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# RESPONSE, REMEDIATION AND RISK MANAGEMENT OF A CRUDE OIL PIPELINE SPILL

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## ABSTRACT

In December 1995, an oil spill was discovered along a section of pipeline located near the bank of a major river, less than 1 km upstream of the water supply intake of a southern Alberta community. The spill, which involved light crude oil, was observed at ground surface over an area of approximately 3 000 $m^2$ at the top of the river slope and had also migrated downslope through the subgrade soils and along the groundwater table toward the river.

The initial emergency response activities consisted of removing and disposing of oil-stained vegetation and snow, and the containment and recovery of free oil pooled on ground surface. Subsequent subsurface assessments involved the drilling of test holes and boreholes, and installation of groundwater monitoring/recovery wells. Based on the results of these assessments, a remedial action plan was developed. As part of this plan, some of the impacted soils were excavated and placed in lined treatment cells for bioremediation. The limits of the excavation were based on field screening measurements and on soil clean-up criteria developed through an assessment of the human health risk and ecological impacts.

Investigations conducted at the site also indicated that phase-separated crude oil had migrated further downslope and had accumulated at the water table within the flood plain sediments adjacent to the river. Therefore, remediation systems were installed to recover the oil, recover and treat the impacted groundwater, and prevent further migration of the impacted groundwater and oil toward the river. Impacted groundwater recovered from the flood plain deposits was treated onsite and was then injected back into the flood plain deposits via an infiltration gallery. The performance of the pumping and remediation systems was monitored regularly and water samples were recovered from the treatment system, selected monitoring wells and the river. Based on the results of these analyses, the quality of local groundwater steadily improved and the zone of impacted water was effectively contained.

## BACKGROUND

In December 1995, an oil spill was discovered along a section of pipeline near the village of Longview, Alberta. The spill involved between 70 $m^3$ and 160 $m^3$ of light crude oil and occurred within an unstable area near the crest of the Highwood River valley. The location of the spill presented immediate concerns since, in addition to being situated adjacent to a important sport fishery, it was located less than 200 m from a residential development and less than 900 m upstream of the water supply intake for the village. Therefore, emergency response, site assessment and subsequent remedial activities had to be implemented swiftly to minimize potential impacts to the nearby human and aquatic receptors.

This paper describes the emergency response, cleanup and subsequent reclamation activities conducted at the spill site, including the development of site-specific, risk-based remediation criteria to minimize potential health impacts to both human and ecological receptors. The paper also describes how the local geological and hydrogeological conditions were used to advantage to contain and remediate groundwater which was also impacted by the oil spill.

## SITE FEATURES

The spill site is located near the crest of the Highwood River Valley approximately 200 m west of Longview, Alberta. The pipeline consisted of a 4" diameter, welded steel line which was installed in the 1940s and buried approximately 1 m below grade.

The right-of-way is aligned parallel to the crest of the valley wall, approximately 40 m above the valley bottom. The upper section of the valley wall in the area of the spill slopes gently toward the river for a distance of approximately 60 m from the right-of-way where it steepens abruptly; falling to the flood plain (Figure 1). The upper portion of the slope tends to be wet due to the presence of numerous springs and local instabilities are common. The lower, steeper section of the slope is characterized by numerous gully systems.

The valley bottom is relatively broad (60 m to 100 m) downgradient of the spill site and the existing river channel skirts along the western edge of the valley bottom. It is separated from the east valley wall by a flood plain that is approximately 40 m to 65 m wide (Figure 2). The flood plain consists of coarse granular deposits and is relatively flat except for a subtle depression that extends along the toe of the east valley wall. The depression, and a noticeable change in vegetation cover, appears to coincide with a relict channel feature (Figure 2).

The horizontal distance from the pipeline to the existing channel is approximately 180 m at the spill site. The river originates in the Foothills region of the Rocky Mountains to the west and maximum flows normally occur in May and June in response to thawing of the mountain snowpack. However, the flow rate is prone to rapid variations, particularly if significant precipitation occurs concurrent with the peak snowmelt period. This situation occurred in 1995 when the river level rose more than 2 m, submerging the flood plain area.

The village of Longview presently obtains its drinking water supply from the Highwood River. The river intake is located approximately 900 m downstream of the spill site.

## INITIAL ASSESSMENTS AND RESPONSE

### Initial Spill Response

Following discovery of the pipeline leak on December 14, 1995, the flow was stopped and the line was exposed and capped. The slope was covered by oil-stained snow and pools of congealed oil were present in localized surface depressions. The oil covered an area measuring approximately 50 m wide parallel to the right-of-way and extended approximately 60 m downhill to the abrupt change in slope (Figure 2). At this point, the oil appeared to enter an existing gully. Oil was present in the upper sections of the gully but was not observed where it discharged onto the flood plain.

