# USE OF WATERLOO BARRIER IN PROGRESSIVE RECLAMATION OF HYDDROCARBON PLUME

Christoph Wels, Robertson GeoConsultants Inc., Vancouver, B.C., Canada

ABSTRACT

Historic leaks of diesel fuel had resulted in hydrocarbon contamination of soil and groundwater on several neighbouring properties in North Vancouver, B.C. requiring remediation by separate parties. A Waterloo Barrier® cutoff wall was installed over a length of 270m and a maximum depth of 12m effectively splitting the contaminant plume into two separate entities. On one side of the barrier, extraction wells and a shallow drain were installed and operated to prevent overtopping and/or movement of contaminated groundwater around the barrier. On the other side, the contaminated soil was excavated and replaced with clean fill. During excavation, a secondary sheet pile wall with cross beams and/or anchors were used to provide structural support for the cutoff wall. The groundwater extraction system on the up-gradient (contaminated) side of the cutoff wall was operated over a period of three years to prevent recontamination of the remediated area. Detailed monitoring of groundwater levels and water quality has been carried out to demonstrate successful operation of this hydraulic barrier system.

RÉSUMÉ

Des épanchements historiques de carburant diesel ont engendré la contamination de sols et d'eau souterraine aux hydrocarbones sur plusieurs propriétés voisines de North Vancouver, Colombie-Britannique, requérant des travaux de restauration par divers groupes concernés. Un mur de séparation de type "Waterloo Barrier®" a été installée sur une longueur totale de 270 m à une profondeur maximale de 12 m, séparant efficacement le panache de contamination en deux entités distinctes. Des puits d'extraction ainsi qu'un drain de surface ont été installés d'un coté de la barrière, et opérés de façon à prévenir le débordement et/ou le mouvement d'eau souterraine contaminée autour de la barrière. De l'autre côté de la barrière, les sols contaminés ont été excavés et remplacés par des matériaux de remplissage propres. Afin de procurer un support structural à la barrière Waterloo pendant les travaux d'excavation, une seconde barrière de feuilles de métal pourvue de poutres transverses a été utilisée en combinaison avec/ou en remplacement d'ancrages au sol. Du côté amont (contaminé) du mur de séparation, le système d'extraction d'eau souterraine a été opéré sur une période de trois ans afin de prévenir la contamination des terrains restaurés. Un suivie détaillé des niveaux d'eau et de la qualité de l'eau souterraine a été réalisé pour démontrer le succès du système de captage hydraulique.

## 1. INTRODUCTION

Historic operations of a former upgradient bulk plant (Home Oil Depot) dating back to the 1920s resulted in hydrocarbon contamination of soils and groundwater at the Home Oil Depot property and several neighboring properties in North Vancouver, British Columbia (Figure 1). In 1997, Concert Properties Ltd., the owner of one of the neighboring properties, submitted plans to develop a commercial business park on their property. However, local regulations required that the containment portions of the Concert lands and the Fell Avenue right of way (so-called Area A Plus) had to be remediated prior to development.

Remediation of Area A Plus was complicated by the presence of contaminated soils and groundwater located on the upgradient properties, which represented a threat for recontamination during and following site clean-up. Following unsuccessful negotiations with the owner of the neighboring properties to coordinate remedial activities, Concert Properties Ltd. decided to hydraulically isolate the upgradient areas so that they could carry out remediation of their own lands.

Robertson GeoConsultants Inc. (RGC) was retained to design a hydraulic barrier system for Area A Plus that would allow such a partial remediation of the hydrocarbon plume and prevent future recontamination from any up-gradient source. This paper describes the design, construction and performance monitoring of this hydraulic barrier system.

## 2. DESIGN OF HYDRAULIC BARRIER SYSTEM

The hydraulic barrier system had to meet the following design objectives: (i) provide a physical cutoff of two adjacent properties to a depth of 12m with minimum land disturbance, (ii) prevent movement of contaminated

