

## V.6

# Design of a groundwater protection system at an inactive hazardous waste disposal facility: a case study

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### V.6.1. Introduction

Once contamination is discovered, various remedial alternatives are evaluated for protection of human health and the environment, cost effectiveness, implementability, short-term and long-term efficiency, permanence, and public acceptance. One of the major pathways for contaminants to reach receptors is to be leached out of waste and reach groundwater, which is then consumed by the receptors. Other pathways may include direct contact, ingestion, and inhalation. This chapter describes an improved containment and capping remedy to protect groundwater where a secondary slurry wall, called curtain wall, was used to reduce overall remediation costs by approximately \$1.7 million over the conventional remedy.

Remedial alternatives considered at a hazardous waste landfill to protect groundwater typically include natural attenuation (i.e. no further active remediation), containment and capping, excavation/treatment/disposal, *in situ* treatments, or a combination of these options. Natural attenuation may include a long-term monitoring program to ensure that groundwater is protected. Containment and capping protects groundwater by reducing rainfall infiltration and isolating wastes by placing hydrologic barriers between waste, groundwater, and receptors. The excavation/treatment/disposal alternative requires excavation and treatment of waste to achieve waste acceptance criteria of the disposal facility or backfilling before final disposal. A number of treatment technologies are available based on the contaminants of concern. Treated waste may be disposed off-site or on-site. *In situ* treatment may include technologies such as solidification/stabilization, vitrification, geochemical treatment, soil vapor extraction, air sparging, enhanced bioremediation, and soil washing.

Modeling can be used to determine remedial goals protective of groundwater, evaluate future effectiveness, and design selected remedial actions. Modeling can involve evaluation of hydraulics of groundwater flow alone (Dorrance and Chang, 1991; Bumb et al., 1996a) or performing coupled fate and transport analysis (Berglund and Cvetkovic, 1995; Johnson and Rogers, 1995; Bumb et al., 1996a,b). This chapter uses evaluation of groundwater hydraulics to design a groundwater protection system at an inactive hazardous waste landfill in Northeast United States of America where containment and

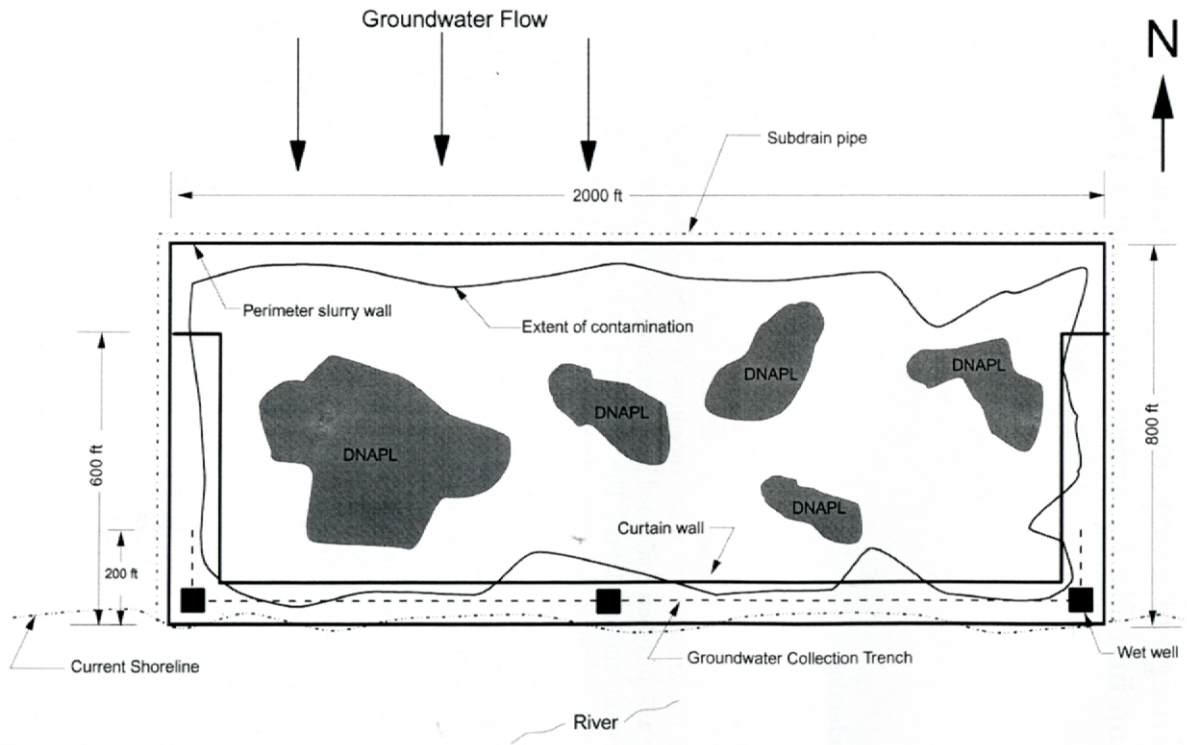


Figure V.6.1. Site map and remediation plan.

capping was the selected remedy. Only a simplified general layout is shown in Figure V.6.1 to avoid revealing the location of the site.

