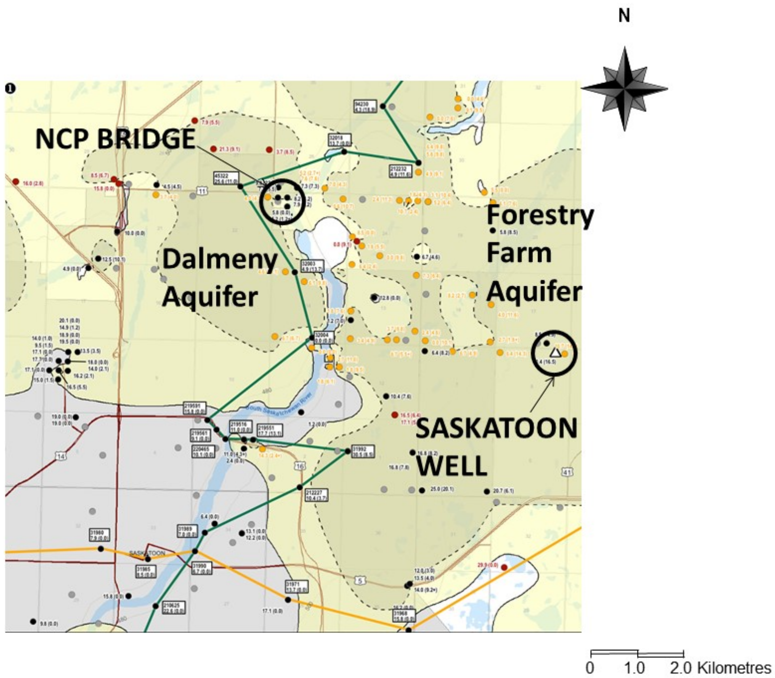

Figure 7 – Intra-till (Floral Formation) aquifers in vicinity of North Commuter Parkway route, Saskatoon, Canada.

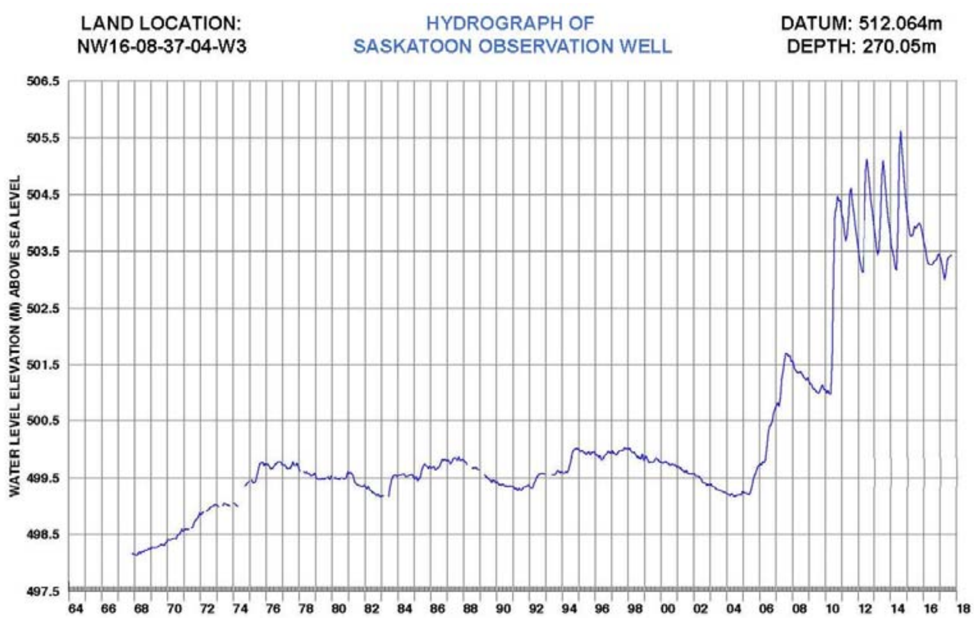

Figure 8 – Hydrograph for WSA Saskatoon observation well representative of water levels in Forestry Farm Aquifer in vicinity of North Commuter Parkway route, Saskatoon, Canada.

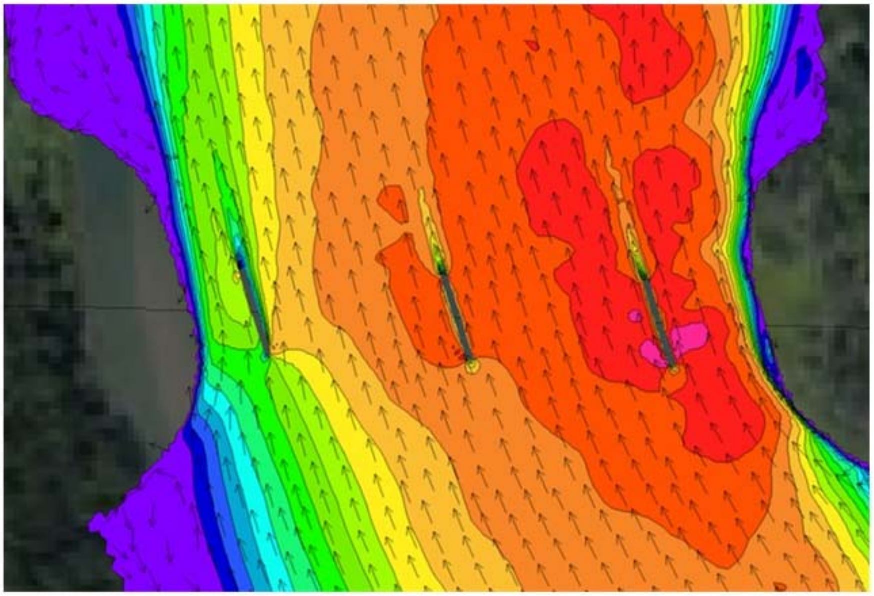

Figure 9 – Typical output from streamflow modeling of the selected bridge configuration for North Commuter Parkway bridge, Saskatoon, Canada.