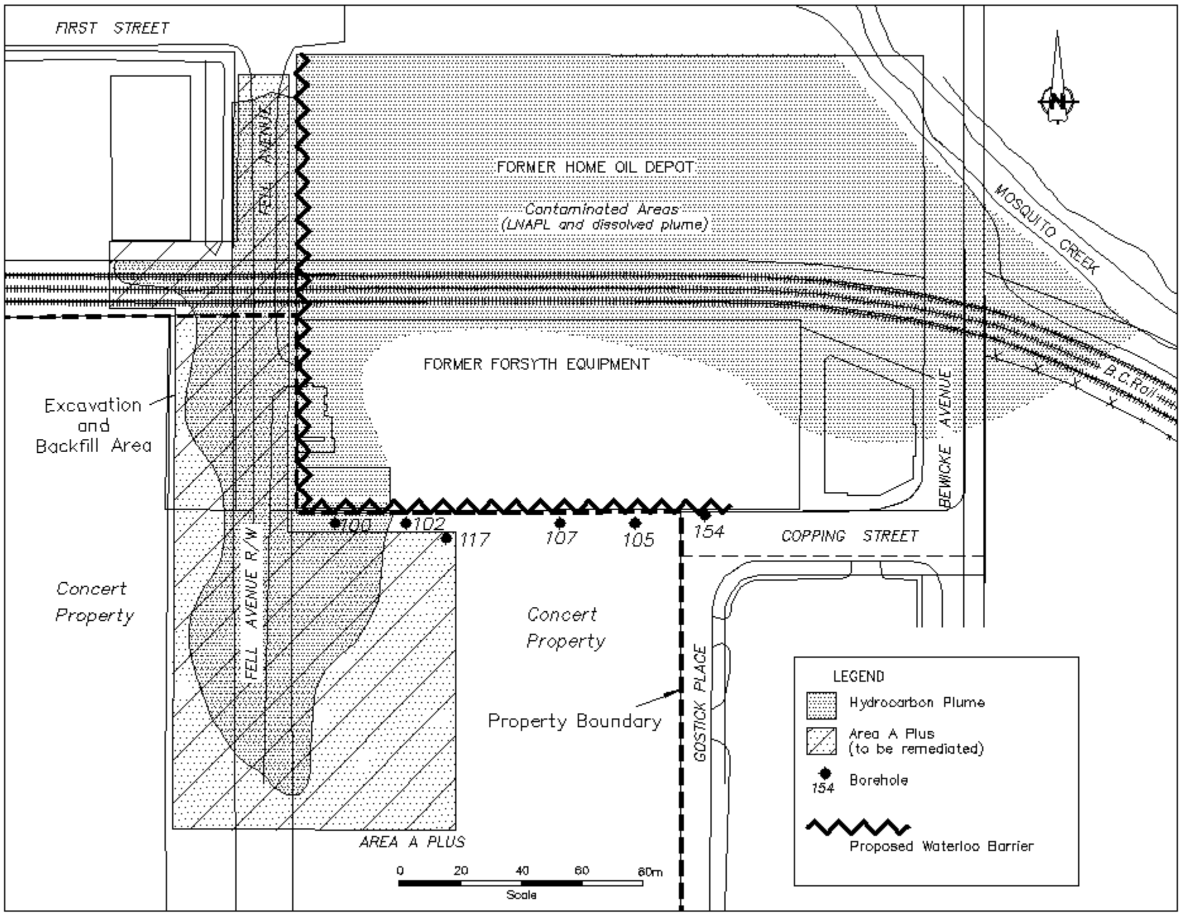


Figure 1. Location map of "Area A Plus" prior to remediation.

groundwater from the upgradient properties (Home Oil Depot and/or Forsyth) onto Area A Plus during and following remediation, and (iii) provide shoring during remedial excavation work to a maximum depth of 5.2m.

Based on these objectives, a Waterloo Barrier® cutoff wall system was selected for this project. The Waterloo Barrier® system consists of interlocking sheet piles that can be sealed with a cement-based grout to develop a hydraulic barrier of very low effective hydraulic conductivity ($<10^{-9}$ m/s) ($C^3$ Environmental, 1998). In this project, the main advantages of the Waterloo Barrier system over other conventional containment technologies such as slurry walls or geomembranes was the ease of installation to significant depths with minimal land disturbance and the potential to provide shoring during remedial excavation.

The conceptual design called for the installation of the cutoff wall along the property boundary between Area A Plus and the up-gradient properties to the east and north (Figure 1). In addition, a groundwater extraction system, consisting of pumping wells and shallow drains was required on the up-gradient side of the cutoff wall to prevent movement of contaminated groundwater around or beneath the cutoff wall and/or overtopping.

Figure 2 shows a detailed hydrostratigraphic section along the east-west run of the cutoff wall based on drilling information. The site is characterized by thin deposits of inter-tidal and fluvial sediments underlain by a hard till-like formation at a depth ranging from 9-14m below ground (Robertson GeoConsultants Inc., 1999). While all stratigraphic units are hydraulically connected, the aquifer system can be subdivided into (i) an upper unconfined aquifer consisting of SAND fill (layer A); (ii) a middle confined aquifer consisting of gravelly SAND to sandy GRAVEL (layer C); and a lower confined aquifer consisting of SAND and GRAVEL (layer E). The middle aquitard (layer D) pinches out towards the north and east resulting in only one single confined aquifer (layer C') being present in these areas (Figure 2). The lower aquitard (layer F) was encountered in all boreholes and has a thickness of at least 2 m. Grain size (hydrometer) analyses suggest that this aquitard unit is predominantly silt (73% silt) with some clay (20%). A dense, till-like silt and sand unit was encountered in all deep boreholes at a depth ranging from 9 to 14 m below grade. This unit likely has a much lower permeability than those of the shallower sand and gravel layers and is considered a (local) aquiclude (Robertson GeoConsultants Inc., 1999).

