PRACTICAL ASPECTS OF HYDROGEOLOGY STUDIES FOR HYDROCARBON MIGRATION IN BRITISH COLUMBIA

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ABSTRACT

Over the last three years, there have been numerous leaks and accidental spills of a variety of hydrocarbon compounds into the ground in southern British Columbia. In the course of searching for and delineating the flow paths of these fugitive hydrocarbons, the writers have reached conclusions with practical implications that may interest other investigators.

In the following paper a brief introduction is presented for four case histories, and one or two unique aspects of either the investigative approach or interpretation of results are described.

The examples involve leaks of gasoline and spills of xylene and ethylene dichloride. Descriptions are given of buried underground services acting as gasoline traps, tidal influences making the interpretation of groundwater flow direction more complex, fluid density causing distortions in interpretation of piezometric head, and a drawdown cone around a nearby well causing an apparent bifurcation of a floating hydrocarbon plume.

At one site, measurement of thickness of hydrocarbon saturated sand in drill core was compared with thickness of floating hydrocarbon fluid in a completed monitoring well. After applying appropriate corrections to the hydrocarbon thickness measured in the well, this value was generally in close agreement with that measured in the saturated sand sample.

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BACKGROUND

When investigating the fate of hydrocarbon fluids that have leached into the subsurface, there are many factors to consider. These factors could include: groundwater flow direction, groundwater velocity, degree of heterogeneity of sediments, octanol water partitioning coefficient of fluid, density of fluid, organic content in sediments, water table levels, etc. However, there could also be other factors that may not always be very obvious, such as effects of pumping in local water wells and flow to buried pipes, and presence of other leaked organics in the sediments. In the following, we have briefly described four case histories of leaks and spills that have occurred in southern and southwestern areas of British Columbia, and have highlighted some of the practical aspects of the hydrogeological investigations. Due to the sensitive nature of many of these case histories, the exact locations of the sites have not been given.

CASE HISTORY NO. 1: GASOLINE MIGRATION INTO BURIED UTILITY CONDUITS

While investigating leaks from underground storage tanks at gasoline stations in two areas in each of the cities of Squamish, Richmond and Victoria, and one in Kelowna, it was found that in each case the gasoline had seeped into manholes and conduits used to house buried telephone cables in the nearby streets. These conduits are usually 100mm diameter PVC pipes and are arranged in duct banks, with manholes spaced every 150 to 250 metres to provide access (see Fig. 1). The 50mm diameter telephone cables are normally inserted into these ducts after construction, and can at any time be removed for repair or replacement without disturbing the road surface. However, in areas where there is a shallow groundwater table present in a low permeability sediment, the conduits and surrounding sand bedding, plus other trenches for sewer and water services, provide a preferred path for the seeping gasoline (see illustrations in Figs. 1 and 2).

Depending on the particular elevation and geometry of any particular site, groundwater could flow into and along the pipes or backfill material at any time of the year. Gasoline floating on top of the water table can also permeate the unsealed joints in the conduit pipes and migrate in the annulus along side the telephone cable. However, whenever the conduit pipe dips below the water table, the undissolved floating gasoline products (float) will concentrate at the prevailing water table. In such circumstances, it is only a matter of time before the gasoline weakens the sheathing material wrapped around the telephone cables, allowing water to seep in and to render the cable useless for telephone transmission. As the water table rises and falls, the float could migrate up and down the cable, thereby damaging a longer length of cable. In relatively flat areas, the resultant flow path could be quite different from the regional groundwater flow direction. Cost of repairs resulting from this type of damage could range up to many hundreds of thousands of dollars.

This example illustrates the need to research the complete history of any site being investigated, and especially to locate all buried pipes or backfilled trenches that could distort the natural flow direction.

CASE HISTORY NO. 2: GASOLINE CONTAMINATION OF MUNICIPAL GROUNDWATER SOURCE

A gasoline tank had been leaking for many years before a gasoline taste was detected in one of this city's water wells, located in south central British Columbia. Eight years later, this well is still contaminated and cannot be used. A series of drilling programs has been conducted to delineate the source of the gasoline and extent of the plume. The probable extent of the gasoline plume is illustrated in Fig. 3, and from this it is apparent that the plume has split, with one tongue (Plume No. 1) migrating with the natural groundwater flow, and the other (Plume No. 2) being drawn towards the municipal well. As this well is located in a relatively flat area, is completed in a very permeable aquifer, and is only used intermittently, plotting of water table elevations and assessment of plume migration when the pump was not being operated could have lead to erroneous conclusions on direction of plume migration. However, when the influence of the well's drawdown cone is superimposed onto the prevailing groundwater flow direction, the split plume can be fully explained.

