Remediating the inactive Blackfoot Landfill

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ABSTRACT A remediation project was initiated at the inactive Blackfoot Landfill by the City of Calgary to rectify deficiencies in the existing landfill containment system. This paper reviews the history of the site and discusses the selection, design and construction of the various remediation components. The inter-related nature of the processes that are active at the site including: regional groundwater flow, precipitation, decomposition of refuse and instability of natural slopes, is illustrated. Mitigative efforts were selected based on their ability to effectively and economically limit the negative consequences of the active processes. The selected remedial components included upgrading of the landfill cover, implementation of a storm water management system, stabilization of a failed slope and extension of an existing leachate collection system. Relevant design details of each aspect of the remedial work are provided. The project, spanning approximately 10 months and totalling almost $2 Million, was completed in October, 2001. The remedial works are performing very well and plans are underway to turn the site into passive park space.

Introduction

Geographic expansion of cities can lead to urban development of the land surrounding inactive landfills. If the landfill is greater than 20 to 30 years old, it is probable that its design will not satisfy current industry standards. In most cases, it will be impossible to meet such standards without excavating and possibly relocating the entire landfill, which would be prohibitively expensive. Funds available for this type of work can be more effectively used to upgrade and add to existing landfill containment components. Remediation of landfills in this manner requires innovative designs that work within the constraints of the site under consideration. A case history of the design and construction of remediation works for such a site is presented herein.

The City of Calgary has recently completed an extensive remediation project at the inactive Blackfoot Landfill. The landfill is located within the City of Calgary in section SW1/4 35-23-1-5, north of Glenmore Trail on the Bow River Valley escarpment. Originally located outside of the developed core of the city, the site is now surrounded by roadways, light industrial buildings and an electrical substation. A remediation project was initiated by the City of Calgary to rectify deficiencies of the existing landfill containment system. The project that was implemented spanned approximately 10 months and totaled almost $2 Million. This paper presents an overview of the history of the landfill and the remediation design and implementation process.

Site history

Prior to initiating the design process, the site history was reconstructed using available landfill construction records, historical aerial photographs and reports from earlier investigations. The results of this review are summarized below.

Operational history

The Blackfoot Landfill operated as a sanitary landfill between 1968 and 1972. The pre-landfill topography of the site consisted of a gullied side slope of the Bow River Valley escarpment, as shown in Fig. 1. The landfill was operated in a manner that maximized storage capacity and minimized cost. Refuse dumping proceeded from north to south, refuse being placed by end-dumping and spreading over the edge of the slope. It appears that, in most locations, trenches were excavated into the native soil prior to placement of refuse in order to increase the available storage volume and to provide material for the landfill cover.

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Fig. 1. Original topography of the Blackfoot Landfill site (2x vertical exaggeration). The solid black line indicates the final extent of refuse.

