DETAILED SITE INVESTIGATION AND RISK ASSESSMENT: BORDER PUMP STATION AND RAINY HOLLOW

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EXECUTIVE SUMMARY

Border Pump Station and Rainy Hollow are adjacent abandoned sites in northern British Columbia, just south of the Yukon border. The sites were originally constructed as part of the Haines-Fairbanks pipeline, and operated by the U.S. military from approximately 1954 to 1972. In 1994, buried canisters containing DDT (dichlorodiphenyltrichloroethane) pesticide were found at Rainy Hollow, prompting an emergency site investigation and clean up. A separate preliminary environmental investigation was conducted at the abandoned Border Pump Station in 1995: Extensive subsurface hydrocarbon contamination was detected in soil samples at depths from the surface to 2 - 24 m. This report provides the findings, interpretations and recommendations of a subsequent detailed site investigation and screening-level risk assessment of Border Station and Rainy Hollow, undertaken by the Applied Research Division at Royal Roads University, in association with UMA Engineering Ltd., and Golder Associates Ltd.

A detailed sampling program was carried out in July and September, 1996. The sampling and analytical program comprised the drilling of fourteen additional boreholes/monitoring wells, analysis of over 200 surface or subsurface soil samples for hydrocarbons, chlorinated pesticides, PCBs and/or metals, and analysis of large numbers of groundwater samples for hydrocarbons and chlorinated pesticides. Additional data were obtained for the purpose of conducting a screening level risk assessment of human health and ecological receptors. The sampling and analytical program included the collection at sites located up to 1.6 km from Rainy Hollow of forest soil and plant samples, trapping of small mammals in the vicinity of the Trench at Rainy Hollow or the Temporary Storage Facility at Border Station, and collection of river water, sediment, and streambed invertebrate samples from the Klehini River. These samples were analyzed for chlorinated pesticides including DDT-type compounds in order to elucidate contaminant migration pathways and expected dose to organisms living in the vicinity of the sites. Three surface soil samples were also collected along right-of-ways and analyzed for dioxins/furans - possible contaminants associated with the historical application of herbicides containing 2,4,5-T.

The major contaminant sources of concern at Rainy Hollow and Border Station were confirmed to be (a) subsurface soils and groundwater at Border Station and Rainy Hollow contaminated with light, diesel-like hydrocarbons (b) DDTs in subsurface soils and groundwater, arising from the earlier burial of DDT-containing canisters in a trench at Rainy Hollow; and (c) DDTs in surface soils at Rainy Hollow near the trench, at Border Station near the Temporary Storage Facility, and on access roads and tracked areas between them. The original burial of canisters containing DDT in an area that is virtually in the centre of the pathway of subsurface migration of hydrocarbons from the upper bench toward the Klehini river represents an extremely unfortunate circumstance. Two main issues emerge: the subsurface movement of hydrocarbons into the Klehini River, and the migration of DDT along the same path.

Beneath the former pumping station facilities, hydrocarbons were not present at surface but were encountered at depths varying from 3 to 15 m. Approximately 4 cm of free product was encountered in one well (TH-8B). The contamination extended as deep as the till surface or 25 m below ground. The till surface seems to be a barrier to further vertical movement. Laterally, the hydrocarbons extended from below the shop to past the utility building. The areal extent of hydrocarbons at the lower bench (Rainy Hollow) is much smaller than at the upper site. The impacted zone comprises a layer of hydrocarbon-contaminated soil and groundwater up to 8 m thick beneath the water table. Near the river, this thickness was reduced to about 4 m. There is a

95 % probability that the mass flux to the Klehini River of light extractable petroleum hydrocarbons lies within the range of 4,819 to 486,778 g/year.

For DDTs, the contaminated subsurface area surrounds the trench area where the drums were recovered and extends to the river. The highest soil concentrations were directly adjacent to the trench, and were in the range of 4 to 5 mg/kg. Further from the trench, subsurface soil concentrations were typically less than 2 mg/kg. At the river's edge, concentrations of DDTs in groundwater were from 1 to 8 ng/L. There is a 95 % probability that the mass flux of DDTs to the Klehini River presently lies within the range of 0.0183 to 0.3497 mg/year. Limited modeling calculations suggest that at steady state, i.e. some time in the future, the groundwater concentration of DDTs at the river outflow face could increase to 37 ng/L. Assuming a dilution factor of 20 to 30 fold for groundwater discharged to the small channel inside the gravel bar of the Klehini River, there is a possibility that the local concentrations of DDTs in the slower flowing river water in the immediate vicinity of the outflow face of the contaminant plume could exceed 1 ng/L, the CCME criterion and B.C. standard for the protection of freshwater aquatic life. It is important to note, however, that dilution factors for introduction of DDTs into the main flow of the Klehini River are undoubtedly much larger than 100-fold. The maximum estimated input of DDTs from Rainy Hollow would not result in concentrations of DDT greater than 1 ng/L across the majority of the river. Predictions of future contaminant fluxes into the Klehini River, however, should be verified.

There is clear evidence that both DDT and hydrocarbons are being introduced to the Klehini River through the discharge of contaminated groundwater; however, the actual instantaneous concentrations of these substances in sediment, river water, or stream invertebrates is presently so low as to preclude any possibility of deleterious biological effects. DDT concentrations were indistinguishable from background levels for sediment and stream invertebrates. Possible risk pathways for contamination of the Klehini River and its inhabitants, therefore, could be confidently ruled out, since the dose to aquatic organisms contributed from contaminated areas at Rainy Hollow *via* sediment or river water was essentially zero. All aquatic ecological risk pathways were excluded for further risk assessment. The same conclusion, with a similar rationale, was made for petroleum hydrocarbons and aquatic receptors.

The presence of DDT in shallow surface soils at the site is a separate issue, both in terms of its underlying cause and possible ecotoxicological implications. The screening risk assessment included an evaluation of risks to non-human receptors in the Klehini River due to DDT inputs *via* contaminated groundwater, and to small mammals and their predators in the terrestrial and riparian habitat within ~ 100 m of the Rainy Hollow Trench. The human health risks associated with ingestion of DDT-contaminated soil, inhalation of DDT in the gaseous phase, or dermal absorption were also assessed. The human health risk assessment indicated that in the context of the exposure scenarios considered for this site, there is no risk to humans from exposure to DDT and its related compounds at Rainy Hollow.

Recommendations for follow-up are provided, based on the premise that the need for any action arises only in situations were there is a possibility of risk to humans and/or other living organisms at present, or some reasonable expectation that risks could occur in the future. Recommendations include the continuation of groundwater monitoring program to validate and improve predictions of contaminant fate, and removal or isolation of contaminated surface soils with DDT concentrations > 10 mg/kg. Other recommendations for follow up or site restoration, e.g., to minimize surface soil erosion are provided.

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1. INTRODUCTION

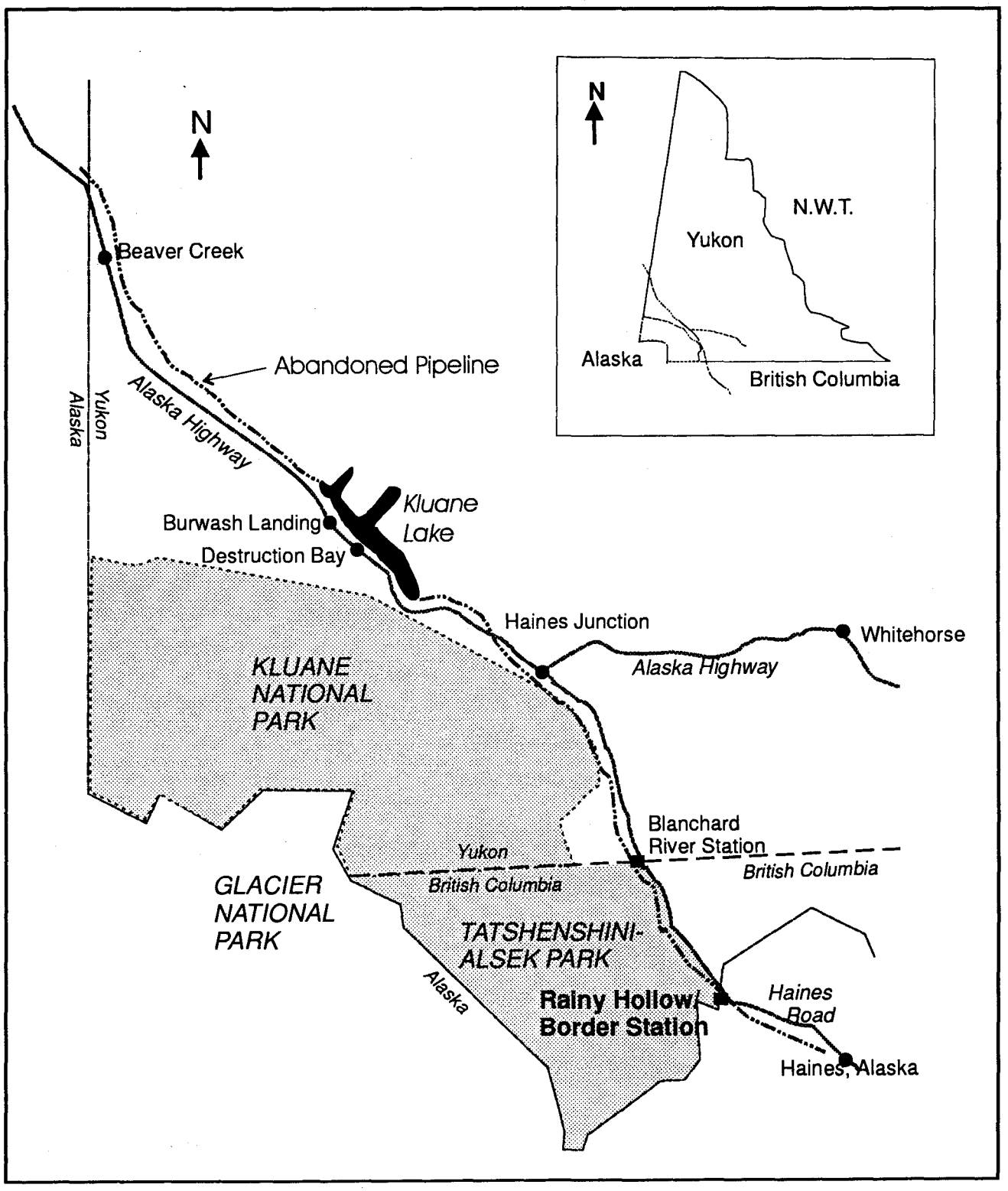
1.1 Background

Border Pump Station and Rainy Hollow site are contiguous abandoned sites in northern British Columbia, just south of the Yukon border. Border Station is situated on an upper bench adjacent to the Old Haines Highway, and Rainy Hollow is located on an lower terrace below Border Station and along the shore of the Klehini River (Maps 1.1 and 1.2; Photographs 1.1 to 1.6). Both areas are located within the southeast corner of the Tatshenshini-Alsek Wilderness Park of British Columbia, within 5 km of the British Columbia - Alaska Border. The sites were originally constructed as part of the Haines-Fairbanks pipeline by the U.S. military, under the guidance of the U.S. Army Corps of Engineers. Rainy Hollow was used as an airstrip for re-supply of the pumping station during construction and operation, from approximately 1954 to 1972. A small pump house at Rainy Hollow served to deliver water from the Klehini River to Border Station. A more complete history of the sites is provided in Bisset and Associates (1995), Royal Roads University (RRU, 1996a), and the summary provided as Chapter 2 of this report.

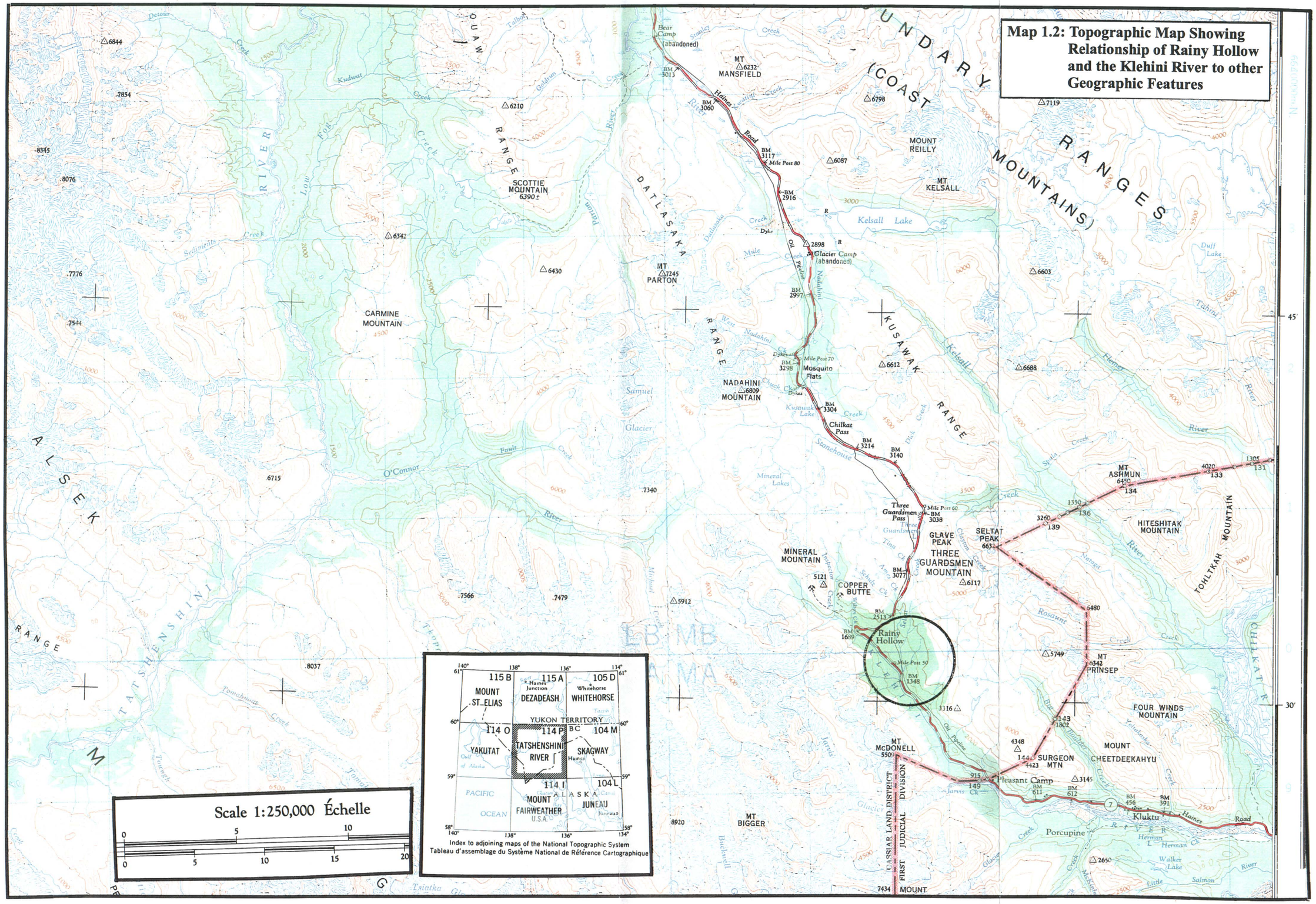
Rainy Hollow gained media and public attention in 1994 when buried canisters containing DDT (dichlorodiphenyltrichloroethane) pesticide were found, prompting an emergency site investigation and clean up. Separate preliminary environmental investigations have been conducted at the abandoned Border Pump Station site by UMA/AMBIO (1995) for Indian and Northern Affairs (Whitehorse), and the Rainy Hollow site by Golder Associates (1995) for Environment Canada (EC, Pacific and Yukon Region). The Border Station preliminary environmental investigation indicated that surface soil contamination was very limited, but subsurface hydrocarbon (probably diesel) contamination was detected in soil samples from three of four boreholes, at depths from the surface to 2 - 24 m, depending on the location. It is important to note that although the two sites have been evaluated separately in recent years, both were operated historically as a single unit, are connected geologically and hydraulically, and may be considered as part of the same regional ecosystem.

The location of Rainy Hollow/Border Station in the recently created Tatshenshini-Alsek Wilderness Park served in 1994 to elevate the public and provincial government concern about the DDT issue. Tatshenshini-Alsek Wilderness Provincial Park was created in 1993 and subsequently designated in 1994 as a United Nations designated World Heritage Site. When combined with Glacier Bay National Park in Alaska to the south and west, and Kluane National Park to the north, the parks comprise the largest protected area in the world. The Alsek and Tatshenshini rivers combine to carve a valley through the park, and through one of the largest glaciers outside of the polar regions. The valley channels marine air masses inland into the Yukon, which combine over short geographic distances with Arctic climatic features to create exceptionally diverse microclimates and habitats.

Map 1.1: General Location of Tatshenshini Wilderness Park, and Rainy Hollow in Northern British Columbia



Map 1.2: Topographic Map Showing Relationship of Rainy Hollow and the Klehini River to other Geographic Features





Photograph 1.1: Aerial view of Border Station and Rainy Hollow (July 1996)



Photograph 1.2: Layout of Border Station - northern portion, July 1996.



Photograph 1.3: Temporary storage facility at Border Station for DDT-contaminated soils isolated during the 1994 emergency response. Soils were disposed off-site in October 1996.



Photograph 1.4: Abandoned airstrip on flood plain of Klehini River, looking South from the north end. The orange snow fencing surrounding the excavated trench from which DDT canisters were removed is visible in distance.



Photograph 1.5: General layout of Rainy Hollow showing trench.



Photograph 1.6: Rust-coloured staining and disturbed soil to the south and west of the trench.

The Klehini River, which runs by Rainy Hollow and Border Station, does not drain into the Tatshenshini-Alsek system, but rather drains south along the eastern periphery of the park and into Alaska, combining with the larger Chilkat River near Haines, Alaska (Map 1.2). A portion of the Chilkat River downstream from the confluence with the Klehini River passes through the Chilkat Bald Eagle Reserve in Alaska, and flows by the first-nations village of Klakwan. Border Station and Rainy Hollow are located within the southern portion of traditional lands of the Champagne-Aishihik First Nations and Southern Tutchone. The land claim for the area has not been settled with the Government of British Columbia.

1.2 Environmental Issues

In early 1996, federal and British Columbia government agencies with jurisdiction over or interests in the sites initiated the detailed site investigation and risk assessment described herein. This study was directly sponsored by Indian and Northern Affairs Canada, Arctic Environmental Strategy, Whitehorse, in consultation with several major stakeholders - presently constituted as the Rainy Hollow Working Group. The stakeholders include Indian and Northern Affairs, B.C. Ministry of Environment, Lands and Parks, Champagne Ashihik First Nations, and Environment Canada.

Although the sites are located in the Tatshenshini-Alsek Wilderness Park, they are presently under different jurisdictions. The upper site, Border Station, is the property of the Government of Canada, under the jurisdiction of Indian and Northern Affairs Canada, and administered by the Whitehorse office. It is currently not included in the park. The lower site, Rainy Hollow, which is within the park is the property of the Government of BC. The detailed investigation represents part of larger efforts to return overall jurisdictional control of the land to the province of British Columbia. This imposed some time limitations on the detailed assessment: All necessary investigations and risk assessment activities were to be completed by the end of 1996.

Prior to commencement of the detailed site investigation, British Columbia Ministry of Environment, Lands and Parks (BC MELP) provided a draft work plan for the detailed site investigation (Evans, 1996), which identified the critical environmental issues at Border Station - Rainy Hollow, and defined both objectives and an anticipated level of effort. This project was undertaken through the cooperative efforts of the Applied Research Division at Royal Roads University, UMA Engineering Ltd., and Golder Associates Ltd.

One of the challenges in the assessment and final clean-up of the sites is the presence of subsurface hydrocarbon contamination beneath Border Station and upgradient from the trench/landfill at Rainy Hollow, where the DDT canisters were originally buried (Golder, 1995; UMA/Ambio, 1995; RRU, 1996 a,b). Derivation of remedial options for contaminated soils and groundwater at the sites required a credible assessment of human

and ecological risk associated primarily with the presence of DDT and hydrocarbons. Interactions between hydrocarbons and DDT, furthermore, could influence their environmental fate in ways not adequately predicted by currently available partition coefficients and scientific models. Two major contaminant receptor areas required examination for an ecological risk assessment: (i) terrestrial food chains - for example, plants-herbivore-carnivore systems, or various soil fauna - primarily in the immediate vicinity of the site; and (ii) aquatic organisms in the Klehini River system downstream from the site, and their predators.

Provincial (e.g., British Columbia) or federal Canadian Council of Ministers of the Environment (CCME) soil quality guidelines or remediation criteria for DDT or its related isomers do not presently exist. Draft CCME guidelines for DDT and the related compounds DDE and DDD are presently being developed. The primary mode of toxicity for DDT, as well as several related persistent organochlorines, is generally accepted to be associated with entry into the food chain and subsequent biomagnification, rather than via direct and acute toxicity.

Federal soil quality criteria, and provincial or federal water quality criteria do not presently exist for the major portion of constituents that comprise petroleum hydrocarbons, except for a small number of polycyclic aromatic hydrocarbons (PAHs), benzene, ethylbenzenes, toluene and xylenes. Alkylated PAHs, which along with terpenoids, hopanes and alkane hydrocarbon fractions comprise the major portion of total petroleum hydrocarbons in the groundwater and subsurface soil at Border Station (RRU, 1996b). Benzene, toluene, ethylbenzenes, xylenes, or unsubstituted PAHs, in contrast, comprised only a small portion of the hydrocarbon contamination.

Outstanding contaminant issues at the sites, as of spring 1996, were summarized by Royal Roads University (RRU, 1996a). Table 1.1, below, is reproduced from that report.

Table 1.1: Summary of Outstanding Issues and Recommended Course of Action at Border Station - Rainy Hollow (reproduced from Royal Roads University, 1996a)

Issue:	Recommendation:
Presence of buried debris at Border Station (6 locations) and Rainy Hollow (4 locations)	• Confirm non-hazardous nature of buried materials using test pits, sub-surface sampling and contaminant analysis including chlorinated organic compounds, total hydrocarbons, and metals. • If contaminant sources found, characterize contaminated soil volumes (via confirmatory testing) and/or expanded suite of laboratory analyses as appropriate
Subsurface hydrocarbon contamination (soils and groundwater)	• Delineate spatial and vertical distribution of contaminant plumes at Border Station and Rainy Hollow through the installation of a series of new nested wells up- and down-gradient and laterally to known (or suspected) areas of contamination; air rotary/casing hammer methods should be used • Characterize groundwater flow and likely seasonal variations with reference to soil permeability, hydraulic conductivity and other factors. • Estimate flux of specific hydrocarbon and DDT contaminants to Klehini River • Characterize contaminant levels and composition in groundwater plumes and subsurface soils via confirmatory testing (field analytical techniques) and laboratory analysis
DDT-contaminated soils in and surrounding the Rainy Hollow Trench enclosure	• Examine the levels of DDT in subsurface soils within the enclosure, in soils and groundwater around the Trench, and between the facility and the Klehini River as part of overall subsurface investigation • Collect geotechnical and analytical data to evaluate mitigative actions for the above if required • Assess the risk of failure and expected longevity of the geotechnical liner in the Trench and subsequent contaminant release, based on its engineering design
Phenoxy-herbicide sources	• This is not considered to be likely based on Golder (1995) and UMA (1995) data. • Limited analysis should be conducted for dioxins (as impurities) in areas which may have received chronic herbicide applications (e.g., right of ways, airstrip)

(continued next page)

Table 1.1: Summary of Outstanding Issues and Recommended Course of Action at Border Station - Rainy Hollow (cont.)

Issue:	Recommendation:
Surface hydrocarbon stain at Border Station	• Investigate the vertical extent of subsurface contamination using test pits and a targeted analytical screen in conjunction with the overall subsurface investigation
DDT and hydrocarbon contaminated soils in the Temporary Storage Facility	• Collection of surface and subsurface soil samples and analysis to define the concentration distribution of DDT and its breakdown products, levels of hydrocarbon and its specific composition, and the physical and geochemical composition of the materials • Assess the risk of failure and expected longevity of the geotechnical liner in the facility and subsequent contaminant release, based on its engineering design[1] • Evaluate remedial options in terms of cost, applicability and practicality, including the transport of materials off site • If the installation will remain in place for an extended period of time, wells should be installed in the vicinity of facility to monitor groundwater quality[1]
Need for a risk assessment of impact to the terrestrial environment, particularly between Border Station and Rainy Hollow	• Assess and predict (where required) hydrocarbon composition, persistence, and impacts through observations and directed sampling of soils, vegetation, and possibly other fauna based on habitat use and exposure pathway(s)
Similar need for risk assessment in the aquatic environment of the Klehini River	• Repeat and extend the electrofishing/gill net fish tissue sampling and analysis program by Golder (1995) with more detailed observations and upstream (control site) and downstream. • The sampling program should be expanded to include other fish and invertebrates with high BSAFs (biological to sediment accumulation factors and/or BMFs (biomagnification factors). • Sediments from quiet eddies at up- and downstream locations should be analyzed for organic contaminants (including DDT and associated compounds) using high resolution analytical methods; include analyses for unsubstituted and alkylated PAHs
Critical evaluation of remedial strategies and estimation of cleanup costs	• Collection of geotechnical data required for an anticipated site cleanup • Accurately estimate volumes of contaminated materials using confirmatory testing methods • Survey in locations of all features including sampling locations using total station (triangulation) methods of other appropriate techniques

1: Not necessary since soils and facility were removed in mid-October, 1996.

1.3 Scope and Objectives

The overall objectives of this study are as follows:

- conduct a detailed site investigation for Border Station - Rainy Hollow, including a site-specific risk assessment;
- recommend site-specific soil and groundwater remedial options;
- interact with Champagne and Aishihik First Nations and other stakeholders through on-site training and discussions, community and risk communication.

The detailed site investigation and risk analysis were designed to address concerns tabulated above, and to provide direct guidance regarding the need and options available for further actions at Rainy Hollow/Border Station.

1.4 Risk Assessment Objectives

Risk assessment is a tool for directly addressing the toxicological implications of environmental contamination, particularly as a result of past human activity. Given the contaminants found at a specific site, it addresses the question: What are the possible adverse effects on living resources and/or human beings, and what is the likelihood of such effects occurring? There are several existing guidance documents on conducting risk assessments, including that produced by the U.S. EPA (1992), the CCME (Canadian Council of Ministers of the Environment, 1994) ecological risk assessment framework, and a recent document on the ecological risk assessment of priority substances, under the Canadian Environmental Protection Act (CEPA) (*in draft*). The CEPA risk assessment framework is similar to the U.S. EPA framework, with modifications that reflect advances since 1992 in the implementation of risk assessment and risk management. Extensive efforts are also underway in the U.S. to re-evaluate contaminant-based risk assessment and risk management strategies (for example, Commission on Risk Assessment and Risk Management, 1996. *Draft Report: Risk Assessment and Risk Management in Regulatory Decision Making*).

The structure of this report, in part, reflects an almost universally accepted framework for human health or ecological risk assessment and includes the following four main elements:

1. **Hazard Identification/Entry Characterization** (≡ detailed site investigation) - identification and quantification of the contaminants present (potential contaminants of concern) in a given area/environment that have at least some possibility of causing adverse effects in humans and/or other living organisms.

2. **Exposure Assessment** - a) determination of the plausible environmental fate pathways for the site and area in question where living organisms, including humans, could be exposed, and b) estimation of the doses that could occur as a result of that exposure.

3. **Dose-response Assessment** - a) evaluation, either directly or through inference from other studies, of the quantitative relationship between contaminant exposure concentrations and b) the incidence of harmful effects.

4. **Risk Characterization** - a) description, based on the state of the knowledge, of adverse effects that are attributable to a contaminant or combinations of contaminants; b) estimation of the likelihood of such effects occurring in the exposed population based on the exposure assessment, and c) critical evaluation of the strength of the evidence, assumptions used to arrive at the conclusion(s), as well as the magnitude of the uncertainty associated with the characterization.