CASE HISTORY NO. 3: XYLENE SPILL

In 1989, approximately 4500 litres of an xylene product was spilled onto the concrete floor of an elevated platform; about 80% of the xylene flowed over the western edge of the platform, and about 20% went over the northern edge. Once over the edge, the xylene flowed down on top of a sand fill and seeped into the ground. Much of it ponded on top of a shallow water table in the sand (see Fig. 4).

The sand is a medium to fine grained, and was originally placed as a 2m thick fill on top of low permeability floodplain silts (see Fig. 5). Depending upon the time of the year, between 0.5 to 1m of the sand is saturated. Xylene is a colourless, flammable liquid with a specific gravity of about 0.86, and solubility in water at 10°C is about 150 mg/L.

The spill area was in and around an important railway spur line and the property owner required that rail cars be able to pass along the line at all times, following about one hour's notice. With these constraints in mind, a relatively portable method of drilling and sampling of test holes was required.

The system selected was developed at the University of Waterloo, and involves the use of a hand held Ponjar (mechanical) hammer to drive a special head that attaches to a diamond drill rod. A 66.4mm diameter aluminum tubing (electrical conduit) is inserted inside the drill rod, along with a special piston sampler. At the xylene spill site, the drill rods were driven into the ground to depths ranging from 2 to 3m. Between 1 and 1.5m lengths of core inside the aluminum tubing were withdrawn from the drill rods, after each drive.

This new piston sampler allowed high quality core samples to be collected from the sand and underlying silty sand. In addition to its portability, this drilling method had the advantage of causing minimal mechanical disturbance of the sand and saturating fluids, thereby enabling a very precise identification of sample depth; it was also possible to determine the position of the top of both xylene and water saturated sand within a few millimeters of accuracy. This was done by drilling holes into the side of the tubing and withdrawing a small amount of fluid.

When each hole was completed, a slotted PVC pipe was inserted in the hole. A few days after drilling was completed, the thickness of xylene floating on top of the water table in the monitoring tubes was measured, using the tape and paste method. The apparent thickness of the product was between 0.33 and 0.4m at the centre of the spill area. However, as is usually the case, drainage of hydrocarbon fluid from the top of the capillary fringe on top of the water table in the sand into the monitoring tube, depressed the water surface until a density equilibrium was established (see Fig. 6); this resulted in measurement of an apparent hydrocarbon thickness which was greater than the true value.

Calculation of true product thickness under even hydrostatic conditions in a porous media is a complex process (Abdul et al, 1989; Lenhard and Parker, 1989; and Testa and Paczkowki, 1989), and is usually estimated by dividing the apparent thickness measured in a monitoring well by a constant value, often between 4 and 6, depending on the density of the hydrocarbon (Fig. 6).

Based on visual inspection, the thickness of the oil capillary fringe (hc) in the fine to medium coarse sand at the site was about 60mm, and the thickness of free xylene (hf) in some of the drill cores was about 30mm; hence, using the simple formula, calculated apparent thickness of product observed in the piezometers (hw + hf) would be about (0.09x4) = 0.36m. This agrees fairly well with field data for thickness of hydrocarbon measured in the tubes, which ranged from 0.33 to 0.40m.

CASE HISTORY NO. 4: DELINEATION OF AN ETHYLENE DICHLORIDE CONTAMINANT PLUME IN A GRAVEL AQUIFER

On Febraury 15, 1986, derailment of a CN Rail freight train near Fort Langley, B.C. resulted in a 247,500 litre spill of ethylene dichloride (EDC). Within a few hours, the spilled chemical had seeped into the ground. Piteau Associates were retained to supervise an investigation to determine the direction and rate of movement of the EDC in the ground.

Ethylene dichloride (or 1,2-dichloroethane) is a heavy (density 1.267 @ 10^{o}C), colourless and flammable liquid (flash point at 13^{o}C), with a moderately low viscosity (1 mPa.s) (Montgomery and Welkom, 1990). As it is moderately soluble in water (8,490 mg/L), it was not surprising to find that there were two EDC plumes in the gravel aquifer underlying the spill site; one was a dissolved plume travelling towards the Fraser River about 350m away, at a maximum rate of about 2.5m/day, and the other was a liquid non-aqueous plume that migrated slowly along the bottom of the aquifer.

The spill area is underlain by more than 100m of unconsolidated sediments, of which only the upper 15m were of interest for the investigation (Armstrong and Hickock, 1986). The sequence of surficial sediments at the spill site is shown in Fig. 7. From ground surface, the sequence consists of 0.5 to 1.0m of silty fine sand surface cover, and 4.5 to 7m of wood waste fill over 3.0 to 5.5m of silty sand. The silty sand is underlain by 3 to 9m of sand and gravel, which in turn is underlain by clayey silt. None of the monitoring holes drilled for the study penetrated more than about 1.2m into the basal unit.