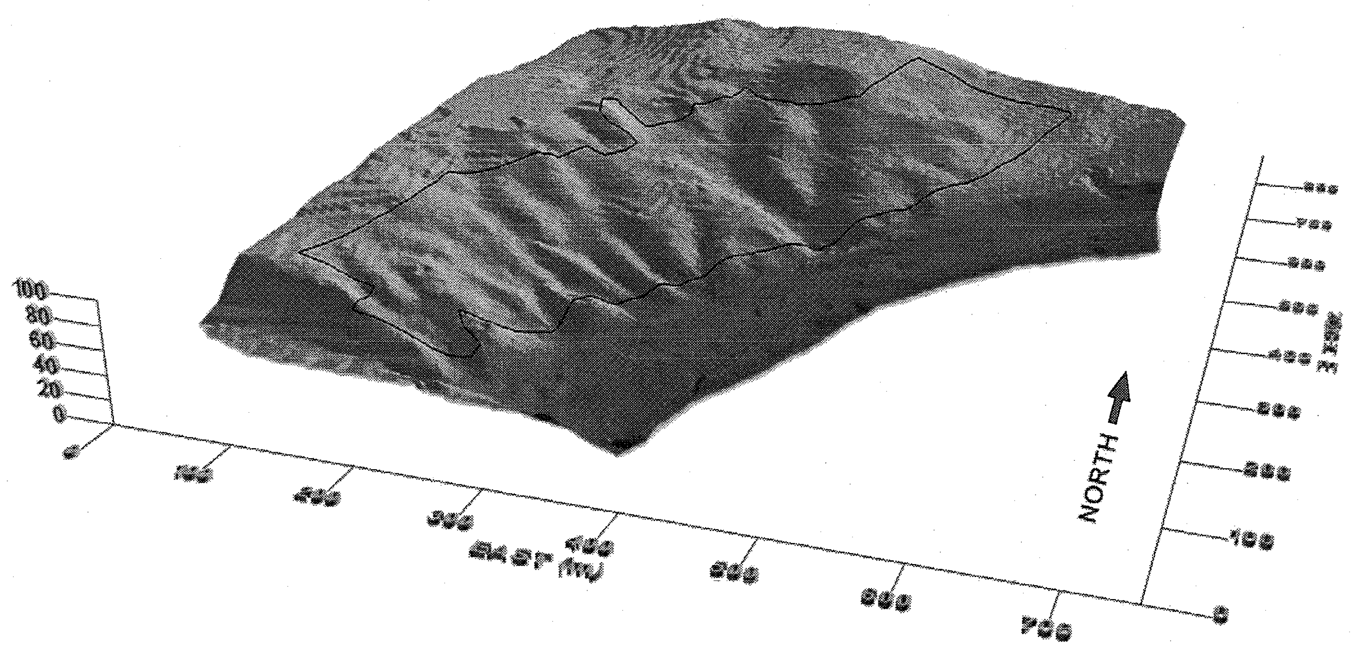
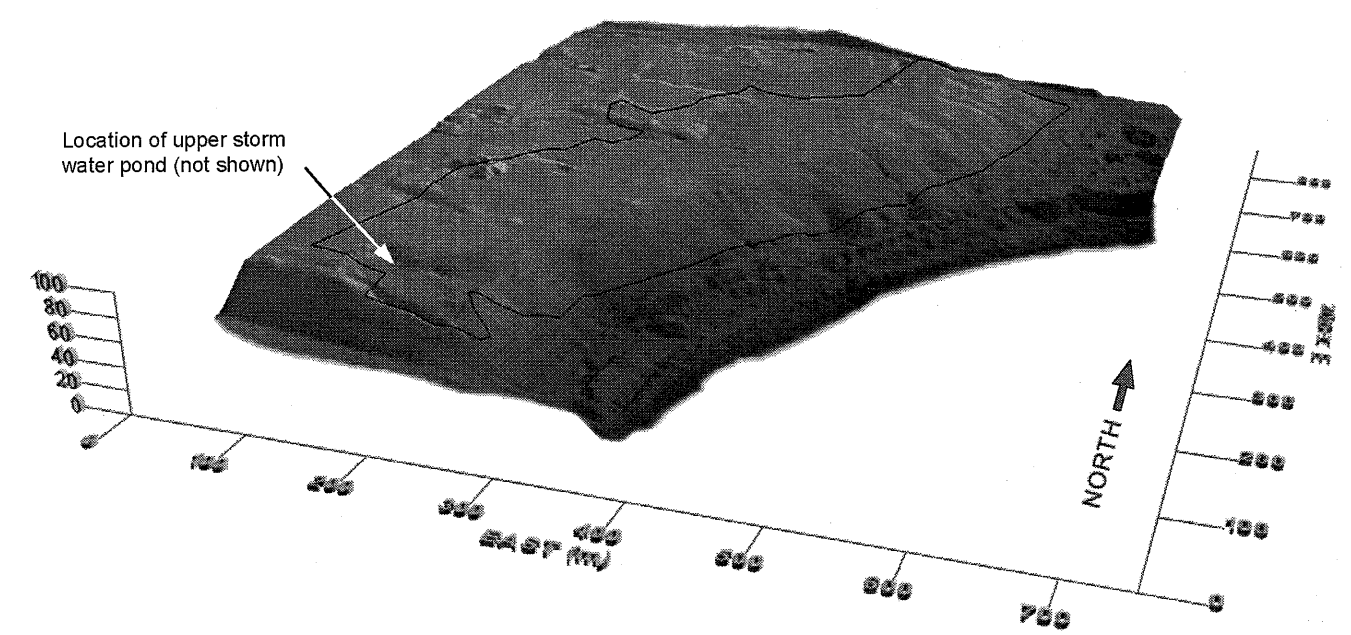


Fig. 2. Topography of the Blackfoot Landfill site following closure, prior to remedial work (2x vertical exaggeration). The solid black line indicates the final extent of refuse.