Initial remedial activities consisted of removing the contaminated snow and impacted shrubbery. The snow was placed in an oilfield tank and subsequently transported offsite. Sorbent pads were also placed in heavily stained areas including the steep gully. The vegetation was retained onsite for future reclamation purposes. Several temporary sumps and a cut-off trench were also excavated to impede downslope migration of the oil. Oil accumulating in the sumps and trench was recovered with a vacuum truck. Approximately 10 $m^3$ of oil were recovered during these initial recovery operations. An interception trench was also excavated at the base of the main gully to prevent potential migration of oil and contaminated runoff onto the flood plain.

A site safety plan was developed prior to conducting the initial response. Significant safety issues included: the low flashpoint of the crude oil and heavily impacted soils; vapours emitted from the crude oil; instability and steepness of the slope; and weather conditions. Safety orientation meetings involving all necessary stakeholders were conducted daily and all procedures were evaluated prior to initiation to determine the potential safety concerns.

### Upper Slope Area

A reconnaissance of the spill site was conducted concurrent with the initial spill response program. Soils exposed in the sumps and trenches were inspected and test holes were excavated on the upper gently sloping portion of the valley wall downgradient from the pipeline break in order to assess potential subsurface impacts, and to

**Fig. 1 - Stratigraphic Cross-Section of Slope and Flood Plain**

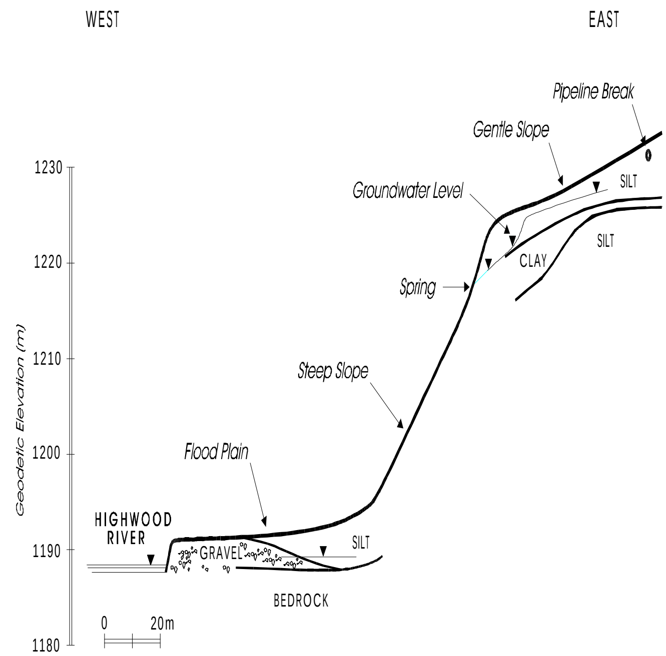
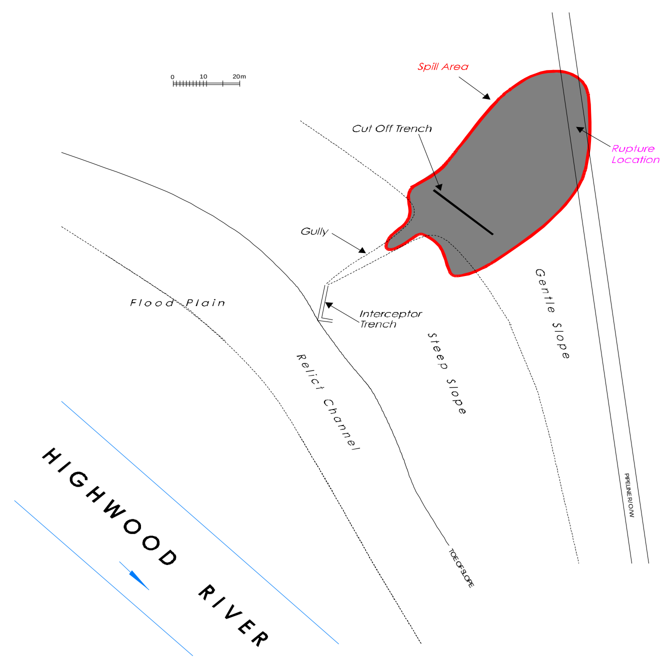
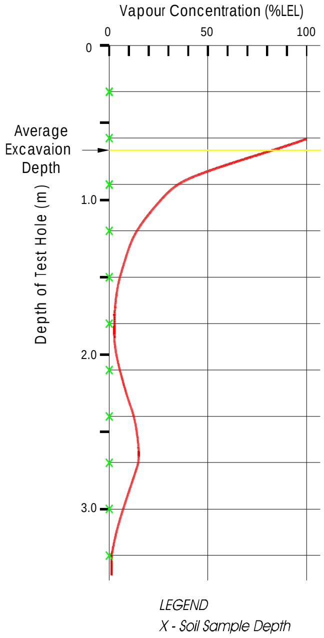