A Becker hammer rig was used to drill the twenty-one test holes. Selection of materials for piezometer construction posed a problem, as PVC dissolves when in contact with high concentrations of EDC. The only readily available alternative to PVC was black steel pipe, stainless steel and polyethylene tubing. Some of the earlier holes were completed with 31mm diameter steel piezometers, and five holes upgradient or most distant from the spill site were constructed of 37mm flush coupled, threaded PVC. All of the remaining piezometers were constructed using a bundel type piezometer design, as illustrated in Fig. 8. A centre steel piezometer constructed from 25mm diameter steel pipe with a slotted bottom was used for the deep piezometer in each hole. Polyethylene tubes, with a 9mm I.D. and a 150mm long stainless steel woven screen tip, were taped around the steel pipe before it was lowered into the hole. The stainless steel tips were placed at different locations along the pipe so that profile sampling could be carried out. While pulling the drill rods out of the hole, small amounts of bentonite slurry were pumped into the hole in the interval between each piezometer tip, to provide a seal against vertical migration of groundwater in the hole annulus. Uniform sand was placed in the intervals where the peizometer tips were located, except in the sand and gravel aquifer.

Water levels measured in the overlying wood waste were higher than that in the underlying aquifer, indicating a perched aquifer (Fig. 7). Water levels in the deep piezometers were observed to fluctuate in response to tidal activity in the Fraser River. The relationship between the water levels measured in the aquifer, the silty sand, the wood waste and the Fraser River for a three day period in March 1986 is shown in Fig. 9. As illustrated in this figure, there is a varying but persistent downward hydraulic gradient between the wood waste and the sand and gravel aquifer.

Groundwater flow in the aquifer is generally in the northwest direction, although for brief periods during flooding of the Fraser river groundwater flow may be to the southwest (Dakin and Holmes, 1988). The average velocity of groundwater flow in the sand and gravel aquifer was estimated to range between 0.7 and 1.3m/day.

A series of plans and sections are presented in Figs. 10 and 11, showing contours of EDC concentration at various times after the spill occurred. The distribution of the EDC in the wood waste and upper silty sand unit, approximately four weeks after the spill, is shown in Fig. 10A. It is evident from this figure, that initial migration of the EDC was in the east-west direction, along the orientation of an old slough.

Within the area of high EDC concentration, some samples of free EDC were obtained, indicating that pockets of non-aqueous phase EDC were accumulating at the base of the wood waste in some areas. However, as illustrated in Fig. 11, these pockets existed for only relatively short periods. Eleven weeks after the spill, concentrations greater than the solubility limit for EDC were rapidly disappearing from the wood waste aquifer.

The vertical migration of the EDC is illustrated in Fig. 11. Monitoring data for the sand and gravel aquifer was not available for the spill area until week four. The first available profile (week four) shows the vertical distribution of EDC concentration under the site, with very high concentrations of EDC at the base of the aquifer. Samples obtained from the base of the aquifer at a location almost directly below the spill area contained greater than 70% EDC from week four, through to week seven. Concentrations fell rapidly to less than 1% by the end of week nine, possibly due to installation of a nearby low capacity recovery well.

The investigation of the EDC spill emphasizes the need to consider the effects of contaminant density and local influences on the water table, such as tidal fluctuations in the level of the Fraser River, when assessing contaminant flow paths. The movement of EDC at the Fort Langley spill site was very similar to that which would have been expected, based on the generally accepted concepts (Feenstra, 1986) for development of dense non-aqueous phase liguid (DNAPL) contaminant plumes in saturated, granular aquifers. Due to density effects, vertical migration of the EDC was very prevalent at the spill site. Lateral migration of EDC in the unconfined wood waste aquifer unit was very limited, and was restricted to migration along the base of a "perched" slough channel at the base of the wood waste fill. In the granular aquifer unit located beneath the wood waste and the silty sand units, lateral migration was very significant due to the high permeabily and significant natural groundwater flow. The density effect resulted in the highest EDC concentrations occurring near the base of each aquifer.