The topography of the site at closure consisted of a level, upper plateau and a relatively uniform slope leading down to the Bow River valley (Fig. 2). Despite the apparent uniformity of the slope, the nature of the cover varied widely over the site. Test hole and test pit data indicate that the final cover thickness ranged from 0.4 m to greater than 5.0 m. In general, the thickness and quality of the cover improved from north to south.

Post-closure history

Since closure in 1972, the well-vegetated final cover had performed adequately on the upper plateau and over most of the northern half of the landfill slope. Problems in this area have been limited to local leachate seepage along the toe of the slope and the occasional appearance of automobile tires at the ground surface, in areas of thin cover. The portion of the slope at the south end of the landfill, however, has had a complex history of flooding, leachate seepage, landfill gas venting, differential settlement and slope stability problems.

The first remedial measures were performed in 1982 and consisted of the construction of a storm water diversion swale along the crest of the slope, a drop structure at the southern end of the landfill and the installation of a leachate collection system at the toe of the landfill slope within the southern problem area. Subsequent remedial measures have been limited to maintenance of the upper drainage swale and upgrading or extension of the leachate collection system. A review conducted in 1998 indicated a propensity for continued deterioration of the soil cover due to deficiencies in the cover, leachate collection and storm water management systems.

Remediation design

The primary objective of the remediation project was to bring the Blackfoot Landfill site up to the standards required for recreational use areas. In terms of cover requirements, the Alberta Environment (AENV) Code of Practice for Landfills stipulates:

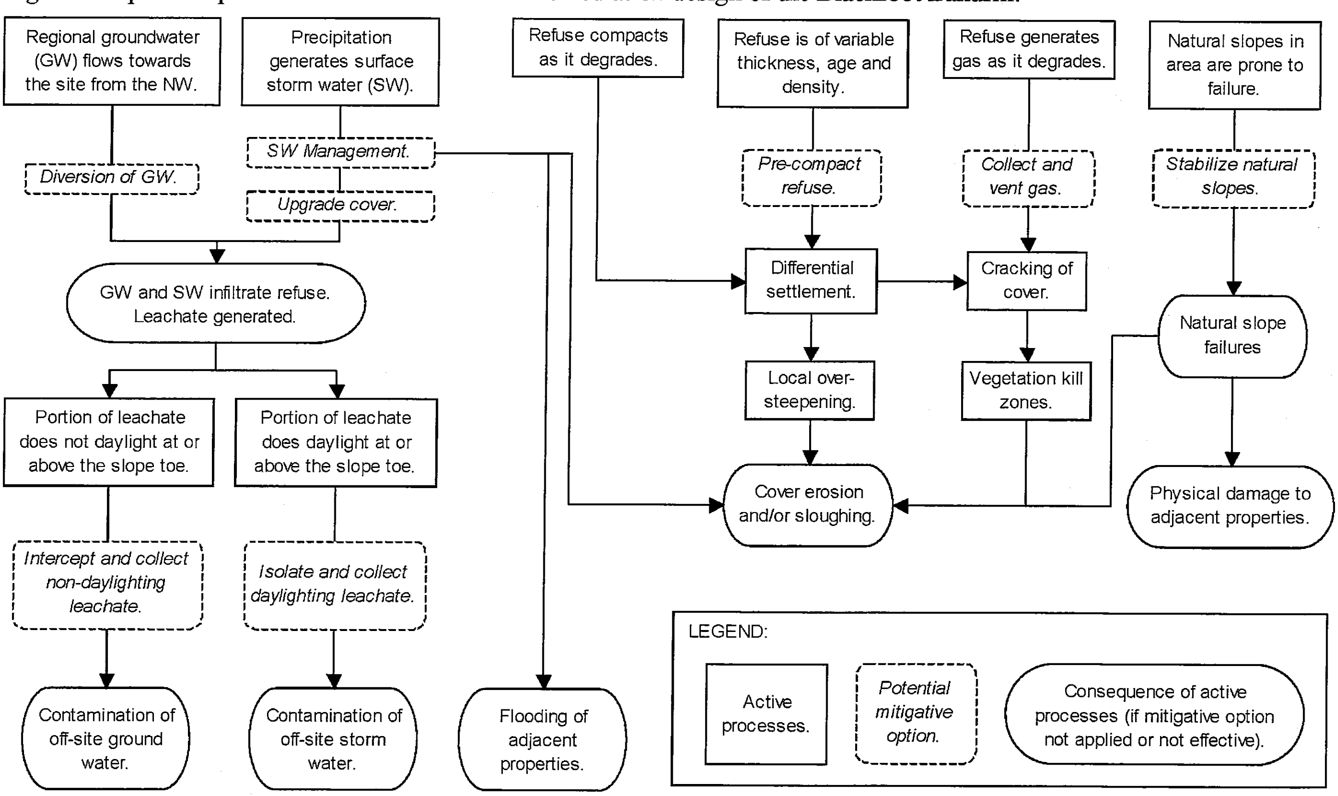
- 0.60 m of earthen material with a maximum permeability of 1 x 10^{-7} m/s, or an alternate material that will achieve equivalent protection, overlain by,
- 0.35 m of subsoil, overlain by,
- 0.20 m of topsoil, seeded with a mixture that is compatible with the intended land use.