## V.6.2. Background and assumptions

The remedial objective of containment/capping is to protect groundwater and direct contact with waste and contaminated water. Design of a containment/capping remedy to be protective of groundwater is illustrated by the following example. Figure V.6.1 shows the general layout of an inactive landfill and groundwater flow patterns. The uncontrolled landfill is approximately 600 m × 240 m (2000 ft × 800 ft) in size and is located just north of a river. Site investigation revealed that the landfill was used to dispose industrial waste containing chlorinated hydrocarbons, pesticides, PCBs, and metals. Dense non-aqueous phase liquids (DNAPLs) were found within the landfill at local depressions in the underlying confining unit, a clay aquitard (see a generalized cross-section in Figure V.6.2). Distribution of DNAPL and extent of contamination as determined from site investigations are shown in Figure V.6.1. Design is based on the results of site investigation.

Shallow groundwater flows from north to south and discharges into an adjacent river. The saturated thickness of the aquifer at the site ranges from 3 to 4.6 m (10–15 ft). The top of the clay aquitard (clay) is relatively constant with some local depressions. All elevations are referred with respect to the average elevation of the top of the clay under the landfill (see Figure V.6.2). The clay aquitard is relatively thick and has low permeability. Site investigations indicated that contaminants have not migrated more than 0.3 m (1 ft) into the clay.

The basic elements of a typical containment/capping remedy at a hazardous waste landfill include a cap over the landfill, a soil/bentonite<sup>1</sup> perimeter slurry wall keyed into the underlying impermeable layer, and a groundwater collection system. The objectives of a groundwater collection system were to create and maintain an inward gradient across the perimeter slurry wall at the landfill, minimize the potential for off-site migration of contaminated groundwater through the perimeter slurry wall, and minimize the potential for contaminant migration through underlying formations. A secondary slurry wall, referred to as “curtain wall”, has been added in this remedy to more effectively create and maintain an inward gradient across the perimeter slurry wall and to reduce the volume of groundwater that is recovered and treated.

The inward gradient across the perimeter slurry wall could be achieved by reducing the static groundwater level inside the perimeter slurry wall and the curtain wall to at least 0.3 m (1 ft) below the minimum river elevation and the natural groundwater levels outside the perimeter slurry wall. Once this level is attained, inflow will consist of water from the following sources:

- precipitation infiltration through the landfill cap,

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<sup>1</sup> Bentonite is highly colloidal, plastic clay first found near Fort Benton, WY, in cretaceous beds. It has unique characteristic of swelling to several times its original volume when placed in water and it forms thixotropic gels with water.

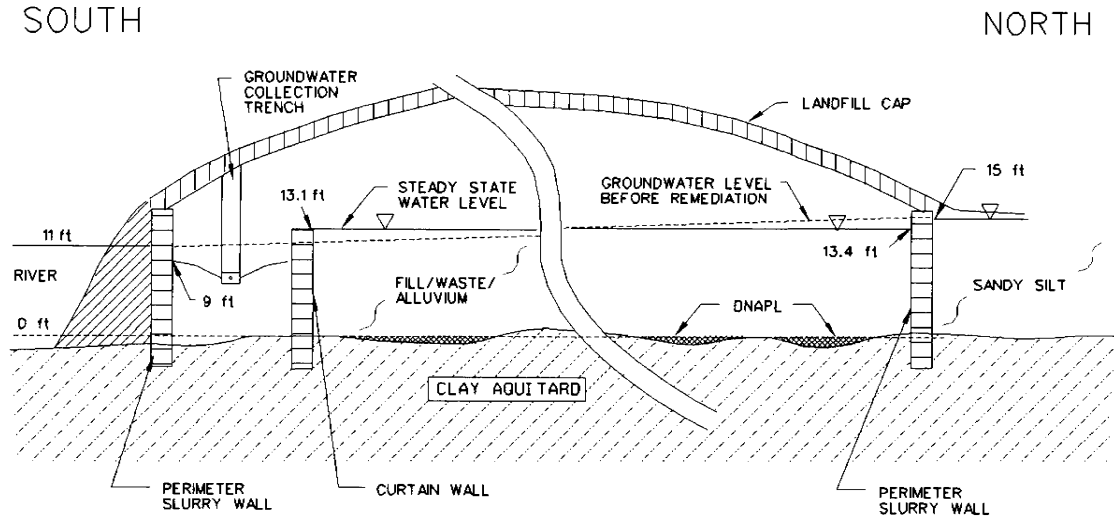


Figure V.6.2. Generalized north-south cross-section.