It should be noted that the risk analysis for this project initially included a "scoping" risk assessment, where the objective was to provide worst-case assessments of risk, with more detailed probabilistic assessments conducted only for exposure pathways with indications of significant risk. In cases where initial efforts and weight-of-evidence interpretations overwhelmingly indicate negligible risk to receptors (flora, fauna, humans or others), or where the source of risk can be easily removed in a cost-effective manner, it is often unnecessary to conduct a probabilistic risk analysis. It is important to appreciate, however, that the credibility of the risk analysis, regardless of level-of-effort applied, may be more dependent in many instances on limitations in the state of our scientific knowledge. For example, a detailed site-specific analysis of the probability of a contaminant to cause liver cancers in recipient salmonids might be a poor indicator of the real risk to the fish population if the primary toxicological mechanism occurs via the biochemical disruption of endocrine control. This is a highly plausible toxicological endpoint for which dose-response relationships have not been adequately elucidated up to the present time. *The risk assessment herein was conducted in accordance with the draft CEPA risk assessment framework and the CCME risk assessment guidance.*

Recent revisions of human health risk assessment methodologies in the U.S. (Commission on Risk Assessment and Risk Management, 1996) recognize the central role of stakeholders. People most directly influenced by site activities and contamination, and who are the primary users of the site or the surrounding environment potentially provide invaluable guidance in the problem formulation stage. Some examples include needed input into the derivation of conceptual risk models, the provision of information on site use and range of activities carried out, and defining relevant receptors leading to human exposure (which may also be considered to be Valued Ecosystem Components within the biosphere). The central role of indigenous people and "traditional knowledge" is increasingly considered to be an essential component of environmental assessments (Stevenson, 1996). *We feel that the risk assessment provided herein is only credible to the extent that it reflects the concerns of, and information provided by, major*

stakeholders in the regions, including members of the Champagne and Aishihik First Nations, and the community at large. Stakeholder consultation and direct involvement during the field investigation is therefore considered to be an integral component of the project.

The detailed analysis of contaminant distributions and concentrations at Rainy Hollow/Border Station was used in concert with the risk analysis to examine the need for remedial measures at the site. Plausible options are discussed, but are limited to technologies or procedures with a proven track record in similar environments in terms of biophysical characteristics and remoteness.

2. ECOLOGICAL SITE DESCRIPTION AND HISTORICAL OVERVIEW

2.1 The Receiving Environment of Rainy Hollow/Border Station

2.1.1 Vegetation

Mixed, mature white and black spruce (*Picea* spp.) forest dominates the region outside of the disturbed areas of the station and includes trees such as large mountain hemlock (*Tsuga mertensiana*), willow (*Salix* sp.), alder (*Alnus* sp.), and balsam poplar (*Populus* sp.) in more open forest as well as a number of forbs, low-lying shrubs and wildflowers. The sites themselves consist of large open areas where the major activities, including demolition and burial took place (Photograph 2.1). Vegetation in these disturbed areas consists of a variety of wildflowers including clover (*Trifolium* sp.), willow-herb or fireweed (*Epilobium* sp.), lupine (*Lupinus* sp.), columbine (*Aquilegia* sp.), dandelion (*Taraxicum* sp.), fleabane (*Erigeron* sp.), yarrow (*Achillea* sp.) cinquefoil (*Potentilla* sp.), plantain (*Plantago* sp.) and milk-vetch (*Astragalus* sp.); as well as horsetail (*Equisetum* sp.), grasses (e.g. bluegrass or *Poa* sp.) and sedges (*Carex* sp.). Small shrubs are also beginning to invade these areas. These include soapberry (*Shepherdia* sp.), and blueberry (*Vaccinium* sp.). Buffer areas immediately outside of the station consist of willow, balsam poplar, blueberry and soapberry which give way to a transitional zone of partially-open, mixed spruce-poplar forest, particularly along the slope separating the two sites. This area is marked by a prominent shrub and herb layer including willow, cow-parsnip (*Heracleum* sp.), raspberry (*Rubus* sp.) horsetail, and fireweed.

2.1.2 Birds, Mammals, and Invertebrates Occurring at the Site

Bird species were not identified during site visits; however, a variety of passerine or songbirds such as Thrush were often seen and heard during site visits, suggesting that the region is an important habitat for boreal forest and meadow species. Raptors, particularly Bald Eagles, have also been seen circling the site and undoubtedly hunt the area for smaller birds, and mammals, as well as scavenging for carrion.

Approximately 125 different bird species have been noted within the region of Tatshenshini-Alsek Wilderness Provincial Park. These include the Peregrine Falcon, Northern Goshawk, Golden Eagle, Trumpeter Swan, Great Grey Owl, Short Eared Owl, King Eider, Arctic Tern, Gray-cheeked Thrush, Lesser Golden Plover, and Pacific Loon. More rare sightings of Smith's Longspur, Snow Buntings, Ptarmigan, Red-throated Loon, Gyrfalcon and Wandering Tattler have also been observed (B.C. Parks, 1995).

Black bears have been spotted near the site and the area is also visited by grizzly bears feeding on soapberry and salmon during the summer months, and large game (e.g., moose, elk) as suggested by the presence of numerous droppings along the old Haines Road and footprints at site (Photograph 2.2). Small mammals, particularly rodents, are also common including red squirrels, chipmunks, deer mice (*Peromyscus* sp.), voles (*Microtus* sp), shrews (*Sorex* sp.), porcupine (*Erethion* sp) and rabbits (*Lepus* sp.). Mosquitoes, blackflies, midges, spiders, and butterflys were also noted in large numbers, but were not identified down to species level (Photograph 2.3).

Up to 53 different species of mammals are estimated to inhabit Tatshenshini area including Dall's sheep, Mountain goats; and species rare in B.C.; these include Collared Pika, Tundra Vole, Arctic Ground Squirrel, and Meadow Jumping Mouse (B.C. Parks, 1995). The aforementioned rare mammals are probably either absent or very uncommon in the immediate vicinity of Rainy Hollow, being more common at higher elevations in sub-alpine and alpine areas, beginning a few kilometers to the north of the site.

2.1.3 Biota Within the Klehini River

The waters of the Klehini River were observed to be extremely swift, even during dry periods in the summer (Photograph 2.4). This has precluded the occurrence of rooted aquatic macrophytes along the river bed, even in the lower energy side pools. A variety of insect larval stages, including dragonflies, occur in the stream, but were not identified. It is also assumed that a basic aquatic food chain consisting of phytoplankton (algae), plankton and small invertebrates exists to support these organisms in addition to higher end predator species such as Dolly Varden char, which also occur in these waters. Only juvenile char were found in the Klehini River during the investigation in 1994 (Golder, 1995) and during our site visit, whereas large adult Dolly Varden were observed both in 1994 and in July 1996 in the Seltat Creek to the north, immediately upstream of its confluence with the Klehini River. It is important to note that there was only a limited amount of periphyton growing on rocks on the river bed near the site, and sediment deposits exhibited extremely low organic carbon concentrations (< 0.5% organic C). The overall picture is of a river with extremely low productivity and high sediment loads contributed by glacial runoff. Chum salmon runs are reported to occur as far up the Klehini River as the Pleasant Camp Canada-US Customs Post 10 km to the south of the station, but are probably limited to the north of this point by long, narrow high-velocity sections of the Klehini River. No other species of salmon are known to frequent the Klehini River north of (upstream from) Pleasant Camp.

2.1.4 Human Activities at or Near the Site

The site is relatively isolated from any major human activity and is located a few kilometers north from the Haines Highway along the Old Haines road. Pleasant Camp Canada-US Customs Post is the nearest permanent habitation which is located just under 6 km south of Border Station/Rainy Hollow. The site has been visited periodically for short periods of time over the past few years by environmental investigators, government

personnel, and various cleanup crews; however, there are no permanent settlements in the vicinity of the site. A locked gate has been installed across the old Haines Road near the Haines Highway which limits vehicle access. Since it is technically part of the Tatshenshini Wilderness Park, however, the area is probably visited periodically by hikers, recreationists using the river (e.g., rafting tours and anglers), and also by Champagne-Aishihik First Nations people who occassionally use these traditional lands for hunting and fishing. In addition, the area has been used recreationally and for hunting in the past by Pleasnat Camp customs personnel and their families.



Photograph 2.1: Edge of Border Station Site showing transition zone to mature mixed white and black spruce (*Picea spp.*) forest.



Photograph 2.2: Grizzly bear track at Rainy Hollow.



Photograph 2.3: Butterfly in patch of hawkweed (*Hieracium* sp.) and horsetail (*Equisetum* sp.).



Photograph 2.4: Receiving environment of the Klehini River showing swift summer currents.

2.2 Previous Site Activities

2.2.1 Construction and Use

The Border Station/Rainy Hollow sites were originally constructed as part of the Haines-Fairbanks pipeline under the guidance of the U.S. Army Corps of Engineers between 1954 and 1955. This site was one of the six pump stations built in the Canada by the US as part of the Korean War effort, to transport fuel and gasoline to military bases in Alaska (Bisset, 1995). The site is located on the west side of the Haines Road on an area of 13 ha at 400 m asl. The Canada-US border at Pleasant Camp is located roughly 9 km to the south, and the terminal is located in Haines, Alaska, 90 km further to the south. Border station was designed to pump products over the Chilkat Pass up to an elevation of 1067 m (Bisset, 1995).

The original site facilities at Border Station consisted of a main line pump building, warehouse-garage-shop, utility building, wood frame construction family housing (10 person dormitory and two apartment-type 6 unit buildings), a cement cold storage locker building, and one 5,000 barrel diesel storage tank above the site to the west which was filled from the pipeline at scheduled intervals for station use (Bisset, 1995).

Rainy Hollow was used as an crude airstrip by small aircraft for light re-supply of the pumping station during construction and operation; it was also used in later years for transporting station personnel to nearby communities. Aviation fuel was probably also located near the airstrip during its operation, along with dumps for station wastes. A small pump house at Rainy Hollow served to deliver water from the Klehini River to Border Station.

A number of fuel spills were recorded along the pipeline during its 17 years of operation (see Bisset, 1995), in addition to frequent, probably un-recorded spills at many of the pump stations. Herbicides were frequently sprayed along the pipeline right of way and stations in the late 1960s. Chemicals used included esteron (mixture of 2,4-D, and 2,4,5-T), fenuron (25 % 3-phenyl-1, 1-dimehylurea), and Tordon 101 (2,4-D, picloram and isopropyl alcohol). Dioxins and furans were also noted as a possible contaminant of 2,4,5-T (Bisset, 1995). It is possible that herbicide application also occurred at or near Border Station/Rainy Hollow.

The Haines Fairbanks pipeline ceased operations in 1971 as the result of reduced fuel needs in Alaska. All remaining and stored fuel along the pipeline was pumped to Tok, Alaska and the pipeline was subsequently flushed. All of the facilities were left in operational readiness with the capability of resuming activity within 30 days, if necessary. Some of the facilities at the pump stations were partially dismantled following the dissolution of the 20-year Canada-US Treaty for the Pipeline in 1973 (Bisset, 1995).

Although little formal documentation exists, the site was used in subsequent years

by Haines-Fairbanks Highway construction crews. The site was also used as a mineral exploration base camp from 1983 to 1987 by Stryker Resources/Freport Resources (Golder, 1995).

2.2.2 Cleanup Activities

A cleanup of the Border Station site was conducted by the B.C. Ministry of Forests in 1987. Details of this effort are not available; it is assumed, however, that cleanup was cosmetic in nature and consisted of the clearing away loose debris to be stockpiled or later salvaged; most buildings and facilities were left intact. Further decommissioning of the site, specifically buildings and facilities, was left up to Indian and Northern Affairs (DIAND) in Whitehorse (Royal Roads University, 1996a).

Salvaging operations began with the removal of the pipeline in 1991-92 followed by the demolition of the buildings on site by DIAND under contract (Golder, 1995). All recoverable materials were dismantled and moved out by truck. Such materials included fuel and water storage tanks, sheet metal, dispensing pumps, storage tank building, antennae, freezer unit, fencing, and a vehicle hoist. Flammable materials were burned, and the remaining waste materials including scrap metal, re-bar, asbestos sheeting/siding, and boiler pipes were buried in apartment building foundations as recommended by BCMELP. Fuel-contaminated soil was removed and stored in the same manner. Additional non-contaminating materials including warehouse concrete slabs and rebar, more scrap metal, and fence post butts were buried in the ground at locations near the warehouse/garage/shop building. The site was subsequently graded and leveled to conform with the original contours of the site. The burial locations at the dormitory site were seeded to promote re-vegetation.

2.2.3 Emergency Contaminant Response

An emergency response team consisting of representatives from CEDA Reactor Ltd. (Edmonton), BCMELP, EC and Golder Associates was assembled in September of 1994 immediately following the discovery of DDT canisters buried in a dump at Rainy Hollow. A total of 40 canisters containing estimated DDT concentrations in the range of 378 to 2,177 ppm (total) in a liquid hydrocarbon carrier were uncovered. Approximately 550 m^3 of contaminated soil (DDT levels ranging from 2.85-25 ppm) was also removed from the excavation during extremely wet weather. The canisters were placed in overpack drums and removed from the site by Phillip Environmental Services Ltd, along with other materials which were suspected to be contaminated such as DDT lab packs, wash water, drummed solids, empty drums, transformer oil, and unknown solids (Royal Roads University, 1996a).

Soils contaminated with DDT were temporarily sorted and stockpiled for contaminant testing, and subsequently moved by truck from Rainy Hollow to a Temporary Storage Facility constructed at Border Station above the Rainy Hollow site. The Trench location where the canisters were excavated was secured using a liner and backfilled with surface materials, including some of the less-contaminated soils from the excavation (0.22

to 0.62 ppm DDT). Heavy precipitation during this period resulted in most of the soils becoming saturated.

2.2.4 Preliminary Environmental Assessments at Rainy Hollow

A preliminary environmental assessment of Rainy Hollow in the vicinity of the trench area was conducted by Golder Associates in September of 1994, in concert with the emergency response actions discussed above (Golder, 1995). Geophysical surveys were first conducted to investigate the site for potential burial areas. Four areas were identified as probable local refuse dumps containing metallic debris, but were not investigated due to time constraints. Hydrocarbons and DDT were reported to be present in intact soils around the trench with an estimated volume of 450 m^3 containing DDT concentrations exceeding 2 ppm (B.C. Environment's 1989 Draft 6 Criteria). High field OVM (organic vapour monitor) readings for soils (> 250 ppm) were noted around the Trench and believed to provide an indication of the presence and release of hydrocarbons and their migration towards the river (Royal Roads University, 1996a).

At the time of the emergency response, a short working window was available to conduct a limited-scope investigation program. Suitable drilling equipment was not available for soil sampling and monitoring well installation. Rather, available field equipment - a rubber tired backhoe - was used to put down a series of shallow test pits in the alluvial flood plain soils surrounding the Trench. Slotted PVC pipewas positioned in each test pit to provide a method of measuring the depth of groundwater. Proper well development and sampling could not be conducted in the crude "monitoring wells". However, as these sampling points were available, it was decided to obtain groundwater samples for analysis to provide an indication of site geochemistry and contaminant plumes. These groundwater samples were, predictably, of limited use in assessing contaminant flux due to sediment problems. The report documenting the emergency response work recommended further, more detailed sampling and analysis using properly installed monitoring wells as discussed in this report.

Hydrocarbons (< 2 to 33 mg/L) and DDT (1 to 6 μg/L) were also reported to be present in groundwater samples at concentrations below the CCME drinking water criteria, but still exceeded the criterion for freshwater aquatic life (1 ng/L). It was proposed that DDT transport in groundwater at some locations at Rainy Hollow may be facilitated by a hydrocarbon carrier which floats on the water table based on the observations that the maximum observed DDT concentration in groundwater (6 μg/L) exceeded its solubility limit in water (3.4 μg/L). The report also provided a very rough estimate of groundwater loading of DDT to the river, based on a number of assumptions about hydraulic conductivity of the substrate and the nature of the aquifer. Potential loading of groundwater DDT to the Klehini River was estimated to be extremely low: In the range of 0.4 to 40 mg/year. The data, however, were still considered to be preliminary based on the presence of suspended sediments in the groundwater samples (Royal Roads University, 1996a).

Concentrations of the isomers DDT, DDE and DDD were found to be below the detection limit for each isomer in both water (<0.05 µg/L) and in young Dolly Varden char (*Salvelinus malma*) (<0.002 ppm) from the river. Concentrations of hydrocarbons analyzed exclusively in the water sample were also below detection including oil and grease (<0.2 mg/L), BETX and VOC. It was recommended, however, that the analysis of sediments and porewater, and additional tissue samples of fish and would be required to properly assess potential impact(s) on the Klehini River ecosystem (Royal Roads University, 1996a).

The report concluded that DDT was probably being moved towards the river dissolved in hydrocarbons, but no conclusions could be derived on the issue of environmental impact(s). It was stressed that only a preliminary assessment had been performed at Rainy Hollow and more detailed investigations and delineation sampling would be required both here and at Border Station above to develop a proper cleanup plan. This included assessing options for treatment and/or off-site disposal of DDT contaminated soils in the Temporary Storage Facility at Border Station (Royal Roads University, 1996a).

In recognition of the sediment problems encountered with groundwater sampling in the Golder (1995) report on Rainy Hollow mentioned above, a second round of groundwater samples were obtained by Environment Canada in June of 1995. Concentrations of DDT and its metabolites in groundwater samples (range <0.05 to 0.21 µg/L) were found to be at least an order of magnitude less than for samples obtained in September of 1994. Hydrocarbon concentrations (<0.2 to 1.4 mg/L) were also at least an order of magnitude less than in well samples with detectable values from September 1994. Oil absorbent swabs taken of floating hydrocarbons found in five of the wells (WP3, WP7, WP10, WP12 and WP13) indicated that light non-aqueous phase liquids were present in only a thin surface film. The trace samples obtained exhibited a hydrocarbon composition (gas-chromatographic pattern) consistent with diesel (Royal Roads University, 1996a).

Seepage with an orange-red precipitate and "a thin waxy hydrocarbon film" layer was also observed to be surfacing from the backfilled trench area 50 m to the south towards the Klehini River during the Environment Canada study. Concentrations of DDT compounds and herbicides (2,4,5-T and 2,4-D) in the seepage water were found to be below detection, and levels of most dissolved metals were comparable to typical values for groundwater. The hydrocarbon film on the surface drainage was suggested to be the result of natural decay from leaf litter; however, no chemical analyses were performed (Royal Roads University, 1996a).

The Environment Canada report concluded that hydrocarbon movement in groundwater either as dissolved constituents or attached to suspended solids was extremely limited. It was also proposed that existing hydrocarbons occurring as thin films on the groundwater surface in some of the wells and those retained in the soils were an historical artifact from old releases of free product which had moved through the site in the past and were now relatively immobile. No specific recommendations were provided (Royal Roads University, 1996a).

2.2.5 Preliminary Environmental Assessments at Border Station

A preliminary environmental investigation was carried out at the Border Pump Station Site in July 95 by UMA Engineering Ltd. and AMBIO Research Associates as part of the Arctic Environmental Strategy, Action on Waste Program. Investigations were limited to the pump station site only and excluded Rainy Hollow where the airstrip and original dump areas were located (UMA, 1995).

A limited electromagnetic (EM) survey was conducted over the west side of the site to detect buried metallic debris and identify zones of elevated conductivity. Numerous small anomalies were found associated with metal debris and former building foundations, along with three zones of elevated conductivity at the eastern portion of the property. Two open ended drain pipes (75 and 200 mm, respectively) were also discovered, during a visual reconnaissance, protruding from under the south side of Old Haines Road at the top of the slope above Rainy Hollow. The drainage path passed through an open area in the forest canopy to an area directly above a well point (WP3) at Rainy Hollow.

Subsurface sampling was carried out using a series of four bore holes along the western perimeter with an air-rotary drilling rig. A pair of nested monitoring wells was established in one of the bore holes. Surface soil samples were also obtained from a hydrocarbon-stained location near the north end of the site (Royal Roads University, 1996a).

High concentrations of total extractable hydrocarbons (TEH) in soils were measured in subsurface soil samples (up to 1,300 μg/g or ppm), which exceeded Alaska State guidelines (200 μg/g). Extremely high concentrations of TEH were found in groundwater from the pair of nested wells (up to 150,000 μg/L in the shallower well). Although these wells had not had adequate time to stabilize before sampling, the extremely high concentrations indicated the possible existence of free product regardless of the presence of particulate matter in the groundwater samples (Royal Roads University, 1996a).

Concentrations of DDT (209 ng/g or ppb) and total extractable hydrocarbons (TEH = 3200 μg/g or ppm) were elevated in a surface soil sample from the hydrocarbon stain (mentioned earlier), but it was suggested that the trucking of DDT contaminated material from Rainy Hollow may have caused an elevated background level of DDT at the site. It was concluded that a very large area of hydrocarbon contaminated soil and groundwater existed at Border Station. The volume of contaminated groundwater and subsurface soil, however, could not be accurately defined based on the preliminary study. There was no evidence for substantially elevated concentrations for any of a larger suite of other potential contaminants, including PCBs, other pesticides, herbicides or volatile organic compounds (VOCs). The primary ecological risk at this site was suggested to be the subsurface aqueous migration of hydrocarbon contaminants through Rainy Hollow to the waters of the Klehini River(Royal Roads University, 1996a).

As a follow-up to the UMA/AMBIO (1995) report, the Royal Roads University - Applied Research Division (ARD) was commissioned by AES in February 96 to address issues arising from the previous study. This was done through the laboratory analysis of archived samples from the UMA/AMBIO investigation (Royal Roads University, 1996a).

High TEH levels (up to 2,800 μg/g) were found in archived soils tested from two borehole locations confirming hydrocarbon contamination determined by previous soil vapour survey data from UMA (1985). Alkylated PAHs were present at considerably higher concentrations (maximum 22,000 ng/g or ppb) than individual parent PAHs (maximum 890 ppb). The alkane results for the subsurface soil samples tested indicated that some hydrocarbon weathering had occurred. Overall, the analytical results indicate that the probable source of subsurface hydrocarbon contamination at Border Station was diesel and/or other petroleum distillates. (Royal Roads University, 1996a).

The Royal Roads report recommended that a full sub-surface investigation be conducted using existing monitoring wells, as well as establishing new ones up- and down-gradient to properly delineate the spatial extent of the contaminant plume, ascertain the short- and long-term fate of contaminants, and conduct a detailed examination/prediction of environmental risks (Royal Roads University, 1996a).

2.2.6 Removal of the Temporary Storage Facility at Border Station

An investigation of the contents of the Temporary Storage Facility for DDT contaminated soils at Border Station was conducted by the Royal Roads University Applied Research Division on behalf of the Arctic Environmental Strategy - Action on Waste Program (Indian and Northern Affairs) in May-June of 1996. The purpose was to confirm the concentrations and relative composition of DDT and it's breakdown products, and of hydrocarbons in soils as required for the evaluation of remedial solutions. Physical parameters of the soil samples were also examined in addition to Special Waste Extraction Protocols (SWEP) and bioassay tests.

The total volume of the soil pile was estimated to be less than 330 m^3 with DDT (DDT + DDE + DDD) concentrations ranging between 3.6 to 57 mg/kg (ppm). Elevated concentrations (2.3 to 4.7 mg/kg) were also detected in the retaining berm. Hydrocarbon in the soils was mostly diesel, with measurable quantities of heavy oils (lubricants and grease). Leachability results for DDT (and metabolites) in the soils was far below the criterion set for B.C. (3.0 mg/L); these results were also highly correlated with total DDT concentrations. The two soil samples submitted for the 96 h trout bioassay exhibited negligible mortality relative to controls at the three different dilutions tested, and were not considered to be dangerous or extremely hazardous in accordance with Washington State Dept. of Ecology Guidelines (Royal Roads University, 1996c).

A number of remediation scenarios for the Storage Facility were considered by Indian and Northern Affairs, including active and passive (*in-situ*) treatment on site, and removal of the soils off-site to either a less environmentally-sensitive location or a hazardous waste disposal facility. Off-site removal to a secure facility was decided to be

the most viable option from an environmental and economic viewpoint. This was conducted by Hazco Environmental Services Ltd. under sub-contract with the Champagne and First Nations in mid October, 1996. The material was transported to an industrial landfill operated by Waste Management of Canada near Edmonton, Alberta. Subsequent on-site inspections were conducted by Indian and Northern Affairs which confirmed the removal of all materials associated with the facility.

3. METHODS

3.1 Field Investigation

3.1.1 Stakeholder Consultation

The project team did not arrange formal community consultations; rather the participation of as many of the key stakeholders as possible was engendered through a direct involvement in the field investigation and in discussions leading up to and subsequent to the field study. Two major stakeholder groups were considered to have a strong interest in the site based on their long term residence within the area surrounding Border Station and Rainy Hollow, i.e. within a travel distance of less than two to three hours away. Both groups potentially conduct a variety of activities within the area. These groups were (i) the Champagne and Aishihik First Nations people, as mentioned in the introduction, and (ii) Canada Customs employees and their families stationed at Pleasant Camp, within 6 km of Border Station/Rainy Hollow. In addition, Yukon Territorial Government employees working at Blanchard River, to the North, occasionally use the area for recreational purposes. Informal discussions were held with Gord Allison and Harold Kane in Haines Junction. Three members of the Champagne and Aishihik First Nations provided assistance in conducting the field investigation: Glen, Darrell Brown and Chris Williams. Additional informal discussions were conducted with Marinka Darling and Bruce Erickson from the Pleasant Camp Customs Post.

Other key stakeholders include personnel from B.C. Parks, B.C. Environment (BCMELP), representatives of the U.S. government involved in similar investigations in Alaska, and members of the general public. Doug Crow, B.C. Parks administrator of the Tatshenshini-Alsek Wilderness Parks visited the site on July 12th, 1996, as well as on September 17th, and provided input into the field sampling program. Peggy Evans, Industrial Waste and Hazardous Contaminants Branch, BCE, provided advice on field sampling on July 11th and 12th. Sam Swearingen, Alaska Department of Public Works provided helpful advice based on his experience at contaminated military sites in Alaska. David Lye, Emergency Response Officer from the Smithers office of B.C. Environment directly assisted with the field investigation during July 18th to 20th. Personnel from Indian and Northern Affairs, Action on Waste, Whitehorse provided extensive assistance as well. Brett Hartshorne visited the site in late July, shortly after the field program. Derek Fraser provided assistance during 15 to 19 July. Werner Liebau and Nicki Krocker, DIAND Whitehorse, provided invaluable assistance during the field investigation.