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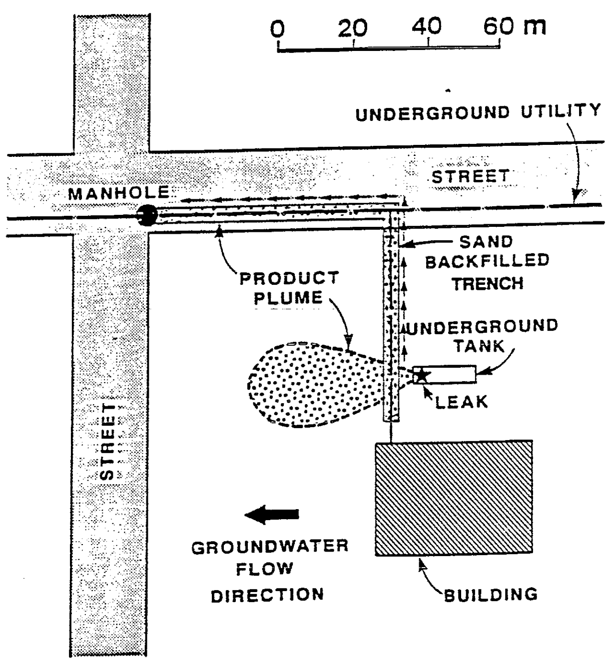

Figure 1. Plan of a typical gasoline plume in an area with high water table and permeable service trenches.

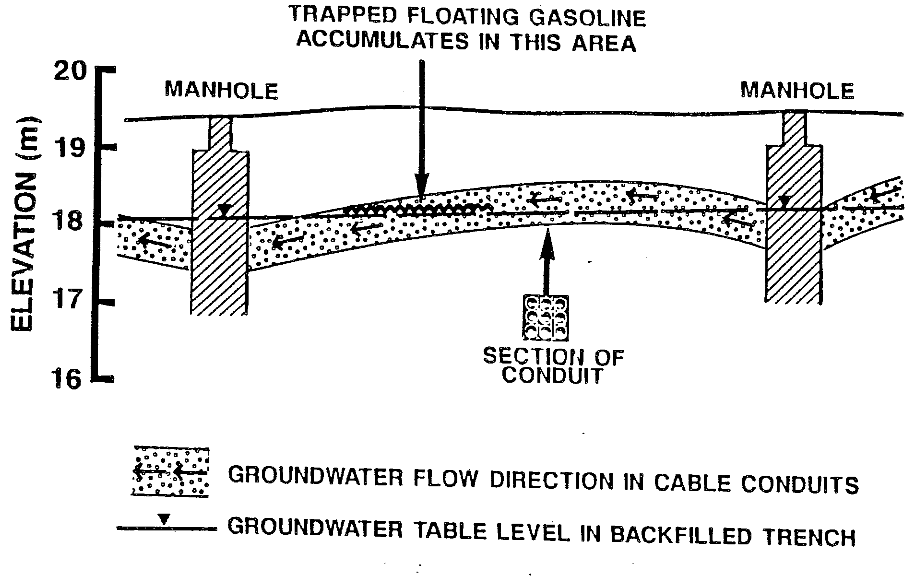

Figure 2. Profile along buried telephone cable conduits.