- groundwater infiltration through the perimeter slurry wall, and
- groundwater infiltration through the clay under the perimeter slurry wall.

A volume of water equal to the infiltration listed above must be pumped to maintain these steady-state water levels. Each of the water sources must be evaluated to estimate steady-state pumping requirements. Conservative assumptions are typically made to estimate maximum infiltration. The following assumptions were used in the calculations:

- The average width of the perimeter slurry wall is 0.9 m (3 ft).
- The average hydraulic conductivity of the perimeter slurry wall is  $1 \times 10^{-7}$  cm/s.
- The average hydraulic conductivity of the underlying clay is  $2 \times 10^{-7}$  cm/s.
- The minimum river elevation is 3.0 m (10 ft) with respect to the top of clay.
- The average river elevation is 3.35 m (11 ft) and significant extended variations from this level do not occur.
- A minimum of 0.3 m (1 ft) differential in water levels should be maintained across the perimeter slurry wall. This essentially means that water level elevations between the perimeter slurry wall and the curtain wall should be maintained at approximately 2.75 m (9 ft).
- The area enclosed within the perimeter slurry wall is approximately 149,000 m<sup>2</sup> (1.6 million square feet).

Installation of the perimeter slurry wall will change the groundwater flow pattern outside the encapsulated landfill and result in groundwater level increase just north of the landfill. The extent of the groundwater mounding was evaluated with the help of a finite-difference model based on the United States Geological Survey modular flow model, known as MODFLOW (McDonald and Harbaugh, 1999; Harbaugh et al., 2000; Mehl and Hill, 2001; Zheng et al., 2001; see also Chapter V.5). Calculations indicated that significant mounding could take place. A subdrain pipe (Fig. V.6.1) was added to the remedy to relieve groundwater mounding north of the landfill.

### V.6.3. Curtain wall

If a perimeter slurry wall alone is installed and groundwater is pumped to maintain an inward gradient, water levels within the landfill will continue to decline until steady-state water levels (approximately 2.75 m (9 ft)) are attained. A curtain wall has been included in the remedial design to reduce water recovery and treatment, and to minimize contaminant concentrations in the extracted water by isolating DNAPL contaminated soils.

To maintain the inward gradients across the perimeter slurry wall, water levels between the perimeter slurry wall and the curtain wall will be maintained approximately 0.3 m (1 ft) below the lowest river elevation and the natural groundwater levels outside the perimeter slurry wall. Water levels within the curtain walled area may remain at a higher elevation. This will reduce water treatment requirements.

A minimum distance of 9 m (30 ft) is required between the perimeter slurry wall and the curtain wall to allow construction of the groundwater recovery system. Therefore, the curtain wall is located 9 m (30 ft) north of the south slurry wall. The top of the curtain

wall, 4.0 m (13 ft), is set at the average water level between the south curtain wall (3.4 m (11 ft)) and the north slurry wall (4.6 m (15 ft)) so that all the water initially in the area contained within the curtain wall will stay in that area. Once all the remedial actions have been implemented, water levels within the curtain walled area should equilibrate to a nearly flat surface due to the bathtub effect (see Appendix A). Water levels north of the perimeter slurry wall are approximately 4.6 m (15 ft). Therefore, a curtain wall is not required on the north side. Similarly, the curtain wall is not required for the northern 60 m (200 ft) segments of western and eastern parts of the slurry wall. The proposed location of the curtain wall is shown in Figure V.6.1.

### ***V.6.3.1. Reduction in initial water treatment requirements***

The alluvium and fill in the landfill will gravity drain from initial water level to final water level after the perimeter slurry wall, curtain wall, and cap are constructed. Water content of the drained alluvium and fill will decrease from full saturation (total porosity) to the field capacity. The difference between total porosity and field capacity is the specific yield. The specific yield of the alluvium/fill was assumed to be 25%. Therefore, the volume of groundwater to be pumped initially, in excess of additional infiltration, to achieve steady-state groundwater levels is calculated by:

$$\text{Volume} = (\text{Area}) \times (\text{Average Head Difference}) \times (\text{Specific Yield})$$

Note that this estimate does not include infiltration to the encapsulated landfill as calculated later.

If curtain wall is not installed, the average water level of 3.96 m (13 ft) inside the perimeter slurry wall would be reduced to the steady-state water level of 2.75 m (9 ft). The total area enclosed within the slurry wall is 149,000 m<sup>2</sup> (1,600,000 ft<sup>2</sup>). Therefore, the total volume of water to be pumped to achieve steady state is then estimated to be 45,400 m<sup>3</sup> (12,000,000 gal).