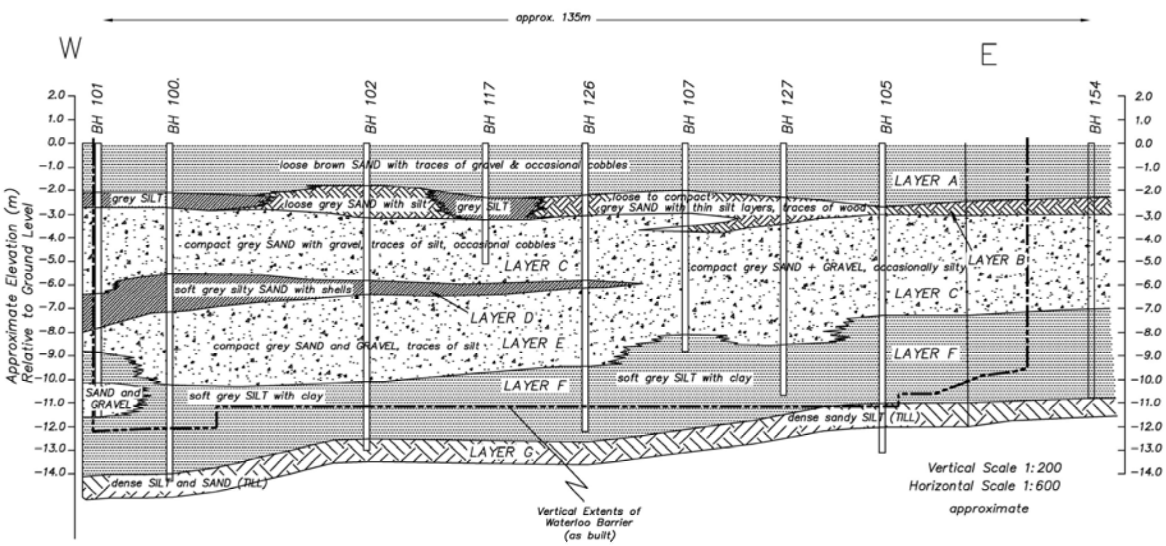


Figure 2. Hydrostratigraphic section along East-West run of Waterloo Barrier.

Detailed groundwater, soil and vapour analyses from samples collected during numerous drilling investigations suggested that the hydrocarbon contamination in Area A Plus was limited to the top 4.0-4.5m below grade (Next Environmental, 1998). However, and the remediation program entailed over-excavation of at least 0.5 m to ensure removal of all hydrocarbon-impacted soils. Note that there was insufficient information on the vertical extent of hydrocarbon contamination on the up-gradient properties. Hence, it could not be ruled out that groundwater flowing in the deeper aquifer units (layer E and lower parts of layer C') may also be contaminated.

The hydraulic properties of the various aquifer and aquitard units were determined using slug tests and several 24-hour pump tests (RGC 1998). The hydraulic testing results and static water level monitoring were used to calibrate a three-dimensional groundwater flow model for the site (using MODFLOW). The calibrated flow model was then used to determine the detailed specifications for the hydraulic barrier system, including vertical and horizontal extent of the cutoff wall, location and number of extraction wells and drains required, and the required extraction rates to maintain adequate drawdown on the up-gradient side of the barrier (for sizing of a water treatment plant).

Detailed sensitivity analyses indicated that a partial cutoff (e.g. to a depth of ~6m bgs) would be adequate to protect Area A Plus from recontamination, provided sufficient groundwater would be pumped to maintain a differential drawdown across the cutoff wall. However, a partial cutoff would require significantly higher pumping rates (and water treatment costs) and provide less structural support for the cutoff wall during excavation. Based on these factors and the uncertainty about the depth of contamination on the up-gradient property, it was decided to key the cutoff wall into the lower silt aquitard. This way, the Waterloo Barrier also provided a complete cutoff for the deeper aquifer units (layer E and layer C').

Figure 3 shows the simulated piezometric surface for the middle aquifer (layer C) for the case of the cutoff wall keyed into the lower aquitard and the use of six extraction wells screened in the middle aquifer (layer C and upper layer C', respectively) and an assumed drawdown of 0.5-0.8m. Particle tracking (with MODPATH) was used to ensure capture of any potentially contaminated groundwater originating within the perimeter of the hydrocarbon plume on the up-gradient properties (Figure 3). The model further suggested, that a shallow drain would be required along the east-west run of the cutoff wall to prevent overtopping of the shallow groundwater during the wet winter season (Robertson GeoConsultants Inc., 1998).

## 3. CONSTRUCTION OF WATERLOO BARRIER

The cutoff wall and temporary shoring system was installed during the period between July 12th and August 21st, 1998. C$^3$ Environmental (Breslau, Ontario) was responsible for coordinating the installation of the cutoff wall and shoring systems and for performing the QA/QC program (C$^3$ Environmental, 1998).