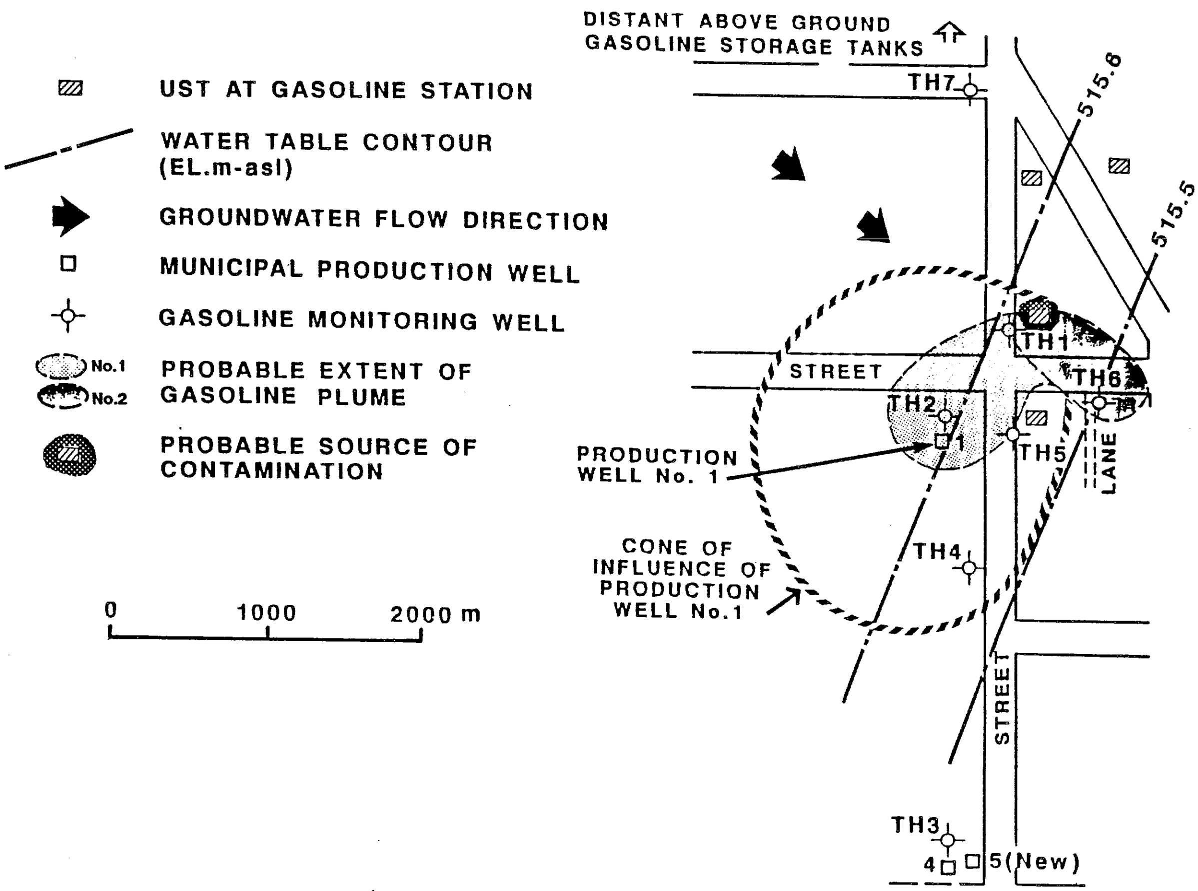

Figure 3. Plan of gasoline plumes in vicinity of municipal wells.

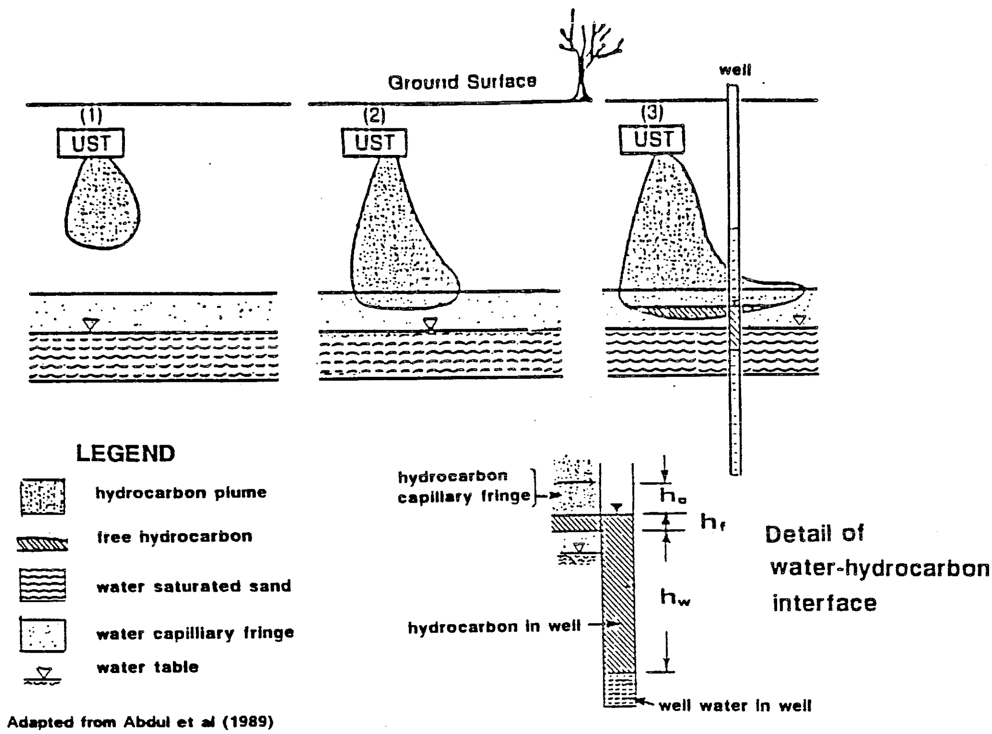

Figure 6. Three stages of hydrocarbon migration onto a sand aquifer.