**Fig. 2 - Site Features**






Concentrations (mg/Kg)

| B | T | E | X | TPH |
|---|---|---|---|---|
| 77 | 300 | 39 | 260 | 9400 |
| | | | | |
| 0.5 | 1.4 | 0.14 | 1.4 | 126 |
| 0.005 | 0.01 | <0.005 | 0.13 | <6 |
| <0.005 | 0.005 | <0.005 | 0.005 | 21 |
| | | | | |
| 0.064 | 0.012 | 0.01 | 0.11 | 42 |
| | | | | |
| 1.1 | 0.76 | 1.4 | 9.3 | 290 |
| | | | | |
| 0.98 | 0.093 | 0.14 | 0.55 | <12 |
| 0.05 | 1.0 | 0.5 | 1.0 | Not Specified |
| ALBERTA TIER I CRITERIA | | | | |

**Fig. 3 - Subsurface Conditions in Spill Area**

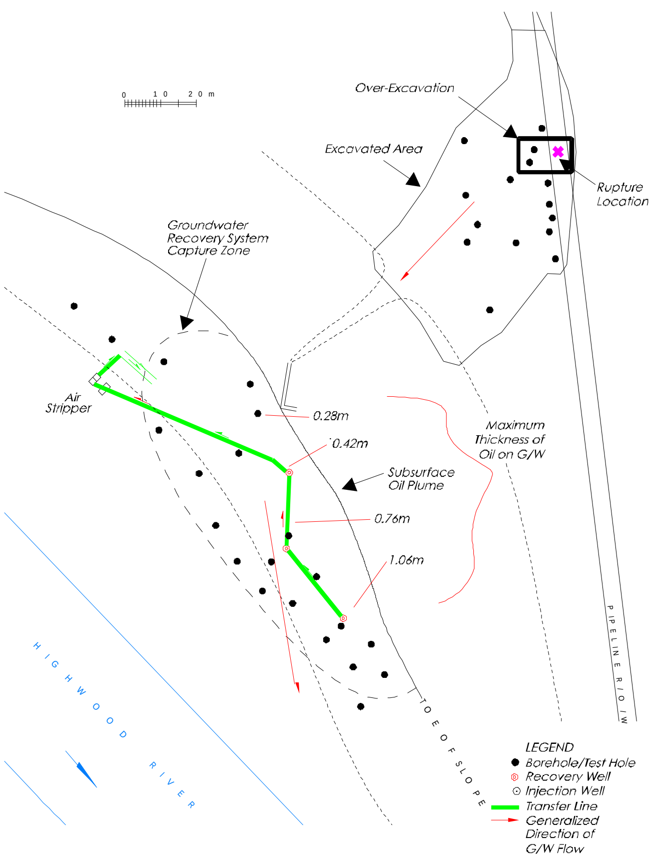



**Fig. 4 - Remedial Activities**

formulate an initial remedial action plan. Soil samples were recovered at regular depth intervals for visual assessment, measurement of hydrocarbon vapour concentrations using a combustible gas detector, and laboratory analyses. Generalized subsurface conditions beneath the upper portion of slope are summarized in Figure 3. Free oil was observed in voids and fissures within the upper 0.3 m of the soil profile and elevated vapour concentrations were detected to a depth of at least 0.9 m below grade. Elevated concentrations of benzene, toluene, ethylbenzene and xylenes (BTEX) were also detected in this zone.

Based on the available data and the apparent mobility of the light crude oil through fissures in the upper frozen soils, the initial remediation plan involved excavation of the impacted soils to a depth of 0.6 m to 1.0 m below ground surface. The depth of excavation was controlled in the field based on visual inspection (free oil) and measurement of hydrocarbon vapour concentrations in recovered soil samples. On this basis, approximately 3 000 $m^3$ of impacted soils were removed from the immediate area of the pipeline break during the period from 95/12/21 to 96/01/05 (Figure 4). Due to safety concerns and inclement weather conditions, excavation activities were terminated at the abrupt change in slope approximately 60 m downslope of the pipeline break. The excavated soils were placed in 2 diked containment cells constructed at site. Each cell measured approximately 30 m by 40 m in plan and was lined with a continuous 25 mil reinforced polyethylene (RPE 25) geomembrane.

Following completion of the excavation, soil samples were recovered on a grid pattern across the base for measurement of hydrocarbon vapour concentrations and confirmatory laboratory analyses. For initial assessment purposes, the results of these analyses were compared to the Alberta Tier I Criteria for Contaminated Soil Assessment and Remediation (1994) for hydrocarbon constituents (Figure 3). BTEX concentrations locally exceeded the Tier I criteria at several sample locations.

Upon completion of the excavation activities, confirmatory test holes were dug within and around the limits of the excavation. Boreholes were also drilled within the excavated area and monitoring wells were installed to permit groundwater sampling (Figure 4). Soil and groundwater sampling conducted as part of these investigations indicated the presence of free oil at the groundwater table in the immediate vicinity of the break. To prevent potential downslope migration of the oil and impacted groundwater, this area was subsequently over-excavated (Figure 4).

### Flood Plain Area

Concurrent with the excavation activities on the upper slope, boreholes were also drilled using an air hammer rig in the flood plain downslope of the pipeline spill site. Initial drilling results at the toe of the slope near the mouth of the existing gully revealed the presence of free oil at the water table. Based on these findings, additional boreholes (monitoring wells) were advanced to delineate the hydrocarbon plume (Figure 4).