### 3.1 Materials

The Waterloo Barrier® sheet pile is a patented section with an enlarged joint which allows for the installation of a site-specific sealant material to reduce the permeability of the barrier wall. Due to the fact that the barrier system was also to be used as temporary shoring during the contaminated soil removal phase of the site remediation project, structural design considerations required the use of a sheet piling with a thickness of 9.5mm (0.375 inches). Table 1 summarizes the general section properties of the WEZ-95 sheet pile used for this project.

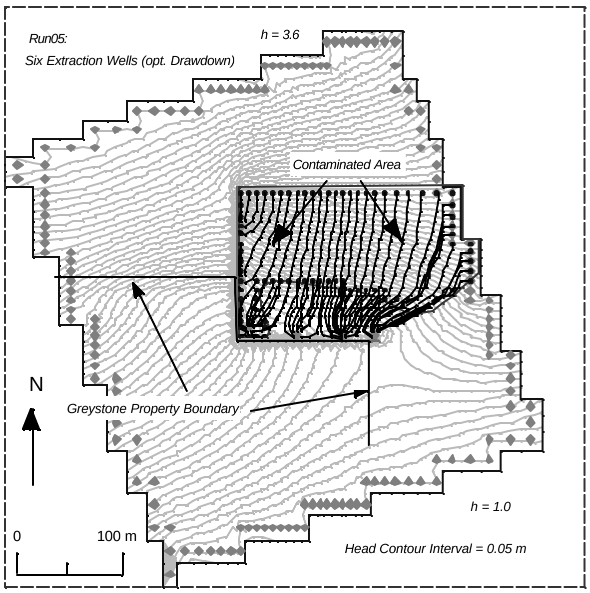


Figure 3. Simulated capture of contaminated groundwater in middle aquifer.

Table 1. Section Properties of WEZ-95 Sheet Piling.

| Parameter | Sheet Pile Specifications |
|---|---|
| Nominal Width | 635 mm |
| Height | 275 mm |
| Thickness | 9.5 mm |
| Section Area | 96.2 $cm^2$ |
| Weight | 75.2 kg per lineal meter |
| Moment of Inertia (I) | 18,300 $cm^4$/wall m |
| Radius of Gyration (r) | 110 mm |
| Section Modulus (S) | 1340 $cm^3$/wall m |

A pre-packaged silica fume modified, cementitious based grout (WBS-301) was used to seal the joints of the sheet piles. WBS-301 consists of a blend of fly ash, silica fume, cement and chemical admixtures, which forms a stable and impermeable grout.

Figure 4 shows the as-built alignment of the constructed cutoff wall, which generally followed the design specifications. The depth of the cutoff wall ranged from 9m at the eastern end to a maximum of 12m near the centre (Figure 2). In total, approximately 3,251 square metres of Waterloo Barrier® WEZ-95 sheet piling was installed and approximately 4,800 lineal metres of sealable cavity was grouted.

3.2 Sheet Pile Driving

Vancouver Pile Driving, of North Vancouver, B.C., was contracted to install the WEZ-95 sheet piles. Individual sheet pile sections were lifted into a driving frame using a 70-ton mobile crane. The driving frame acted as a guide to assist in setting and "stabbing" the sheet piling, (ie. initial driving of the sheet piling to a depth sufficient to support the weight of the pile). This method helped the pile driver to maintain the plumbness of the vertical axis and to follow the desired line of the barrier (Photo 1).

A key procedure in ensuring proper installation of the WEZ-95 pile is the attachment of a driving shoe (foot plate) at the base of every enlarged joint. The driving shoe prevents the entry of debris through the base of the sheet pile joint during pile installation.

In general, the piles were driven to the depth of the frame, the frame was then moved and another group of piles were "stabbed". At that stage, the previous group of piles were driven to the full design depth. The purpose of this procedure was to ensure that the enlarged joint, with the footplate, was driven onto the smaller interlock thus minimizing the entry of debris in the cavity. All sheet pile sections were driven into place using an ICE 416 vibratory pile driver/extractor. Under normal circumstances two neighbouring sheet piles were driven simultaneously.

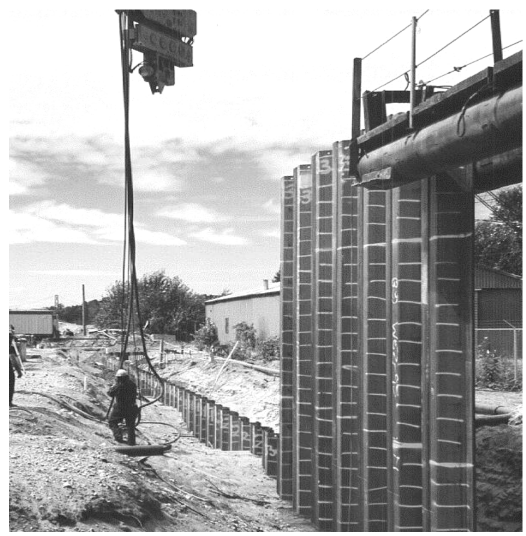

Photo 1. Driving WEZ-95 sheet pile using driving frame.