An extensive test pitting and drilling investigation revealed that there were areas of cover that did not meet the AENV standard and the simplest approach was to upgrade the entire cover. The area to be covered was approximately 145,000 m^2. A design was developed that would upgrade the cover so that it met or exceeded the AENV standard.

The flowchart shown in Fig. 3 is a somewhat simplified version of the decision-making process employed during the design of the remediation works. The items in square boxes are the primary active processes at the site. Dashed boxes are potential mitigative options (some of which had already been applied to some extent), and rounded boxes are the anticipated consequences of not applying the noted mitigation. Mitigation options include:

- excavation of all refuse, and disposal at another landfill or by incineration (not shown in Fig. 3),

Fig. 3. Simplified optimization flow chart for the remediation design of the Blackfoot Landfill.



- diverting groundwater upstream of the site,
- effective management of storm water,
- collection of leachate daylighting at or above the toe of the slope,
- collection of contaminated groundwater at the toe of the slope,
- pre-compaction of refuse to avoid excessive differential settlement (e.g. by means of dynamic compaction),
- collecting and venting landfill gas, and,
- stabilizing natural slopes.

Removal of the refuse was ruled out because of cost and environmental implications. Likewise, the expense of diverting groundwater from the 800 metre long northwest edge (upgradient side) of the site precluded that option. Pre-compaction of refuse through dynamic compaction was a potential option, particularly at the location of the storm water pond. Unfortunately, areas of interest were generally on or directly above the landfill slope where dynamic compaction would be impractical and could result in slope failures. The remaining mitigation options were all applied to some extent in the remediation design.

Storm water management

The reasonable expense and wide array of anticipated consequences that would be positively affected by efficient storm water management supports the implementation of that option during earlier remediation efforts. It is believed that, due to the relatively low permeability of the native clay tills underlying the landfill, the majority of the leachate generated at the site is derived from infiltration of surface water through the cover, both on and above the landfill slope. Thus, leachate generation can be reduced by an upgraded cover and by the efficient collection, transport and disposal of storm water. Other benefits of an effective storm water management system include reduced flooding of adjacent properties and reduced cover erosion.

As the storm water control measures in place prior to remediation were insufficient to prevent flooding of adjacent properties, a much more comprehensive system was required. In order to quantify the design requirements of such a system, the catchment area contributing to surface flow on the landfill was assessed using existing topographical information and information gathered during several site visits. These data were then used to model a 1:100 year storm event, predict the overland flow magnitudes and hence estimate required storm water detention capacities.

The final storm water management plan included the incorporation of an enlarged swale in the upgraded cover along the crest of the slope and the construction of two detention ponds, located at the top and bottom of the slope. The ponds would temporarily store and discharge storm water runoff from adjacent upslope commercial properties and the landfill slope, respectively.

The pond at the base of the slope is underlain by native soils only and was constructed using a standard compacted clay liner. The areas available for construction of the upper pond were all underlain at least partially by refuse. Figures 2 and 4 indicate the selected location of the pond. This location was selected largely because the south end of the upper plateau is at a lower elevation than the north end and thus an advantageous natural gradient exists. Other advantages included a relatively thick existing cover and a convenient location for the concrete outlet structure that is underlain by native soils only.

It was anticipated that the pond would only be required to store water during and immediately after infrequent storm events. However, the possibility of the detained storm water infiltrating the underlying refuse during these time periods was considered unacceptable because additional leachate could be generated and because elevated groundwater levels in the slope below the pond could create stability problems.

Other important design issues included a) the potential for differential settlement resulting from both mechanical and biological breakdown of underlying refuse, and b) the depth to refuse in the pond area. There was a desire to minimize the quantity of refuse that required excavation, hauling and disposal. The depth to refuse and the thickness of the pond liner therefore limited the base elevation of the pond. As a result, the liner thickness and the height of the pond berm were the only variables that could be modified to meet the required storage capacity. Because pre-compaction of the refuse was not an option, it was considered advantageous to minimize the liner thickness and hence the required containment berm height in order to minimize the additional vertical load that would be applied to the refuse.