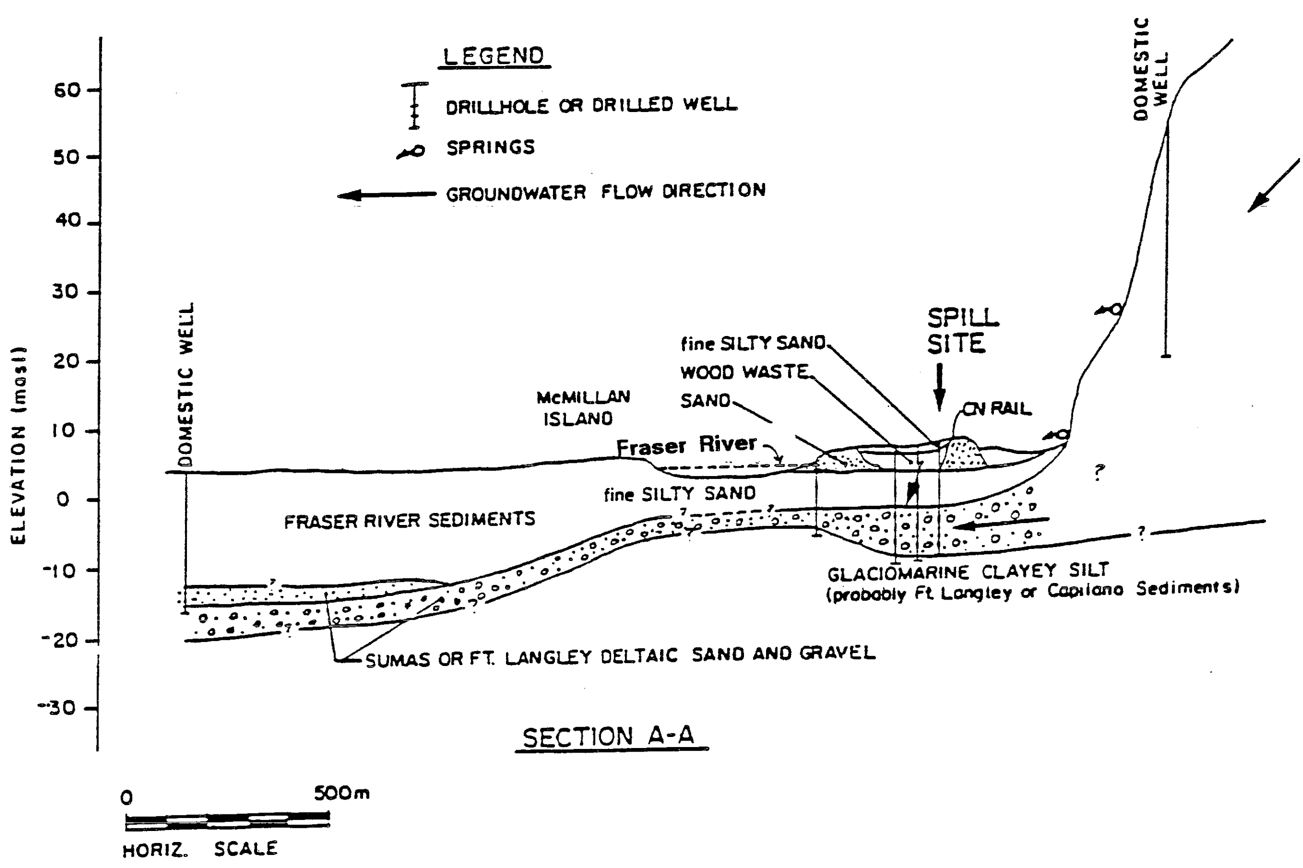

Figure 7. Regional section through ethylene dichloride spill site.

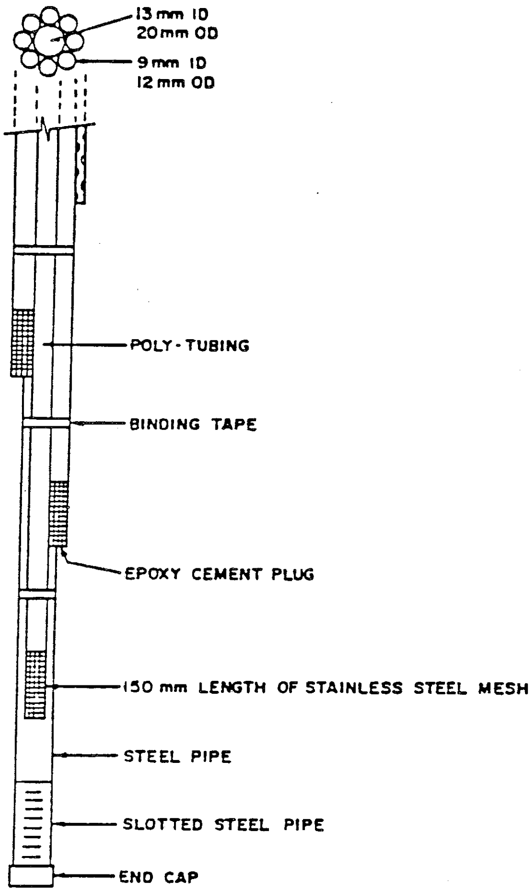

Figure 8. Bundle type multiple point pizometer.