Due to the proximity to the river channel and the water supply intake for Longview located downstream, temporary pumping systems were installed immediately to recover the oil and limit further migration toward the river. The remedial actions included installing slim hole piston (SHP) pumps in the affected monitoring wells. The water/oil was pumped to temporary tanks, which were emptied on a regular basis. These remedial systems were maintained until a more permanent system was designed and installed. Approximately 4 to 5 $m^3$ of oil were recovered by the temporary recovery system during this period. The initial limits of the oil plume beneath the flood plain are shown on Figure 4.

### Analytical Methods

Soil analyses for BTEX and total volatile hydrocarbons (TVH) were performed using modified EPA Method 5021 or 5030 and 8015/8021. Total extractable hydrocarbons (TEH) analyses were conducted using modified EPA Method 3550/3580 and 8000. Polyaromatic hydrocarbons (PAHs) were analyzed using modified EPA Method 3510/3520 and 8270. Mineral oil and grease in soil was performed using APHA 5S20F Method.

Water analyses from BTEX and TVH were conducted using Modified EPA Method 5030; while TEH analyses were performed using Modified EPA Method 35010 and 8000. PAHs in water were analyzed using Modified EPA Method 3510/3520 and 8270.

## SUBSURFACE CONDITIONS

### Stratigraphy

The regional geology consists of Quaternary deposits (gravel, sand, silt and clay) overlying Cretaceous bedrock of the Brazeau Formation. The Brazeau Formation consists of interbedded sandstones and mudstones with thin coal beds.

The stratigraphic profile encountered in test holes and boreholes installed in the upper portion of the valley slope consisted of alternating layers or lenses of silt and clay to the maximum depth of investigation (9.1 m). Since this area appears to have experienced historical instabilities, these units are probably disrupted near surface. Thin saturated layers or lenses of sand were also observed throughout the profile. Bedrock was not encountered in any of the boreholes drilled in the upper slope (Figure 1). Due to access constraints, investigations could not be conducted beneath the steeper section of the slope. Bedrock exposures were not apparent.

The generalized stratigraphy encountered in the flood plain consisted of an upper silt unit which is underlain by coarse fluvial deposits (sand, gravel and cobbles). The silt layer thickens toward the east valley wall (Figure 1), perhaps as a result of historical slope processes (erosion and instabilities). The fluvial deposits were underlain by bedrock consisting of siltstone, sandstone or shale which was encountered approximately 3.0 m to 5.2 m below ground surface. The elevation of the bedrock contact was highly variable beneath the flood plain reflecting prior erosional activity by the river. Furthermore, based on the observed geology, changes in vegetation cover and analysis of aerial photography, it appears that a relict fluvial channel exists near the toe of the slope (Figure 2).

### Hydrogeology

The depth to the groundwater table ranged from 1.5 m to 2. 5 m below grade near the pipeline right-of-way but it approached ground surface further downhill near the abrupt change in slope (Figure 1). The ground in this area was soft and wet due to seepage from saturated sand layers. Groundwater data could not be collected beneath the steeper section of the slope due to access constraints. However, seepage originating from the upper portion of the slope in the spill area migrated toward the existing gully. Under normal conditions, the runoff stream would travel a short distance down the gully and disappear into the subsurface. During periods of snowmelt, however, the flow in the gully persisted to the bottom of the slope where it discharged onto the flood plain.

Hydrogeological conditions beneath the flood plain, downgradient from the pipeline spill site, are complex since the groundwater regime at any particular time can be influenced by the river stage, groundwater recharge from the adjacent valley slope and surface runoff. However, under normal conditions, groundwater flow in the flood plain area is sub-parallel to the river channel. During 1996 and 1997, the groundwater table was located in the coarse fluvial deposits approximately 2.2 m to 3.7 m below grade. Field conductivity tests conducted in 3 representative monitoring wells installed in the fluvial sediments indicate that the hydraulic conductivity of these deposits ranges from 1.9 x $10^{-3}$ cm/sec to 2.9 x $10^{-3}$ cm/sec.

### Oil Migration

Oil from the pipeline break appears to have primarily migrated downslope across the ground surface and through fissures in the near-surface soils. Upon reaching the abrupt change in slope, much of the oil entered the existing gully where it flowed downhill at surface for a short distance (Figure 2). It appears the oil then infiltated into the underlying soils and migrated via subsurface pathways to the flood plain deposits at the base of the slope where it pooled on the groundwater along the toe of the valley wall. Oil thicknesses in this area prior to remediation ranged from trace quantities to 1.06 m. Maximum thicknesses are shown on Figure 4.

Free oil was also observed at the groundwater table in the immediate vicinity of the pipeline break but was removed during remedial excavations conducted in this area.

## SOIL REMEDIATION

### Soil Remediation Criteria

Following the remedial excavation work at the spill site, some of the soils exposed at the base of the excavation and the soils that were placed in the containment cells contained elevated hydrocarbon concentrations. At the time of the spill, Alberta Environmental Protection (AEP) normally defaulted to the Alberta Tier I criteria. Alternatively, AEP would consider risk-based remediation criteria that pertain specifically to the site conditions, contaminant characteristics, and human/ecological receptors. Due to the large volume of impacted soils at the spill site, and safety concerns associated with conducting additional excavation activities on the hillside, a site-specific risk-based remediation approach was adopted.