Based on the above design issues, it was decided that the optimum liner for the pond would be thin, flexible to allow for differential settlement, and essentially impermeable. The selected design utilized geosynthetic materials to address the design issues, as shown in Figures 5 and 6. A "very flexible polyethylene" (VFPE) membrane was specified to act as the impermeable layer. Due to the undesirable consequences of leakage through the liner, an additional underlying layer of self-healing geosynthetic clay liner (GCL) was included in the design to reduce the possibility of puncture failures. The design includes protective cushion layers above and below the VFPE / GCL layer and the pond liner is integrated with the upgraded cover within the pond berm.

Leachate collection

Remediation options related to reducing the potential for contamination of off-site storm and ground water were given high priority. Drilling records indicated that the underlying native soils were of relatively low permeability. Considering this in combination with historical observations of leachate daylighting at boundaries between refuse and native soils, it was decided that the funds available for leachate collection would be best expended on the collection and disposal of daylighting leachate and shallow groundwater at the toe of the landfill slope.

It was anticipated that the amount of surface water infiltrating through the cover and, accordingly, the quantity of leachate generated at the site would be reduced by the upgraded cover and storm water management systems.

Fig. 4. Plan view of Blackfoot Landfill upper storm water detention pond (contour interval = 0.5 m).

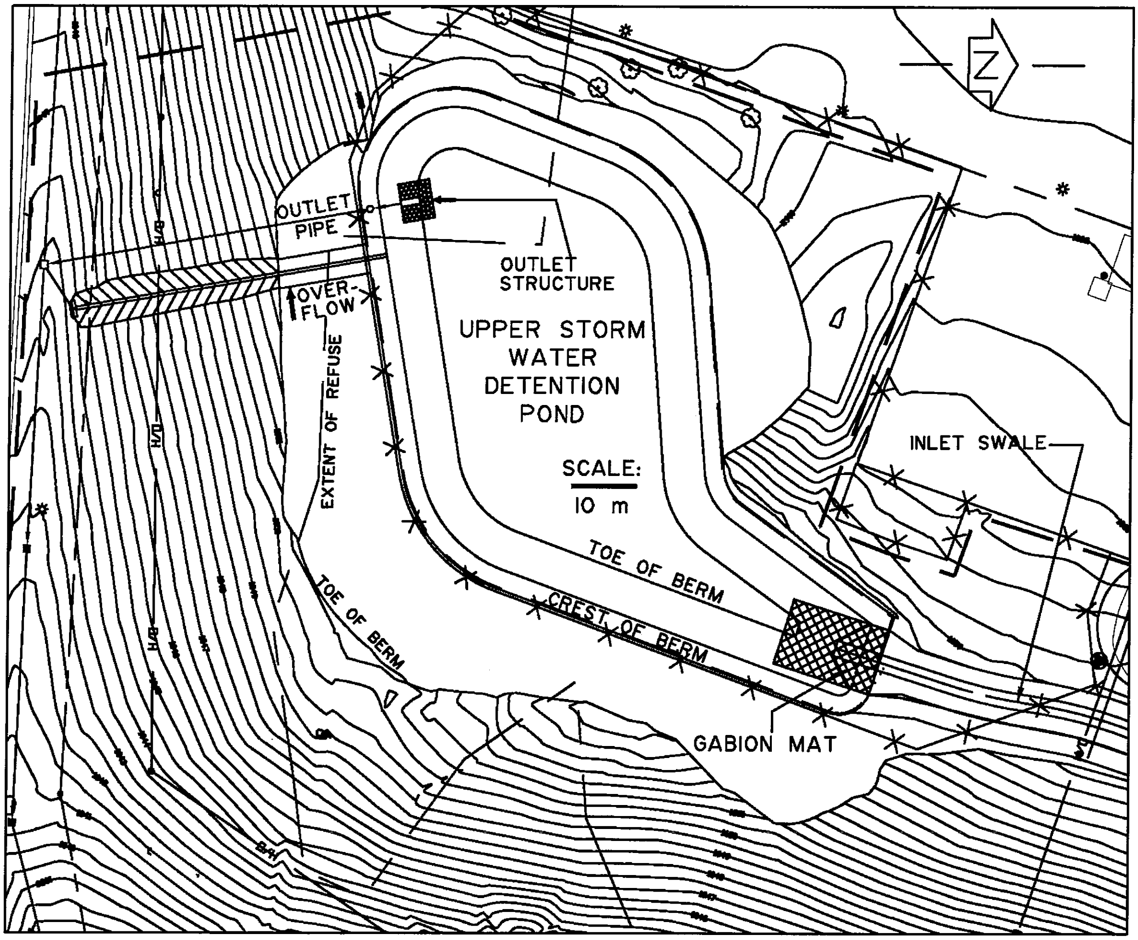


Fig. 5. Typical detail of Blackfoot Landfill upper storm water detention pond liner.