When the curtain wall is installed, all the groundwater initially in the area contained within the curtain wall will stay in that area (as per the design of the top of the curtain wall). Therefore, only groundwater in areas on the south, east, and west between the curtain wall and the perimeter slurry wall needs to be lowered to 2.75 m (9 ft). It represents an area of 9000 m<sup>2</sup> (94,000 ft<sup>2</sup>) and amount of water to be pumped to achieve steady state is estimated to be 1700 m<sup>3</sup> (460,000 gal). Therefore, installation of the curtain wall results in reducing initial water treatment requirements from 45,400 m<sup>3</sup> (12 million gallons) to 1700 m<sup>3</sup> (0.46 million gallons), i.e. a reduction of 43,700 m<sup>3</sup> (11.5 million gallons) or a 96% reduction. Using calculations similar to that presented later, it can be shown that 16% reduction in steady-state water treatment requirements is also achieved as gradients across the perimeter slurry wall are reduced.

Using a water treatment cost of \$53 per cubic meter (20 cents per gallon), reduction of groundwater pumping by 43,700 m<sup>3</sup> (11.5 million gallons) results in reducing water treatment costs by \$2.3 million. The cost of installing a 957 m (3140 ft) long by 5 m (16.4 ft) high curtain wall (including 1 m tie-in) is estimated to be approximately \$600,000. Therefore, a net cost reduction of \$1.7 million is achieved by installing the curtain wall.

#### V.6.4. Water balance within the curtain wall

The inflow to the area within the curtain wall then consists of:

- surface water infiltration through the cap,
- groundwater infiltration through the northern portion of perimeter slurry wall, and
- groundwater infiltration beneath the northern portion of perimeter slurry wall.

The outflow from the curtain walled area consists of movement through and under the curtain wall and any overflow.

##### V.6.4.1. Infiltration through the cap

Infiltration through the cap was estimated using the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1988; Scientific Software Group, 2003) for two landfill cap designs shown in Figure V.6.3. Both designs are similar except “Alternate A” incorporates a 30 cm (12 in.) silty clay layer under a 60 mil very low density polyethylene (VLDPE) or equivalent liner while “Alternate B” uses a prefabricated geosynthetic clay liner, with maximum permeability of  $1 \times 10^{-9}$  cm/s, under a 40 mil VLDPE or equivalent liner. The “topsoil” was simulated as sandy loam, “select fill” was simulated as silty loam, and the geotextile/geonet layer was simulated as a 2.5 cm (1 in.) layer of coarse sand with a hydraulic conductivity of  $1 \times 10^{-2}$  cm/s. Soil properties were taken from Rawls et al. (1982) and the HELP model documentation. A hydraulic conductivity range of  $10^{-5}$ – $10^{-6}$  cm/s was used for the silty clay layer.

An intact liner does not allow any water to infiltrate. However, liners are known to develop small leaks during installation and due to differential settling over its life. The number of leaks is a function of the method of installation, construction material used, waste in the landfill, and quality assurance/quality controls used. Thick liners are expected to develop a smaller number of leaks than thin liners. The “Alternate B” liner was assigned a leakage factor of 0.01 (maximum value of typical range), which corresponds to leaks in the liner on an approximately 15 m (50 ft) square grid. This is a conservative assumption that results in overestimating the seepage through the cap. The 60 mil VLDPE liner (“Alternate A”) was assumed to develop fewer leaks and therefore was assigned a leakage factor of 0.003, which corresponds to leaks on an approximately 30 m (100 ft) square grid. Average climatological data for the local area were used as input to the HELP model. The area enclosed by the curtain wall is approximately 140,000 m<sup>2</sup> (1,506,000 ft<sup>2</sup>).

For “Cap Section – Alternate A” (Fig. V.6.3), the HELP model calculated infiltration of 8300 liters per day (l/d) (2200 gallons per day (gpd)) through the cap using a hydraulic conductivity of  $10^{-5}$  cm/s for the silty clay layer below the 60 mil VLDPE liner. If  $10^{-6}$  cm/s hydraulic conductivity of silty clay layer could be achieved, the infiltration through the cap is estimated to be 844 l/d (223 gpd). In comparison, if the leaks in the 60 mil VLDPE liner occur on an approximately 15 m (50 ft) square grid, then the infiltration is estimated to be as high as 25,700 l/d (6800 gpd).