A site-specific human health and environmental risk assessment was conducted to evaluate the potential health and environmental risks resulting from the crude oil pipeline leak. Specifically, the purposes of the risk assessment were: to evaluate the potential health risks to occupants of residential dwellings and other users of the land in the vicinity of the pipeline leak; to evaluate the potential impacts to ecological receptors in the vicinity of the leak; and to develop appropriate site-specific risk management (cleanup) criteria for the identified contaminants in soil and groundwater that are protective of these potential receptors. The assessment was confined to the upper portion of the slope in the immediate vicinity of the spill site.

The methodology for estimating human health/ecological risks associated with the crude oil contamination involved the following steps:

C hazard identification/receptor characterization;
C exposure assessment;
C toxicity assessment/hazard assessment; and
C risk characterization.

The risk characterization stage also involved the development of cleanup criteria for selected hydrocarbon constituents.

The risk assessment addressed possible exposure pathways for both humans and ecological receptors. Ecological receptors included: native trees, shrubs, forbs and grasses (balsam poplar, slender wheat grass, etc.); small and large mammals (Richardson's ground squirrel, deer, coyote, etc.); ground nesting birds, water fowl and raptors (ducks, red tailed hawk, etc.), cattle and soil invertebrates and micro-organisms. Although domestic consumption of groundwater is not an issue on the upper slope area, other exposure pathways originating in the groundwater in this area were considered, such as dermal contact (groundwater springs), casual ingestion (e.g. by children) and inhalation of vapours.

Based on analyses of the light crude oil (Figure 5), the principle contaminants of concern were identified to include the monoaromatics BTEX and PAHs including naphthalene and methyl naphthalene, acenophthene, fluorene, anthracene and benzo(a)anthracene. The selection of these compounds for the risk assessment is supported by published literature which indicates that the toxicity of hydrocarbon mixtures is typically governed by these substances. Aside from the toxicity and mobility of these compounds, the lack of available data for most of the several hundred other compounds present in crude oil frequently precludes the adoption of other compounds as indicators or surrogates.

Based on the foregoing considerations, fate and exposure analyses were conducted to derive site-specific, risk-based cleanup criteria for soil and groundwater that are protective of human health for critical receptors considered in this assessment (Table 1).

The ecological risk assessment conducted for the site consisted of two parts: deterministic exposure modelling and calculations of the risks to higher level ecological receptors, and a comparison of published ecotoxicity test results to assess the effects on lower level ecological receptors (plants, invertebrates, etc). The deterministic calculations demonstrated that the measured soil and groundwater concentrations of specific hydrocarbon constituents from samples collected at or below the base of the excavation at the site were not expected to result in any unacceptable impacts to relevant ecological receptors. Similarly, ecotoxicity test results compiled by Visser and Danielson (1994) for a comparable light hydrocarbon mixture in soil indicated that the measured concentrations of different groups of hydrocarbon fractions (Table 2) were not expected to result in any unacceptable impacts to lower level ecological receptors relevant to the site.

Based on the results of the risk assessment, it was concluded that:

C further remediation of the soils in the base of the remedial excavation was not required, which permitted reclamation activities to proceed;

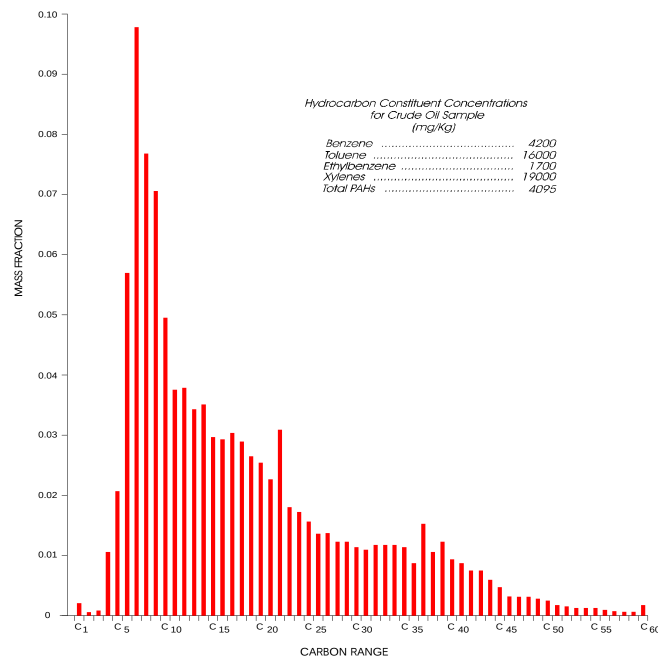



**Fig. 5 - Results of Gas Chromatographic Analyses of Crude Oil Sample**

C remediation of the groundwater beneath the spill site on the upper portion of the site was not required; and
C if the hydrocarbon concentrations in the soils excavated from the spill site (stored in the containment cells) could be reduced to the risk management criteria derived by the risk assessment, they could be returned to the slope or used for some equivalent purpose.