3.1.2 Subsurface Investigation

The site was visited from July 9th to 22nd, 1996 and again on September 16th to 18th. A major portion of field work revolved around the delineation of subsurface hydrocarbon and DDT contamination, and the prediction of contaminant fate. One set of nested wells was established in July 1995 as part of the Border Station preliminary site

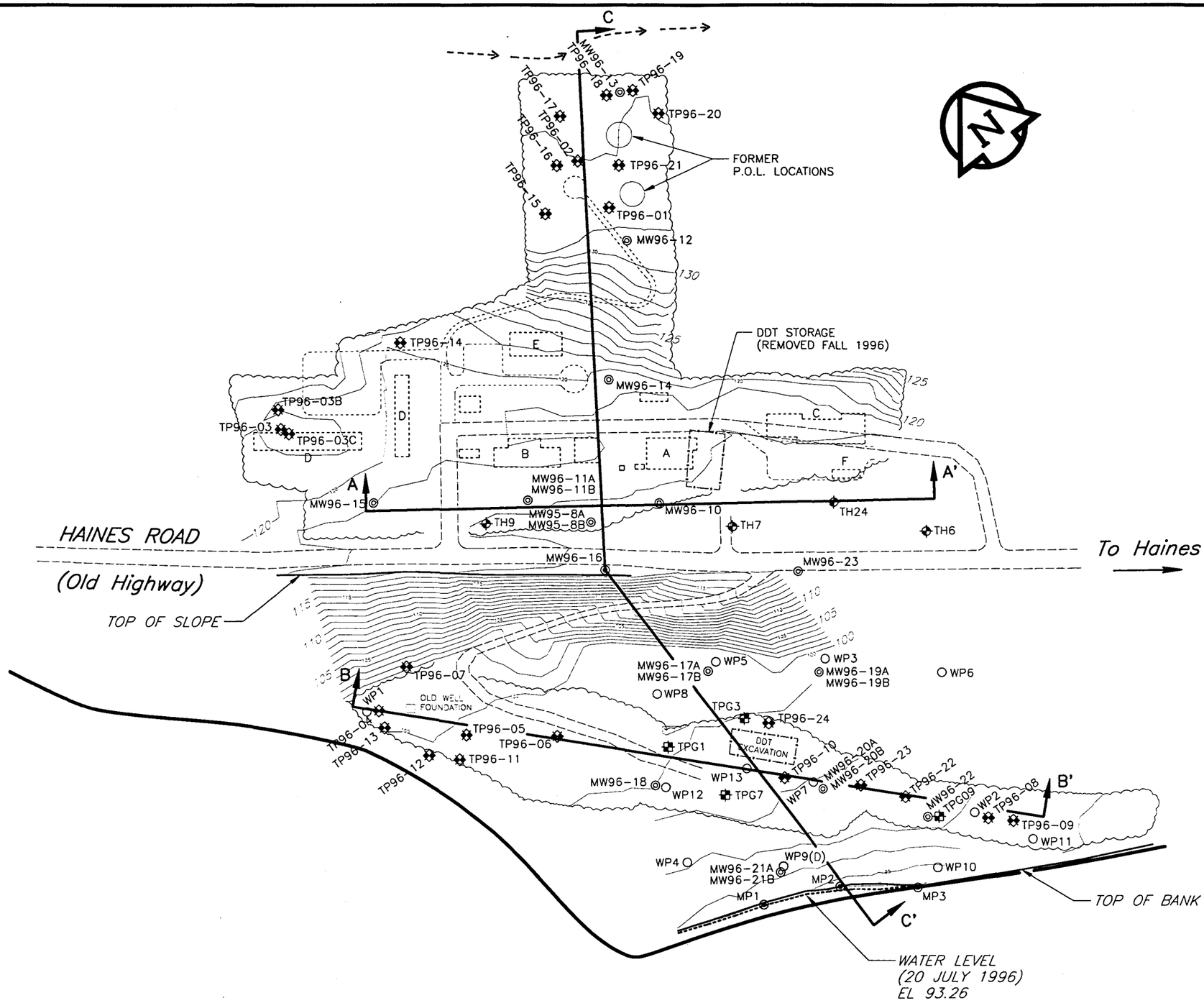
investigation; i.e., borehole TH-6,7,8 and 9 (UMA, 1995). The monitoirng wells installed TH-8 employed methods similar to those used in this investigation (see below). In addition, well point style groundwater monitoring wells were previously installed in September 1994 on the lower terrace at Rainy Hollow (Golder, 1995). Eleven of these were still intact as of July and September 1996. The installation method consisted of excavation of a test pit down to below the water table followed by vertical placement of 50 mm diameter well points with PVC riser sections, and then by back filling around the well points. Data derived from the sampling of these well during the 1994 investigation of Rainy Hollow have been suspect due to the original method of installation, and apparently unavoidable presence of suspended particulates within collected water samples (EC, 1995).

Field work undertaken in 1996 as part of the subsurface investigation included four interrelated components:

- excavation of test pits using a backhoe as a rapid investigative technique in looking for possible shallow buried debris and/or subsurface contaminants;
- drilling of boreholes using an air-rotary drill rig to obtain vertical subsurface profiles of contaminants in soils and elucidate subsurface stratigraphy;
- installation of groundwater monitoring wells in selected boreholes, for subsequent sampling of groundwater; and
- conducting water level monitoring and *in situ* tests on installed wells after development/stabilization, to estimate the hydraulic conductivity.

3.1.2.1 Test Pits

Non-invasive electromagnetic (EM) geophysical surveys conducted during preliminary investigations (UMA, 1995; Golder, 1995) provided evidence of buried debris. Some of the areas were subsequently investigated through the excavation of test pits; however, several others were not. New test pits were excavated as part of this study in all suspect areas that had not been previously investigated. The locations of both the previously established test pits (designated as TP-G1 to -G14 for Rainy Hollow) and newly excavated test pits are provided on Map 3.1. All test pits were excavated using a backhoe to a depth of between 0.5 and approximately 2.5 m. Shallower strata were sampled directly from the bottoms of the test pits, into pre-cleaned glass jars, using pre-cleaned stainless steel scoops. Samples from strata greater than approximately 80 cm were retrieved directly from the backhoe bucket, taking care to avoid inclusion of soils that had been in direct contact with the bucket. The depth of each test pit, description of subsurface soils and debris found, as well as a list of samples collected at various depths are provided in Table 3.1. In particular, test pits TP96-6 and TP96-11 to -13 were established on the NW portion of the old Rainy Hollow airstrip/pump house site, to the west of the pump house foundation (Photos 3.1 to 3.3).



LEGEND

- TEST HOLE
- MONITORING WELL (UMA 1995, 1996)
- MINI PIEZOMETER (UMA 1996)
- WELL POINT (Golder Associates 1994)
- TEST PIT (Golder Associates 1994)
- TEST PIT (UMA 1996)
- (D) DESTROYED
- A A' SECTION LINE
- EDGE OF ROAD
- FORMER EDGE OF ROAD
- TREE LINE
- ELEVATION CONTOUR
- CREEK
- A APPROX. LOCATION OF FORMER BUILDINGS
  - A – MAIN LINE PUMP BUILDING
  - B – UTILITY BUILDING
  - C – WAREHOUSE/SHOP/GARAGE
  - D – APARTMENT COMPLEX
  - E – DORMITORY
  - F – PUMP ISLAND

Scale 1:2000

ROYAL ROADS UNIVERSITY

UMA Engineering Ltd. Engineers & Planners

Golder Associates

Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW GENERAL SITE PLAN		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	3-1
CHECKED:	AH		

Test pits were also used as a screening tool to identify areas of hydrocarbon contamination in shallow soils. An historical input of hydrocarbons leaking or discharged from a utility (above-ground storage tank, pipeline or other structure) should lead to a continuous zone of hydrocarbon contamination, starting at the surface and variously distributed with increasing subsurface depth. Detection of hydrocarbon contamination at or near the surface, therefore, is useful in the identification of the original source of input. Nine test pits (TP96-1, -2, - 15 to -21) were established in areas around the original site of the above-ground storage tanks (ASTs) on the top-most shelf at Border Station; their locations are shown on Map 3.1, and details of the depth, soil appearance, and samples collected are provided in Table 3.1.

Another set of test pits was established in the northern portion of the upper (Border Station) site, in two locations. The first location (shown on Map 3.1 as TP96-03, -03B, -03C) was the site of a discrete stain on the surface of the soil (approximately 20 m^2) identified during the preliminary site investigation (UMA, 1995) to have soils with elevated total extractable hydrocarbons (3,200 µg/g or ppm). The second location, where TP96-14 was excavated, was the site of a second surface stain discovered during the 1996 field study (Photos 3.4, 3.5). This stain consisted of a black, tar-like substance over an area of approximately 40 to 50 m^2. The visible staining was limited to the surface 3 to 6 mm of soil with no detectable hydrocarbon odors in soils deeper than this. Plants were absent from portions of the stain, and were more sparsely distributed in the rest of the stain relative to areas outside of the stain.

Finally, seven test pits were excavated at the lower site (Rainy Hollow) in the vicinity of the trench where the DDT canisters were originally found (Photos 3.6 to 3.8). Test pits TP96-10 and TP96-24 were established downgradient and upgradient respectively, and within 3 to 5 m of the edge of the trench cover in order to examine the soil DDT concentration at and immediately below the depth of the groundwater table. This allowed a direct examination of the possibility that substantial masses of soils with high DDT contamination (> approx. 5 ppm) at the base of the trench were still acting as sources to the surrounding subsurface environment. Test pits TP96-06, -08 -09, -22, and -23 were dug in various locations around the Rainy Hollow site as a means of visually examining the lateral spread of hydrocarbon contamination (and possibly DDT as well), perpendicular to the direction of groundwater flow. The test pits were also useful for assessing local variations in the groundwater table on the old flood plain.

Table 3.1: Summary of Test Pit Program at Border Station/Rainy Hollow - 1996.

Test Pit	Location	Maximum Depth	Description	Sample Descriptions
TP96-01	Former AST area	~110 cm	rust-brown to black sandy soils with humus; apparently natural; no odor noted.	TP96-01-1 (10 -20 cm depth) TP96-01-2 (6—70 cm in sand unit)
TP96-02	Former AST area	~ 130 cm	just NW of where smaller to two ASTs stood; faint hydrocarbon odor; rust-coloured sand and cobble soils).	TP96-02-1 (10-20 cm) TP96-02-2 (60-70 cm) TP96-02-3 (120-130 cm)
TP96-03	Border Station, main bench near former location of residences; stained area identified in 1995.	~ 270 cm	Hydrocarbon-stained silty-sand soils with loam near surface; odor resembling heating oil.	TP96-03-1 (20-30 cm) TP96-03-2 (~100 cm) TP96-03-3 (~140 cm) TP96-03-4 (~270 cm)
TP96-03B			Lateral to surface stain (south). (no odor)	TP96-03B (~80 cm)
TP96-03C			Lateral to surface stain (north). (no odor)	TP96-03C (~80 cm)
TP96-04	Rainy Hollow -near well house foundation (within 4 m); to determine possible secondary source of DDT contributing to observed DDT levels in WP01	~200 cm	silty sands with course rounded cobble; no unnatural odors.	TP96-04-1 (just above *water level at ~1.9 m depth) TP96-04-2 (just below water level)
TP96-05	18 m. to east of well house foundation and 6.7 m from edge of brush toward river	~200 cm	as above	TP96-05-1 ((just above water level at ~1.9 m depth) TP96-05-2 (just below water level)
TP96-06	30 m. east of TP96-05, and approx. ½ way between trench and well house pad.	~200 cm	as above	TP96-06-1 (just above water level at ~1.9 m depth) TP96-06-2 (just below water level)
TP96-07	N. of well house foundation	~200 cm	as above	TP96-07-1 (just below water table depth at 1.9 m)

(continued, next page)

Table 3.1 (cont'd)

TP96-08	Between Golder (1995) WP02 and WP11 in order to examine local changes in subsurface soil type and water table level	~200 cm	Loam layer near surface, underlain by cobble and silt layer (old river bed); water table at 90 cm depth.	No sample collected.
TP96-09	As above	~200 cm	as above; water table at 128 cm depth.	No sample collected.
TP96-10	Near S.E. corner of trench cover, within ~4 m of edge of tarp, to delineate DDT concentration in subsurface soils lateral to trench	~220 cm	Silty-sand and cobble; grey brown at surface, and slate-grey (reduced) below approx. 40 cm; very strong hydrocarbon odor.	TP96-10-1 (15-30 cm) TP96-10-2 (80-140 cm) TP96-10-3 (~ 200 cm; below water table depth)
TP96-11	Near well house foundation at edge of clearing in fireweed; area of geomagnetic anomaly as identified from 1994 EM survey	~ 150 cm	loose, brown sandy soils; found an old fence pipe, flat piece of iron, small amounts of ferrous, non-hazardous debris.	TP96-11-1 (~100 cm) TP96-11-2 (field duplicate of above)
TP96-12	As above	~90 cm	loose, brown sandy soils; some wire and scrap metal	TP96-12-1 (~50 cm)
TP96-13	As above	~110 cm	loose, brown sandy soils; beer can, 1981 Yukon commercial license plate.	TP96-13-1 (~100 cm)
TP96-14	Vicinity of tar-like stain at Border to N. of site	130 cm	No vegetation over most heavily stained areas; no sign of subsurface contamination. Excavated through old culvert.	TP96-14-1
TP96-15	Border upper plateau; former AST location	90 cm	NW corner of clearing; no odor. Sandy, brown - rust coloured soils with large boulders	No lab. sample
TP96-16	As above	160 cm	N. edge of AST clearing; apparently clean.	TP96-16-1

(continued, next page)

Table 3.1 (cont'd)

TP96-17	As above	100 cm	N. corner of AST clearing; sand, gravel and cobble to depth; some reduced, grey-stained soils, very strong hydrocarbon odour.	TP96-17-1
TP96-18	As above	170 cm	Near mid-point of back berm of AST area (NE side); very strong hydrocarbon odor to bottom of pit.	TP96-18-1
TP96-19	As above	160 cm	E corner of AST clearing; very strong hydrocarbon odour.	TP96-19-1
TP96-20	As above	120 cm	Outside of old berm on S.E. edge of AST area; no hydrocarbon odor or obvious signs of staining.	TP96-20-1
TP96-21	As above	150 cm	Inside berm, where larger AST tank was previously located. Sand, grave, boulders; faint hydrocarbon odour.	
TP96-22	Rainy Hollow, proximity of trench	~170 cm	Half way between trench and Golder (1995) WP02; light brown sand and cobble at top, grey sand below ~60 cm depth. No hydrocarbon odor	TP96-22-1 (just above water table at 152 cm depth) TP96-22-2 (just below water table)
TP96-23	As above	~150 cm	17.8 m toward trench from TP96-22. Moderate hydrocarbon odor.	TP96-23-1 (just above water table at 109 cm depth) TP96-23-2 (just below water table)
TP96-24	As above	~240 cm	Upgradient side of trench within 4 m of trench tarp edge, and adjacent to bush at trench mid-point; very strong hydrocarbon odour.	TP96-24-1 (just above water table at 212 cm depth) TP96-24-2 (just below water table) TP96-24-3 (field duplicate of above)

* Water table depth as of July, 1996.



Photograph 3.1: Test pit TP96-12, excavated where magnetic anomalies were previously identified using an EM survey (Golder, 1995).



Photograph 3.2: Front to back - Locations of test pits TP96-11, -5, and -6.



Photograph 3.3: Licence plate excavated from TP96-13, which places the time of burial of metal debris after 1980. The U.S. Military abandoned the site in 1972.



Photograph 3.4: Tar-like stain where TP96-14 was excavated.



Photograph 3.5: Test pit TP96-14.



Photograph 3.6: Test pit TP96-10, approximately 4 m down gradient of the excavated trench at Rainy Hollow from which canisters with DDT pesticide was removed. Note the hydrocarbon-saturated slate-coloured soils approximately 0.5 m below the surface.



Photograph 3.7: Test pit TP96-24, 4-5 m upgradient from the trench.



Photograph 3.8: Test pits TP96-08 (foreground, near well point WP02) and TP96-09 (background, to south).

3.1.2.2 Boreholes and Monitoring Wells

The site plan (Map 3.1) illustrates the previously established boreholes and monitoring wells. An additional nine boreholes were advanced at the Border Station site (upper plateau) in July 1996 (BH96-10, 11a, 11b, 12 - 16, 23, 24). An air-rotary drill equipped with an ODEX system, supplied by Midnight Sun Drilling, Whitehorse, was used (Photo 3.9, 3.10). This.drilling metdod advances casing a the bit cuts the hole. Cuttings are delivered to the surface between the drill rods and casing using compressed air. This method provides for control of sample depth and piezometer installation.

The first borehole at the Border Station site, BH96-10, included a component of split spoon sampling to evaluate the silt layers and the role they might play in the creation of perched water levels or ponding of phase separated hydrocarbons (Photo 3.11). BH96-11b was drilled within 2 m of BH96-11a. The latter of these was dry after piezometer installation; therefore, a deeper screen setting was needed to determine the water level and facilitate groundwater sampling. All of the upper site boreholes were developed as monitoring wells, with the exception of BH96-24, since subsurface soils from this borehole showed no indication of contamination (see Section 5.3). The details of borehole depth and piezometer construction for all boreholes are provided in the borehole logs, (Appendix B) discussed in more detail in Chapter 5.

Six new boreholes were established at the lower Rainy Hollow site (Map 3.1: BH96-17 through -22). All of these were developed into groundwater monitoring wells. Nested wells were placed in four of the six boreholes; i.e., BH96-17, 19, 20 and 21. Into each of these boreholes was placed a shallower piezometer, designated "A", and a deeper piezometer, designated "B".

Two inch threaded and coupled casing was used for all but one monitoring well (MW96-15), in order to permit future use of an interface probe as well as down-hole geophysical techniques. Geophysical techniques, however, were considered to be of low priority and excluded from this detailed site investigation.

Three mini-piezometers were also established by hand along the bank of the Klehini River. The mini-piezometers consisted of a conical stainless-steel drive point threaded to four foot sections of 19 mm galvanized metal riser pipes. The point included water intake holes over which fine stainless steel screening were attached. The mini-piezometers were assembled and driven into the ground using a gas-powered impact hammer.

Following installation of the wells, Waterra™ dedicated sampling systems were placed in each well, for retrieval of groundwater. All wells were developed by intermittently pumping large volumes of water (>> 5 to 20 well volumes) over a two to six day period. Groundwater samples were subsequently retrieved into appropriate containers using prescribed sampling methods for the analysis of hydrocarbons (volatile, light, or heavy extractable hydrocarbons); benzene, ethylbenzene, toluene, and xylenes (BETX);

and/or chlorinated organic pesticides including DDT and the associated compounds DDD and DDE. Monitoring well BH96-11b was installed on the last day of the field visit in July; therefore, it was not sampled until the return visit in September. Samples for hydrocarbon and chlorinated pesticide analysis were sampled into 1 L pre-cleaned and proofed amber jars. Samples for BETX were sampled into duplicate 25 mL glass vials having lids with teflon septae, with care taken to ensure that no air was trapped. The BETX vials contained $CuSO_4$ preservative, as per standard methods. All samples were shipped to the analytical laboratory, stored cool, carefully decanted, and extracted within one week of collection. Monitoring well TH-8A, installed during the 1995 preliminary investigation was also re-sampled for contaminants. Well TH-8B, the deeper of the nested pair or piezometers, was not sampled for contaminants, since an approximately 1 to 4 mm layer of free product (light non-aqueous phase liquid: LNAPL); i.e., diesel was floating on the groundwater surface (Photo 3.12). It was assumed that the contaminant data for various hydrocarbon constituents would simply reflect their aqueous solubility.

The majority of well points (nine) established during the 1994 emergency response (Golder, 1995) were also re-sampled during July, 1996. These included WP-01,-02, -04, -06 to -08, -10, -11, and -13. This allowed for an examination of temporal trends in contaminant concentrations over a two year period [September 1994 (Golder, 1995), July 1995 (EC, 1996), and July/September 1996 (this study)]. Using the existing sampling systems in the well points, at least three well volumes were purged prior to collection of the samples. Fine silt was found in water from the well points in spite of the prior removal of large purge volumes and a period of two years since the initial installation. Similarly, groundwater samples from most of the wells installed in July, 1996, were very cloudy due to suspended silt particles. For all samples, however, the samples were observed to clear within ten to fifteen minutes when left undisturbed; the silt particles rapidly settled.

Several of the monitoring wells established by air-rotary drilling were re-sampled during the third week of September 1996, in order to examine effects of well stabilization (and particulates), assess seasonal variability in subsurface contaminant migration, and re-analyze some samples in order to achieve improved detection limits for hydrocarbons. The re-sampled wells included BH96-10, -17A, -17B, -19, -20 and -21. These were chosen as being within the subsurface contaminant plume as determined from previously collected groundwater and soil data.

Field data were collected during the September 1996 visit in order to calculate the hydraulic conductivity of the soils surrounding the monitoring wells. Rising head tests were carried out on the wells by lowering water levels to the maximum extent possible with the dedicated sampling systems. The high hydraulic conductivity of the coarse, granular material around some piezometers did not allow for drawing the water levels down more that 10 to 30 cm; other wells took more than two to three hours to fully recovery. For those wells that responded very rapidly, an attempt was made to also estimate hydraulic conductivity from falling head tests. Water was pumped from the well into a five gallon bucket to create a source to surcharge the head in the well. This water was then rapidly pored into the well and a decline in water level measured..



Photograph 3.9: Air rotary drill rig used to excavate bore holes through interspersed large rocks and silt at Border Station and Rainy Hollow. Site of borehole BH96-10, near temporary storage facility, and where warehouse/garage once stood.



Photograph 3.10: Drilling at borehole BH96-12, at front of bench where above-ground storage tanks were located.



Photograph 3.11: Split-spoon sampler used in borehole BH96-10.



Photograph 3.12: Thin layer of free hydrocarbon product on surface of groundwater sampled from TH-8b. The thickness of the layer was estimated to be approximately 3 mm, using an interface probe.

3.1.3 Surface Soils

During the early stages of planning for this study, the primary environmental concerns at Rainy Hollow/border Station revolved around hydrocarbons and DDT pesticides in subsurface soils and groundwater, and the associated risks to humans and wildlife. It was observed, however, during the confirmatory testing of DDT-contaminated soils in the Temporary Storage Faciliity (RRU, 1996c) that some surface soil samples outside of the facility also contained DDT and associated compounds DDE and DDD at total concentrations exceeding 2 ppm (or mg/kg). One objective of the field sampling program was to delineate the range of concentrations and spatial distribution of DDT compounds in surface soils, both within the vicinity of the Temporary Storage Facility and around the trench at Rainy Hollow.

There are at least four mechanisms by which DDT could have been introduced to surface soils around Rainy Hollow/Border Station; i.e. -

- Application from aerial spraying or other forms of DDT use prior to 1972;
- Tracking of DDT-contaminated soil by vehicles and heavy equipment during the 1994 emergency response;
- Surface runoff from more contaminated areas, entrainment of contaminated particles, and geochemical focusing in pools; and
- Short range re-distribution from source areas through atmospheric pathways (wind-blown dusts, aerosols, volatilization, iterative desorption-adsorption phenomena).

A total of 87 surface soil samples were collected at Border Station/Rainy Hollow, from areas designed to distinguish between the different redistribution mechanisms and estimate the overall spatial distribution of DDT in surface soils. It was deemed necessary to distinguish among the possible re-distribution pathways in order to develop an understanding of the practices or circumstances involved. This, in turn, was required for the extrapolation of surface soil data to areas not thoroughly sampled. The sampling locations are shown on Maps 3.2 and 3.3 for the Temporary Storage Facility and Trench area, respectively. The samples were analyzed for DDT using Millipore immunoassay based field test kits (see section 3.2, below). Approximately 20% of all samples were also analyzed for chlorinated pesticides by ASL Laboratories, Vancouver.

An additional eleven soil samples, designated Tr96-01 to -11, were collected from the soils used to backfill the trench during the 1994 emergency response and DDT removal, as shown on Map 3.4. According to Golder (1995) -

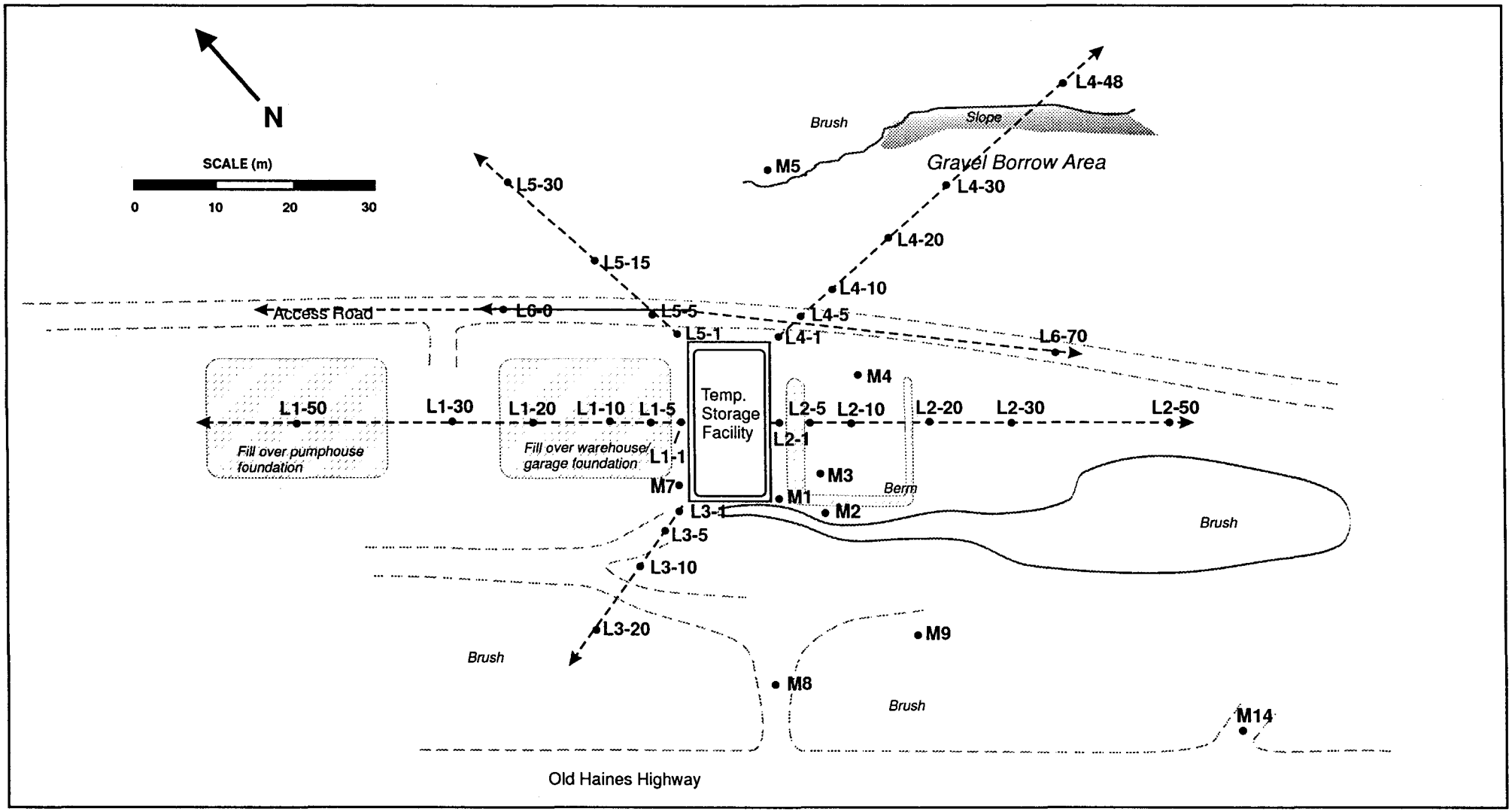
> "Upon completion of the excavation and sampling of the Trench, a polyethylene membrane (i.e., an Arctic 30 liner) was placed in the excavation and the Trench

> excavation was backfilled with surface materials, including the soils represented by sample T-1 to T-5 in Table 6.1. ...A reinforced polyethylene membrane liner (i.e., RPE15) was placed over the backfilled materials to prevent further infiltration.