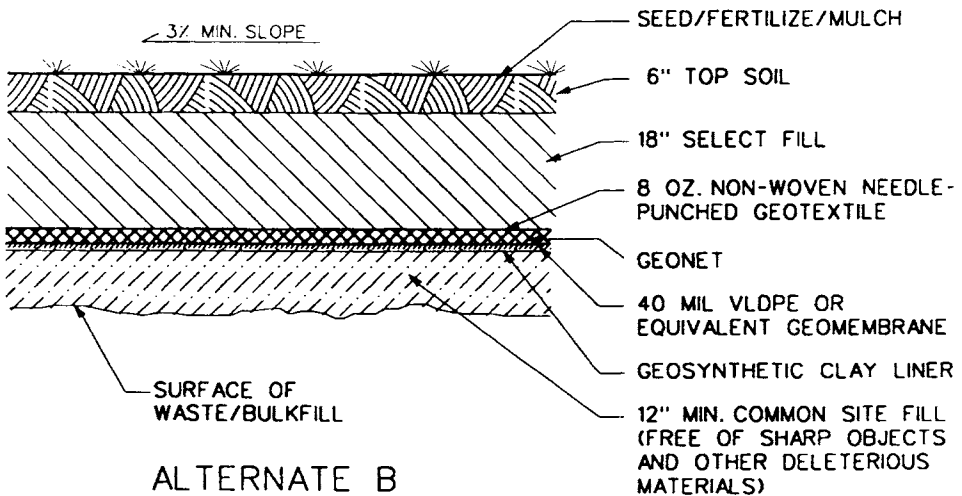
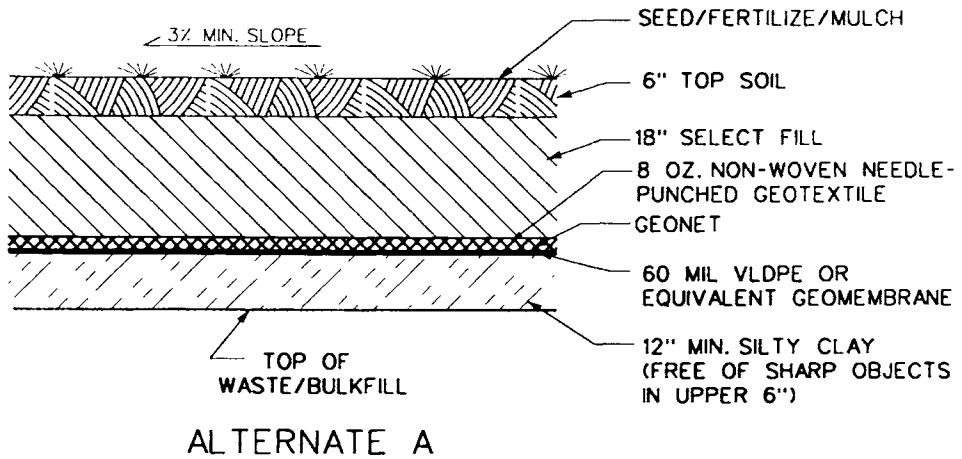


Figure V.6.3. Alternate landfill cap sections.

For "Alternate B" cap (Fig. V.6.3), the HELP model estimated infiltration to be 606 l/d (160 gpd) through the cap. Note that the liner in "Alternate B" cap was assumed to develop leaks on an approximately 15 m (50 ft) square grid.

Based on these cap design calculations the "Alternate B" cap design would allow less infiltration than the "Alternate A" cap design. Additionally, it may be difficult to install a 30 cm (12 in.) silty clay layer ("Alternate A") and obtain the desired hydraulic conductivity of  $10^{-6}$  cm/s, which is required to obtain performance essentially equal to that of "Alternate B" cap design. Therefore, "Alternate B" cap design was selected, and will be used in the remainder of this chapter.

#### V.6.4.2. Groundwater infiltration through perimeter slurry wall

It was assumed that the saturated thickness on the north side will not change appreciably, from the data presented in Figures V.6.1 and V.6.2, once the subdrain pipe to control groundwater mounding is in place. Overall steady-state flow rate is not very sensitive to small changes in the saturated thickness as infiltration under and through the slurry wall is small compared to the total inflow to the landfill. The average head difference across the northern perimeter slurry wall was estimated to be 0.6 m (2 ft). Infiltration is calculated using Darcy's Law:

$$Q = KiA = K\left(\frac{\Delta h}{W}\right)A \quad (\text{V.6.1})$$

where:

- $A$  = saturated area of the perimeter slurry wall, 2790 m<sup>2</sup> (30,000 ft<sup>2</sup>),
- $i$  = hydraulic gradient across the perimeter slurry wall,
- $K$  = hydraulic conductivity of the perimeter slurry wall,  $1 \times 10^{-7}$  cm/s,
- $Q$  = infiltration through the perimeter slurry wall,
- $W$  = perimeter slurry wall thickness, 1 m (3 ft), and
- $\Delta h$  = average head difference across the perimeter slurry wall.

The calculations shown in Table V.6.1 indicate that the infiltration through the perimeter slurry wall to the curtain wall enclosed area is approximately 184 l/d (49 gpd).