The QA/QC program for the sheet pile installation included (i) visual inspection of the WEZ-95 piles prior to installation; (ii) documentation of driving times for each pile and/or pile pair driven, (iii) inspection and documentation of the vertical alignment of each sheet pile, and (iv) flushing/probing of each joint to confirm that the sealable cavity was free of obstructions and installed to the required depth.

3.3 Temporary Shoring

In order to excavate contaminated soil adjacent to the barrier a temporary shoring system was required to support the sheet piling. The maximum depth of the ex-

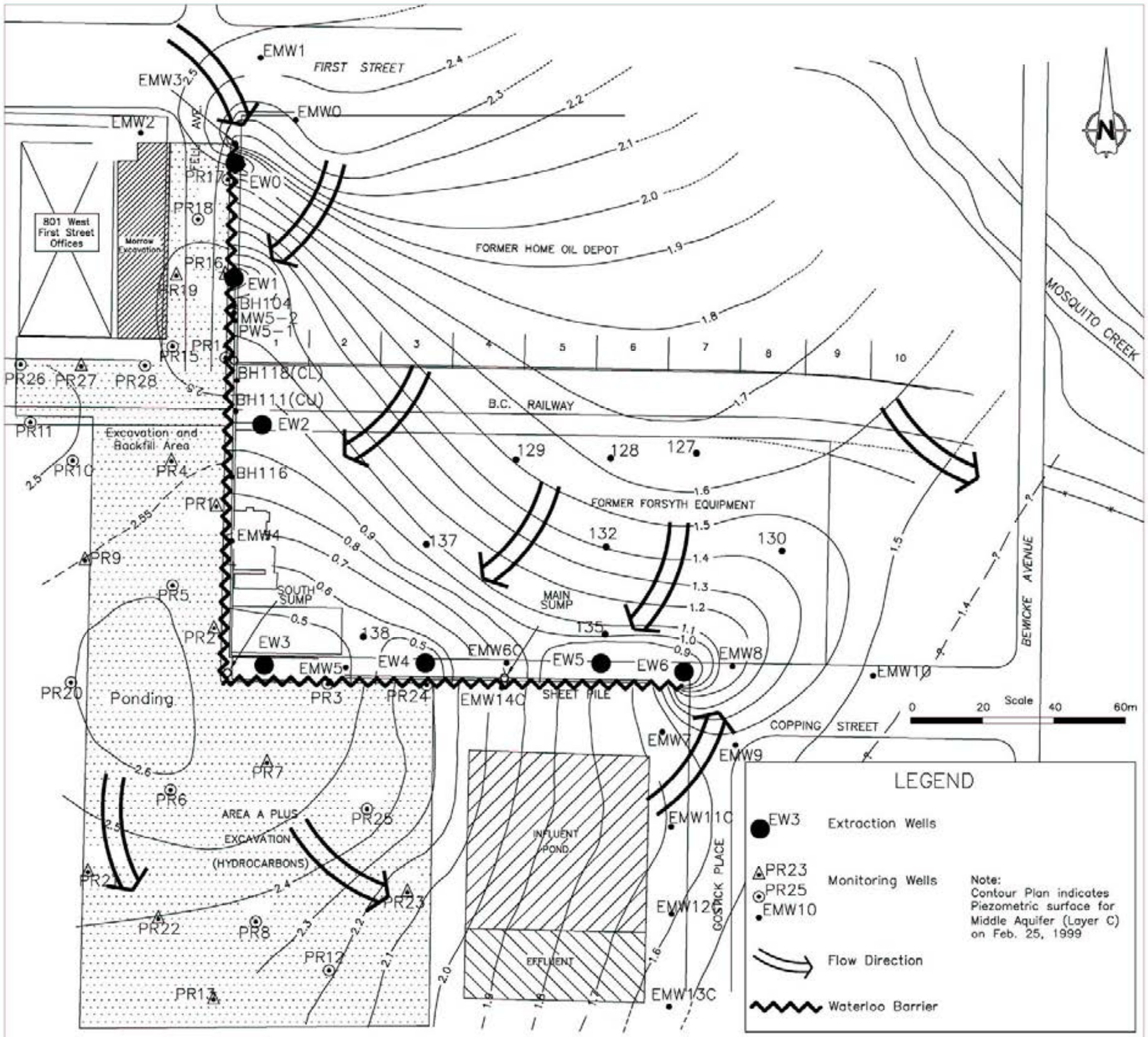


Figure 4. Performance monitoring of hydraulic barrier system (Feb. 25, 1999).

cavation on the down-gradient side of the barrier was set at 5 metres. Villholth Jensen & Associates Ltd. (Vancouver, B.C.) was contracted to design the shoring in accordance with the engineering requirements of the Province of British Columbia.