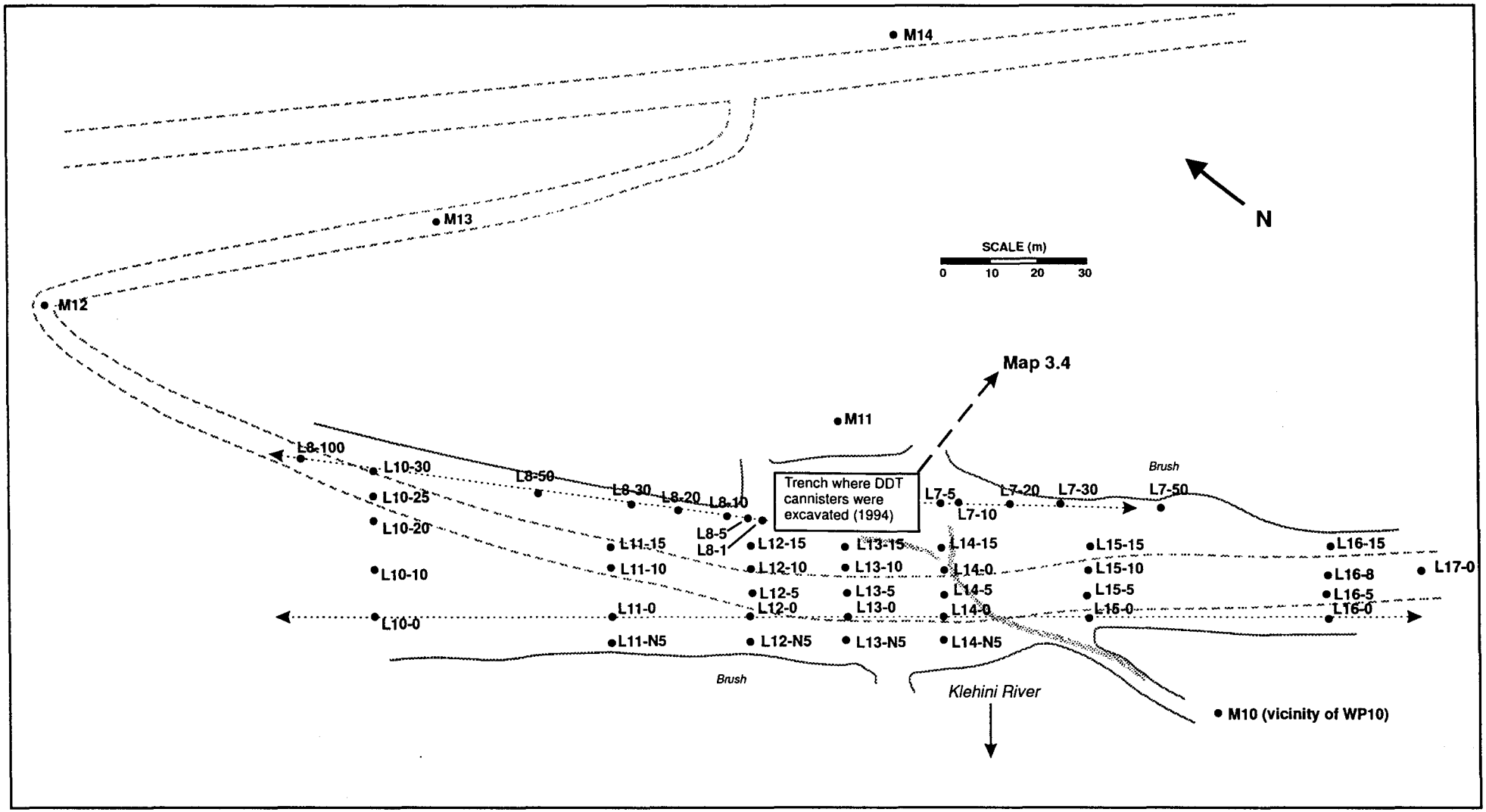
The soil samples T-1 to T-5 were reported to contain total DDT isomer concentrations in the range of 0.22 to 0.62 ppm (mg/kg). With regard to recommendations for clean-up, it was necessary to confirm DDT and hydrocarbon concentrations in the soils between the two tarps, enroute to assessing the possible implications of the eventual removal of the upper tarp and surrounding snow fence, as well as the possible loss of integrity in the lower tarp. A composite soil sample (made up of five discrete samples) collected from the bottom of the trench prior to placement of the lower-most tarp and backfilling contained 48 ppm DDT.

The samples collected from within the trench during July 1996 (this study) were chosen based on a semi-randomized selection, across the western half of the trench only (it was assumed that the two halves of the trench, divided length-wise, would contain similar DDT concentration distributions). The samples were collected at depths varying from 0 to 90 cm using a stainless-steel soil auger. All eleven samples were analyzed at ASL for chlorinated pesticides and extractable petroleum hydrocarbons (C10-C18 hydrocarbons, or C19-C30 hydrocarbons). Samples Tr96-02, -05, -06, and -09 were also analyzed for volatile petroleum hydrocarbons (VPH) and BETX compounds.

Map 3.2: Sampling scheme for DDT confirmatory sampling in the vicinity of the temporary storage facility, Border Station (July, 1996)

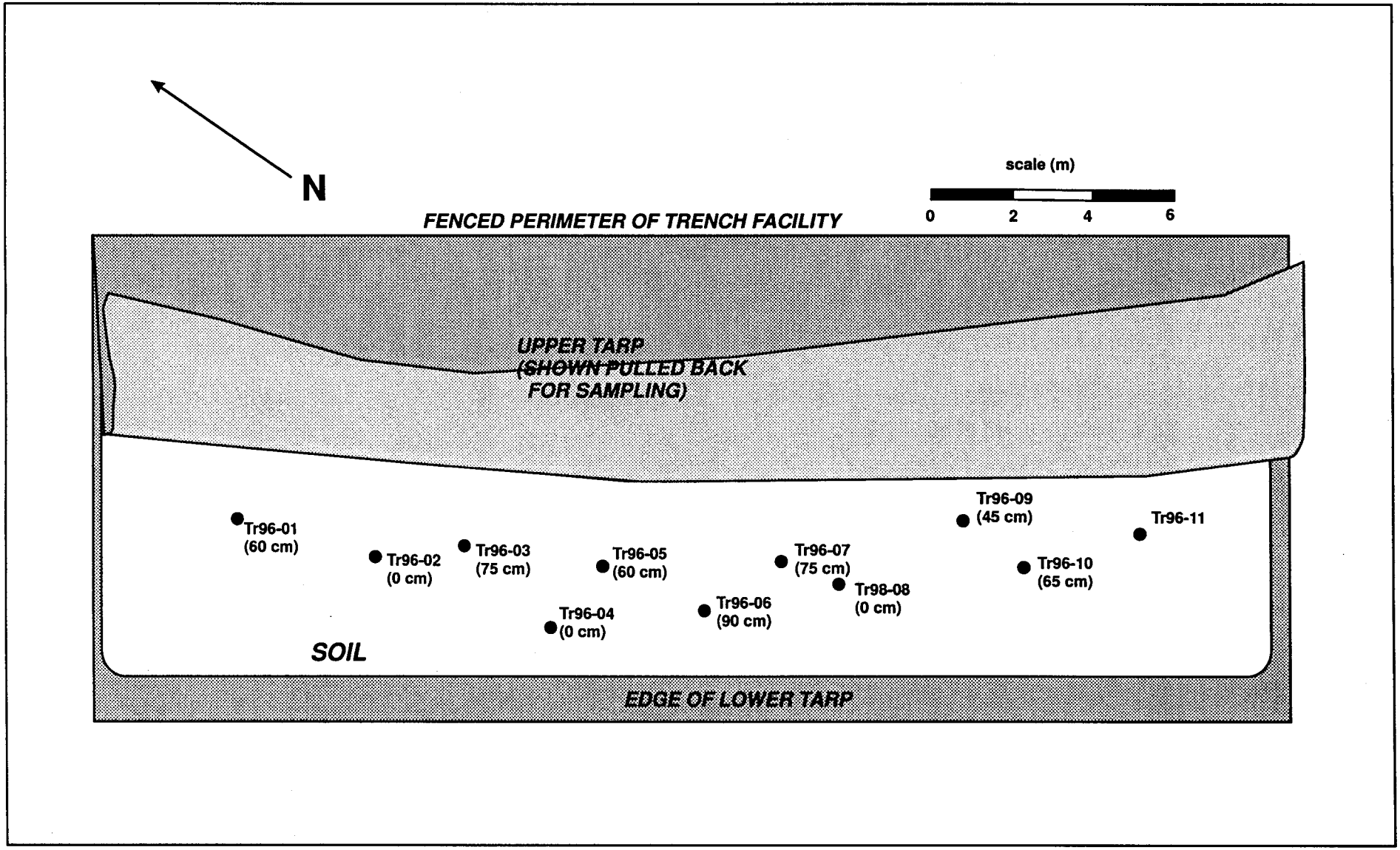


Map 3.3: Sampling scheme for DDT confirmatory sampling in the vicinity of the DDT trench, Rainy Hollow (July, 1996)



Map 3.4: Sampling scheme for soils between the tarps, within the excavated trench at Rainy Hollow.

(Numbers in brackets are depth below surface that sample was collected)





Photograph 3.13: Temporary storage facility at Border Station (removed in October 1996) showing access roads, and less-recently disturbed berms (vegetated areas) over building foundations.



Photograph 3.14: Access road through re-seeded area to the south of the temporary storage facility.



Photograph 3.15: Hand-dug test pit in disturbed area near temporary storage facility (L4-20). The gravel borrow area is in the background.



Photograph 3.16: Excavated trench at Rainy Hollow with upper tarp pulled back for sampling. Sampling locations are marked with spikes and flagging tape.



Photograph 3.17: Point of origin of rust-coloured surface stain and drainage path toward the Klehini River, near the DDT trench.



Photograph 3.18: Stained drainage path, where it enters the brush toward the river.



Photograph 3.19: Stained drainage path leading to well point WP10, and location were soil sample M96-10 was collected.

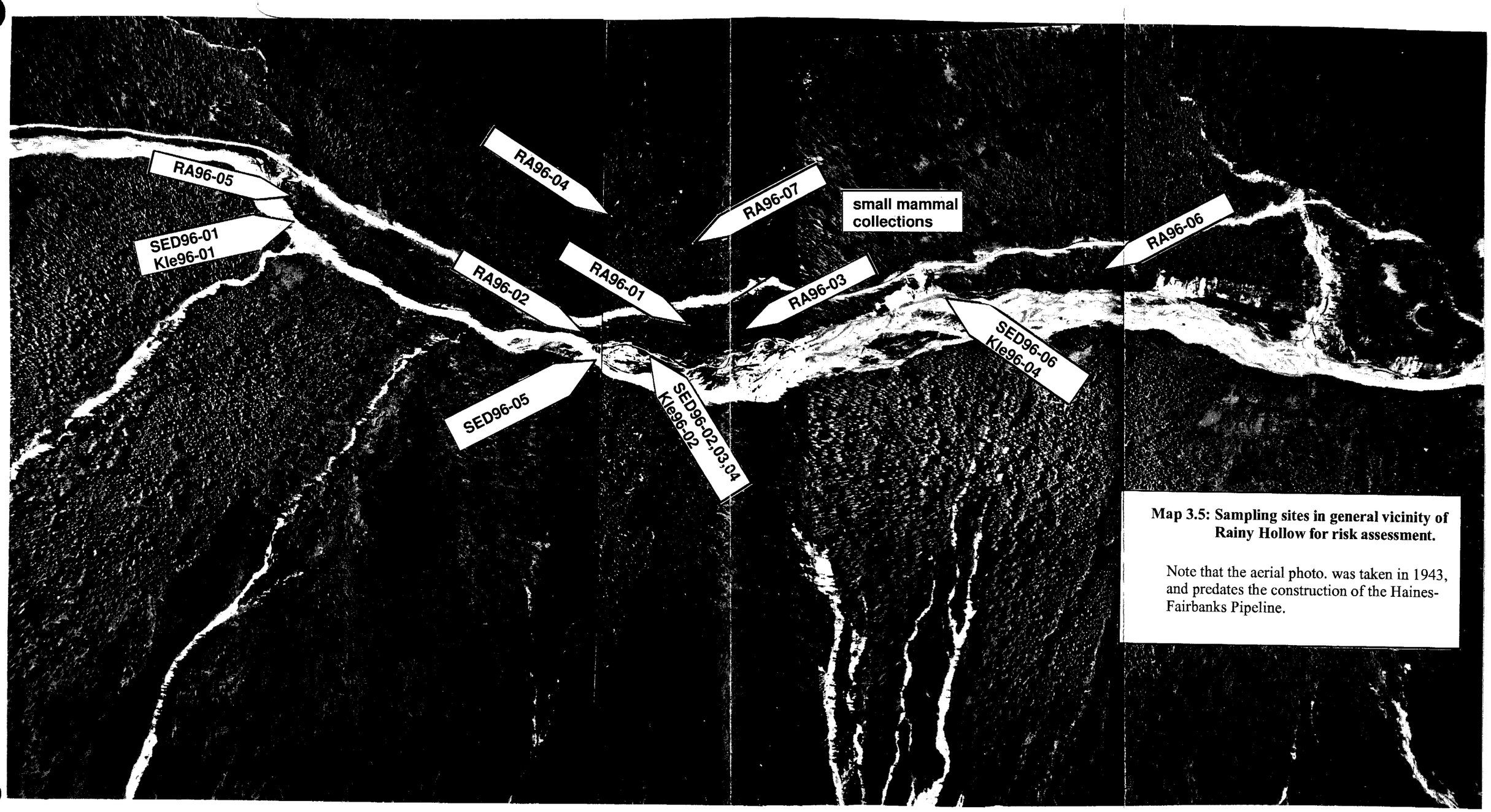
3.1.4 Riverine and Terrestrial Sampling for Risk Assessment

Prior to the field investigation, a preliminary conceptual model was developed in light of the known contaminants of concern and possible environmental receptors. A targeted sampling program was subsequently designed to quantify contaminant redistribution into environmental compartments enroute to receptor organisms, and to directly assess contaminant bioaccumulation in the organisms or their food substances. Mobilization of DDT compounds and/or hydrocarbons into two major suites of environmental compartments was considered: (i) inputs into the aquatic environment of the Klehini River and subsequent food-chained related contaminant transfer (including biomagnification in fish-eating birds), and (ii) inputs from surface soils and surface runoff to terrestrial receptors. Uptake of contaminants by terrestrial organisms, including humans, could occur via the direct inhalation of contaminated soils or breathing and absorption of vapour-phase forms, or through the food-chain. Two models for food-chain related contaminant transfer were considered: i.e., along a soil - plant - herbivore - predator pathway, or along a soil - soil invertebrate - small omnivore - larger predator pathway. The detailed conceptual models and risk assessment framework are described in Chapter 6.

3.1.4.1 Klehini River Sampling Program

Table 3.2 lists the samples of water, sediment, and biota collected from the Klehini River. Representative samples were obtained in the vicinity of Rainy Hollow where subsurface contaminants inputs were most pronounced, at an upstream reference location immediately downstream from the confluence of Seltat Creek and Klehini River, and a site approximately 1.6 km downstream from Rainy Hollow. The locations are shown on an aerial photograph composite (Map 3.5).

The presence of a large sand and gravel bar on the nearshore side of the Klehini River at Rainy Hollow serves to divide the flow of the river, such that the major volume of water, probably comprising >> 99% of the total annual river volume, is deflected away from the shoreline area of contaminated groundwater input. A small channel separates the gravel bar from the Rainy Hollow side of the river. This channel is dry during the lowest flow conditions, but has greater volume and current velocity when the river is higher. The River carries a massive load of glacial silt which is very low in organic content (see results section), has a particle size in the range of coarse silica sands to fine silts, and which settles out in small scale eddies and areas along the river were the channel becomes braided. The water in the river is slate grey, and transparency is limited to distances of 10 - 15 cm or less, owing to the sediment load.



Map 3.5: Sampling sites in general vicinity of Rainy Hollow for risk assessment.

Note that the aerial photo. was taken in 1943, and predates the construction of the Haines-Fairbanks Pipeline.

Table 3.2: Samples Collected for the Assessment of Risk to Aquatic Receptors

Sediment	Water	Stream Invertebrates	Comments
1. Upstream Reference Area: immediately downstream from confleunce of Seltat Creek and Klehini River (approx. 1.1 km N. of Rainy Hollow)			
SED96-01	**Kle96-01** (3 L)	**SED96-01-Bio** (pooled; 3.0 g wet wt)	-in quiet water on inside of gravel bar; similar to hydraulic regime of Rainy Hollow samples; slate-coloured to tan sandy silts
2. Downstream Reference Area: south of Rainy Hollow (approx. 1.6 km downstream)			
SED96-06	**Kle96-04** (4 L)	**SED96-06-Bio**	- quiet to fast, shallow water in braided river channels; slate coloured silts
3. Inside of Gravel Bar Adjacent to Rainy Hollow in Klehini River			
SED96-02	none	see SED96-03 below	In stream, adjacent to mini-piezometer MP96-01, on bank; top end of gravel bar; slate coloured silts
SED96-03	**Kle96-02** (4 L)	**SED96-03-Bio** (pooled insect larvae from sediment sampling sites SED96-02, -03 and -04, all inside gravel bar and adjacent to Rainy Hollow; 2.2 g. wet wt.)	In stream, adjacent to mini-piezometer MP96-02, on bank; shallow, gently flowing water in channel two-thirds of the way downstream along the gravel bar; red-stained rocks in local extent of channel; hydrocarbon odors; slate coloured silts (Photo 3.20)
SED96-04	none	see SED96-03	In stream, adjacent to mini-piezometer MP96-03, on bank; approximately 5 m downstream from gravel bar where main channel meets channel adjacent to Rainy Hollow; slate coloured silts
3. Outside of Gravel Bar Adjacent to Rainy Hollow in Klehini River			
SED96-05	none	**SED96-05-Bio** (pooled; 3.4 g wet wt.)	In stream near top end and outside of gravel bar, in main river channel away from the site; in fast water; substrate was cobble with coarser sands in eddies

With regard to sampling and contaminant fate, the small channel at the inside of the gravel bar at Rainy Hollow would be expected to exhibit worst-case concentrations of contaminants because the dilution of emerging groundwater here is probably many orders of magnitude lower than in the main channel, and since - at least seasonally - there is greater deposition and accumulation of finer, silt-sized particulates that would tend to adsorb the hydrophobic contaminants.

Water samples were collected into 1 L high-density Teflon containers that had been previously cleaned and solvent-rinsed with hexane followed by dichloromethane, and then rinsed four times with ddH_2O. The sample containers were further rinsed three times with river water at the sampling site, before the sample was collected. Three or four 1 L samples of river water from each site were collected for subsequent decanting and pooling prior to extraction in the laboratory. All samples were clear and had no colour after decanting. The sample Kle96-03, a 1 L traveling blank, was opened in the field and subsequently analyzed to determine levels of chlorinated pesticides attributable to sampling methods and containers, or laboratory contamination.

Sediment samples were collected from shallow pools, channels or eddies in an attempt to capture the finest particulate fractions available (fine silts). Surface sediments comprising the upper 2 - 4 cm were collected into previously cleaned and proofed 500 mL wide-mouth amber glass jars with teflon-lined lids. The samples represented a composite collected over an area of river bed approximately 2 to 10 m in area.

Bottom-dwelling stream invertebrates were collected using a small kick net with a mesh size of approximately 0.5 cm. The kick net was placed downstream against the river bed, and cobble and sediments 0.5 to 1.5 m upstream were overturned by kicking. Approximately 95% of the stream invertebrates collected were dragonfly fly nymphs (Photo 3.21) with the remainder comprised of other emergent insect nymphs, a very small number of chironomids and oligochaetes. The biota samples were subsequently hand sorted to separate the invertebrates from organic detritus and other debris, rinsed in drinking water from Blanshard River without allowing the invertebrates to remain in standing water for lengths of time exceeding 10-15 sec., wrapped in pre-cleaned (baked) aluminum foil, and immediately frozen. Owing to insufficient wet tissue mass for separate chemical analyses, stream invertebrate samples from collection sites along the inside of the gravel bar at Rainy Hollow were pooled; i.e., from sediment sampling sites SED96-02, -03 and -04.

All water, sediment and stream invertebrate samples were subsequently shipped to Axys Analytical Services and analyzed for chlorinated organic pesticides, including DDT by HRGC/HRMS (see below).

Three small young-of-the-year dolly varden were also collected during kick net sampling in the channel adjacent to Rainy Hollow. These were all smaller than 4 cm in size. Similar-sized fish, caught in minnow traps, were analyzed for DDT compounds in 1994 (Golder, 1995). The fish caught during this study were not analyzed due to the small tissue mass and poor likelihood of having bioaccumulated detectable concentrations of DDT; the bioaccumulation of persistent organic contaminants increases with age in salmonids.



Photograph 3.20: Small channel on inside of gravel bar, adjacent to minipiezometer MP-02. Note the localized rust-coloured staining on the rocks - indicative of hydrocarbon-contaminated groundwater inflow. Hydrocarbon odors were also noted.



Photograph 3.21: Benthic invertebrates collected from the Klehini River for DDT analysis.

3.1.4.2 DDT Concentrations in Terrestrial Vegetation and Berries in the Vicinity of Rainy Hollow

Herbivores that frequent the site include small rodents, rabbits, small birds, porcupines, moose, and various other animals. High-bush blueberries (*Vaccinium membranaceum* Dougl.) were selected as a model plant for examination of the uptake into or onto plants from DDT-contaminated dust or via other mechanisms associated with short-range aerial transport from the source at Rainy Hollow. The blueberry plants were abundant in the immediate vicinity of both the trench at Rainy Hollow and the Temporary Storage Facility at Border Station. Furthermore, the blueberries bore fruit in various stages of ripeness at the time of the field investigation - a possible source for ingestion of DDT compounds to black or grizzly bears or other herbivorous or omnivorous birds and mammals. It was expected that the main route of uptake by the plants was via aerial redistribution, and - therefore - that contaminant concentrations should exhibit a logarithmic decline away from sources areas. Sampling areas were selected in the immediate vicinity of directly contaminated soils, within approximately 100 m, and approximately 1 km away, both to the north and south of the site. At each of seven locations, samples of soil, blueberry roots, leaves and shoots produced during the most recent growing season, and fruit were collected. Specific details of the sample locations and types are provided in Table 3.3 and Map 3.5.

Table 3.3: Samples Collected for the Assessment of DDT Uptake in Plants (Blueberries and Soils: RA96-*n*-01 - leaves and shoots from current growing season; RA96-*n*-02 - root tissue; RA96-*n*-03 - ripe or partially ripe fruit; RA96-*n*-04 - composite soil within collection area (~ 100 m^2)

Sample I.D.	Location
RA96-01	Just east of trench (within 15 m)
RA96-02	~130 m N. of trench, parallel to river*
RA96-03	~ 110 m S. of trench, parallel to river*
RA96-04	~ 50 m to N. of AST clearing at Border Station, in woods*
RA96-05	1.1 km N. of Rainy Hollow, along Klehini River (upstream)
RA96-06	1.6 km S. of Rainy Hollow, toward new Haines Highway and parallel to river
RA96-07	~ 150 m E. of Temporary Storage Facility at Border Station*

* collected in an area not disturbed in 1994.

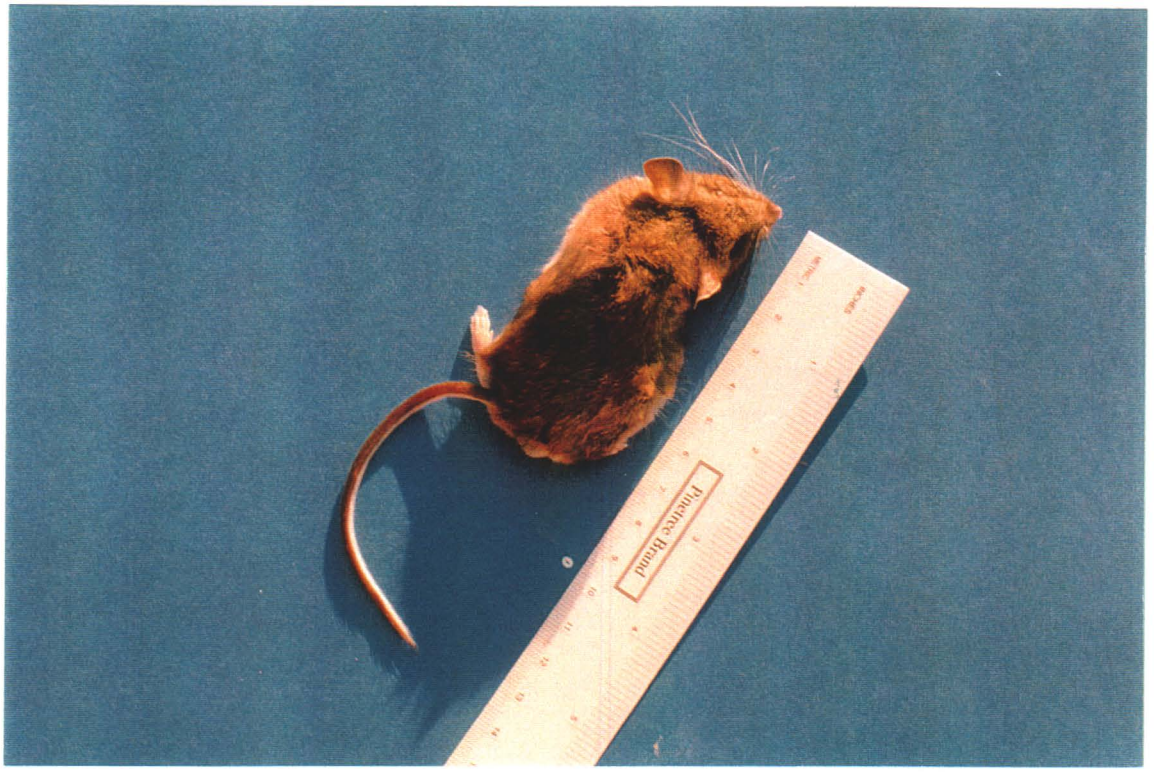
Soil samples, comprising the top five to ten cm of topsoil were collected into 250 mL pre-cleaned glass jars and shipped to ASL for analysis of chlorinated organic pesticides and organic carbon content. Root, shoot, and fruit samples were washed in drinking water, wrapped in baked aluminum foil and shipped to Axys Analytical Services for the analysis of chlorinated organic pesticides and lipid content. Details of analytical methods are provided in Section 3.2.

3.1.4.3 Sampling Program for DDT Compounds in Herbivorous and Insectivorous Small Mammals

Small mammals were collected at Rainy Hollow and analyzed for chlorinated pesticides as one of a small number contaminant dose end-points within the terrestrial food chain. A total of 12 Victor mouse or rat traps (spring traps: 6 of each) were placed in the brush or vegetated areas either within a 100 m radius of the trench at Rainy Hollow (8 traps) or the temporary storage facility at Border Station (4 traps). The traps were secured to a nearby tree or bush with a length of wire, and placed under logs or covered with a shelter made up of stones in order to prevent incidental small bird catches. The traps were set up and monitored over a four day period for a total of 48 trap days (12 traps x 4 days each). The traps were baited on the first day with portions of a cheese sandwich and with rolled oats and peanut butter on subsequent days. A total of 11 rodents or insectivores were caught (Photos 3.22 to 3.25), including three shrews (*Sorex* sp. - probably the masked shrew *S. cinereus*), 6 deer mice (*Peromyscus maniculatus*) and 2 voles [probably the meadow vole, *Microtus pennsylvanicus*, but could be *M. montanus* (mountain vole) or *M. longicaudus* (longtail vole)].

Only one of the rodents, a deer mouse (RA96-105), was caught near the temporary storage facility at Border Station. All others were trapped around the Rainy Hollow trench in the smaller snap traps (Victor mouse traps) except one vole which was caught in a rat trap. No attempt was made to estimate small mammal population sizes based on this modest trapping effort; however, it appears that the riparian (riverside) habitat to the southwest of the Rainy Hollow Airstrip and the brush immediately behind the trench contain substantial populations of small mammals. More shrews would undoubtedly have been caught if baiting with cheese sandwich or another substance appealing to an insectivore had been continued for more than one 24 h period, since the shrews were not captured in traps baited with rolled oats and peanut butter.

Although not sampled, red squirrels and several species of small birds were abundant around both Rainy Hollow and Border Station, based on visual observations.