#### V.6.4.3. Groundwater infiltration under the perimeter slurry wall

The perimeter slurry wall will be keyed into the confining clay layer. Flow paths may be created beneath the wall and into the encapsulated landfill area, driven by the head differential across the perimeter slurry wall. Along the north side and 60 m (200 ft) sections of east and west sides, infiltration under the slurry wall will be to the curtain walled area. The remaining infiltration, along the south side and three-fourths of east and west sides, under the perimeter slurry wall is isolated from the area contained by the

Table V.6.1. Infiltration under and through the slurry wall to the area contained by the curtain wall.

Side	Length, m (ft)	Average saturated thickness, m (ft)	Average head difference, m (ft)	Infiltration, l/d (gpd)	
				Through slurry wall	Under slurry wall
North	610 (2000)	4.6 (15.0)	0.61 (2.0)	160.5 (42.4)	32.2 (8.5)
East	61 (200)	4.4 (14.5)	0.46 (1.5)	11.7 (3.1)	2.3 (0.6)
West	61 (200)	4.4 (14.5)	0.46 (1.5)	11.7 (3.1)	2.3 (0.6)
Total	732 (2400)			183.9 (48.6)	36.8 (9.7)

curtain wall. The infiltration rate for this source is estimated using Darcy's Law:

$$Q = KiA = K\left(\frac{\Delta h}{L_f}\right)(L_s W_f) = K\Delta h L_s \left(\frac{W_f}{L_f}\right) \quad (\text{V.6.2})$$

where:

$A$  = cross-sectional area for flow path under the perimeter slurry wall,

$i$  = hydraulic gradient across the perimeter slurry wall,

$K$  = hydraulic conductivity of the clay,  $2 \times 10^{-7}$  cm/s,

$L_f$  = length of flow line (across which head difference is used),

$L_s$  = length of the perimeter slurry wall,

$Q$  = infiltration under the perimeter slurry wall,

$W_f$  = width of flow zone under the perimeter slurry wall, and

$\Delta h$  = head difference across the perimeter slurry wall.

Flowlines under the slurry wall have to at least traverse the flow width twice, once going down and once coming up. Therefore, a conservative estimate of 1/2 for the ratio of flow width to flow length is used. Total infiltration under the perimeter slurry wall to the area contained by the curtain wall is estimated to be approximately 37 l/d (10 gpd) (Table V.6.1).

#### **V.6.4.4. Groundwater movement through a curtain wall**

At steady state, water levels in the area enclosed by the curtain wall should be 3.96 m (13 ft) and the water level between the curtain wall and the perimeter slurry wall should be 2.75 m (9 ft). Therefore, the head difference across the curtain wall is calculated to be 1.2 m (4 ft). The hydraulic conductivity of  $1 \times 10^{-7}$  cm/s was used for a 1 m (3 ft) wide soil/bentonite curtain wall, and groundwater movement is estimated using Darcy's Law:

$$Q = KiA = K\left(\frac{\Delta h}{W}\right)A \quad (\text{V.6.3})$$

where:

$A$  = saturated area of the curtain wall, 3792 m<sup>2</sup> (40,800 ft<sup>2</sup>),

$i$  = hydraulic gradient across the curtain wall,

$K$  = hydraulic conductivity of the curtain wall,  $1 \times 10^{-7}$  cm/s,

$Q$  = water movement through the curtain wall,

$W$  = curtain wall thickness, 1 m (3 ft), and

$\Delta h$  = average head difference across the curtain wall, 1.2 m (4 ft).

The estimated groundwater movement through a soil/bentonite curtain wall is 435 l/d (115 gpd).

#### **V.6.4.5. Groundwater movement under the curtain wall**

The curtain wall will be keyed into the confining clay layer. Flow paths may be created beneath the wall, driven by the head differential across the curtain wall. Water movement

rate under the curtain wall is estimated using Darcy's Law:

$$Q = KiA = K\Delta hL_s \left( \frac{W_f}{L_f} \right) \quad (\text{V.6.4})$$

where:

- $A$  = cross-sectional area for flow path under the curtain wall,
- $i$  = hydraulic gradient across the curtain wall,
- $K$  = hydraulic conductivity of clay,  $2 \times 10^{-7}$  cm/s,
- $L_f$  = length of flow line (across which head difference is used),
- $L_s$  = length of the curtain wall, 957 m (3140 ft),
- $Q$  = water movement under the curtain wall,
- $W_f$  = width of flow zone under the curtain wall, and
- $\Delta h$  = head difference across the curtain wall, 1.2 m (4 ft).

Flowlines have to at least traverse the flow width twice, once going down and once coming up. Therefore, a conservative estimate of 1/2 for the ratio of flow width to flow length was used. The estimated water movement under the soil/bentonite curtain wall is 98 l/d (26 gpd).