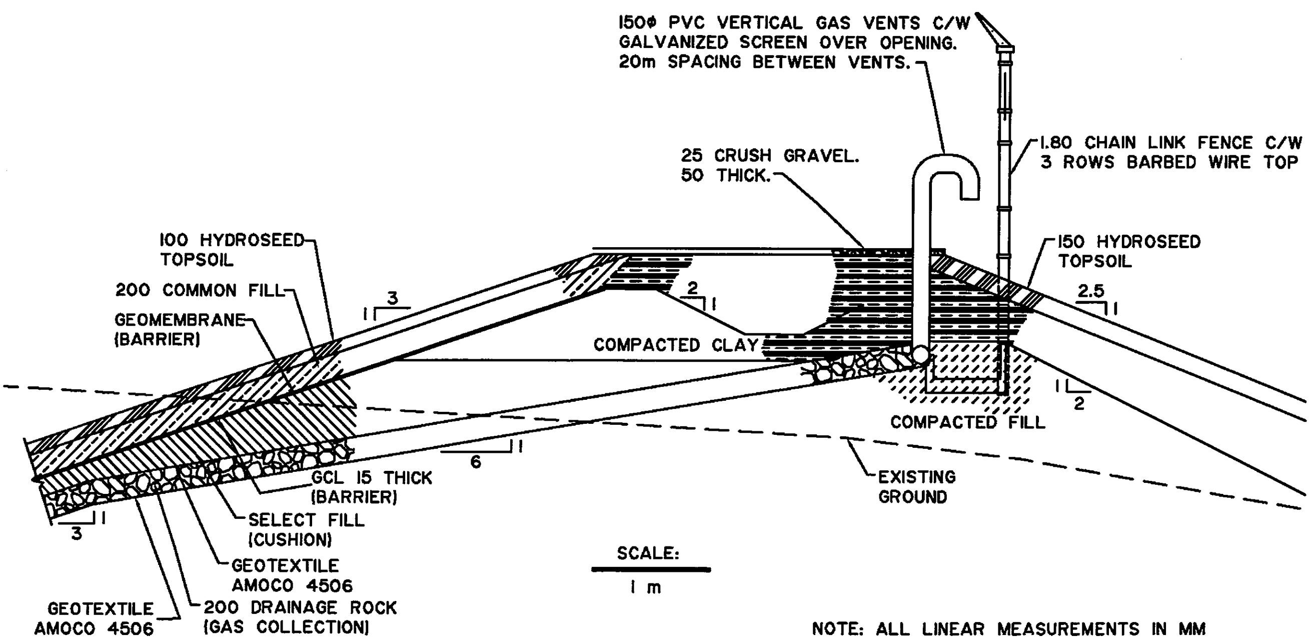
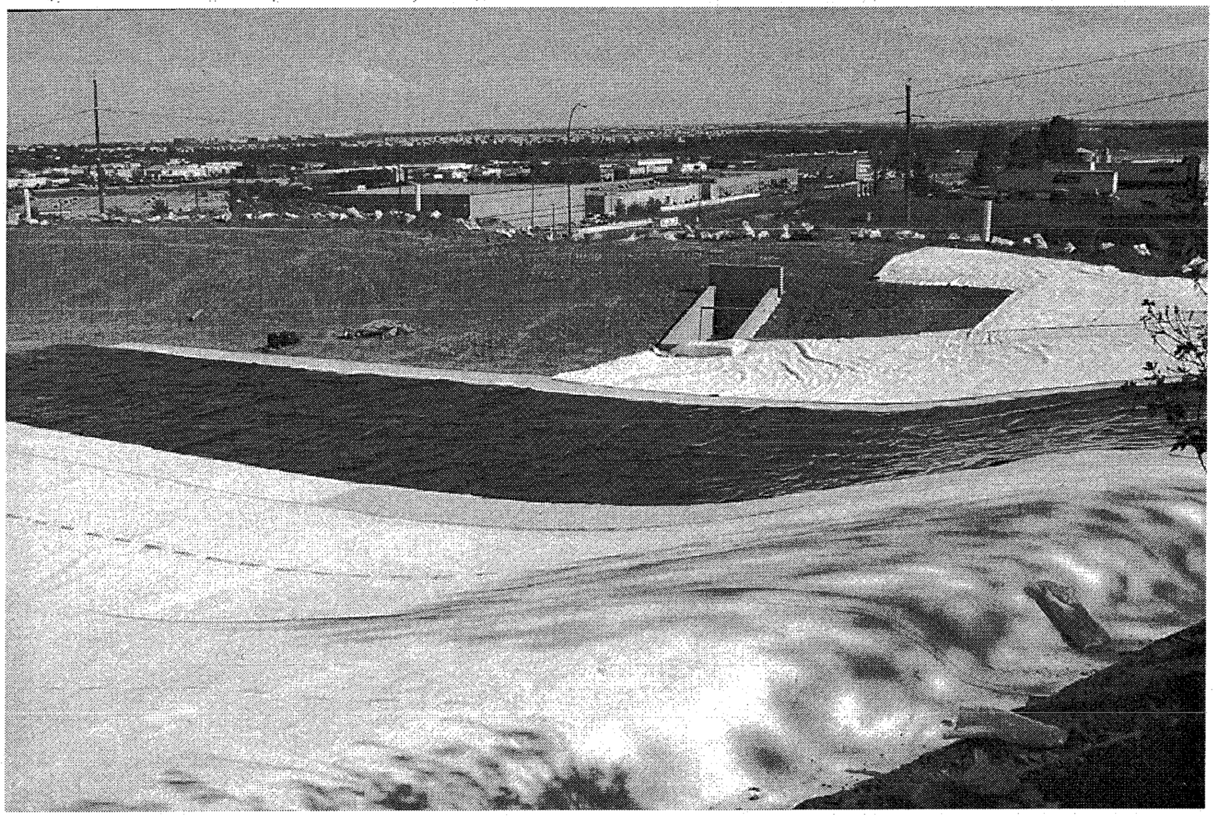