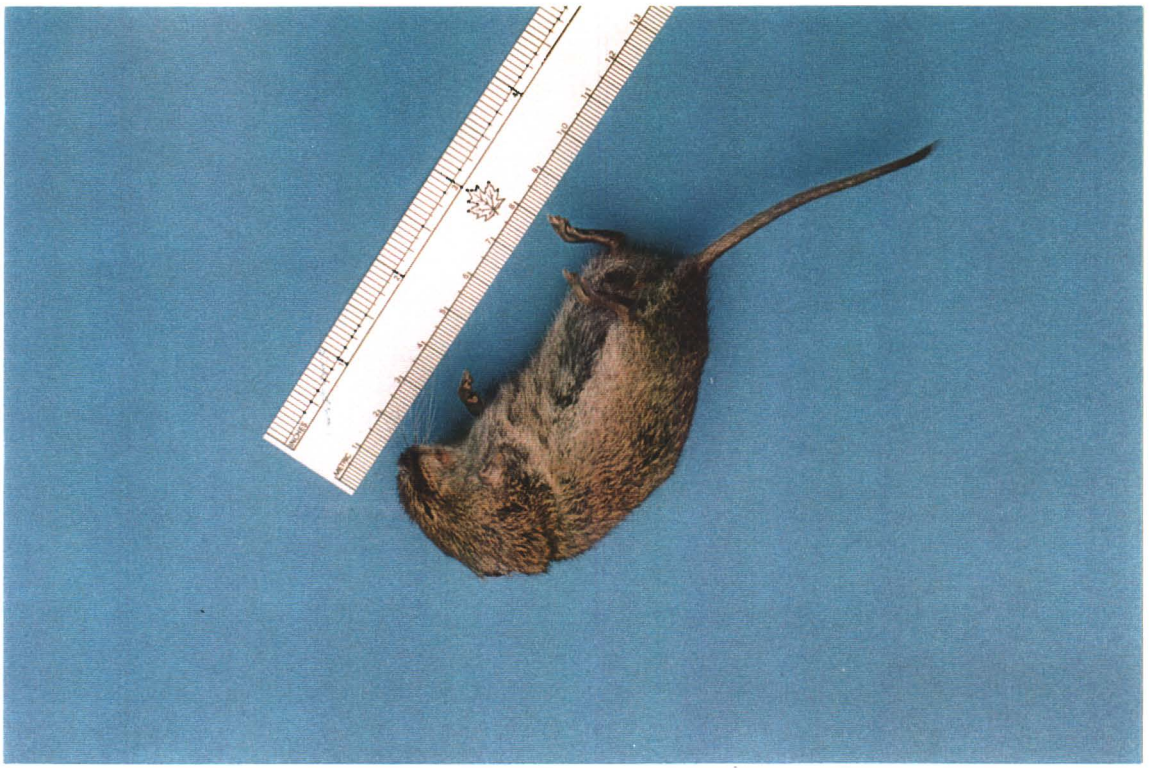
Photograph 3.22: Deer mouse, *Peromyscus maniculatus*, trapped at Rainy Hollow.



Photograph 3.23: Deer mouse, *Peromyscus maniculatus*; lateral view.



Photograph 3.24: Insectivorous shrews, *Sorex* sp.



Photograph 3.26: Vole, *Microtus* sp.

Table 3.4: Samples Collected for the Assessment of Risk to Rodents and their Predators

Sample I.D.	Species	Comments
RA96-100	shrews - *Sorex* sp.*	3 pooled individuals. Stomach contents included yellowish to black soft mass, probably insect remains. Internal viscera appeared normal. Snout-vent lengths (SVLs) 4.9, 4.5 and 4.4 cm.
RA96-101	deer mouse -*Peromyscus maniculatus*	Stomach contents were greenish mass, probably plant remains.
RA96-102	deer mouse	Stomach contents were greenish mass, probably plant remains. Internal viscera normal. SVL = 7.5 cm
RA96-103	deer mouse	Stomach contents were greenish mass, probably plant remains. Internal viscera normal. SVL = 8.0 cm
RA96-104	vole - *Microtus* sp.**	Stomach contents were greenish mass, probably plant remains. Internal viscera normal. SVL = 8.5 cm
RA96-105	deer mouse	SVL = 6.5 cm. *Collected from area ~50 m S. of Temporary Storage Facility at Border Station, not Rainy Hollow.*
RA96-106	deer mouse	
RA96-107	deer mouse	
RA96-108	vole	

* probably *S. cinereus* (masked shrew)

**probably meadow vole, *Microtus pennsylvanicusI,* but could be *M. montanus* (mountain vole) or *M. longicaudus* (longtail vole)

The rodent samples were placed into ziploc bags after recovery from traps, and were subsequently photographed for later confirmation of identification, measured from the tip of the snout to the vent (anus), examined for external abnormalities, and dissected

for the analysis of gross internal abnormalities as well as stomach contents. No abnormalities were observed either externally or internally. The whole carcasses and viscera were then wrapped in baked aluminum foil and frozen. Individuals were analyzed for chlorinated pesticides at Axys Analytical Services using GC/ECD. The three shrews were pooled prior to analysis due to the small tissue mass of each. Analyses were conducted on homogenized whole body tissue as an estimate of ingestion dose to higher predators. The lipid content was determined gravimetrically from a tissue homogenate subsample.

3.1.4.4 Hydrocarbon Re-distribution from Historical AST Spills to the Nearby Creek and Wetland

Hydrocarbon-contaminated soils and groundwater were discovered during the field study where the ASTs were previously located. The local surface drainage from this area is to the east toward a wetland and small creek, and then south toward the Klehini River downstream from the site. In order to assess the extent of hydrocarbon migration into the wetland and down the creek, samples of surface and subsurface soil, creek water and/or creek sediment were collected immediately behind the AST clearing and at a location approximately 500 m downstream from the suspected initial point of entry. The sampling program is summarized in Table 3.5.

Table 3.5: Contaminant Redistribution in the Wetland Area and Creek to the East of the AST site, Border Station.

Sample	Location	Comments
SS96-01	In wetland, among ferns to east of berm originally surrounding ASTs. Approx. 7-9 m from top of berm and 5-6 m from creek. Adjacent to BH96-13.	0-10 cm depth; high organic content soils; lots of wood, fern and other plant detritus. No hydrocarbon odor.
SS96-02	As above	55-65 cm depth; collected using soil auger. Brown-black, organic-rich soils. Moderate hydrocarbon odor.
SS96-03	In centre channel of small creek, farther away from the AST clearing	Fine, light surface sediments. No hydrocarbon odor.
SS96-04	As above	20-30 cm below stream bed (collected by hand auger until refusal). Mixed loam with some fine gravel and sand. No hydrocarbon odor.
Cr96-01	As above	Gently flowing, small creek < 1 m across and ~ 0.5 m deep. Creek water sampled into 250 mL plastic container for metals analysis, 2 x 60 mL acidified vials for BETX and 1 L amber jars for petroleum hydrcarbons.
Cr96-02	In creek, approximately 0.5 km downstream from Cr96-01, and roughly equidistance from AST site to crossing of Old Haines Highway.	As above.

3.1.4.5 Residual Polychlorinated Dibenzo-p-Dioxins and Dibenzofurans Along the Pipeline Right-of-Way or Rainy Hollow Airstrip

It became apparent during discussions with several members of the Champagne and Aishihik First Nations and well as DIAND that there is public concern about the effects on humans of polychlorinated dibenzo-p-dioxins and dibenzofurans (dioxins and

furans, respectively) that have been introduced in the vicinity of pipeline right-of-ways and other clearings as a result of past applications of defoliants containing 2,4,5-T (2,4,5-trichlorophenoxyacetic acid). Prior to the early 1980s, commercial formulations of 2,4,5-T contained residues of dioxins and furans as a byproduct of their production. To address this concern, three soil samples were collected near Rainy Hollow. Two of the samples were collected along the pipeline right-of-way to the north of Border Station/Rainy Hollow. One sample was collected from the southern end of the airstrip at Rainy Hollow, near the Klehini River. For all three samples, soil samples were collected in low-lying areas where runoff from larger areas of the clearing tends to pool, and where fine particulates and their associated contaminants would tend to be concentrated or focused. Samples were collected into duplicate 500 mL cleaned and proofed amber jars, using pre-cleaned stainless steel scoops.

Sample ROW(Right-of-Way)96-01 was collected in the middle of the Haines-Fairbanks pipeline right-of-way, approximately 600 m north of the north-most edge of the Border Station clearing. The sample was collected from a shallow depression, in organic-rich soils amongst small willows and grasses. Sample ROW96-02 was collected approximately 250 m north of the Border Station clearing, also in a shallow depression. The soil and surrounding vegetation were similar to that of ROW96-01. Finally, ROW96-03 was collected from the south end of the Rainy Hollow airstrip, in an area that appeared to be undisturbed during the 1994 emergency response.

The samples were shipped to Axys Analytical Services, Sidney, B.C. for the analysis of 2,3,7,8-substituted tetra- to octachlorinated dioxins and furans by gas chromatography - high-resolution mass spectrometry (GC-HRMS), as described in Section 2.2, below.

3.2 Analytical

The analytical program consisted of a field screening component which utilized portable analytical equipment and an analytical laboratory component which involved more detailed characterization. The advantage of incorporating field analytical work into this program was the ability to direct both the continuing field work and the selection of analytes for further laboratory analysis. The methods used included a photoionization detector to detect the volatile organic compounds and the immunoassay-based field methods that recognize an epitope (molecular binding site) that is usually indicative of some organic compound (e.g., DDTs).

Laboratory analyses were carried out at either Axys Analytical Services, Sidney, BC, or Analytical Services Laboratories Ltd. (ASL), Vancouver, BC. For routine analyses of chlorinated pesticides or hydrocarbons in soil or water, where a relatively high method detection limit was not anticipated to interfere with data interpretation, samples were sent to ASL. ASL also carried out the analyses for metals by ICP, BETX and volatile petroleum hydrocarbons (VPH), light (C10-C18) and heavy (C19-C32) extractable hydrocarbons (LEPH and HEPH respectively), PCBs as Aroclors, PAHs and total organic carbon (TOC).

Water samples for which chlorinated pesticide analytical results in the low parts per trillion were required were analyzed by Axys Analytical Services, using methods which involve more detailed sample clean up procedures and injection on a GC - MS. Similarly, samples of river sediment were also analyzed by Axys in order to obtain detection limits in the mid pg/g (ppt) range. All plant and rodent tissue samples were also analyzed by Axys, as were soil samples for dioxins and furans.

3.2.1 Field Screening Program

3.2.1.1 Volatile Organic Compounds (VOCs)

A soil vapour probe survey was carried using an HNU® photoionization detector (Model PI-101). This detector measures air the concentrations of VOCs in the 1-2000 ppm range. Soil samples were collected in 125 mL glass jars and sealed with aluminum lined screw-on lids. The jars were half filled with soil. The half-filled jars were shaken thoroughly for 30 s, and the headspace was allowed to equilibrate for 10 min. The lid was carefully removed leaving the aluminum foil lining in place. The foil was pierced using the vapour probe. Care was taken to sample only the headspace. The maximum reading was recorded. Samples with detectable levels of VOCs were retained and some were analyzed for TPH by immunoassay test kits.

3.2.1.2 Immunoassay Test Kits

Millipore EnviroGard™ immunoassay test kits which were obtained from

Diagnostix Inc., Mississauga, Ontario were used. These test kits are capable of screening for a variety of contaminants. In this program, kits were used for the detection of total petroleum hydrocarbons (TPH), BTEX, PCBs and DDTs. The kits utilize the enzyme-linked immunoabsorbent assay technique which is based on antibodies that are designed to bind to specific analytes. These antibodies are bonded onto polystyrene coated test tubes and operate on the principles of competitive immunoassay where the absorbance signal is inversely proportional to the concentration of the analyte (i.e., the greater the concentration of analyte, the lighter the colour). When solutions containing an analyte of interest (e.g., DDTs) are incubated in the tube along with an enzyme conjugate, the analyte binds to the antibodies while the conjugate binds to the unoccupied antibody binding sites. After incubation the unbound conjugate is decanted and the tube washed thoroughly. A solution containing a chromogene peroxidase substrate is then added to the tubes. This interacts with the bound enzyme conjugate to form a coloured product. Quantitation is achieved by comparing the colourimetric signal generated by a unknown sample with a set of standards using a portable spectrophotometer.

The immunoassay was carried out on-site according to the manufacturer's instruction. A 5 g portion was weighed and extracted with 5 mL methanol. The soil-methanol mixture was filtered and an aliquot of the extract used for subsequent analysis. At least 20% of the samples were also subjected to laboratory analysis as per US EPA protocols for field test kits.

3.2.2 Laboratory Analysis

3.2.2.1 Moisture Content - ASL

The percentage content of moisture in the soil samples was determined gravimetrically by drying the sample to constant weight at 103° C.

3.2.2.2 Metals in Soil - ASL

This analysis was carried out using procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 Method 3050 or Method 3051, published by the US EPA. The procedure involved a digestion using a 1:1 ratio of nitric acid and hydrochloric acid, along with hot plate or microwave heating. Instrumental analysis was by atomic absorption spectrophotometry (EPA Method 7000) and/or inductively coupled plasma - optical emission spectrophotometry. A limitation of this method is that the stated acid digestion will provide excellent results for total recoverable metals; however, it is only partially effective on mineralized or non-environmentally available metals. The metals analyzed included antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), molybdenum (Mo), nickel (Ni), selenium (Se), silver (Ag), tin (Sn), vanadium (V) and zinc (Zn).

3.2.2.3 Metals in Water - ASL

This analysis was carried out using procedures described in "Standard Methods for

the Examination of Waste Water", 19th Edition, 1995, published by the American Public Health Association, and with procedures adapted from "Test Methods for Evaluating Solid Waste" SW-846 Method 3050 or Method 3051, published by the US EPA. The procedure involves a preliminary sample treatment by acid digestion or filtration (EPA Method 3005) followed by instrumental analysis by atomic absorption spectrophotometry (EPA Method 7000), inductively coupled plasma (EPA Method 6010) and/or inductively coupled - mass spectrometry (EPA Method 6020).

All the samples were acidified immediately after collection and analyzed for total metals. Elements analyzed included aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), bismuth (Bi), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), nickel (Ni), phosphorus (P), potassium (K), selenium (Se), silicon (Si), silver (Ag), sodium (Na), strontium (Sr), Thallium (Th), tin (Sn), Titanium (Ti), vanadium (V) and zinc (Zn)

3.2.2.4 Mercury in Water

This analysis was carried out using procedures described in "Standard Methods for the Examination of Water and Wastewater", 19th Edition, 1995, published by the American Public Health Association. A cold oxidation procedure involving bromine monochloride was used, followed by cold-vapour atomic absorption spectrophotometry (CVAAS).

3.2.2.5 Non-Halogenated Volatiles in Sediment/Soil - Headspace Method - ASL

This analysis was carried out in accordance with US EPA Methods 3500/3810 and 8020/8015 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involves extracting the sample with methanol. An aliquot of this methanol extract is added to a sealed vial containing a constant volume of water. This vial is sealed and heated, causing the volatile compounds to partition into the gaseous headspace above the sample. A portion of this headspace is then analyzed by gas chromatography with photo-ionization detection (GC-PID) in conjunction with flame ionization detection (GC-FID).

3.2.2.6 Non-Halogenated Volatiles (BTEX) in Water - Headspace Method - ASL

This analysis was carried out in accordance with US EPA Methods 3810/8020 and 3810/8015 (Publ. # SW-846, 3rd ed., Washington DC 20460) and BC Ministry of Environment Land and Parks Method "Volatile Petroleum Hydrocarbons in Water". The procedure involved the use of a headspace technique in which volatile non-halogenated compounds volatilize into the headspace of a sealed vial. A portion of this headspace was then analyzed by gas chromatography with flame ionization detection (GC-FID). Samples requiring further confirmation were re-analyzed in accordance US EPA Methods5030/8240. This procedure uses a purge and trap extraction with subsequent analysis by capillary GC with mass spectrometric detection. The analytes comprised benzene, ethylbenzene, toluene, meta- & para-xylene, and ortho-xylene.

3.2.2.7 Volatile Petroleum Hydrocarbons in Soil - ASL

The analysis was carried out in accordance with the BC Ministry of Environment Land and Parks Method "Volatile Petroleum Hydrocarbons Soil". The procedure involved extracting the sample with methanol and adding an aliquot of the methanol to a vial containing a constant volume of water. This vial was sealed and heated, causing the volatile compounds to partition into the gaseous headspace above the sample. A portion of this headspace was then analyzed by gas chromatography with flame ionization detection (GC-FID).

3.2.2.8 Volatile Petroleum Hydrocarbons in Water - ASL

The analysis was carried out in accordance with the BC Ministry of Environment Land and Parks Method draft methodology for "Volatile Petroleum Hydrocarbons in Water". The procedure involved the use of a headspace technique in which volatile compounds volatilize into the headspace of a sealed vial. A portion of this headspace was then analyzed by gas chromatography with photo-ionization detection (GC-PID) in conjunction with flame ionization detection (GC-FID).

3.2.2.9 Light Hydrocarbons in Soil - ASL

The analysis was carried out in accordance with US EPA Method 3810/8015 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved extracting the sample with methanol and adding an aliquot of the methanol to a vial containing a constant volume of water. This vial is sealed and heated, causing the volatile compounds to partition into the gaseous headspace above the sample. A portion of this headspace is then analyzed by gas chromatography with flame ionization detection (GC-FID). This analysis covered carbon atoms in the C5 - C9 range.

3.2.2.10 Light Hydrocarbon in Water - ASL

The analysis was carried out in accordance with US EPA Method 3810/80205 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved a headspace technique which caused the non-halogenated volatiles to volatilize into the gaseous headspace. The gas was then analyzed by capillary gas chromatography with flame ionization detection (GC-FID). This analysis covered carbon atoms in the C5 - C9 range.

3.2.2.11 Extractable Petroleum Hydrocarbons (EPH) in Soil - ASL

The method used was equivalent to the BC Ministry of Environment Land and Parks Method for "Extractable Petroleum Hydrocarbons (EPH) in Soils by GC/FID, January 1996" but does not provide correction for Polycyclic Aromatic Hydrocarbons (PAH). The procedure involved hexane/acetone extraction and analysis using GC/FID. EPH results are presented for components in the C10 to C18 and C19 to C32 ranges.

3.2.2.12 Extractable Petroleum Hydrocarbons (EPH) in Water - ASL

The analysis used was equivalent to the BC Ministry of Environment Land and Parks Method for "Extractable Petroleum Hydrocarbons (EPH) in Water by GC/FID, January 1996" but does not provide correction for Polycyclic Aromatic Hydrocarbons (PAH). The procedure involved methylene chloride extraction and analysis using GC/FID. EPH results are presented for components in the C10 to C18 and C19 to C32 ranges.

3.2.2.13 Polycyclic Aromatic Hydrocarbons (PAHs) in Soil - ASL

Several samples were also analyzed for PAHs in accordance with US EPA methods 3500, 3630 and 8270 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved a microwave assisted extraction with dichloromethane followed by a cleanup on a silica gel column. This cleanup effectively removed aliphatic and heterocyclic hydrocarbons which could potentially interfere with the analysis. The final extract was analyzed by capillary column GC with mass spectrometric detection. The analytes included acenaphthene, acenaphthylene, acridine, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene and pyrene.

3.2.2.14 Polycyclic Aromatic Hydrocarbons (PAHs) in Water - ASL

This analysis was carried out using a procedure adapted by ASL from US EPA methods 3510, 3630 and 8270 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved extraction of the sample with methylene chloride followed by a cleanup on a silica gel column. This cleanup effectively removed aliphatic and heterocyclic hydrocarbons which could potentially interfere with the analysis. The final extract was analyzed by capillary column GC with mass spectrometric detection. The analytes included acenaphthene, acenaphthylene, acridine, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenz(a,h)anthracene, fluoranthene, fluorene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene and pyrene.

3.2.2.15 Light and Heavy Extractable Petroleum Hydrocarbons in Soil - ASL

This method was carried out as outlined in the method descriptions for Extractable Petroleum hydrocarbons and Polycyclic Aromatic Hydrocarbons. As per BC MELP Draft 3 Contaminated Sites Regulations, the concentrations for light extractable hydrocarbons (LEPH) were derived by the subtraction of naphthalene concentrations from the EPH (C10-C18) values. Similarly, heavy extractable hydrocarbons (HEPH) were calculated by subtracting the concentrations of benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenz(a,h)anthracene, indeno(1,2,3-c,d)pyrene phenanthrene and pyrene from the EPH (C19-C32) data.

3.2.2.16 Light and Heavy Extractable Petroleum Hydrocarbons in Water - ASL

This method was carried out as outlined in the method descriptions for Extractable Petroleum hydrocarbons and Polycyclic Aromatic Hydrocarbons. As per BC MELP Draft 3 Contaminated Sites Regulations, the concentrations for light extractable hydrocarbons (LEPH) were derived by the subtraction of acenaphthene, fluorene and naphthalene concentrations from the EPH (C10-C18) values. Similarly, heavy extractable hydrocarbons (HEPH) were calculated by subtracting the concentrations of acridine, anthracene, benzo(a)anthracene, fluoranthene, pyrene and benzo(a)pyrene from the EPH (C19-C31) data. There is, however, no water quality standard within B.C. for LEPHs or HEPHs in water.

3.2.2.17 Organochlorine Pesticides (OCPs) in Soil - ASL

Organochlorine pesticides in soils was determined with methodology adapted from US EPA Methods 3540, 3610 and 8081 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved a soxlet extraction with dichloromethane. The extract was then solvent exchanged to hexane followed by an alumina column clean up. The final extract was analyzed by dual capillary column gas chromatography with electron capture detector.

The analytes included the following pesticides: Aldrin, alpha-BHC (Benzene HexaChloride or hexachlorocyclohexane), beta-BHC, delta-BHC, cis-Chlordane, trans-Chlordane, o,p'-DDD (Dichloro Diphenyl Dichloroethane), p,p'-DDD, o,p' DDE (Dichloro Diphenyl Ethylene) p,p'-DDE, o,p'-DDT (Dichloro Diphenyl Trichloroethane), p,p'-DDT, Dieldrin, Endosulfan, Endrin, Heptachlor, Heptachlor epoxide, Lindane, Metoxychlor, Mirex, cis-Nonachlor, trans-Nonaclor, Oxychlordane and Toxaphene.

3.2.2.18 Organochlorine Pesticides (OCPs) in Water - ASL

This analysis was carried out in accordance with US EPA Methods 3510, 3610 and 8080 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved a soxlet extraction with dichloromethane. The extract was then solvent exchanged to hexane followed by an alumina column clean up. The final extract was analyzed by dual capillary column gas chromatography with electron capture detector.

3.2.2.19 Polychlorinated Biphenyls (PCBs) in Sediment/Soil - ASL

This analysis was carried out using a procedure adapted from EPA Method 8082 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involves a solid-liquid extraction of the sample with hexane/acetone and back extraction with water. The hexane extract was cleaned and analyzed by capillary column gas chromatography with electron capture detection. The results were reported as total polychlorinated biphenyls.

3.2.2.20 Polychlorinated Biphenyls (PCBs) in Water - ASL

This analysis was carried in accordance with EPA Method 3510/8080 (Publ. # SW-846, 3rd ed., Washington DC 20460). The procedure involved sample extraction with dichloromethane followed by column chromatography cleanup. The final extract was analyzed by capillary column gas chromatography with electron capture detection. The results were reported as total polychlorinated biphenyls.

*3.2.2.21 Polychlorinated Dibenzo-*p*-dioxins and Dibenzofurans - Axys*

All soil samples were spiked with an aliquot of ^{13}C-labeled surrogate standard solution (tetrachlorodioxin, tetrachlorofuran, pentachlorodioxin, pentachlorofuran, hexachlorodioxin, hexachlorofuran, heptachlorodioxin, heptachlorofuran and octachlorodioxin) prior to analysis. The samples were homogenized and a subsample of soil was dried for moisture determination. A wet soil sample was ground with sodium sulfate to a free-flowing powder. The mixture was loaded onto a soxhlet thimble, an aliquot of surrogate standard solution added and the soxhlet refluxed with acetone:toluene for 16-20 hours. The cooled extract was sequentially washed with potassium hydroxide solution, distilled water, concentrated sulphuric acid and distilled water. The organic layer was dried over anhydrous sodium sulfate, the solvent evaporated to dryness and redissolved in hexane.

The extract was transferred to 10 g layered silica gel columns (neutral:basic:neutral:acidic:neutral) and eluted with hexane. The eluate was loaded onto a 10 g basic alumina column and eluted with 3% dichloromethane:hexane followed by 1:1 dichloromethane:hexane. The latter extract was loaded onto a carbone celite column. The first fraction (F1), which eluted with 1:1 cyclohexane:dichloromethane followed by 1:1 toluene:ethyl acetate was discarded. The column was then inverted and eluted with toluene. This fraction was evaporated to near dryness and then redissolved in hexane and loaded onto an alumina column. The first fraction, eluted with 3% dichloromethane:hexane was discarded. The next fraction, eluted with 1:1 dichloromethane:hexane was retained and concentrated to 1 mL.

The 1 mL hexane solution was evaporated just to dryness and an aliquot of recovery standard solution (^{13}C-labeled 1,2,3,4-tetrachlorodibenzodioxin and 1,2,3,7,8,9-hexachlorodibenzodioxin) was added. The analysis was carried out on a VG 70 SE mass spectrometer equipped with an HP 5890 GC using a 60 m DB5 column (0.25 mm i.d × 0.1 mm film thickness) and a CTC autosampler. Data were acquired in the voltage selected ion recording (SIR) mode to enhance sensitivity. At least two ions were monitored for each group of isomers. Two ions were used to monitor each of the ^{13}C-labeled surrogate standards and five additional ions were monitored to check for interference from chlorinated diphenyl ethers.

3.2.2.22 Chlorinated Pesticides in Water, Sediment or Tissue - Axys

Pesticides analyses were conducted by Axys Analytical Services Ltd. of Sidney, B.C. Each sample was clearly labeled and locked in a secure frozen storage area until retrieved by the analyst.

All samples were spiked with an aliquot of surrogate standard (2,4,5,6-tetrachloro-m-xylene, PCB 209 and d4-alpha endosulphan) prior to analysis by gas chromatography with electron capture detection (GC/ECD); for gas chromatography with mass spectrometry (GC/MS), the samples were spiked with aliquots of ^{13}C labeled standard (PCB 101, PCB 180, PCB 209 and d4-alpha endosulphan).

Sediment samples was thoroughly homogenized and a subsample taken for the determination of wet weight/dry weight ratio. Wet sediment to which an aliquot of surrogate standard had been added, was extracted once with 80 mL of 1:1 dichloromethane/methanol by shaking on a shaker table for 30 minutes. The extraction procedure was repeated twice more with 80 mL of dichloromethane. The extracts were combined, washed with solvent-extracted water, dried over anhydrous sodium sulfate and concentrated by rotary evaporation. After the addition of activated copper to remove sulphur, the extract was separated on a Florisil column.

The extract was quantitatively transferred to a Florisil column. The column was eluted with hexane followed by 15/85 dichloromethane/hexane. The eluates were combined (Fraction-1). The column was eluted with 50/50 dichloromethane/hexane (Fraction-2)

Each fraction was concentrated, transferred to a microvial and spiked with an aliquot of recovery standard (^{13}C-PCB 153) prior to instrumental analysis.

- Fraction-1 was analyzed by GC/MS for non-polar and moderately polar chlorinated pesticides.

- Fraction-2 was analyzed by GC/ECD for the most polar chlorinated pesticides.

Fraction-1 was analyzed using a Finnigan INCOS 50 mass spectrometer equipped with a Varian 3400 GC, a CTC autosampler and a DG 10 data system running INCOS 50 (Rev 9) software. Chromatographic separation of pesticides was achieved with a 60 m DB-5 column (0.25 mm i.d. and 0.10 μm film thickness). The mass spectrometer was operated in the electron impact (EI) mode at unit mass resolution in the multiple ion detection (MID) mode acquiring two characteristic ions for each target analyte and surrogate standard.

For high resolution GC/MS analysis, a VG 70 SE mass spectrometer equipped with a Hewlett Packard 5890 GC, a 60 m DB-5 chromatographic column (0.25 mm i.d. and 0.10 μm film thickness) and a CTC autosampler was used. Data was acquired in the

MID mode to enhance sensitivity. Two characteristic ions for each target analyte and surrogate standard were monitored.

3.3 Site Topographic Survey

A total station was used by personnel from Yukon Engineering Services, Whitehorse to complete a formal survey of Rainy Hollow and Border Station. The surveyors used benchmarks established during the 1994 emergency response as well as references provided earlier as part of a U.S. Army Corp of Engineers survey of the pump station in the late 1950s. The survey conducted for this study included the locations and elevation of all wells and test pits. Topographic contours were also established (Map 3.1).

4. POTENTIAL HAZARD IDENTIFICATION

4.1 Compounds of Interest

The previous preliminary site investigations (Chapter 2) indicated that the following possible contaminants may be of concern with regard to human health or ecological risk at or around Border Station/Rainy Hollow:

- **Hydrocarbons** (including constituents of partially weathered diesel fuel, and xylenes used as a DDT carrier);
- **DDT** (dichlorodiphenyltrichloroethane) and related compounds in pesticidal formulations, or produced as metabolites or through chemical degradation;
- **Phenoxy- herbicides** (2,4,5-T and it's breakdown products), especially along pipeline and road right-of-ways; and
- **Polychlorinated dibenzo-*p*-dioxins and dibenzofurans** present as environmentally persistent impurities in phenoxy- herbicides;

PCBs and metals/metalloids were not identified as contaminants of concern during the preliminary site investigations, but were analyzed in a limited number of additional soil samples owing to their previously demonstrated presence as contaminants at other arctic and sub-arctic sites such as Aishihik and Snag Airstrip.