#### ***V.6.4.6. Inflow vs. outflow from the area contained by the curtain wall***

Estimated total inflow to the area contained by the curtain wall is:

Through the cap "Alternate B"	606 l/d	160 gpd
Through the perimeter slurry wall	184 l/d	49 gpd
Under the perimeter slurry wall	37 l/d	10 gpd
<b>Total inflow</b>	<b>827 l/d</b>	<b>219 gpd</b>

Estimated total outflow from the area contained by a soil/bentonite curtain wall is:

Through the curtain wall	435 l/d	115 gpd
Under the curtain wall	98 l/d	26 gpd
<b>Total outflow</b>	<b>533 l/d</b>	<b>141 gpd</b>

The estimated potential total outflow from a soil/bentonite curtain wall is smaller than the estimated inflow to the area contained by the curtain wall. Therefore, excess groundwater will flow over the top of the curtain wall and be collected in the groundwater collection system.

#### **V.6.5. Steady-state groundwater pumping requirements**

To achieve the purpose of the groundwater collection system, it will be necessary to create and maintain inward gradient across the perimeter slurry wall. This could be achieved by

reducing the static groundwater level inside the area between the perimeter slurry wall and the curtain wall to approximately 0.3 m (1 ft) below the river elevation and the natural groundwater levels outside the perimeter slurry wall. Once this level is attained, infiltration will consist of water from the following sources:

- inflow to the area contained by the curtain wall,
- precipitation infiltration through that portion of the cap, which overlies the area between the perimeter slurry wall and the curtain wall,
- groundwater infiltration through the perimeter slurry wall, and
- groundwater infiltration beneath the perimeter slurry wall.

An equivalent volume of water must be pumped to maintain steady-state water levels.

#### ***V.6.5.1. Inflow to the area contained by the curtain wall***

Total inflow to the area contained by the curtain wall was estimated to be 827 l/d (219 gpd) (see calculations in the preceding section). All the inflow to the area contained by the curtain wall will eventually drain to the groundwater collection system either as flow under, through, or over the curtain wall.

#### ***V.6.5.2. Additional infiltration through the cap***

In the previous section, it was shown that the average infiltration through “Alternate B” cap over 140,000 m<sup>2</sup> (1,56,000 ft<sup>2</sup>) area was approximately 606 l/d (160 gpd). The area between the curtain wall and the perimeter slurry wall is approximately 9000 m<sup>2</sup> (94,000 ft<sup>2</sup>). Therefore, the average infiltration through the cap over this 9000 m<sup>2</sup> area is estimated to be 38 l/d (10 gpd).

#### ***V.6.5.3. Groundwater infiltration through the perimeter slurry wall***

The saturated area of the perimeter slurry wall, through which water may infiltrate, varies around the site with the elevations of the top of the confining clay layer and the water table. For illustration purposes, average elevation of the top of the clay layer is used. An inward head difference of 0.3 m (1 ft) across the slurry wall on the south side (near the river) is the controlling factor in selecting water levels in the encapsulated landfill area because the river is on the downgradient side. Water levels inside the perimeter slurry wall are designed to be maintained at 2.75 m (9 ft). Average water level data, on the east, west, and south sides were used to determine the steady-state gradients. Infiltration was estimated using Darcy’s Law identically as it was used in the calculations in groundwater infiltration through the perimeter slurry wall described in the previous section (see Equation (V.6.1)). Table V.6.2 shows that the total infiltration through the perimeter slurry wall to the area between the perimeter slurry wall and the curtain wall is estimated to be 257 l/d (68 gpd).

Table V.6.2. Infiltration through and under the perimeter slurry wall to the area contained by the perimeter slurry wall and the curtain wall.

Side	Length, m (ft)	Average saturated thickness, m (ft)	Average head difference, m (ft)	Infiltration, l/d (gpd)	
				Through slurry wall	Under slurry wall
South	610 (2000)	3.35 (11.0)	0.61 (2.0)	117.3 (31.0)	32.2 (8.5)
East	183 (600)	3.81 (12.5)	1.07 (3.5)	70.0 (18.5)	17.0 (4.5)
West	183 (600)	3.81 (12.5)	1.07 (3.5)	70.0 (18.5)	17.0 (4.5)
Total	976 (3200)			257.3 (68.0)	66.5 (17.5)

#### V.6.5.4. Groundwater infiltration under the perimeter slurry wall

The perimeter slurry wall will be keyed into the confining clay layer. Flow paths may be created beneath the wall and into the encapsulated landfill area, driven by the head differential across the perimeter slurry wall. The infiltration rate for this source is estimated using Darcy's Law analogously as it was shown in the previous section (see Equation (V.6.2)). Calculations for infiltration under the perimeter slurry wall are summarized in Table V.6.2. Total infiltration under the perimeter slurry wall is estimated to be 66 l/d (18 gpd).