## Ex Situ Soil Treatment

Approximately 3 000 $m^3$ of impacted soils excavated from the spill site were placed in two lined containment cells. Due to bulking of the soils, the total thickness of soil in the cells exceeded 2 m which was excessive for effective treatment. Therefore, a third cell (polishing cell) was constructed to permit batch treatment of the impacted soil. This cell was constructed in a similar manner to the initial cells and incorporated a leachate collection system. Remediation of the soils proceeded as follows:

C soil was transferred from the temporary containment cells and placed in the polishing cell to a maximum thickness of 1 m;
C the soil in all 3 cells was aggressively aerated using a backhoe at regular intervals during the summer seasons;

- liquid nutrients (high nitrogen fertilizer) were applied to the soils during the aeration process ( as required); and
- once the concentrations of hydrocarbon constituents in the soil in the polishing cell were reduced to the site-specific cleanup criteria, it was removed and a new batch was added.

The 3 000 $m^3$ of impacted soils were progressively remediated during the 1996 and 1997 summer seasons. The average residence time for each batch in the polishing cell was 2.5 months. Soil samples were recovered for analyses of TPH and mineral oil and grease (MOG) to monitor the progress of remediation. Prior to removing the soils from the polishing cell, confirmatory soil samples were recovered for analyses of BTEX, TPH, MOG and PAH. In addition, a water sample

**TABLE 1**
**RESULTS OF SOIL AND LEACHATE ANALYSES**
**CRUDE OIL IMPACTED SOIL**

| CONSTITUENT | SOILS | | | WATER |
|---|---|---|---|---|
| | PRE-TREATMENT[a] (DOWNSLOPE OF EXCAVATION) (mg/kg) | POST-TREATMENT[a] (TREATMENT CELL) (mg/kg) | CRITERIA SITE-SPECIFIC (SOILS) (mg/kg) | LEACHATE (POLISHING CELL) (mg/L) |
| Benzene | 31 | 0.0165 | 4.2 | <0.005 |
| Toluene | 123 | 0.121 | 27 | 0.0012 |
| Ethylbenzene | 16 | 0.018 | 26 | <0.005 |
| Xylenes | 126 | 121 | 244 | 0.0043 |
| Total Petroleum Hydrocarbons[b] | 5 667 | 1 219 | c | <0.15 |
| Total Polycyclic Aromatic Hydrocarbons | 1.91 | 2.8 | c | <0.012 |

a - average of multiple samples
b - total volatile plus total extractable hydrocarbons
c - site-specific criteria were determined for individual PAH compounds

**TABLE 2**
**RESULTS OF ALUMINA FRACTIONATION**
**SOIL ANALYSES**
**(NEAR PIPELINE LEAK AND VISSER STUDY)[a]**
**(mg/kg)**

| FRACTION | SPILL SITE | VISSER[a] STUDY | CHEMICAL CLASS REPRESENTED |
|---|---|---|---|
| 1 | 550 | 9 100 | Alkanes, Alkenes and |
| 2 | 71 | 4 400 | Polycyclic Aromatic Hydrocarbons (PAHs) and Polycyclic Aromatic Sulphur Hydrocarbons (PASHs) |
| 3 | <2 | 1 200 | Polycyclic Aromatic Nitrogen Hydrocarbons (PANHs) |
| 4 | <2 | 1 950 | Hydroxylated Polycyclic Aromatic Hydrocarbons (HPAHs) |
| TPH[b] | 720 - | 21 500 | |

a - Soil characterization results presented by Visser and Danielson (1994) for the fractions noted in soil sample treated in a bio-reactor/bio-pile for 16 months prior to conducting ecotoxicity tests
b - Total Petroleum Hydrocarbons

was recovered from the leachate collection system for analyses of leachable hydrocarbon constituents (BTEX and PAH). Analytical data for a typical batch treatment cycle in the polishing cell are presented in Table 1.

Once the soils were successfully remediated to the site-specific risk management criteria, approval was received from AEP to use the treated soils to restore an abandoned gravel pit on nearby private property. The end use of the treated soils for this purpose was considered to be environmentally beneficial since the previously sterile gravel pit could be returned to productive pasture land.

## SLOPE RECLAMATION

Based on the results of the human health and ecological risk assessment, it was determined that the residual hydrocarbon concentrations remaining in the soils and groundwater beneath the excavated spill site would not pose significant risks to human or ecological receptors. Therefore, reclamation efforts could proceed without the need to conduct additional excavation or remediation beyond that which had already been conducted. The main objective of the reclamation effort was to revegetate the disturbed area with native species. A key element in the design was to manage the surface water (seepage and runoff) and shallow groundwater to minimize erosion and improve the shallow slope stability. The surface water management scheme was based on channelling runoff and seepage toward the existing gully for two reasons. Firstly, since the oil followed this route during the spill, encouraging water to flow down the gully should promote flushing of any residual hydrocarbons in underlying the soils. Furthermore, any impacted water arising from this flushing action would eventually emerge in the groundwater beneath the flood plain where it could be managed by the groundwater remediation/treatment system installed at this location. Secondly, since runoff water has a high oxygen content, it would assist in promoting intrinsic biodegradation of dissolved hydrocarbons when it co-mingled with the impacted groundwater beneath the flood plain.