The possible sources and properties of each of the contaminant classes are briefly discussed immediately below. Substances for which adverse effects on living organisms were considered to be at least remotely possible are discussed in more detail in Section 4.2, with emphasis on soil and water criteria.

4.1.1 Hydrocarbons (aliphatics, simple aromatics such as benzene and ethylbenzene, isoprenoids, hopanes, unsubstituted polycyclic aromatics and substituted PAHs)

Several past activities at the sites could have contributed a complex suite of hydrocarbons to the surface or subsurface; for example, leaks in the pipeline, shut-off valves or storage tanks on site; shunting of product during line cleaning; general spillage and the discarding of used oil; and release along with other contaminants such as DDT, where hydrocarbons were used as a carrier.

Xylenes were found during the 1994 emergency response as part of the hydrocarbon carrier in the DDT pesticide formulation. Xylenes, like other BETX substances (benzene, ethylbenzenes, toluene, xylenes) are highly volatile and readily destroyed through photolysis and other degradation pathways. Xylenes tend to persist only in subsurface environments. Risk to humans or other biotic receptors from these suspected carcinogens is generally greatest in association with inhalation. At some sites,

but not at Rainy Hollow/Border Station, there may be a risk to human health in association with consumption of contaminated drinking water.

Virtually all unweathered and weathered petroleum-based products will have an extremely complex mixture of individual substituents. Each substituent will exhibit slight to substantial differences in environmental partitioning, environmental persistence, bioavailability, and acute or chronic toxicity. Whereas many of the substituents of hydrocarbon contamination are virtually benign, some are either acutely toxic at moderate doses, potent carcinogens, and/or capable of exerting other negative effects such as immunosuppression or endocrine disruption.

Routine site investigations usually take advantage of "surrogate" measures of hydrocarbon contamination, or group parameters; for example, (i) use of a photoionization detector, or soil vapour probe to detect the most volatile hydrocarbon fractions; (ii) use of immunoassay-based field methods based on molecular recognition of an epitope (molecular binding site) that is usually indicative of some fraction of extractable hydrocarbons or PAHs; (iii) oil and grease - usually a simple extraction and gravimetric method, or (iv) total extractable hydrocarbons (TEH), total petroleum hydrocarbons (TPH) or other operationally defined subsets such as volatile, light extractable or heavy extractable petroleum hydrocarbons (VPHs, LEPHs, HEPHs, respectively).

The application of these surrogates for field investigations is predicated on the implicit assumption that they predictably co-vary with the actual constituents in a hydrocarbon mixture. The surrogates, therefore are adequate predictors of variations over space or time of the hydrocarbon fractions that could be of concern. It must be emphasized, however, that the relationships between surrogates and various other analytes should be established for a given site or hydrocarbon source (for example, diesel) before these surrogate measures are used to predict hydrocarbon environmental fate or the associated human health and ecological risk. Otherwise, at least some understanding must be achieved for each site of the major hydrocarbon substituents present in the environment.

The detailed composition of hydrocarbons found in subsurface soils from Border Station was previously examined (RRU, 1996b). The make-up and relative proportions of individual components is expected to be similar for the broader subsurface zone of hydrocarbon contamination at Rainy Hollow/Border Station. Some gradational bias in the relative proportions of individual constituents would be expected, however, from differences between various hydrocarbon substances in the aqueous solubility and resistance to degradation in subsurface environments.

Overall, the hydrocarbon fingerprint for subsurface water and soil samples collected during 1995 and 1996 was consistent with a predominantly diesel source at all sampling locations. It is interesting to note that DDT-contaminated soils previously removed from the trench at Rainy Hollow, placed in the temporary storage facility, and subsequently removed off-site contained both a lighter diesel-like fraction and a distinct

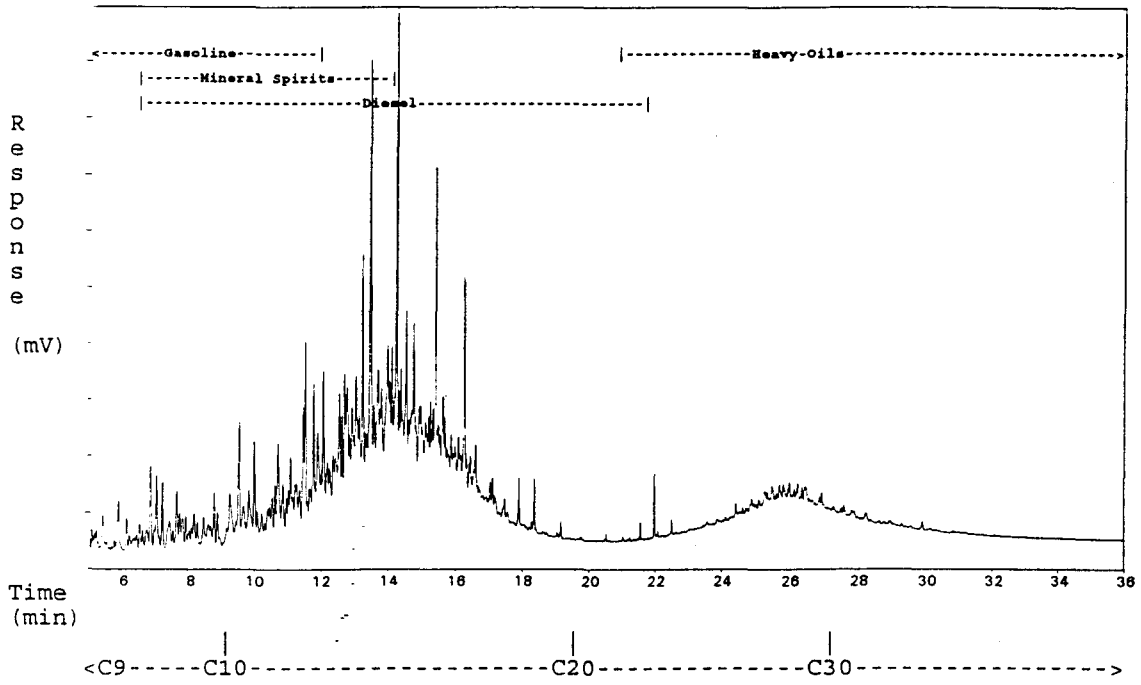


Figure 4.1: Typical profile of hydrocarbons in subsurface soils excavated from the trench at Rainy Hollow in 1994 (based on confirmatory sampling of the Temporary Storage Facility). Note both the lighter fraction, similar to diesel and the heavier fraction.

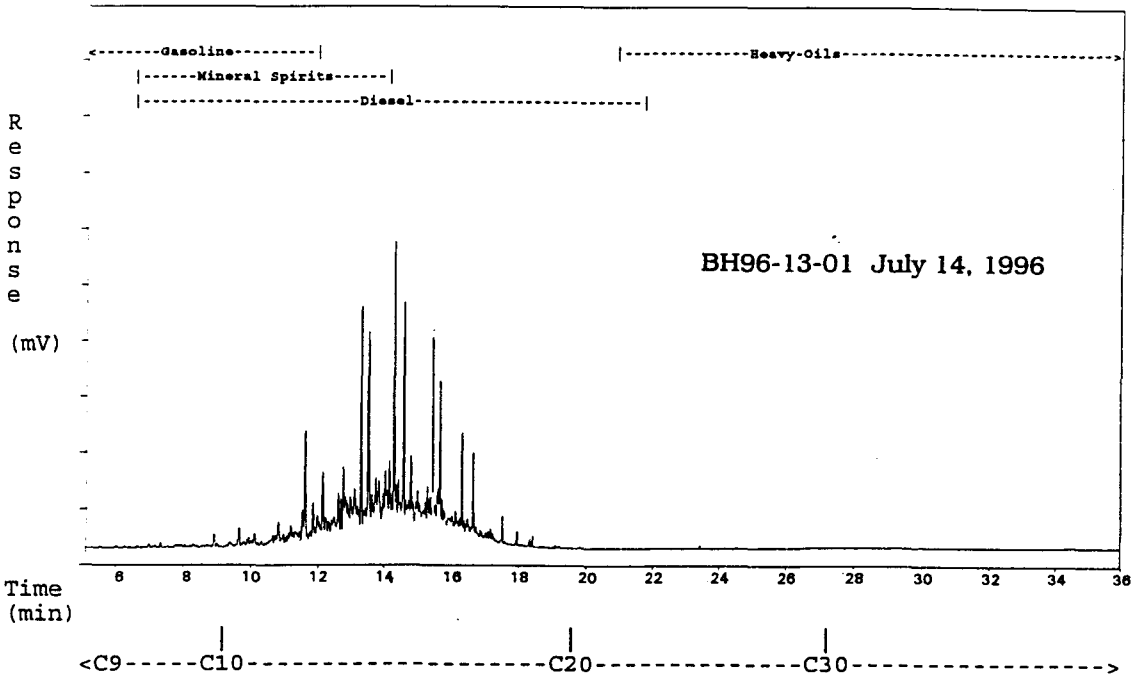


Figure 4.2: Typical profile of hydrocarbons in subsurface soils from Rainy Hollow and Border Station, July 1996.

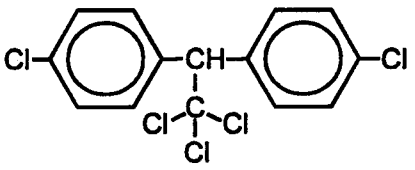
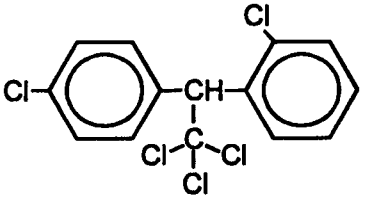
heavier fraction (predominantly C20 to C30 hydrocarbon fraction)(Figure 4.1; see also RRU, 1996c). The gas chromatographic signature of this heavier fraction is consistent with heavier oil grades, such as crankcase or some grades of lubricating oil. Several samples exhibited large and distinct peaks that eluted from the GC column in the C20 - C30 range. The presence of this heavier hydrocarbon fraction in soils removed from the trench in 1994 may indicate that used or unused oils were also disposed during or prior to 1972 in the same pit as the DDT canisters. The heavier fraction, however, was not found in significant quantities in subsurface or surface soil samples, or water samples, collected in 1996 outside of the temporary storage facility (Figure 4.2).

4.1.2 DDT, related isomers, and other chlorinated pesticides.

The discovery of DDT-containing pesticides in buried canisters at Rainy Hollow prompted the 1994 emergency response by the Canadian and British Columbian government.

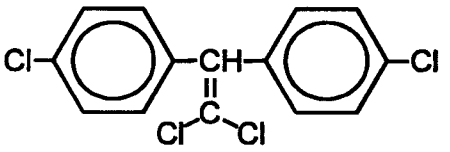
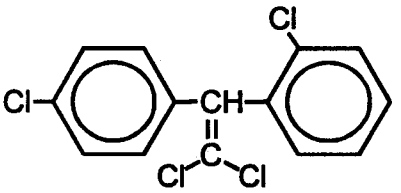
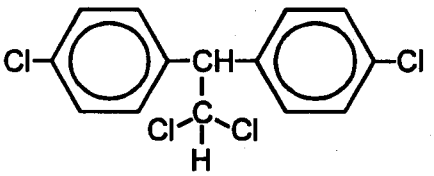
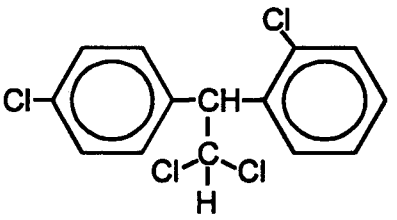
The name DDT is derived from DichloroDiphenylTrichloroethane and is the generic name for 1,1,1-trichloro-2,2-*bis*-(p-chlorophenyl) ethane. Pure DDT is a white, crystalline, tasteless, odourless solid. It has limited volatility (vapour pressure at 20 ° C = $1.5x10^{-7}$ mm Hg) and has a very low water solubility but high solubility in organic solvents. Technical grade DDT is a white amorphous powder containing several similar compounds. The two principal isomers of DDT are given in Table 1.1 below. The o,o'-DDT or 2,2'-DDT isomer 1,1,1-trichloro-2,2-*bis*-(o-chlorophenyl) ethane also occurs in smaller quantities.

Table 4.1: Chemical names and structures of DDT isomers

Common Name	Chemical Name	Composition in Technical Mixture	Structure
p, p'-DDT or 4,4'-DDT	1,1,1-trichloro-2,2-*bis*-(p-chlorophenyl) ethane	70-80%	
o, p'-DDT or 2,4'-DDT	1,1,1-trichloro-2- (o-chlorophenyl)-2-(p-chlorophenyl) ethane	up to 30%	

DDE (dichloro-diphenyl-ethylene) and DDD (dichloro-diphenyl-dichloroethane) occur in small quantities as impurities in technical DDT mixtures: chemical names and structural formulae for DDE and DDD isomers are given in Table 4.2. DDE and DDD are also produced either metabolically or photochemically in the environment from the dechlorination of DDT.

Table 4.2: Chemical names and structures of DDE (dichloro-diphenyl-ethylene) isomers

Common Name	Chemical Name	Structure
p, p'-DDE or 4,4'-DDE	1,1-dichloro-2,2-*bis* (p-chlorophenyl) ethylene	
o, p'-DDE or 2,4'-DDE	1,1-dichloro-2- (o-chlorophenyl)-2-(p-chlorophenyl) ethylene	
p, p'-DDD or 4,4'-DDD	1,1-dichloro-2,2-*bis* (p-chlorophenyl) ethane	
o, p'-DDD or 2,4'-DDD	1,1-dichloro-2-(o-chlorophenyl)-2-(p-chlorophenyl) ethane	

DDT was discovered to have insecticidal properties during the second world war and its use significantly reduced the incidence of insect borne diseases such as malaria and typhus. From approximately 1943 onward, the U.S. military sponsored hundreds of research studies annually on DDT and other pesticides including hexachlorobenzene,

chlorinated napthalenes, pyrethroids, phthalates, chlordane, camphene (polychlorobornanes), organophosphates and others. Earlier studies were designed to address alternative application methods, efficacy, improved synthesis, analytical methods, and toxicity to mammals and invertebrates. DDT was first used in field applications in tropical or semi-tropical environments, where mosquitos and other insects are vectors of endemic and occasionally epidemic disease in human populations. DDT was probably not routinely used in the Arctic, where insects are a nuisance but not a direct risk to human health, until after 1947-48. Extensive field trials were conducted near Alaska military sites and near Churchill, Manitoba on the efficacy of DDT, starting in 1947 (War Department, Army Committee for Insect and Rodent Control, The Pentagon. Minutes of the Twenty-Fourth Meeting of the Army Committee for Insect and Rodent Control, 3 July 1947; Declassified documents - National Archives, College Park Maryland. Record Group 337, Entry 90, Box 47, File 337-2).

The low cost of DDT, its high activity against insects, ease of application and persistence encouraged its use by civilians after the war. It was used extensively to control a wide ranges of insect pests on agricultural lands. Swamps, forests as well as residential areas were sprayed with DDT to control insect pests.

Early investigations indicated that excessive use of DDT could kill fish, birds and other wildlife. Residues of DDT were found in plant and animal tissue and cows milk, but these were accepted as unavoidable hazards and of little concern. During the 1950's and 1960's, residues of DDT and other organochlorine insecticides were detected in soils and small amounts in water and sediments. Dead birds and fish were found around areas sprayed with DDT. Thinning of bird egg shells and birth deformities in birds were also linked to DDT and other organochlorine compounds. Humans were exposed to DDT through ingesting food containing DDT residues and there were indications that DDT and other organochlorine insecticides were concentrated into the upper trophic levels of the food chain (biomagnification). For example, high levels of DDT were detected in mother's milk. Other pathways for human exposure to DDT include ingestion of contaminated soil particles, inhalation of contaminated air and adsorption through the skin. Short term exposure to DDT affects the primarily the nervous system; highly exposed soldiers in the second world war had suffered aching joints, tremors and depression. Long term exposure to low doses results in some reversible changes in the level of liver enzymes. Because of these observed effects and the potential harm to human beings (such as carcinogenesis and endocrine disruption), the use of DDT was banned in many developed countries including Canada and the USA in the early 1970's. It is still, however, in use in some countries including Mexico.

The presence of DDT in the Canadian environment is generally a result of contamination due to past use or incorrect disposal practices, as is the case in Rainy Hollow. The volatility of DDT (vapour pressure $\approx 1.5 \times 10^{-7}$ mm Hg at 20° C) is sufficiently high that it may be transported in the air over short and long distances in the gaseous or vapour phase, and adsorbed onto small particulates. DDT degrades rapidly in air *via* photolysis, with a half life of less than two days. It is not readily soluble in water (estimated aqueous solubility in water for DDT, DDE and DDD is approximately 0.003

mg/L, 0.04 mg/L, and 0.16 mg/L respectively at ~ 20° C.). The low aqueous solubility of DDT and the related compounds results in a strong adherence to soil and sediment particles. Once bound, DDT tends to be highly persistent (half life of up to 15 years). Metabolites (degradation products) in the soil are usually DDE and DDD. No numerical soil guidelines exist in Canada (see next section).

Overall, the major mechanisms for the physical transport of DDT, DDE and DDD away from a local source include -

- transfer from surface soil and water to air masses through volatilization or entrainment of fine particulates; and
- surface runoff primarily of entrained particulates.

There is also limited potential for transport in groundwater; however, the low aqueous solubility of DDT and tendency to remain tightly sorbed to soil particles constrains the rate of transport.

It is becoming evident that several chlorinated pesticides in addition to DDT were used at some arctic military sites from around 1949 onward (Bright, unpublished results: review of declassified U.S. military records housed in the National Archives, Washington, D.C.). Pesticides that were used experimentally and possibly routinely included chlordanes, hexachlorohexanes, camphenes (polychlorobornanes) and other non-chlorinated pesticides. Chlordanes, in particular, were discovered in 1996 to be contaminants of concern at Snag Airstrip, western Yukon - a site built by the U.S. Army Airforce (AAF; in 1949 superceded by USAF) as a node of the Northwest Supply Route. Based on correspondence from the Alaskan Air Command, it is likely that chlordane was used to control "cockroachs" around residential and office buildings and mess facilities in Alaska and some Yukon sites.

The analysis of chlorinated pesticides in soils removed from the Rainy Hollow trench to the Temporary Storage Facility indicated that the only chlorinated pesticides detectable were DDT, DDE, and DDD compounds and one other pesticide breakdown product (Royal Roads University, 1996c). Oxychlordane, a major degradation product of chlordane, was consistently detected in soil samples from the temporary storage facility at concentrations in the range < 0.001 to 0.054 mg/kg (ppm), or < 1 to 54 ppb. The concentrations of oxychlordane found in the soils removed from the DDT trench demonstrate that chlordane probably was also used at Border Station/Rainy Hollow. Oxychlordane was not detected, however, in any of the soil (<0.001 to < 0.005 mg/kg) or groundwater samples (< 0.010 mg/L) collected in 1996 (see Section 5.3 and 5.4, below). Nor were any other chlorinated pesticides detected, excluding DDT, DDE, and DDD. Furthermore, oxychlordane was not detected in any of the sediment samples from the Klehini River analyzed at Axys by HRGC/HRMS (all samples < 0.001 ng/L). Chlordanes, therefore, were not considered to be of concern at Rainy Hollow/Border Station and were excluded from more detailed investigation and risk assessment.

4.1.3 Phenoxy- herbicides, including co-contamination by polychlorinated dibenzo-*p*-dioxins and dibenzofurans

Other studies have demonstrated that phenoxy- herbicides were used to defoliate power line, road and pipeline right-of-ways. While the phenoxy- herbicides themselves have very limited mammalian or avian toxicity, and are rapidly degraded in the environment, some formulations used prior to the 1980s, including 2,4,5-T, contained polychlorinated dibenzo-*p*-dioxins and dibenzofurans (PCDDs/PCDFs) as impurities. Chronic use of phenoxy- herbicides, therefore, might have resulted in PCDD/PCDF inputs: As part of this investigation, a screening evaluation was undertaken of the soil concentrations of PCDD/PCDFs and associated risk (Chapter 5).

4.1.4 PCBs

The preliminary site investigation at Border Station (UMA, 1995) did not reveal the presence of PCBs in soil or water at concentrations of concern. PCBs are not likely to be a problem at Border Station (RRU, 1996b). The presence, however, of as-yet-to-be investigated refuse burial sites (four total) at Rainy Hollow, and the presence in 1994 of one piece of electrical equipment in the DDT-contaminated trench/landfill suggested a small possibility of PCB release into the environment at Rainy Hollow.

4.1.5 Metals and metalloids

Metals/metalloids have not been confirmed to be contaminants of concern as a result of either the Rainy Hollow study (Golder, 1995) or Border Station preliminary site investigation (UMA, 1995); however, the presence of uncharacterized, subsurface refuse disposal areas required the examination of an expanded contaminant suite, including metals/metalloids, which could have been contributed from a large number of sources such as car battery disposal.

4.2 Relevant Soil and Water Quality Criteria, and Other Toxicological Benchmarks

Two contaminant classes were evaluated in detail, based on the earlier assessment of potential contaminants of concern (Section 4.1), and the expanded contaminant screen during the 1996 investigation. The contaminant classes include (i) DDT and related isomers, and (ii) hydrocarbon constituents.

The risk to humans and other living things at or near contaminated sites must be reduced to an acceptable level; however, clearly defining contaminant levels that increase risk to humans or other living organisms is not always a simple task. The presence of a chemical substance does not, in itself, indicate a deleterious environmental effect or impact. Criterion-based methods define numerical values or limits that can be compared

with measured environmental levels. These methods establish baseline concentrations for various substances below which the impact on the environment is assumed to be negligible. Environmental samples which contain concentrations above this limit may require further investigation, often in the form of a risk assessment, depending on the extent to which the level is exceeded. This approach benefits from the ease with which it can be administered. A contaminant concentration is simply measured in an environmental sample, and compared to tabulated criteria adopted by the appropriate regulators.

In most regulatory jurisdictions, the prescribed practice embraces site-specific investigations of environmental impact which draw on both site-specific strategies and numerical criteria. Numerical values such as remediation criteria are commonly used as a screening tool. Environmental samples with levels of substances that fall below the criteria do not catalyze either additional assessment of risk or corrective action unless site-specific conditions suggest an uncharacteristically large potential for impact. The presence of ecologically sensitive areas/species or aqueous contaminant migration are examples of site-specific conditions that require special consideration.

In Canada, federal remediation criteria (CCME, 1991) and contaminated site cleanup criteria or regulation adopted by several provinces (e.g., BCMELP, 1995) specify the guarded use of criteria in conjunction with site-specific investigations of risk. A similar approach has also been advocated recently by the US EPA [e.g., see US EPA (1994) Region IX Preliminary Remediation Goals].

4.2.1 DDT, DDE and DDD

Table 4.3 provides a list of soil and water quality values for DDT and related substances presently in use in North America. Screening level values for DDT were not available as part of the CCME (1991) Soil Quality Criteria, but were under development at the time of this study (late 1996). The United States does not have any federally-adopted, formally accepted soil remediation criteria, guidelines or standards at the present time. Draft guidelines, however, have been proposed on several occasions, and draft sets of numbers exist. These have typically been used at contaminated sites to prioritize cleanup activities, and screen for problems pending a more complete risk assessment.

One example of draft screening criteria is the list of "Preliminary Remediation Goals" (PRGs) circulated by the US EPA (1994). These are intended as estimates of "safe" contaminant levels in environmental media (soil, air, drinking water) based on EPA human toxicity data, major exposure pathways, and estimates of partitioning and assimilation. The PRGs attempt to provide lists of contaminant concentrations for both non-carcinogenic and carcinogenic chemicals below which the risk to humans is minimal.

Table 4.3: Standards, Criteria, or Guidelines for DDT Response Levels

Agency/ Jurisdiction	Criterion or Guidance Level	Applicability	Notes
A) Soil			
• CCME - Canadian/ Federal (1991)	- no criteria for chlorinated pesticides except chlorobenzenes and HCH		-DDT soil criterion under development by CCME at the time of this study.
• British Columbia MELP (1989) Draft 6 Criteria for Managing Contaminated Sites	- 2 mg/kg total pesticides	- Residential/Parkland areas	
• USEPA (1990): Concentrations Meeting Criteria for Action: Solid Waste Management Units (Federal Register, 40 CFR Part 264)	- 2 mg/kg DDT - 2 mg/kg DDE - 3 mg/kg DDD	- Soils: protection of "human health and the environment"	- Trigger levels for further action at Hazardous and Solid Waste Management Facilities in U.S.; Assumes exposure of humans through soil consumption 365 days/year
• USEPA Draft Soil Screening Levels (SSLs: 1995)	- 2 mg/kg DDT - 80 mg/kg DDT - 2 mg/kg DDE - 3 mg/kg DDD	- Human health, soil ingestion - Human Inhalation-Human health, soil ingestion - Human health, soil ingestion	All values assume human exposure pathways in a residential scenario. Adapting modeled levels to Rainy Hollow would result in much higher site-specific SSLS, since periods of human exposure are infrequent, limited to summer months when ground is not covered with snow, as well as of short duration.
B) Sediment			
• CCME Draft Interim Sediment Quality Criteria (1994)	- 7.0 ng/g DDT, total - 4450 ng/g DDT, total - 1.42 ng/g p,p'-DDE - 6.75 ng/g p,p'-DDE - 3.54 ng/g p,p'-DDD - 8.51 ng/g p,p'-DDD	- Threshold Effect Level[1] - Probable Effect Level[2] - Threshold Effect Level - Probable Effect Level - Threshold Effect Level - Probable Effect Level	- draft., pending further review.

(continued next page)

Table 4.3 (cont'd)

• Ontario Ministry of Environment, Aquatic Sediment Quality Guidelines (1992)	- 7 ng/g DDT (total) - 8 ng/g o,p'+ p,p'-DDT - 71,000 ng o,p' + p,p'-DDT/ g organic C - 5 ng/g p,p'-DDE - 8 ng/g p,p'-DDD	- Lowest Effect Level[3] - Lowest Effect Level - Severe Effect Level[4] - Lowest Effect Level - Lowest Effect Level	- based on organic C normalized values.
C) Water			
• CCME - Canadian/ Federal	- 1 ng/L DDT - 30 µg/L	- Freshwater Aquatic Life - Drinking Water	- from Canadian Water Quality Guidelines, CCREM (1987) -from Health and; Welfare Canada, 1989.
• British Columbia, MELP Draft 3 Contaminated Sites Regulation (1995)	- 1 ng/L DDT - 30 µg/L DDT	- Aquatic Life - Live Stock, Drinking Water	- includes DDT metabolites
• USEPA (1990): Concentrations Meeting Criteria for Action: Solid Waste Management Units (Federal Register, 40 CFR Part 264)	- 100 ng/L DDT	- Water: protection of "human health and the environment"	- Trigger level for further action at Hazardous and Solid Waste Management Facilities in U.S.
D) Air			
• USEPA (1990): Concentrations Meeting Criteria for Action: Solid Waste Management Units (Federal Register, 40 CFR Part 264)	- 10 mg/m^3 DDT	- Air: protection of "human health and the environment"	- Trigger level for further action at Hazardous and Solid Waste Management Facilities in U.S.
E) Human Consumption - Food Substances			
• Health and Welfare Canada	- not defined for DDT, DDE, DDD		

1: Calculated as the geometric mean of the lower 15th percentile concentration of the effect data set and the 50th percentile concentration of the no effect data set.
2: Calculated as the geometric mean of the 50th percentile concentration of the effect data set and the 85th percentile concentration of the no effect data set.
3: Based on 5th percentiles of Screening Level Concentrations.
4: Based on 95th percentiles of Screening Level Concentrations.