Fig. 6. Photograph taken during installation of the upper storm water pond liner showing placement of VFPE geomembrane (black) over GCL (white). Note white landfill gas vents along the crest of the pond berm.



The existing leachate collection system consisted of a series of slotted pipes installed in gravel filled ditches along the toe of the slope in the southern half of the landfill. A camera inspection of the existing system revealed that the pipes were intact and transporting leachate as intended. One branch of the system was 2/3 full of soil and apparently stagnant water. The presence of coarse soil particles and occasional construction debris indicated that the pipe was likely clogged during installation. The entire system was flushed prior to implementation of the remediation design.

The remediation design included the installation of two new branches of leachate collection pipe totaling roughly 850 m in length. The "mid-slope" branch extends up the slope to an area of historical seepage in the southern problem area. The collection pipe was then installed along a contour of the slope in a gravel-filled ditch. A gravel blanket installed under the upgraded cover in this area was tied into the ditch. A similar approach was used to collect leachate from an area of historical seepage at the north end of the site.

Gas collection and venting

Uncontrolled gas venting had apparently resulted in localized vegetation kill zones, usually around cracks in the landfill cover. It was noted that these zones contributed very little to the erosion of the cover. For this reason, it was decided that the expense of installing a landfill gas collection and venting system over the entire site was not justified. Passive collection and venting systems were installed at two locations, however, for the reasons described below.

The inclusion of an essentially impermeable geomembrane layer in the design of the upper storm water detention pond necessitated the inclusion of a gas collection and venting system. Geomembranes placed over landfills have been known to develop large pockets of landfill gas and even to balloon out under low confining stress. A passive collection system in which the gas is mobilized under natural gradients of concentration and pressure within a layer of drainage rock was selected. The gas is collected in slotted pipes running along the top of the berm and vented to the atmosphere through riser pipes at regular intervals (Figures 5 and 6).

A similar system was installed extending up the slope from the mid-slope leachate collection pipe. This area was the location of the majority of the vegetation kill zones that had been historically observed. The system was installed at relatively low additional cost because the gravel blanket was necessary for leachate collection.