#### V.6.5.5. Total flow into the groundwater collection trench at steady state

Sources of inflow to the encapsulated landfill area and related rates based on the "Alternate B" cap design are summarized in Table V.6.3. A conservative estimate of total water inflow of less than 1500 l/d (400 gpd) into the groundwater collection trench is anticipated at steady state. These numbers are based on an annual average basis. The actual daily inflow will vary with fluctuations in river elevation, seasonal water table, and changes in rainfall and climatologic conditions.

Table V.6.3. Sources of water to the groundwater collection system.

Source	Inflow rate, l/d (gpd)
Total inflow to (outflow from) area contained by the curtain wall	827 (219)
Infiltration through cap between the curtain wall and the perimeter slurry wall	38 (10)
Infiltration through the perimeter slurry wall	257 (68)
Infiltration under the perimeter slurry wall	66 (18)
Total	1188 (315)

### V.6.6. Groundwater collection system

The groundwater collection system can consist of vertical wells, horizontal wells, or a trench with a number of wet wells. Use of both the vertical wells and trench with wet wells to recover groundwater and control gradients are proven technologies. However, due to low permeability of silty sand near the river and small saturated thickness at this site, a large number of vertical wells would be required to ensure minimum of 0.3 m (1 ft) inward gradient along the southern section of the slurry wall. Therefore, vertical wells were eliminated in favor of the trench and wet well system. Horizontal wells have gained popularity in last few years. However, it may be difficult to install horizontal wells in an uncontrolled landfill containing construction debris. A trench can be installed by conventional excavation technology with side slopes followed by installation of a perforated pipe in a pea gravel bed and backfilling. A trench can also be installed by use of biodegradable slurry to keep a small trench open while the perforated pipe is installed. Use of biodegradable slurry is preferred, as this will minimize contact with potentially contaminated soils and groundwater. Therefore, a groundwater collection trench installed using biodegradable slurry was selected for this application. Three wet wells, as shown in Figure V.6.1, at low points in the groundwater collection trench will be used to pump the contaminated water and maintain inward gradients.

Anticipated groundwater mounding within the enclosed landfill area is minimal (see Appendix A). Therefore, the trench along the full length of the perimeter slurry wall on the east and west sides is not required. As shown in Figure V.6.1, the groundwater collection trench will extend 60 m (200 ft) on east and west sides.

### V.6.7. Summary

A curtain wall has been added to a typical remedy to reduce the total volume of groundwater that will be recovered and treated, to maintain groundwater levels within the curtain wall at current levels, and to minimize migration of DNAPL to the groundwater collection trench. Installation of a curtain wall is expected to save approximately \$1.7 million in remediation costs.

The “Alternate A” cap design uses a 30 cm (12 in.) silty clay layer beneath a 60 mil VLDPE liner while “Alternate B” uses a geosynthetic clay liner beneath a 40 mil VLDPE or equivalent liner. The “Alternate B” cap design has been shown to be more effective in reducing rainfall infiltration and was selected in the remedial design.

A conservative estimate, i.e. more than anticipated, of total water inflow of less than 1500 l/d (400 gpd) into the landfill area is estimated at steady state for cap design “Alternate B”. These numbers are based on annual averages. The actual daily inflow will vary with fluctuations in river elevation, seasonal water table, and bedrock head potential, and changes in rainfall and climatologic conditions.

Approximately 1900 m<sup>3</sup> (500,000 gal) of groundwater will be pumped out of the landfill before a 0.3 m (1 ft) head differential across the perimeter slurry wall and a steady-state infiltration and pumping requirement of less than 1500 l/d (400 gpd) is achieved.

**Appendix A: Maximum mounding within the area contained by the curtain wall**

Maximum groundwater mounding within the area contained by the curtain wall is estimated using the equation (Bear, 1979):

$$h_{\max} = \left[ \frac{L^2 I}{4K} + h_0^2 \right]^{0.5} \quad (\text{A.1})$$

where:

$h_{\max}$  = maximum hydraulic head,

$h_0$  = hydraulic head at the southern section of the curtain wall,

$I$  = inflow rate per unit area,

$K$  = hydraulic conductivity of alluvium/fill, and

$L$  = two times the distance between the south curtain wall and north perimeter slurry wall.

Using 235 m (770 ft) for the distance between the south curtain wall and north perimeter slurry wall,  $5 \times 10^{-4}$  cm/s for the hydraulic conductivity of alluvium/fill, 3.99 m (13.08 ft) for the hydraulic head at the south curtain wall (measured from the confining layer), and a total inflow of 829 l/d (219 gpd) over 140,000 m<sup>2</sup> (1,506,000 ft<sup>2</sup>) area,  $h_{\max}$  is calculated to be 4.01 m (13.16 ft). Therefore, the maximum groundwater mound within the area contained by the curtain wall will be 0.02 m (0.08 ft). Actual mounding may be less because of overflow on the east side and the west side curtain walls. Therefore, a uniform water level of approximately 4 m (13.1 ft) should be maintained within the area contained by the curtain wall.

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