Two different shoring systems were used in this project. Along the east-west run and at the BC Rail R/W a tieback anchoring system was used for temporary shoring. The tieback shoring system was installed by EBS Engineering Construction and consisted of A.B. Chance® SS-175 (8"-10"-12" & 14" helical plates) earth tieback anchors installed on the up-gradient side of the barrier wall every 1.3 metres. This shoring system provided support to the barrier wall by connecting the earth tiebacks to a W310 x 158 waler on the down-gradient side of the wall.

The helical tiebacks were installed by exposing the upper ~1.5m of the sheet pile, cutting out an opening into the sheet pile (approximate dimensions 200 mm x 255 mm) about 0.4 m below ground surface, and installing the anchor at a 15° angle 12m deep into the ground. Once shoring was no longer required the tiebacks were removed and the window was welded shut with a steel plate.

Along the Fell Avenue right of way, a supplementary sheet pile wall was required because no access was granted to drill tiebacks into the neighboring properties (Photo 2). The secondary sheet pile wall consisted of Arbed AZ-13 sheet piling and W310x158 walers and cross-struts. The secondary sheet piling and cross-struts were removed after all remedial work was completed.

Photo 2. Excavation with secondary sheet piling shoring.

3.4 Sealing

Once all shoring work was completed, the joints of the sheet piles were sealed. Due to the properties of the sealant, a colloidal mixer was required to develop the necessary shear-force to mix the materials properly.

Prior to sealing, each sealable cavity was flushed with high pressure water to remove any loose material. Flushing was conducted until the return water was free of debris. Next, the grout line was inserted to the base of the clean joint and the sealant was tremied into the cavity. Once sealant was observed to be flowing out the top of the sealable cavity, or once 2.5 times the theoretical volume of the sheet pile joint was pumped into the sealable cavity, the installation line was slowly withdrawn. In most cases some sealant loss occured in the surrounding porous media prior to the sealant setting requiring a secondary grouting process to seal the top of the joint cavities.

4. INSTALLATION OF GROUNDWATER EXTRACTION SYSTEM

Robertson GeoConsultants Inc. was responsible for the installation of the groundwater extraction system. The system consisted of seven extraction wells screened in the middle aquifer (layer C) and shallow drains completed in the upper unconfined aquifer (layer A) along the entire length of the cutoff wall (Robertson GeoConsultants, 1999a).

4.1 Extraction Wells

All extraction wells were drilled by driving a 250 mm casing to design depth using a truck-mounted cable-tool rig. Next the well assembly consisting of a short sump, a 1.2m long screen (stainless steel wire wound continuous slot) and a steel riser pipe (all 127 mm ID) was placed through the casing. Each well was developed for 8 to 20 hours by surging, bailing and pumping.

The well performance of the extraction wells was tested prior to the start of sheet pile driving using step-drawdown and/or constant rate tests to (i) confirm feasibility of the pumping design (number of wells, spacing etc.) and (ii) to estimate maximum well yields for sizing of pumps and discharge lines.

Each well point was equipped with a submersible pump (downhole) and a concrete-cast valve box (just below grade) containing a flow sensor, a sampling port and a precision globe valve. The water level in the extraction well is monitored continuously by a pressure transducer (KPSI 0-20') located at the bottom of the well screen.

Digital panel meters (Model "Texmate DI-50D Tiger") are used to display the pumping level and to control the pump. The panel meter turns the pump off if the pumping level drops below a specified level (e.g. the top of the well screen) and restarts the pump once the water level has recovered to a specified level. The automatic pump controllers proved very effective in preventing exposure of the well screen and/or running the pump dry during periods when the available drawdown was limited.

Two self-powered 7-channel data loggers "Smart Reader™ 7 Plus" (supplied by ACR Systems Inc) were used for continuous monitoring of the water levels and flow rates in the various extractions wells (Robertson GeoConsultants, 1999a).

4.2 Shallow Drains

The shallow drains consist of a 150mm dia perforated PVC pipe (DR35) enclosed in drain rock (19mm dia) and wrapped in a non-woven geofabric (Nilex 4545) to prevent coarser soil particles from entering the drain rock. The drain rock is located at the base of the upper aquifer (layer A) and into the upper aquitard (layer B) and collects shallow groundwater from these layers. The groundwater reaching the drain flows by gravity to a central sump (manhole) from where it is pumped to the holding pond.

The drain sections along Fell Avenue (north-south run) were added at a later stage once it became apparent that shallow groundwater could overtop the Waterloo Barrier in this area during heavy precipitation events (see below).