Slope stability

The natural slopes of the Bow River Valley escarpment in the area are prone to failure. A large failure scarp with up to 0.5 m of vertical displacement developed on the southern end of the landfill slope in native soils in 1998. This problem was addressed by the installation of a geogrid reinforced earthen toe berm to load the toe of the slope. It was anticipated that lowered groundwater levels associated with the upgraded cover and improved storm water management would further improve stability.

It was also noted that occurrences of minor sloughing and erosion of the existing landfill cover were concentrated in the southern end of the landfill. The surface slope of the cover in the southern portion of the site was often steeper than 3:1. The landfill cover in areas to the north, with slopes less than 3:1, was generally stable. For this reason, a target maximum slope of 3:1 was selected for the entire landfill cover. In over-steepened areas, this was achieved by the installation of a geogrid reinforced earthen berm along the downslope edge of the landfill cover.

Implementation

In general, implementation of the design proceeded as planned. Construction commenced in April, 2001, beginning with the two storm water detention ponds and the large toe berm at the south end of the site. The project then progressed from south to north, stripping the existing landfill cover to the required design elevation in a series of wide panels (Fig. 7). As much as possible, organic soils were segregated and stockpiled for re-use as topsoil in the final cover. The remaining stripped soil was stockpiled for re-use in the subsoil layer. Clay for the required low permeability layer was imported from a pre-approved off-site source. A suitable hydroseed mixture was applied following placement and compaction of the three layers of the final cover.

Due to construction safety concerns, it was necessary to place the material for the compacted clay layer slightly dry of optimum on the sloped portion of the site. Although there were no problems achieving the specified dry densities, it was anticipated that the permeability of the soil might be higher than if it had been compacted at or slightly higher than the optimum moisture content. Quality control permeability testing revealed, however, that the AENV requirement of 1×10^{-7} m/s had been exceeded.

Refuse was encountered during the excavation of the upper storm water pond. The refuse was excavated and transported to an alternate landfill for disposal. Consideration was given to adding a layer of geogrid over the exposed refuse to increase the tensile strength of the composite pond liner, however it was decided that the original design would be sufficient to accommodate any differential settlement. The installation of a conventional compacted clay liner would have required the excavation, hauling and disposal of a much larger quantity of refuse, at considerable expense.

Construction was completed in October, 2001. A QA/QC program was carried out, which included drilling several shallow test holes along the crest of the slope to confirm the thickness of the cap and to obtain samples for laboratory testing; including grain size distribution, Atterberg limits and permeability testing. The results showed that the upgraded cover exceeded the requirements prescribed by Alberta Environment for recreational use areas.

Fig. 7. Aerial photograph taken during construction of the upgraded landfill cover. Note panel construction method and close proximity of commercial development.

Performance

A recent inspection of the site showed that the remedial measures are performing extremely well, despite the requirement for some minor erosion repair and cracking due to minimal differential settlement. Overall, vegetation has taken well without any notable kill zones or daylighting leachate, which were typical prior to the remediation. Stormwater is also effectively channeled to each of the two stormwater retention ponds and the innovative upper detention pond has not exhibited any signs of distress due to settlement. The successful remediation of this former industrial site will allow it to be converted to a passive park space and "birth forest", where up to 7,000 native trees and shrubs will be planted to commemorate the birth of new Calgarians through a jointly sponsored private / public program.

Summary

A remediation project was initiated at the inactive Blackfoot Landfill by the City of Calgary to rectify deficiencies of the existing landfill containment system. The soil cover required upgrading to meet Alberta Environment standards for recreational area. A history of flooding, leachate seepage, landfill gas venting, differential settlement and slope stability problems indicated that further improvements were required to prepare the site for recreational use. Following a historical review, the remediation design process was initiated by identifying the active processes at the site, the end results of those processes and potential mitigative options. The most efficient and effective mitigative options were incorporated in the remediation design. In addition to an upgraded cover, these options included a comprehensive storm water management system, extensions to an existing leachate collection system, landfill gas collection and venting (as necessary) and slope stabilization using reinforced earthen toe berms. Each planned component of the remediation design was checked against the list of active processes to determine if solutions were breeding new problems. For example, it was anticipated that construction of the upper storm water detention pond could result in differential settlement due to increased loading of the underlying refuse and trapped landfill gas due to the use of impermeable geosynthetics. These problems were addressed by using a thin, flexible liner and by the installation of a passive gas collection and venting system, respectively. The remediation project, spanning approximately 10 months and totalling almost $2 Million, was completed in October, 2001. The remedial works are performing very well, and plans are underway to turn the area into a passive park.

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