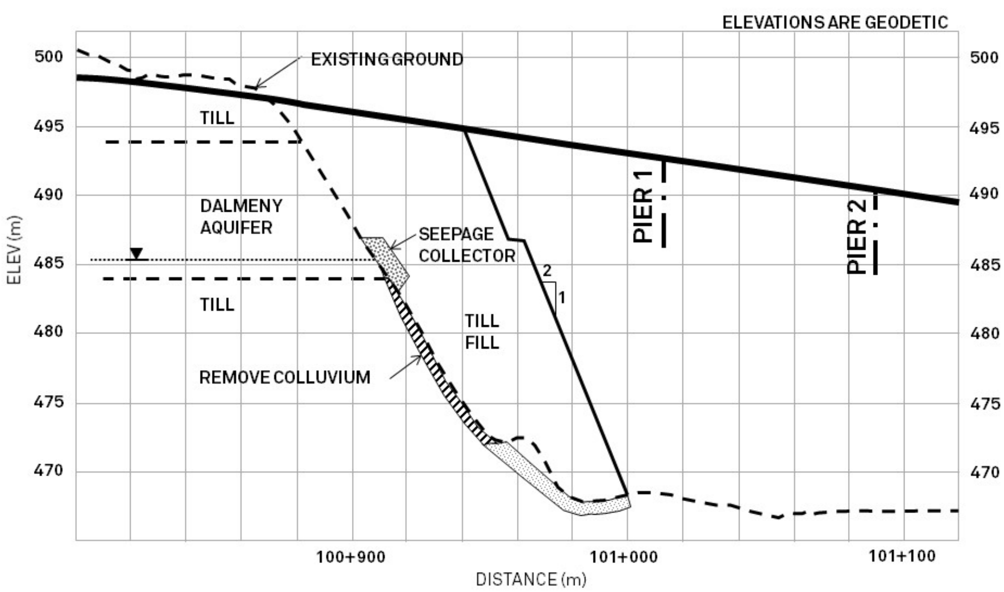

Figure 10 – West approach fill profile showing seepage collection concept at west valley wall, North Commuter Parkway project, Saskatoon, Canada.

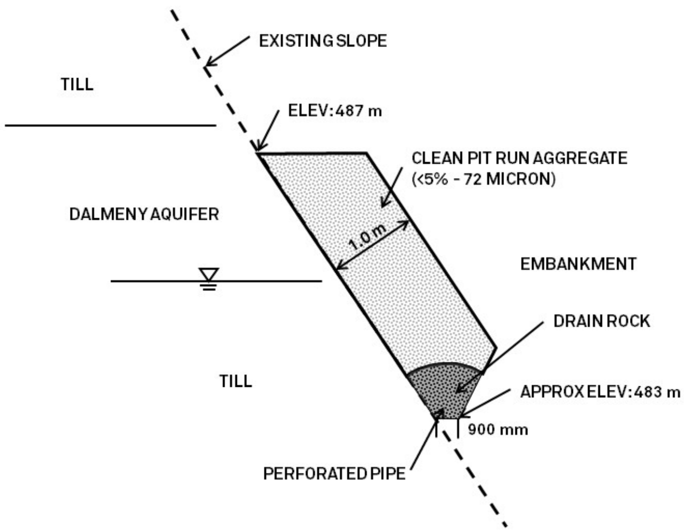

Figure 11 – Typical seepage collection system detail at west valley wall, North Commuter Parkway, Saskatoon, Canada.

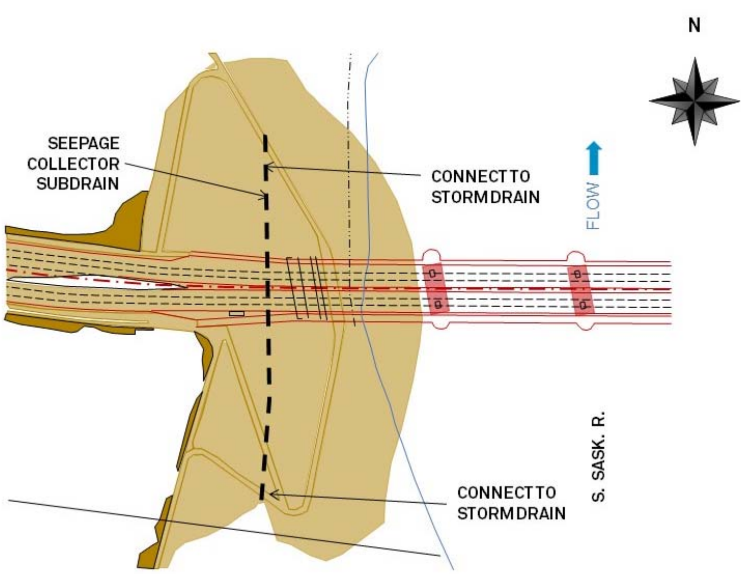

Figure 12 – Conceptual plan of seepage collection and drainage system, north valley wall, North Commuter Parkway, Saskatoon, Canada.