Reclamation of the upper slope was initiated in June 1996 and involved the following activities:

C contouring the edges of the excavated area;

C installation of erosion berms (water bars) and shallow drainage channels to divert surface runoff and seepage toward the existing gully;

C contouring of the gully and lining it with a jute erosion blanket to prevent erosion and encourage revegetation;

C trees and brush salvaged during the initial remedial activities were chipped and spread, together with aged manure, as a top soil substitute on the lower (steeper) section of the slope;

C since top soil could not be salvaged during the initial excavations at the spill site, organic-rich soil was imported from offsite and applied to the upper (flatter) portion of the disturbed area to provide a growing media; and

C a buried synthetic drain (Multi-Flow®) was installed across the slope to dewater the wetter areas in order to improve geotechnical stability; the discharge from the drain was diverted to the existing gully.

Following the recontouring and stabilization activities, fertilizer was applied to the disturbed area and 170 native shrub and forb seedlings were hand-planted along the water bars. The entire reclaimed area was then broadcast-seeded with a mixture of native grasses and legumes. In June 1997, a jute erosion blanket was installed on the steep portion of the slope and approximately 1 200 native forbs and grass seedlings were hand-planted within the erosion blanket and along the drainage channels. Weed control was conducted in late summer and vegetation inspections were also undertaken periodically to assess plant health and density.

## GROUNDWATER REMEDIATION

### Groundwater Treatment System

Subsurface investigations in the flood plain area revealed the presence of a plume of oil and impacted groundwater near the toe of the valley wall downslope of the spill site (Figure 4). Following discovery of the plume, slim hole piston pumps were temporarily installed in selected monitoring wells to recover the oil and impacted water until a proper groundwater remediation system could be installed. The main design objectives of the remediation system were to:

C recover the free oil at the groundwater table;
C recover and treat the impacted groundwater so that it could be safely re-injected back into the flood plain; and
C prevent migration of the oil and impacted groundwater toward the Highwood River.

A system to recover the oil and capture and treat the impacted groundwater, was commissioned in late January 1996. A schematic of the pumping/treatment/injection system is shown on Figure 6; the general lay-out is shown on Figure 4. The main components of the system included:

C three 1 000 mm diameter recovery wells located near the leading edge of the oil plume. Each well was equipped with a water table depression pump and, where appropriate, with a skimmer pump for recovery of the floating oil;
C oil storage tanks installed within a lined and bermed area;
C transfer piping from each recovery well, equipped with an instantaneous and totalizing flow meter and a sample port, to a manifold system located within a heated enclosure;
C a 900 mm diameter air stripper to treat contaminated groundwater, which was heat-traced and insulated, and was equipped with a 10-hp blower and a 15 KW pre-heater to permit winter operation; and
C two 1 000 mm diameter infiltration wells connected by a gravel-filled trench for re-injection of the treated groundwater from the air stripper.

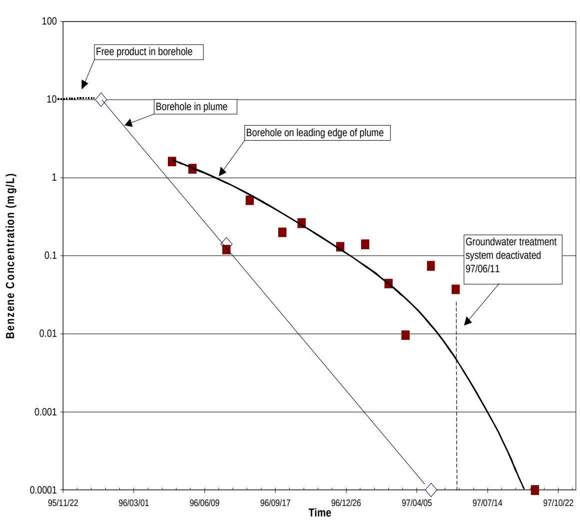



**Fig. 7 - Benzene Concentrations in Groundwater**

The infiltration wells are located upgradient of the groundwater recovery wells within the apparent relict channel feature which runs along the toe of the valley wall. The injection wells were located within this feature since any treated water that was re-injected should flow downgradient along the relict channel and back into the capture zone of the recovery wells. In this manner, the treated water could be recaptured and cycled back through the treatment system, if required.

The groundwater remediation system was operated from January 1996 to June 1997. The combined average pumping rate from the 3 recovery wells during this period was approximately 30 L/min. Continuous pumping from the 3 wells created a capture zone that was effective in preventing migration of the impacted oil and water toward the Highwood River. The capture zone is shown on Figure 4.