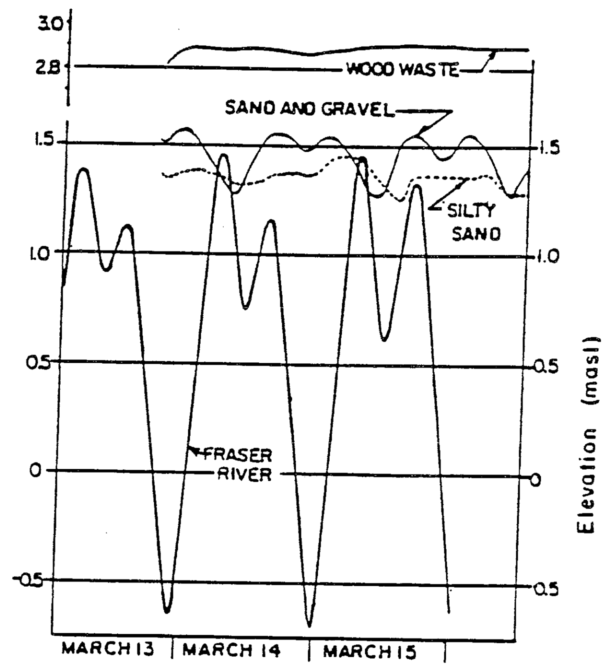

Figure 9. Hydrograph showing relationships between Fraser River level and piezometric levels under spill site.

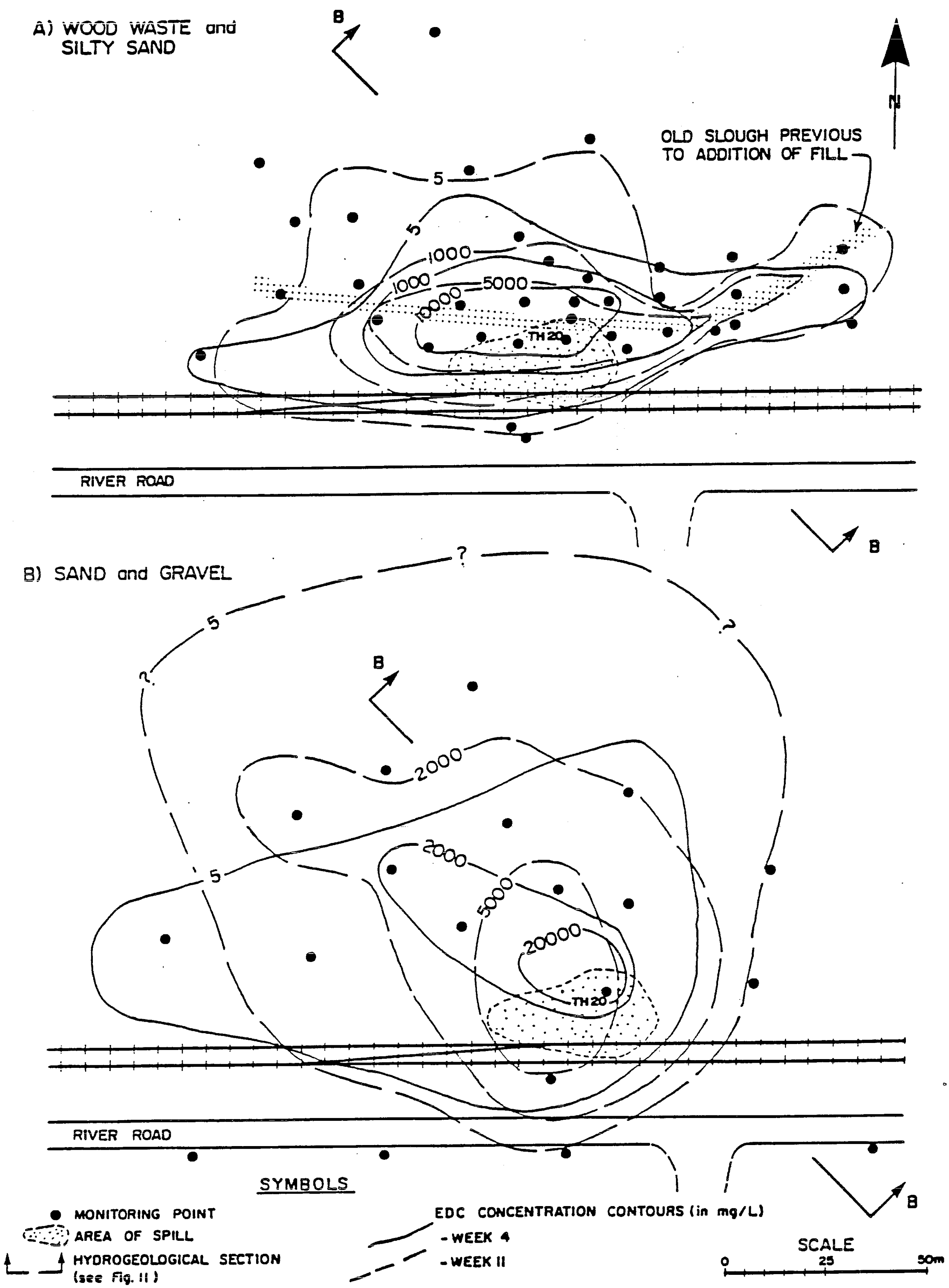

Figure 10. Plan of ethylene dichloride plume.