Another set of numerical guidelines for contaminants in soils, "Draft Soil Screening Levels" (SSLs) has also been circulated in draft form (revised in December 1994) by the USEPA, to be used for delineating soils at United States National Priorities

List Sites under the Superfund program. These are assessment values applicable to screening areas of sites in order to determine the need for further action; they are not soil remediation criteria. They are not advocated by the US EPA for other than their intended use.

4.2.2 Hydrocarbons

Table 4.4 provides a list of soil, sediment and water quality values in use in Canada and British Columbia for total hydrocarbons or individual hydrocarbon constituents. Screening level guidance for hydrocarbons is generally scarce. There is considerable variance between provinces in the application of group parameters for soil screening and remediation; for example, there is no consensus between regulatory jurisdictions on criteria for oil and grease (O&G) total petroleum hydrocarbons (TPH), total extractable hydrocarbons (TEH), or Volatile, Light and Heavy Extractable Hydrocarbons (VPHs, LEPHs, and HEPHs, respectively).

Since Border Station/Rainy Hollow are within British Columbia, Draft (1995) Regulations for VPHs, LEPHs, and HEPHs have been used to initially interpret the data (see Methods Section 3.2 and Section 4.1 for a more detailed discussion of hydrocarbons). There are no standards of criteria for VPHs, LEPHs, or HEPHs in sediment, groundwater, or river water either in British Columbia or elsewhere. Few criteria exist for individual polycyclic aromatic hydrocarbons (PAHs), especially in sediment, groundwater or surface water.

Table 4.4: Standards, Criteria, or Guidelines for Hydrocarbon Response Levels

Substance	Criterion or Guidance Level (in mg/kg, or ppm, unless noted otherwise)	Applicability/Notes
A) Soil		
• Volatile Petroleum Hydrocarbons (VPHs)[1]	200	**Urban Park/Residential**; BCMELP Draft 3 Contaminated Sites Reg. (1995)
• Light Extractable Petroleum Hydrocarbons (LEPHs)[2]	1000	as above
• Heavy Extractable Petroleum Hydrocarbons (HEPHs)[3]	1000	as above
• Nonaqueous phase liquids (NAPL)	not present	as above
• Benzene	0.5	**Residential/Parkland**; CCME (1991)
• Ethylbenzene	5	as above
• Toluene	3	as above
• Xylenes	3	as above

1: **VPHs** include volatile petroleum hydrocarbons with the exception of benzene, ethylbenzene, toluene and xylenes; 2: **LEPHs** include light (C10-C18) hydrocarbons with the exception of PAHs included separately in the regulation; 3: **HEPHs** include heavy (C19-C32) hydrocarbons with the exception of PAHs included separately in the regulation.

(continued next page)

Table 4.4 (cont'd)

• Naphthalene	5	as above
• Phenanthrene	5	as above
• Pyrene	10	as above
• Benzo(a)anthracene	1	as above
• Benzo(a)pyrene	1	as above
• Benzo(b)fluoranthene	1	as above
• Benzo(k)fluoranthene	1	as above
• dibenz(a,h)anthracene	1	as above
• Indeno(1,2,3-c,d)pyrene	1	as above
B) Freshwater Sediment		
• Phenanthrene	0.042	**CCME Draft Interim Freshwater Sediment Quality Guidelines** (Threshold Effects Levels: TELs: 1994)
• Benz(a)anthracene	0.032	as above
• Benzo(a)pyrene	0.032	as above
• Chrysene	0.057	as above
• Fluoranthene	0.11	as above
• Pyrene	0.053	as above
• Oil and Grease	0.15%	**Ontario Ministry of Environment, Aquatic Sediment Quality Guidelines** (1992)
C) Water (Protection of Freshwater Aquatic Life)		
• Nonaqueous phase liquids	Not present	**BCMELP Draft 3 Contaminated Sites Reg.** (1995)
• Benzene	300 µg/L	**CCME Remediation Criteria for Water** (1991)
• Ethylbenzene	700 µg/L	as above
• Toluene	300 µg/L	as above
• Xylenes	---	as above
D) Water(Drinking Water - Human Consumption)		
• Nonaqueous pahse liquids	Not present	**BCMELP Draft 3 Contaminated Sites Reg.** (1995)
• Benzene	5 µg/L	**CCME Remediation Criteria for Water** (1991)
• Ethylbenzene	≤ 2.4 µg/L	as above
• Toluene	≤ 24 µg/L	as above
• Xylenes	≤ 300 µg/L	as above
• Benzo(a)pyrene	0.01 µg/L	as above

5. RESULTS OF DETAILED SITE INVESTIGATION

5.1 Data Reliability: Analytical Quality Assurance/Quality Control

5.1.1 Accuracy and Precision of Laboratory Analyses

Measures taken to ensure the reliability of the analytical data provided by ASL Analytical Services Laboratory and Axys Analytical Services included -

- **avoidance of false positive results:** inclusion of blanks in each analytical batch and adjustments to interpretations of data for batches with detectable analytes in the blanks;
- **reproducibility associated with laboratory procedures:** analysis of at least one duplicate sample per batch;
- **reproducibility associated with field sampling and sub-sampling for analyses:** blind submission of field duplicates for approximately 10% of the samples;
- **accuracy:** analysis of certified or standard reference materials; and
- **accuracy through avoidance of analyte losses during extraction and analysis:** evaluation of recoveries following extraction and work-up of ^{13}C-labelled surrogates during analysis of PCDDs/PCDFs, and chlorinated pesticides by high-resolution mass spectrometry.

A brief synopsis of the QA results is provided in Table 5.1. **Overall, the analytical precision and accuracy was within acceptable limits for all batches, and all data were deemed reliable. In consideration of the overall sampling and analytical program, there were three major issues that were considered to influence the quality and subsequent interpretation of the data, and that may not be reflected in the tabulated QA data.**

The first issue was related to the possible cross-contamination of samples during the field study. The test pit and well point soil and water data collected during the 1994 Emergency Response appear to be unreliable. Hydrocarbons and especially DDT may have been introduced from areas of high concentration in and near excavated Trench to outlying areas as residual soils on heavy equipment (including the backhoe used to excavate test pits). In particular, DDT or hydrocarbon data from test pit TPG3 and G10 and well points WP1, 11 or 12 are suspect. Attempts were made during this study to avoid cross-contamination during sampling through the rigorous decontamination by steam-cleaning of drilling equipment between boreholes, as well as the backhoe bucket following excavations made in contaminated areas of the site.

The second issue was the unavoidable presence of fine silt particulates in ground water samples collected both from the original well points (Golder, 1994) and the newly established monitoring wells. Great effort was taken to stabilize the monitoring wells after installation of piezometers in July, 1996. For some wells, hundreds of litres of groundwater were purged prior to the final sampling. Whereas particulate concentrations in some wells improved following well stabilization, groundwater samples from other wells remained cloudy. No obvious decrease in suspended particulate load was observed in the wells that were re-sampled in September, 1996. The quantity of suspended silt was probably related to both the length of piezometer screen installed and localized differences in the surrounding soil matrix. To overcome the problem of suspended particulates in groundwater samples, all samples were allowed to settle and then decanted prior to analysis. All groundwater samples were observed to clear very rapidly when left undisturbed for five or more minutes. Analytical results for chlorinated pesticides and hydrocarbons from the July 1996 sampling of Rainy Hollow well points were comparable to or even slightly lower than data obtained by Vic Enns, Environment Canada (EC, 1995) using extremely low pumping rates to avoid entrainment of suspended silt (see Section 5.3). **Prior decanting of samples was deemed to be an effective method for obtaining reliable data for truly dissolved contaminant concentrations.** Several of the monitoring wells were sampled both in July and September, 1996. As shown in Figure 5.1, the data were virtually identical for the two sampling periods, with the exception of a pair of samples from monitoring well BH96-19A. This provides additional evidence for the reliability of the groundwater monitoring data.

The third and final issue is related to the comparability of data collected using different field and analytical methods. For example, hydrocarbon contaminants in subsurface soils obtained from test pits and boreholes were assessed through the use of -

- a hand-held photoionization detector in the field;
- immunoassay-based field test kits for total petroleum hydrocarbons (TPH);
- laboratory analysis by GC/FID for light extractable hydrocarbons (LEPHs: C10-C18), and heavy extractable hydrocarbons (HEPHs: C19-C31) with and without analysis for PAHs; and
- laboratory analysis for volatile extractable hydrocarbons (VPHs), benzene, ethylbenzene, toluene and xylenes (BTEX).

Similarly, DDT was measured both by GC/ECD in the laboratory following sample extraction and clean-up, and immunoassay-based field test kits. A comparison of the different analytical methods is provided in Section 5.1.2 below.

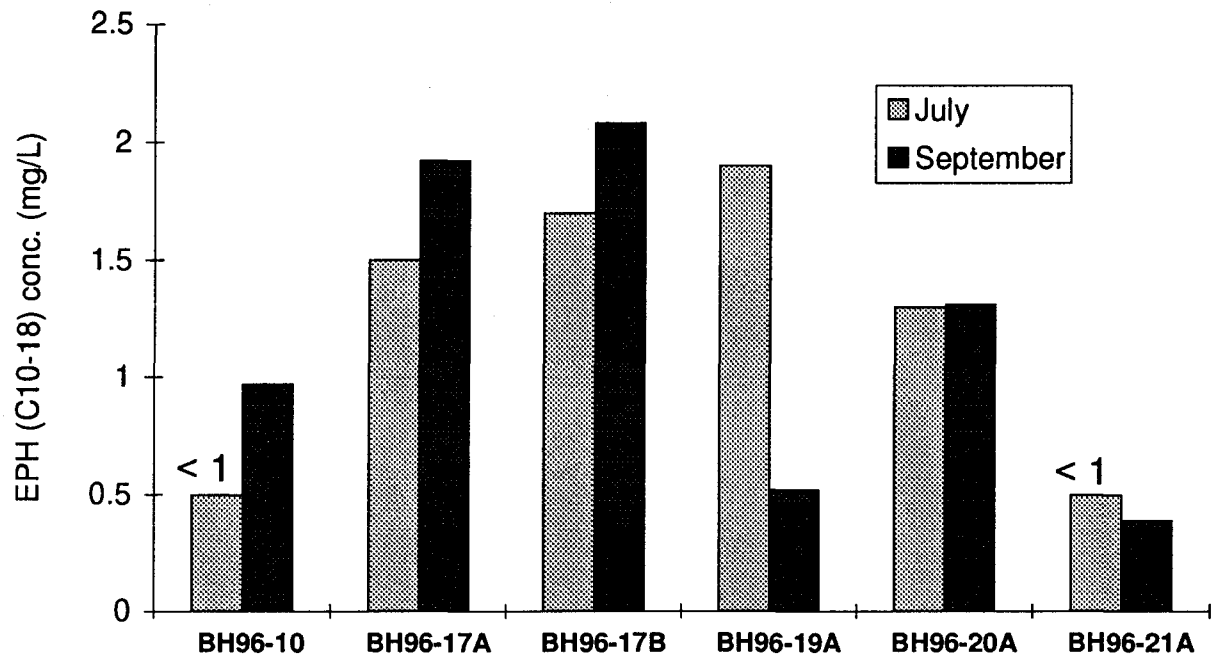


Figure 5.1: Comparability of groundwater hydrocarbon data for samples collected in July and September, 1996.

Table 5.1: Summary of Analytical Quality Assurance

a) Axys Data

	No. of Samples Analyzed	Maximum Conc in Blanks (ng/g)	Surrogate Recoveries Mean (Range)	Average Reference or Matrix Spike Recoveries	Duplicates Av. Rel. St. Dev
1) Soils/Sediment					
PCDDs/PCDFs	3	all < MDL[b]	84% (50 - 110)		
p,p'-DDT	6	0.06	63% (38 -95)	99% (n=2)	see footnote a
o,p'-DDT	6	0.03		82% (n=2)	see footnote a
p,p'-DDE	6	all < MDL	60% (40 - 81)	91% (n=2)	see footnote a
o,p'-DDE	6	all < MDL		98% (n=2)	see footnote a
p,p'-DDD	6	0.01		83% (n=2)	see footnote a
o,p'-DDD	6	0.004		88% (n=2)	see footnote a
other chlorinated pesticides	6	0.04	41 - 87% (range)	65 - 122% (range)	see footnote a
2) Water					
p,p'-DDT	7	all < MDL	78% (29 -127)	86% (n=2)	
o,p'-DDT	7	all < MDL		84% (n=2)	
p,p'-DDE	7	all < MDL	91% (57 -127)	84% (n=2)	
o,p'-DDE	7	all < MDL		100% (n=2)	
p,p'-DDD	7	all < MDL		98% (n=2)	
o,p'-DDD	7	all < MDL		98% (n=2)	
other chlorinated pesticides	7	0.02	60 - 120% (range)	59 - 130% (range)	
3) Biota					
p,p'-DDT	32	all < MDL	84 (59 - 130)	95% (n=4)	4.5% (n=2)
o,p'-DDT	32	all < MDL		101% (n=4)	4.8% (n=2)
p,p'-DDE	32	all < MDL	100 (66 -130)	81% (n=4)	4.2% (n=2)
o,p'-DDE	32	all < MDL			all < MDL
p,p'-DDD	32	all < MDL		70% (n=4)	11% (n=2)
o,p'-DDD	32	all < MDL		77% (n=4)	7.44% (n=1)

a. A sample belonging to a different client was analyzed as the batch duplicate. The results satisfied QC specifications for precision and the results are available for inspection upon request.

b. < MDL: less than sample detection limit

Table 5.1: Summary of Analytical Quality Assurance
b) ASL Soil Data

	No. of Samples Analyzed	Maximum Conc in Blanks (ng/g) (n = no. of blanks)	Average Matrix Spike Recoveries (%) (n = no. of spikes)	Average Rel. Std. Dev Lab Duplicates & (n = no. of replicates)	Average Rel. Std. Dev Field Duplicates
PCBs	4	all < MDL[a] (n=2)	102% (n=2)	all < MDL (n+6)	-
o,p'-DDD	75	all < MDL (n=6)	95% (n=6)	1.8% (n=7)	all < MDL (n=4)
p,p'-DDD	75	all < MDL (n=6)	96% (n=6)	2.2% (n=7)	all < MDL (n=4)
o,p'-DDE	75	all < MDL (n=6)	95% (n=6)	1.1% (n=7)	all < MDL (n=4)
p,p'-DDE	75	all < MDL (n=6)	95% (n=6)	1.1% (n=7)	all < MDL (n=4)
o,p'-DDT	75	all < MDL (n=6)	106% (n=6)	10% (n=7)	all < MDL (n=4)
p,p'-DDT	75	all < MDL (n=6)	104% (n=6)	4.3% (n=7)	all < MDL (n=4)
other chlorinated pesticides (OCPs)	75	all < MDL (n=6)	73 - 108% (range of other OCPs recovered in 3 samples)	all < MDL	all < MDL (n=4)
benzene	19	all < MDL (n=3)	90% (n=3)	all <MDL (n=3)	-
ethylbenzenes	19	all < MDL (n=3)	88% (n=3)	all <MDL (n=3)	-
toluene	19	all < MDL (n=3)	88% (n=3)	all <MDL (n=3)	-
o-xylene	19	all < MDL (n=3)	84% (n=3)	all <MDL (n=3)	-
m- and p-xylenes	19	all < MDL (n=30	88% (n=3)	all <MDL (n=3)	-
EPH (C10-C18)	103	all < MDL (n=6)	82% (n=5)	7.4% (n=8)	4.1% (n=8)
EPH (C19-C32)	103	all < MDL (n=6)	82% (n=5)	all < MDL (n=8)	all< MDL (n=8)
LEPH	11	all < MDL (n=2)	-	-	<MDL (n=1)
HEPH	11	all < MDL (n=2)	-	-	
polycyclic aromatic hydrocarbons (PAHs)	11	all < MDL (n=3)	87 - 98% (range of PAHs recovered in 3 samples)	-	

a. < MDL: less than sample detection limit

Table 5.1: Summary of Analytical Quality Assurance
c) ASL Water Data

	No. of Samples Analyzed	Maximum Conc in Blanks (ng/g)	Average Matrix Spike Recoveries	Average Rel. Std. Dev Lab Duplicates	Average Rel. Std. Dev Field Duplicates
PCBs	1	<MDL[a] (n=1)	88% (n=2)	-	-
o,p'-DDD	25	all <MDL (n=2)	105% (n=2)	<MDL (n=1)	all < MDL (n=2)
p,p'-DDD	25	all <MDL (n=2)	107% (n=2)	0% (n=1)	1<MDL, 1≈ MDL (n=2)
p,p'-DDE	25	all <MDL (n=2)	106% (n=2)	<MDL (n=1)	all < MDL (n=2)
o,p'-DDE	25	all <MDL (n=2)	105% (n=2)	<MDL (n=1)	all < MDL (n=2)
o,p' -DDT	25	all <MDL (n=2)	107% (n=2)	<MDL (n=1)	all < MDL (n=2)
o,p'-DDT	25	all <MDL (n=2)	112% (n=2)	<MDL (n=1)	all < MDL (n=2)
other chlorinated pesticides	25	all <MDL (n=2)			
benzene	29	all <MDL (n=2)	94% (n=2)	<MDL (n=1)	all < MDL (n=2)
ethylbenzenes	29	all <MDL (n=2)	97% (n=2)	<MDL (n=1)	all < MDL (n=2)
toluene	29	all <MDL (n=2)	92% (n=2)	<MDL (n=1)	all < MDL (n=2)
o-xylene	29	all <MDL (n=2)	98% (n=2)	<MDL (n=1)	all < MDL (n=2)
m- and p-xylenes	29	all <MDL (n=2)	93% (n=2)	0% (n=1)	all < MDL (n=2)
EPH (C10-C18)	32	all <MDL (n=2)	70% (n=2)	1.5% (n=3)	2<MDL, 1≈ MDL (n=3)
EPH (C19-C32)	32	all <MDL (n=2)	70% (n=2)	18% (n=3)	all < MDL (n=3)
polycyclic aromatic hydrocarbons	3	<MDL (n=1)	73 -89% (range of PAHs recovered in 3 samples)	-	

a. < MDL: less than sample detection limit

5.1.2 Validation of Field Test Methods for Hydrocarbons and DDT

It became evident during the field investigation that a good understanding of the magnitude and spatial pattern of DDT concentrations in surficial soils was required for decisions regarding risks at and the possible clean-up of Rainy Hollow. The use of immunoassay-based field test kits for DDT (Millipore™), therefore, was explored as a possible analytical method for confirmatory testing. A total of 87 surface soil samples were collected at Rainy Hollow within 100 m of the Trench or at Border Station within 100 m of the Temporary Storage Facility. The complete results are provided in Section 5.4. Of these samples, 24 were analyzed in the laboratory at ASL, 29 were analyzed using field test kits, and 13 were analyzed using both field test kits and laboratory analyses (the total number of samples analyzed was 66).

A comparison of results derived from the two analytical techniques is provided as Figure 5.2. For the 13 samples, the field test kit results accurately estimated the 'true' concentration as determined by GC/ECD for ten of the samples. For the remaining three samples, the DDT concentration was over-estimated by the field test kits. Two factors might account for the three erroneous results: (i) the soil samples were relatively dry with very low organic carbon content, which may have resulted in atypically good extraction efficiency of DDT, DDE and DDD into methanol as part of the field test kit methodology. The DDT calibration standards provided are probably suitable for soils with a higher organic content. (ii) The binding efficiency to the polyclonal antibody used in the field test kit is different for DDT than DDE or DDD. The binding affinity of DDE is approximately 3x higher than DDT; therefore a predominance of DDE over DDT in the sample could result in a higher apparent total DDT concentration than calculated as the sum of DDT, DDE and DDD.

The field test kits typically are used to provide information on whether the total DDT concentrations in the soil samples are less than 0.2 ppm, between 0.2 and 1.0 ppm, between 1.0 and 10 ppm, or greater than 10 ppm. While some analyses may be over-sensitive (i.e., over-estimate the true total DDT concentration), in no case did a sample determined to contain < 1.0 ppm DDT using the field test kits have a real total DDT concentration greater than 1 ppm. **In conclusion, the DDT field test kit data should provide a reliable indication of soil samples at the sites with DDT concentrations above or below 1 ppm.**

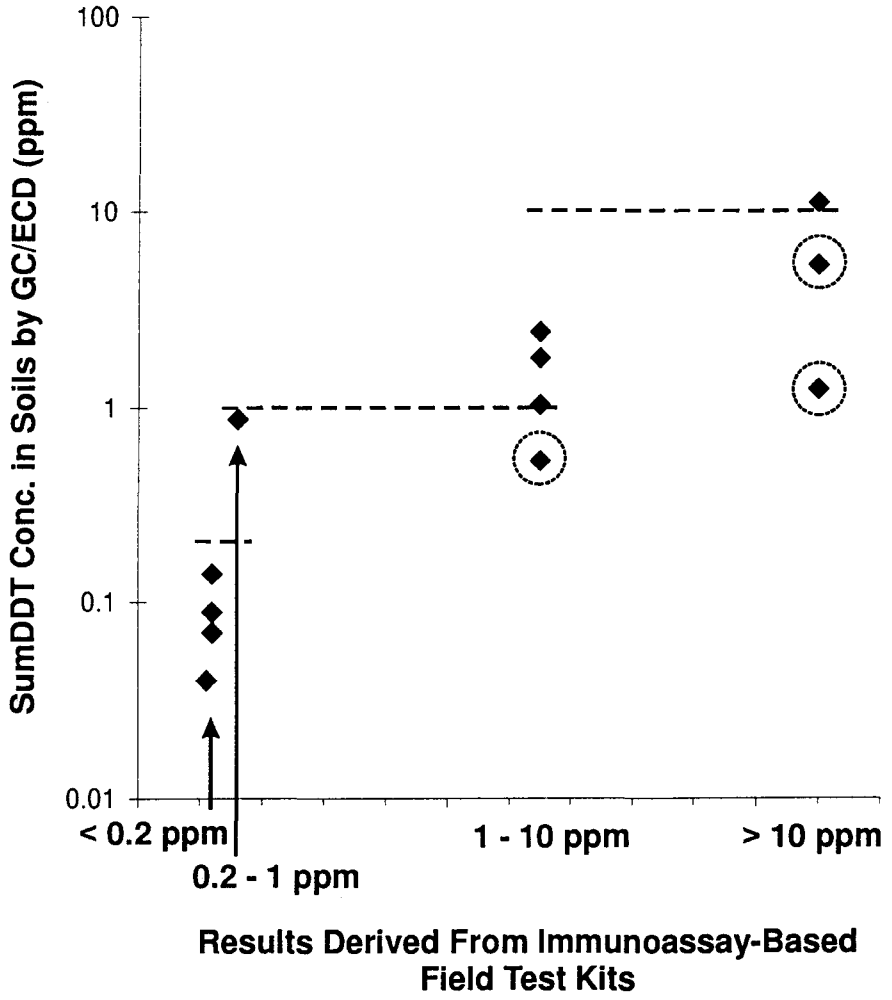


Figure 5.2: Validation of Field Test Kits for DDT

(circled data points represent samples for which DDT concentrations were over-estimnated using field test kits)

Comparisons between field test kit data for total petroleum hydrocarbons in soils, results obtained using a HNU photoionization detector (PID), and laboratory results for extractable petroleum hydrocarbons are illustrated in Figures 5.3 and 5.4. All three techniques have as their objective the quantitative or semi-quantitative evaluation of hydrocarbons as a group parameter. There was little comparability, however, between the three measures. In general, high PID readings for subsurface soil samples obtained in the field corresponded with high EPH readings, but there would be virtually no ability to predict one from the other for a specific sample (Figure 5.3). Strictly speaking, the PID and EPH analytical techniques will not be directly comparable since they measure different fractions of the hydrocarbon mixture. The PID detects hydrocarbons in the molecular range C1 (e.g. methane) to C7 (e.g., toluene), whereas the EPH data are for hydrocarbons in the range C10-C18.

The antibody of the TPH field test kits recognize a wide variety of different predominantly aromatic hydrocarbons including one-ring (e.g., benzene; 1,2,4-trimethylbenzene, m-xylene) to three-ring (e.g., naphthalene) hydrocarbons. The response to different compounds, however, varies substantially. For example, 55 mg/kg benzene will exhibit the same level of antibody response as 0.6 mg/kg naphthalene (Millipore kit instructions, 1996). The calibrations standards provided with the commercially sold kits are made up from home heating oil, which exhibits only a slightly greater response than diesel fuel; the latter generally induces 56 to 95% of the response exhibited by home heating oil at the same concentration. Given that diesel spillage was undoubtedly the source of the vast majority of contamination at Rainy Hollow and Border Station, it can be assumed that the field test kit results for TPH in site soils underestimate the concentration by a factor of 1.5 to 1.8. However, this does not in itself account for the discrepancy between GC/FID results and field test kit results as shown in Figure 5.4.

Despite the fact that the three analytical techniques recognize different fractions of the hydrocarbon mixture, the different components should be highly inter-correlated since there was only one predominant source type: i.e., diesel. We may have observed a good correlation between EPH(C10-C18) and FID results (Figure 5.3) if there were accurate data for the large amount of EPH results less than the method detection limit of 250 mg/kg. A better correlation between BETX laboratory data and FID results for the same set of samples would be expected, but unfortunately there was insufficient BETX above the analytical detection limit to make a comparison. **In light of the uncertainty regarding the accuracy of field test kit results, they were not included in the interpretation for the detailed site investigation. The FID results are interpreted only in the relative sense - to define the relative spatial distribution of hydrocarbons.**

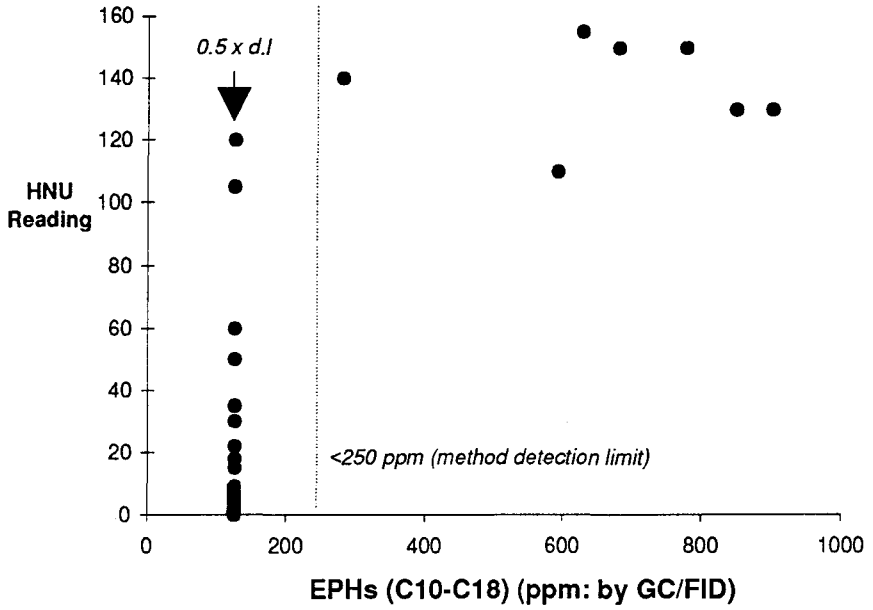


Figure 5.3: Relationship Between Light Extractable Hydrocarbon Concentrations in Site Soils as Determined by Laboratory Analyses (GC/FID) and Using a Photoionization Detector in the Field

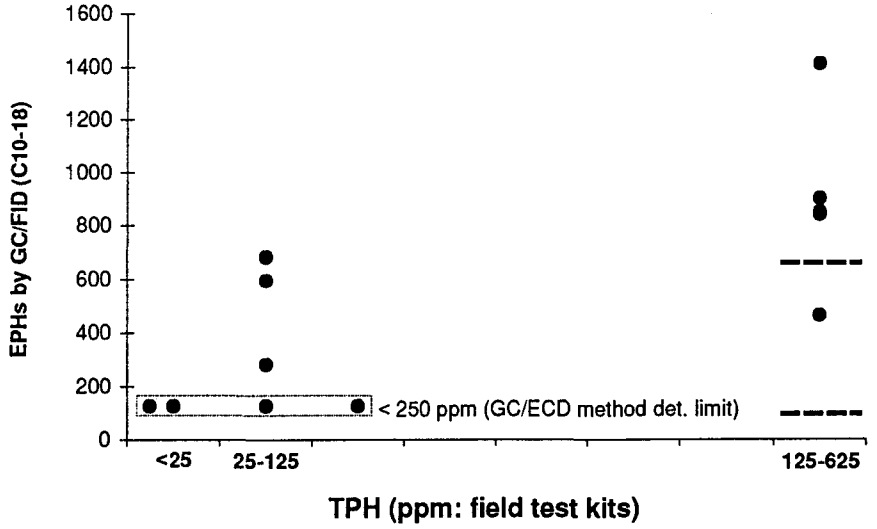


Figure 5.4: Validation of Field Test Kits for Total Petroleum Hydrocarbons

5.2 Assessment of Expanded Contaminant Screen, and Localized Surface Stains at Border Station

The requirement to analyze for a broader range of contaminants during the 1996 detailed site investigation was borne directly out of the identification during preliminary environmental investigations of possible previous burial activity. Six sites at Border Station and four sites at Rainy Hollow were identified in 1994 or 1995 using non-intrusive electromagnetic (EM) surveys as having subsurface debris. None of the ten burial sites had been previously assessed in terms of either the nature of the buried debris or possible contaminants, although the burial sites at Border Station were created during site decommissioning and building demolition activities (RRU, 1996b) and some documentation on the types of materials buried exists.