The air stripper was effective in remediating the pumped groundwater, whereby over 21 million litres of water were recovered from the subsurface, treated and re-injected. Hydrocarbon concentrations measured in treated water from the air stripper prior to re-injection into the flood plain deposits were generally less than the Canadian drinking water guidelines. Effective winterization of the system permitted continuous winter operation to temperatures of -39$^{o}$C.

Within 12 months of commissioning the system, the free oil at the water table had been removed. In total, approximately 10 $m^3$ of oil were recovered during the pumping operations. The recovered oil was temporarily stored onsite pending recycling.

Within 17 months of commissioning the system, BTEX levels in the groundwater had been reduced to less than Freshwater Aquatic Life (Canadian Council of Ministers of the Environment) criteria for most of the dissolved plume. The reductions in benzene concentrations for selected boreholes are shown in Figure 7. In addition to the pumping operations, the observed reduction in dissolved hydrocarbon concentrations within the plume area is partially attributed to intrinsic biodegradation which was enhanced by the flow of oxygenated groundwater from the gully system.

### Intrinsic Remediation

The groundwater pumping and treatment system was de-activated on a trial basis in June 1997. The purpose of the trial was to assess the feasibility of completing the remediation process using a more passive (intrinsic) approach. In this case, nutrients and oxygen-releasing compounds (hydrogen peroxide and magnesium dioxide) were added to selected wells to promote biodegradation. During the trial, wells installed in the flood plain were closely monitored and sampled to assess potential migration of the plume and changes in groundwater quality. Concentrations of dissolved oxygen and nitrate, pH levels and heterotrophic micro-organism counts were performed

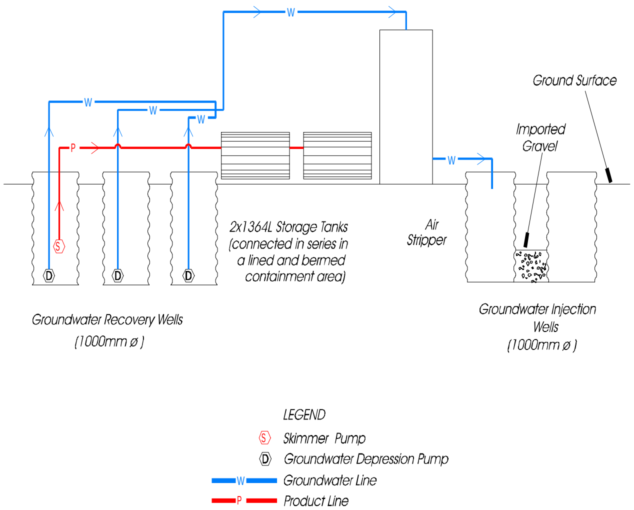



**Fig. 6 - Process Schematic of Groundwater Treatment System**

at regular intervals. As agreed with AEP, the remediation systems, while having been de-activated, would to remain in place as a contingency measure for at least one year in the event that continued pumping and treatment are required. To date (6 months), hydrocarbon concentrations appear to be declining and significant migration of the impacted plume toward to river has not been observed. Monitoring of selected groundwater parameters is also continuing in order to obtain information regarding biodegradation rates.

## SUMMARY

In December of 1995 a ruptured crude oil pipeline was discovered immediately west of the village of Longview, Alberta. The spill occurred in a precarious location, along the crest of a slope adjacent to the Highwood River. In addition to being located in close proximity to the Highwood River, the spill was also up-river of the village of Longview water supply intake.

An initial response plan was implemented to recover free oil and impacted soil and vegetation. Site investigations were also conducted on the upper slope area, as well as on the flood plain, downgradient of the pipeline spill.

Approximately 3 000 $m^3$ of oil-impacted soils were excavated from the upper slope area near the pipeline break. A human health and ecological risk assessment was conducted in order to develop site-specific, risk-based remediation criteria for the impacted soils. The focus of the risk assessment was to evaluate the potential risks to human and ecological receptors in the vicinity of the pipeline leak. Two lined containment cells and a polishing cell were constructed nearby to remediate the soils. All impacted soils were adequately remediated by the winter of 1997 and the containment cells were decommissioned.

Site investigations conducted on the flood plain area, downslope of the pipeline spill, indicated the presence of a plume of oil and impacted groundwater along the toe of the valley wall. The oil recovery system recovered approximately 10 $m^3$ of oil. Oil has not been detected on the water table in any of the monitoring wells since December 1996. A groundwater treatment system, comprised of large diameter recovery wells, an air stripper and a re-injection gallery was active for 17 months. The system was deactivated in June 1997 in favour of a more passive remediation approach. BTEX concentrations in the dissolved-phase plume have been significantly reduced, as a result of the pump and treat system and subsequent intrinsic remediation.

Slope reclamation was conducted following the excavation of the impacted soils and concurrent with other remedial activities. The primary focus of the reclamation effort was to stabilize the affected slope and revegetate the disturbed area with native species. In order to manage surface water and shallow groundwater on the slope, enhancements were conducted which channelled runoff toward an existing gully. The system encouraged water to flow down the gully, eventually entering the capture zone of the groundwater treatment system on the flood plain. Revegetation of the upper rehabilitated area with native species was successful and the stability of the slope appears to be intact.