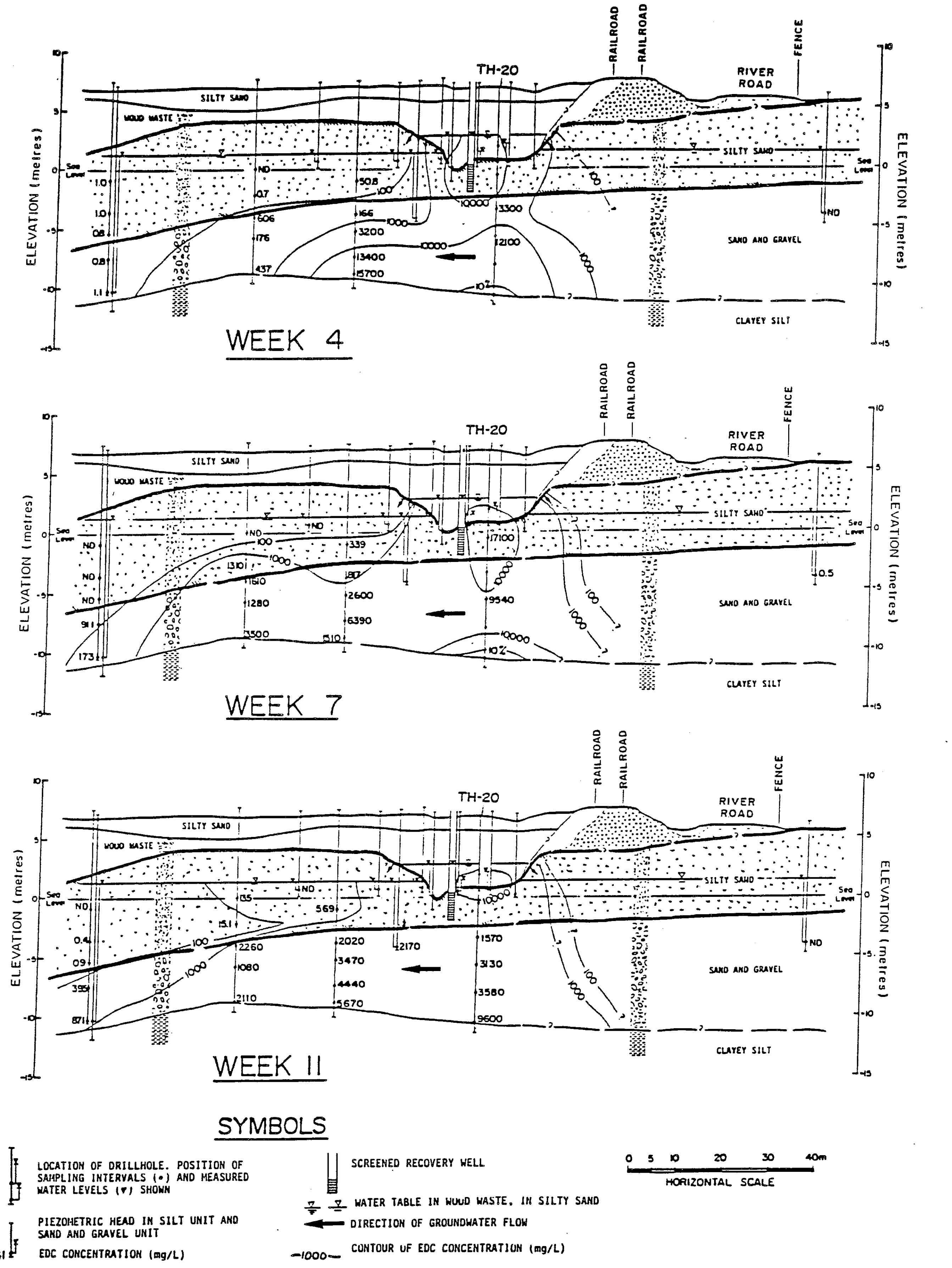

Figure 11. Concentration of ethylene dichloride through spill site.