4.3 Water Treatment and Discharge

All groundwater collected from the extraction system is pumped to a water treatment plant (1000 $m^3$/day capacity) to remove any hydrocarbons and elevated concentrations of iron and other metals. The treatment method comprised settling ponds to remove suspended solids, oil/water separators to remove any free-phase oil, sand filters and potassium permanganate filters to remove metals, and activated carbon vessels for final polishing and to remove trace, residual hydrocarbons from the waste stream. The treated effluent was then discharged to the municipal sanitary sewer system.

## 5. PERFORMANCE MONITORING

### 5.1 Initial Performance Monitoring

The initial performance monitoring included selected well testing and water level monitoring during soil excavation in the immediate vicinity of the cutoff wall (Robertson GeoConsultants, 1999a). Single well testing was performed immediately after sealing of the Waterloo Barrier was completed. As expected, the presence of the cutoff wall significantly reduced the well yield. For example, the specific capacity of EW-3 decreased from 84.6 $m^3$/day/m to 30 $m^3$/day/m, a reduction of 65%. Note that a similar reduction in well yield was already observed prior to sealing the joints of the cutoff wall. Single well testing also indicated that the zone of influence of individual wells overlapped (with typically 0.2-0.5m drawdown at neighbouring wells) confirming adequate redundancy in the extraction system.

Remedial work in Area A Plus involved excavation of the contaminated soil to a maximum depth of 5.2m below grade (Photo 3). During excavation the pit had to be completely dewatered resulting in a local drawdown of the middle aquifer (layer C) downgradient of the cutoff wall in the order of 1.5 to 2.0m. Groundwater levels on the up-gradient side of the cutoff wall were monitored to evaluate the performance of the Waterloo Barrier.

Figure 5 shows the geodetic water levels measured in the excavation pit and several wells (EMW4C, EW2 and EW3) in close proximity of the excavation on the up-gradient side of the cutoff wall. Despite the large drawdown in the excavation (up to 2m below sea level) the groundwater levels inside the barrier remained nearly constant. These observations indicated that the Waterloo Barrier had a very low bulk hydraulic conductivity, which was sufficient to hydraulically isolate the upgradient, contaminated area from Area A Plus.

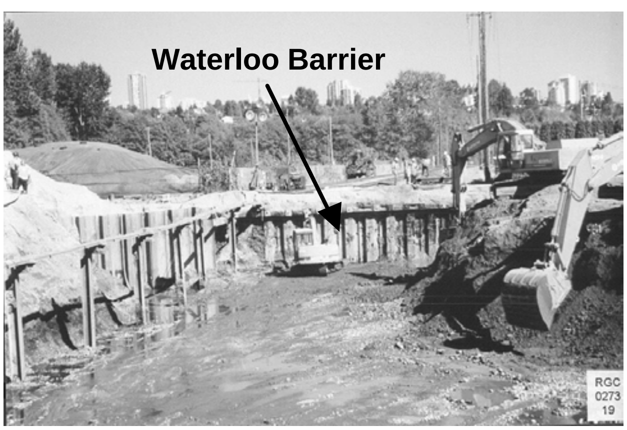


Photo 3. Soil excavation adjacent to Waterloo Barrier.

### 5.2 Compliance Monitoring

After all remedial work in Area A Plus had been completed a compliance monitoring program was implemented to monitor the performance of the hydraulic barrier system. The monitoring program included biweekly water level readings and quarterly sampling of groundwater for water quality analyses.

#### 5.2.1 Water Level Monitoring

A total of 31 monitoring wells were installed in different stratigraphic units for the purpose of monitoring water elevations both upgradient and downgradient of the Waterloo Barrier (see Figure 4 for locations).

Figure 4 shows the interpreted piezometric surface in the middle aquifer (layer C and C') at the end of the first winter season (February 25, 1999). The groundwater level survey indicated that groundwater in layer C is drawn into the interior (contaminated) region of the Waterloo Barrier thus preventing any recontamination of the remediated Area A Plus. Note that the capture zone of extraction well EW-0 extended beyond the northern terminus of the Waterloo Barrier and the capture zone of EW5 & EW6 extended beyond the eastern terminus, as required (Robertson GeoConsultants, 1999b).

The monitoring program also included piezometric readings in several nested piezometers on both sides of the barrier to assess the potential for groundwater flow beneath the cutoff wall. Figure 6 shows typical piezometric levels observed along a cross-section near the center of the barrier (see Figure 4 for location). The data indicate that the groundwater levels on the remediated (western) side of the Waterloo Barrier remained significantly higher (as much as 0.5m) compared to the eastern (contaminated) side preventing any potential underflow of contaminated groundwater beneath the cutoff wall and onto the remediated area.

The only compliance issue encountered during the three years of operation of the hydraulic barrier system was related to overtopping of shallow groundwater along the BC Rail R/W where the top of the sheet piling had been driven significantly (0.5-1.0m) below grade. The brief events of overtopping resulted from a lack of proper surface runoff originating from the neighbouring property (Robertson GeoConsultants, 1999b). Additional drainage on the neighbouring property was required to control this mounding of shallow groundwater.

#### 5.2.2 Groundwater Quality Monitoring

Following remediation of Area A Plus, Next Environmental Inc. (Burnaby, B.C.), the engineering firm in charge of all remedial work, installed a number of monitoring wells in the clean fill and analyzed water quality samples taken from these wells to confirm that the Site had been cleaned up (see Next Environmental, 1999 for details). The water quality in all monitoring wells showed hydrocarbon con-

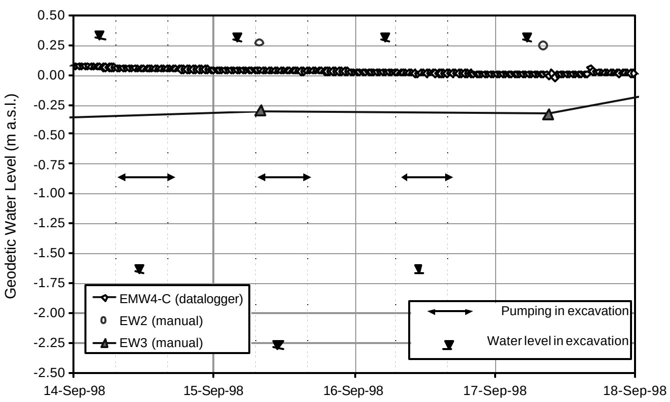


Figure 5. Water level monitoring during excavation adjacent to Waterloo Barrier.

centrations were undetectable, or well below the applicable regulatory standards for all hydrocarbon parameters immediately after remediation.

A total of 24 monitoring wells located in vicinity of the Waterloo Barrier were selected for routine water quality monitoring until final clean-up of the upgradient portion of the hydrocarbon plume had been completed (by others) in the summer of 2001. During these three years of operation, hydrocarbon concentrations remained below the detection limit in most wells and below applicable standards in all wells monitored within the remediated Area A Plus.

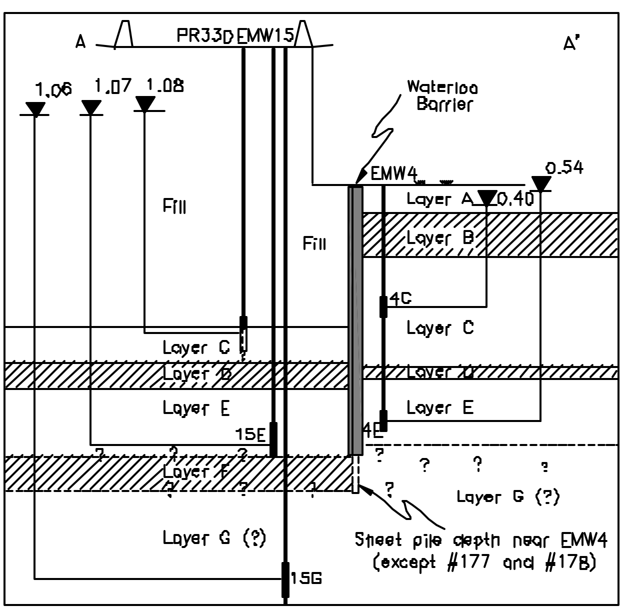


Figure 6. Vertical gradients across Waterloo Barrier.

## 6. CONCLUSIONS

The Waterloo Barrier was used successfully in the progressive remediation of a hydrocarbon plume of a shallow aquifer system. This project demonstrated the potential of using the Waterloo Barrier for shoring during remedial excavations (to a depth of at least 5.5m) without any noticeable change in the effective bulk hydraulic conductivity of the sealed cutoff wall.

## 7. ACKNOWLEDGEMENTS

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## 8. REFERENCES

C$^3$ Environmental 1998. Waterloo Barrier System Sheet Pile and Sealant Installation Report. Report submitted to Greystone Properties Ltd., October 1998.

Next Environmental Inc. 1998. Detailed Site Investigations Summary Report - Area A Plus; Report submitted to Greystone Properties Ltd., June 1998.

Next Environmental Inc. 1999. Confirmation of Remediation – Area A Plus; Report submitted to Greystone Properties Ltd. , February 2nd 1999.

Robertson GeoConsultants Inc. 1998. Final Design of Hydraulic Barrier System, Fullerton Site, North Vancouver, B.C.; Report No 053006/1 submitted to Next Environmental, June 1998.

Robertson GeoConsultants Inc. 1999a. Installation and Initial Performance Monitoring of Hydraulic Barrier System, Area A Plus, Fullerton Site, North Vancouver, B.C.; Report No 053007/1 submitted to Next Environmental, January 1999.

Robertson GeoConsultants Inc. 1999b. Performance Monitoring of Hydraulic Barrier System, Area A Plus, Fullerton Site, North Vancouver, B.C.; July 1998 – March 1999; Report No 053007/2 submitted to Next Environmental, May 1999.