As described in the methods section (Chapter 3), representative areas within previously un-investigated burial sites at Rainy Hollow were examined using test pits excavated to a depth of between approximately one and three meters using a backhoe. In all cases, the final depth of excavation extended well below natural, undisturbed soil horizons.

Soil and groundwater samples were collected from a borehole an monitoring well (BH96-15) installed downgradient from buried debris within the subs rface foundations of buildings in the northern portion of Border Station. Substantial subsurface migration of the contaminants investigated should have been detected in the subsurface soil samples, although the absence of contaminated soil samples from the borehole would not preclude the possibility that a contaminant source in the old foundations exists but is presently immobile.

The concentrations of various analytes in soil samples collected from the test pits are provided in Table 5.2. The relevant CCME Soil Quality Criteria are also tabulated.

The detection limits achieved for arsenic (As) and selenium (Se) by ICP were too high relative to the CCME Soil Remediation Criteria; however, (i) all soil samples exhibited no visual or olfactory sign of contamination, and (ii) all other analytes were within the range of natural uncontaminated soils. Therefore, the possibility of any hitherto undiscovered contamination is extremely unlikely. **Excluding test pit TP96-03, the results clearly indicate that none of the areas investigated were contaminated at levels that are of concern; in other words, all analytes were within the range expected for background soils, and none of the values exceeded the Draft B.C. Contaminated Sites Standards or CCME Soil Quality Criteria for residential/parkland areas.** This helps to confirm earlier conclusions (Golder, 1995; UMA, 1995; RRU, 1996a) that PCBs and inorganic elements generally are not a problem at the site, whereas hydrocarbons and DDT (including DDE and DDD) are contaminants of concern. Samples TP96-11-1 and -2 (a field duplicate of -1) contained detectable levels of DDT (p,p'-DDT $\leq$ 0.133 ppm, or mg/kg) as well as DDE and DDD; however, the

Table 5.2: Analyte concentrations in subsurface soil samples collected from Rainy Hollow/Border Station near areas of debris burial.

Sample	1: CCME R/P Criterion and/or 2: B.C.Draft Reg. for Parkland	BH96-15-2	BH96-15-4	TP96-03-1	TP96-11-1	TP96-11-2*
Moisture (%)		6.2	3.7	35.7	22.5	17
1) Total Metals (mg/kg dry wt. or ppm)						
a) Biochemically non-essential metals/metalloids						
Antimony	20	<20	<20	<20	<20	<20
Arsenic	30	<100	<100	<100	<100	<100
Cadmium	5	<2	<2	<2	<2	<2
Lead	500	<50	<50	<50	<50	<50
Selenium	3	<50	<50	<50	<50	<50
Silver	20	<2	<2	<2	<2	<2
Tin	50	<10	<10	<10	<10	<10
b) Essential elements that are also common contaminants						
Chromium	250	27	43	42	51	57
Cobalt	50	9	10	7	12	11
Copper	100	24	28	56	22	16
Nickel	100	16	20	11	17	17
Zinc	500	60	51	97	60	61
c) Elements with very limited toxicity, which are naturally abundant in soils/sediment						
Aluminum	---	16600	17200	20100	17100	16500
Barium	500	160	139	94	77	81
Beryllium	4	<0.5	<0.5	<0.5	<0.5	<0.5
Bismuth	---	<10	<10	40	22	28
Calcium	---	24900	9010	10700	9710	11100
Lithium	---	15	11	14	10	9
Magnesium	---	8670	10600	10200	9110	9570
Manganese	---	397	416	459	456	476
Molybdenum	10	<4	<4	<4	<4	<4
Phosphorus	---	181	321	1980	624	656
Potassium	---	2910	1840	2800	992	953
Sodium	---	910	656	343	477	535
Titanium	---	464	294	1040	996	1340
Vanadium	200	60	66	135	88	98
2) Extractable Petroleum Hydrocarbons						
EPH (C10-18)	---	<250	<250	5910	<250	<250
EPH (C19-31)	---	<250	<250	1740	<250	<250
HEPH	1000	-	-	1730	-	-
LEPH	1000	-	-	5890	-	-
Light Petroleum Hydrocarbons (LPH)				259	<5	<5
Volatile Petroleum Hydrcarbons (VPH)	200	<10	-	151	<10	<10

* Field Duplicate of TP96-11-1

(continued next page)

Table 5.2 (cont'd):

Sample	1: CCME R/P Criterion and/or 2: B.C.Draft Reg. for Parkland	BH96-15-2	BH96-15-4	TP96-03-1	TP96-11-1	TP96-11-2*
3) Non-halogenated Volatiles (mg/kg dry wt. in soil)						
Benzene	0.5	<0.05	-	<0.05	<0.05	<0.05
Ethylbenzene	5	<0.05	-	<0.4	<0.05	<0.05
Toluene	3	<0.05	-	<0.2	<0.05	<0.05
meta- & para-Xylene	5 (total xylenes)	<0.05	-	11.2	<0.05	<0.05
ortho-Xylene		<0.05	-	7.6	<0.05	<0.05
4) Polycyclic Aromatic Hydrocarbons						
Acenaphthene	---	-	-	3.5	-	-
Acenaphthylene	---	-	-	0.8	-	-
Anthracene	---	-	-	1.2	-	-
Benzo(a)anthracene	1	-	-	0.2	-	-
Benzo(a)pyrene	1	-	-	<0.1	-	-
Benzo(b)fluoranthene	1	-	-	<0.1	-	-
Benzo(g,h,i)perylene	---	-	-	<0.1	-	-
Benzo(k)fluoranthene	1	-	-	<0.1	-	-
Chrysene	---	-	-	0.4	-	-
Dibenz(a,h)anthracene	1	-	-	<0.1	-	-
Fluoranthene	---	-	-	0.4	-	-
Fluorene	---	-	-	3.6	-	-
Indeno(1,2,3-c,d)pyrene	1	-	-	<0.1	-	-
Naphthalene	5	-	-	20.2	-	-
Phenanthrene	5	-	-	8.7	-	-
Pyrene	10	-	-	1.2	-	-
5) Total Polychlorinated Biphenyls	5	<0.05	<0.05	-	<0.05	<0.05
6) Organochloride Pesticides						
o,p'-DDD	---	<0.001	<0.001	-	0.002	<0.001
p,p'-DDD	---	<0.001	<0.001	-	0.028	<0.001
o,p'-DDE	---	<0.002	<0.002	-	<0.002	<0.002
p,p'-DDE	---	<0.001	<0.001	-	0.013	0.002
o,p'-DDT	---	<0.001	<0.001	-	0.017	0.002
p,p'-DDT	---	<0.002	<0.002	-	0.132	0.010
Aldrin	---	<0.001	<0.001	-	<0.001	<0.001
alpha-BHC	---	<0.001	<0.001	-	<0.001	<0.001
beta-BHC	---	<0.002	<0.002	-	<0.002	<0.002
delta-BHC	---	<0.001	<0.001	-	<0.001	<0.001
Lindane (gamma-BHC)	---	<0.001	<0.001	-	<0.001	<0.001
cis-Chlordane (alpha)	---	<0.001	<0.001	-	<0.001	<0.001
trans-Chlordane (gamma)	---	<0.001	<0.001	-	<0.001	<0.001
Dieldrin	---	<0.001	<0.001	-	<0.001	<0.001

* Field Duplicate of TP96-11-1

(continued next page)

Table 5.2 (cont'd):

Sample	1: CCME R/P Criterion and/or 2: B.C.Draft Reg. for Parkland	BH96-15-2	BH96-15-4	TP96-03-1	TP96-11-1	TP96-11-2*
Endosulfan I	---	<0.001	<0.001	-	<0.001	<0.001
Endosulfan II	---	<0.001	<0.001	-	<0.001	<0.001
Endosulfan Sulfate	---	<0.001	<0.001	-	<0.001	<0.001
Endrin	---	<0.005	<0.005	-	<0.005	<0.005
Heptachlor	---	<0.002	<0.002	-	<0.002	<0.002
Heptachlor Epoxide	---	<0.001	<0.001	-	<0.001	<0.001
Methoxychlor	---	<0.005	<0.005	-	<0.005	<0.005
Mirex	---	<0.001	<0.001	-	<0.001	<0.001
cis-Nonachlor	---	<0.001	<0.001	-	<0.001	<0.001
trans-Nonachlor	---	<0.001	<0.001	-	<0.001	<0.001
Oxychlordane	---	<0.001	<0.001	-	<0.001	<0.001
Toxaphene	---	<0.030	<0.030	-	<0.030	<0.030

* Field Duplicate of TP96-11-1

concentrations are within the range observed for a large number of surface soil samples at Rainy Hollow, as discussed in Section 5.4, below.

Neither visual observations made during test pit excavation, nor records of the burial of debris in building foundations during the aesthetic clean up of the site in 1989 (see Chapter 2), provided evidence for the burial of contaminant containing materials either, excluding asbestos. Subsurface nomalies detected by the 1994 EM31 survey near the pumphouse at Rainy Hollow (Golder 1995) were attributable to small amounts of ferrous and non-ferrous material, as listed in Table 3.1 and shown in the accompanying photographs. The debris included a 1980 Yukon Commercial license plate, which places the time of burial of the materials at the edge of the clearing at some time after 1980, and during a period of site occupation after abandonment by the U.S. Army in the early 1970s. The incidental burial of metal debris may have occurred during the time that Stryker Resources occupied the site, or during a more recent time.

The subsurface soil samples from borehole BH96-15 were collected from an area down gradient from the building foundations in the northern portion of Border Station, and would be expected to be influenced by any substantial contaminant release from the foundation area. The low levels of metals, PCBs, or organochlorines in the BH96-15 soil samples do not provide any cause for concern.

The reason for investigating subsurface soils in the vicinity of test pit TP96-03 was to further delineate a hydrocarbon stain noted during the preliminary site investigation (UMA, 1995). The backhoe was used to dig a test pit near the centre of the approximately 5 x 8 m stain and two additional test pits, TP96-03A and -03B, were dug to the east and west of the visually detectable surface stain, outside of but within 3 m of the stain periphery. In TP96-03 within the stain, we collected samples at depths of 20-30 cm, 100 cm, 140 cm and 270 cm (TP96-03-01, -02, -03 and -04 respectively). There was both

visual and olfactory evidence of hydrocarbon contamination. Soils near the surface exhibited a very strong odor, whereas the sample from the bottom of the excavation had a barely detectable odor. Soils in test pits TP96-03A and -03B did not appear to exhibit hydrocarbon contamination, based on visual appearance or smell. The hydrocarbon concentrations for these samples is provided in Table 5.3.

As indicated in Table 5.2, the surface sample TP96-03-01 contained concentrations of LEPHs, xylenes, naphthalene, and phenanthrene that exceeded the CCME Residential/Parkland Soil Quality Criteria and/ or the B.C. Contaminated Sites Regulation Draft 3 soil standards. The analytical data are consistent with a diesel or heating oil spill in the immediate vicinity of the residences. As indicated in Table 5.3, the spill was limited spatially to the area beneath the surface stain and to a depth of less than three meters. Whereas the surface soil sample exceeded the the the B.C. Contaminated Sites Regulation Draft 3 soil standard for LEPHs and HEPHs, the sample collected at 100 cm depth in test pit TP96-03 did not contain hydrocarbons at a concentration exceeding the method detection limit (<250 mg/kg).

Test pit TP96-14 was excavated in the tar-like surface stain that was also found in the general vicinity of the now demolished residences at Border Station. Visual observations during sampling indicated that the tar like substance was limited to a depth of a few cm or less. The analytical data for BETX constituents and PAHs were less than the method detection limit in sample TP96-14-1 (<0.05 and <0.1 mg/kg respectively; not shown). C19-C32 extractable petroleum hydrocarbons (= HEPHs since the concentrations of PAHs < d.l.) exceeded the B.C. Draft Regulation soil standard of 1000 ppm at the surface (Table 5.3), but there was no contamination in subsurface soils, based on the hydrocarbon data for samples TP96-14-1 and -2. The extent of the surface contamination was readily apparent from the appearance of the soil.

Table 5.3: Concentration of hydrocarbons as extractable petroleum hydrocarbons in test pit samples from hydrocarbon stains at Border Station, in mg/kg.

Sample	Depth	Extractable Petroleum Hydrocarbons (C10-18)	Extractable Petroleum Hydrocarbons (C19-32)
TP96-03-1	**20-30 cm**	**5910**	**1780**
TP96-03-2	**100 cm**	**<250**	**<250**
TP96-03-3	**140 cm**	**<250**	**<250**
TP96-03-4	**270 cm**	**<250**	**<250**
TP96-03B	**100 cm**	**<250**	**<250**
TP96-03C	**100 cm**	**<250**	**<250**
TP96-14-1	**surface**	**<250**	**2490**
TP96-14-2	**10-20 cm**	**<250**	**<250**
TP96-14-3	**130 cm**	**<250**	**<250**

5.3 Subsurface Contaminant Distribution

Prior to the start of this program, subsurface information from the emergency cleanup in 1994 and the preliminary assessment of the former pump station in 1995 was reviewed to develop a plan for this detailed site investigation. The 1994 investigation focussed almost exclusively on the lower bench and consisted of a series of 29 back-hoe test pits - 13 of which were completed as standpipe monitoring wells. The 1995 investigation of the former pumping station consisted of 4 test holes with a pair of standpipe piezometers staggered in one of the holes (TH- 8). Drilling at Border Station in 1995 concentrated on looking at the down gradient boundary conditions in the vicinity of the probable source areas. Electromagnetic surveys showed no unusual subsurface anomalies beyond the former building foundations.

The strategy for additional investigations of subsurface conditions at the upper site was to investigate the source areas in more detail, including the former POL storage area and to evaluate the groundwater flow system including the magnitude and areal extent of dissolved hydrocarbons and the presence of any free product. At the lower site, the strategy was to better delineate the extent of hydrocarbons and DDT in soil and groundwater. There was some question as to the confidence that could be placed on the results from the 1994 well point sampling. This program included the installation of individual and nested monitoring wells in drilled holes to allow for the collection of representative samples and a comparison of vertical variation in water quality. Map 3.1 shows the location of all subsurface data points and indicates whether drilling or test pitting was used and if the hole or test pit was completed as a monitoring well.

A series of plan and section drawings have been prepared to illustrate the stratigraphy, groundwater flow system and distribution both laterally and vertically of DDT and hydrocarbons beneath the upper and lower sites. Drawing 5-1 illustrates the groundwater elevations and inferred flow direction. Drawings 5-2 and 5-3 show the areal

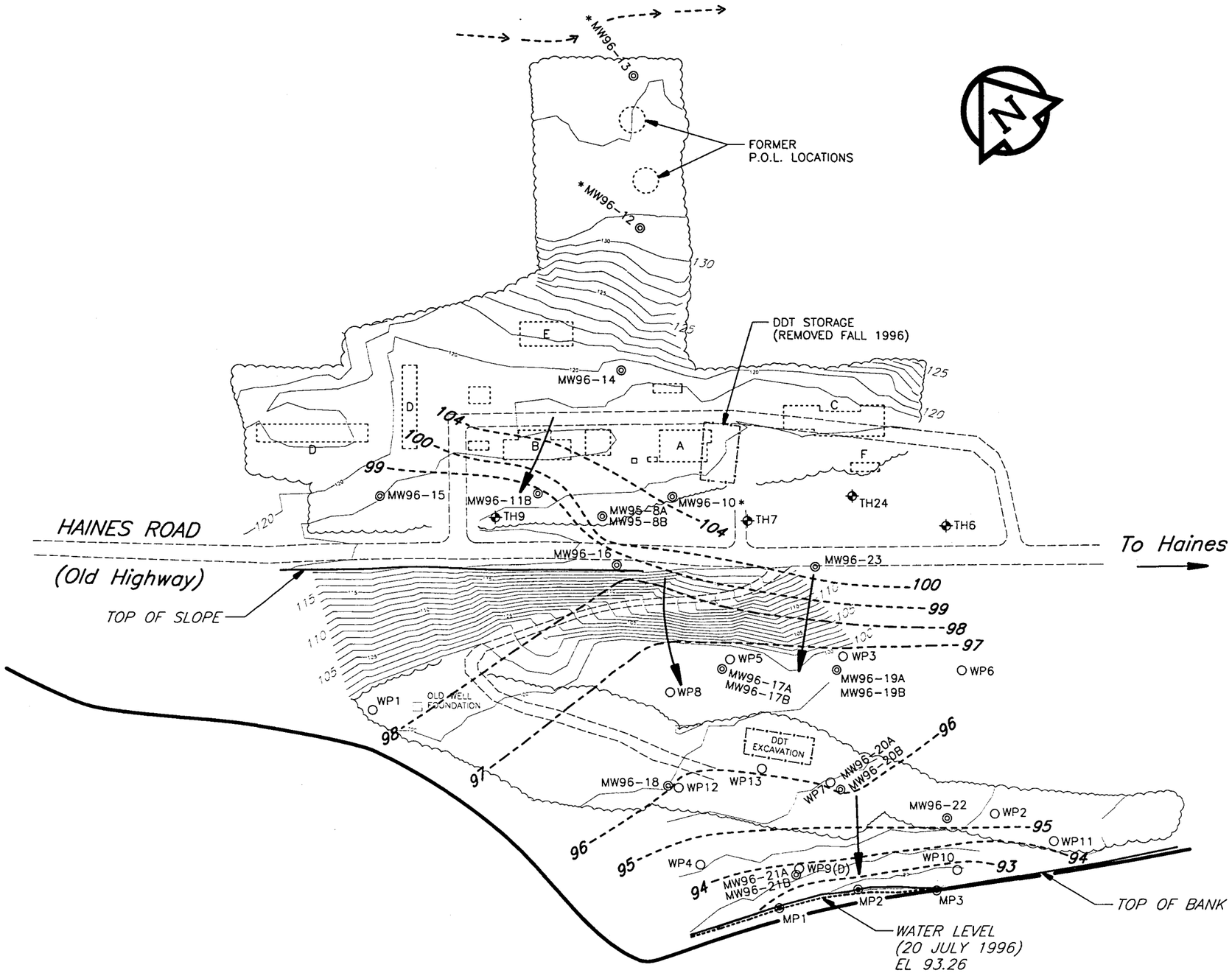
extent of hydrocarbons and DDT in soil and groundwater, respectively. Drawings 5-4 and 5-5 show typical well construction details for single and double monitoring wells. Drawings 5-6, 5-7 and 5-8 are vertical sections drawn parallel and perpendicular to the slope to show the stratigraphy, the vertical position of the water table and the hydrocarbons and DDT in the overburden. The location of the sections is shown on Map 3.1. In addition, the analytical data for soil and groundwater samples collected from test pits, boreholes and monitoring wells are tabulated in Appendix A.

5.3.1 Surficial Geology

The predominant soil type at the upper and lower site is sand. The origin of the overburden is likely outwash deposits associated with the end of the last glacial event coupled with more recent fluvial and alluvial deposition by the modern flows in the Klehini River. The sands vary from fine to coarse grained with 20 to 40 percent gravel sizes and 10 to 20 percent silt and to a minor degree clay. Occasionally the granular material grades to a gravel with maximum particle sizes in the 20 to 40 mm range. Silt lenses occur within the granular section and are believed to create local perched water tables. Beneath the former pumping station, till underlies the granular materials at a depth of 15 to 25 m. The till has a silt matrix typically, but locally grades to a sand matrix. The till gradation includes 20 to 30 percent gravel sizes and 20 to 30 percent clay sizes. The till is typically dry to moist and of lower hydraulic conductivity than the sand and gravel. As a result, the till surface becomes a permeability boundary causing groundwater to preferentially flow along the till surface and downslope to the river. Beneath the uppermost bench where the POL storage tanks were located, bedrock was encountered at a depth of15 to 25 m. Bedrock was not encountered in the test holes beneath the pump station and lower bench. Based on an examination of chip samples recovered, bedrock is described as a fine grained volcanic tuff. Logs of the test holes completed in the 1995 and 1996 investigations are appended along with gradation analyses completed on selected soil samples.

5.3.2 Groundwater Conditions

There appears to be a regional water table beneath the upper site (Border Station), at a depth of 16 to 20 m below ground surface. There are perched conditions beneath the former pumping station as evidenced by the water levels recorded in the wells in TH-8, established in 1995. The water level in the shallow well (TH-8A) is about 9 m below surface and appears to correspond to a silt layer in the middle of the sand unit. The deeper piezometer (TH-8B) has a depth to water of about 17 m which may be either a deeper perched water table or be reflective of the regional water table. The elevation of the deeper water level is slightly higher than the surrounding deep monitoring wells and there is a silt layer corresponding to the interval of the well screen. This well also has 1 to 4 cm of free hydrocarbon floating on the water surface - a condition not observed in any other well and one that could be created by the presence of a silt layer. Two monitoring wells were installed beneath the uppermost bench where the above-ground storage tanks (ASTs) were formerly located. The screens in both of these wells were set across contaminated and saturated sands which seem to be perched conditions above a silt layer.



NOTE: GROUNDWATER ELEVATIONS AS MEASURED ON 17 SEPTEMBER 1996

LEGEND

- TEST HOLE
- MONITORING WELL (UMA 1995, 1996)
- MINI PIEZOMETER (UMA 1996)
- WELL POINT (Golder Associates 1994)
- (100.0) MEASURED PIEZOMETRIC ELEVATION
- (D) DESTROYED
- PIEZOMETRIC ELEVATION CONTOUR
- INFERRED GROUNDWATER FLOW DIRECTION
- * PERCHED GROUNDWATER CONDITIONS
- EDGE OF ROAD
- TREE LINE
- GROUND ELEVATION CONTOUR
- CREEK
- A APPROX. LOCATION OF FORMER BUILDINGS
  - A – MAIN LINE PUMP BUILDING
  - B – UTILITY BUILDING
  - C – WAREHOUSE/SHOP/GARAGE
  - D – APARTMENT COMPLEX
  - E – DORMITORY
  - F – PUMP ISLAND

Scale 1:2000

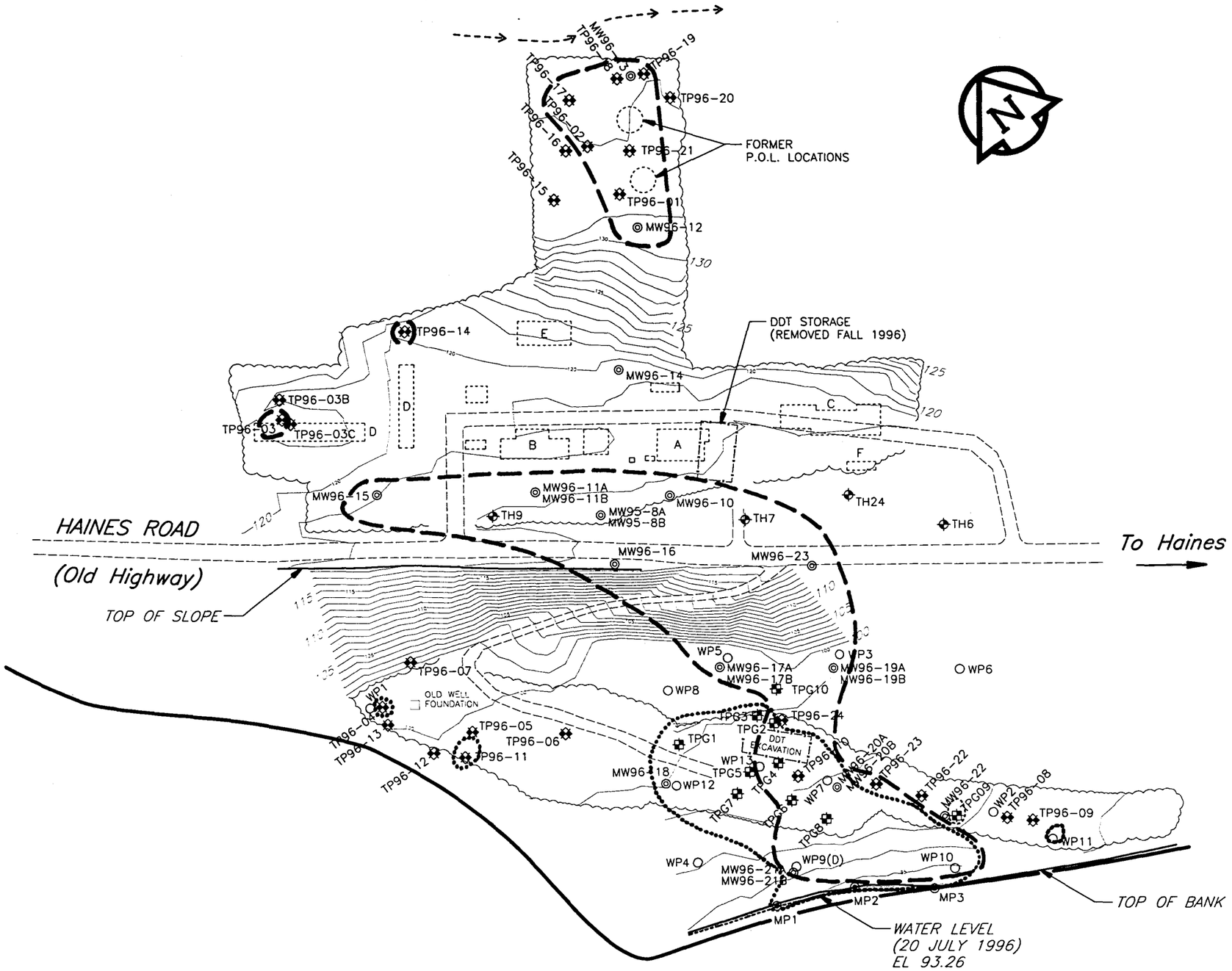
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Golder Associates

Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW PIEZOMETRIC ELEVATIONS AND INFERRED GROUNDWATER FLOW DIRECTION		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5-1
CHECKED:	AH		



LEGEND

- TEST HOLE
- MONITORING WELL (UMA 1995, 1996)
- MINI PIEZOMETER (UMA 1996)
- WELL POINT (Golder Associates 1994)
- TEST PIT (Golder Associates 1994)
- TEST PIT (UMA 1996)
- (D) DESTROYED
- AREAL EXTENT OF SOILS IMPACTED BY HYDROCARBONS (EXTRACTABLE, VOLATILE AND/OR NON-HALOGENATED COMPONENTS)
- AREAL EXTENT OF DDT ISOMERS IN SOIL
- EDGE OF ROAD
- TREE LINE
- GROUND ELEVATION CONTOUR
- CREEK
- A — APPROX. LOCATION OF FORMER BUILDINGS
  - A – MAIN LINE PUMP BUILDING
  - B – UTILITY BUILDING
  - C – WAREHOUSE/SHOP/GARAGE
  - D – APARTMENT COMPLEX
  - E – DORMITORY
  - F – PUMP ISLAND

Scale 1:2000

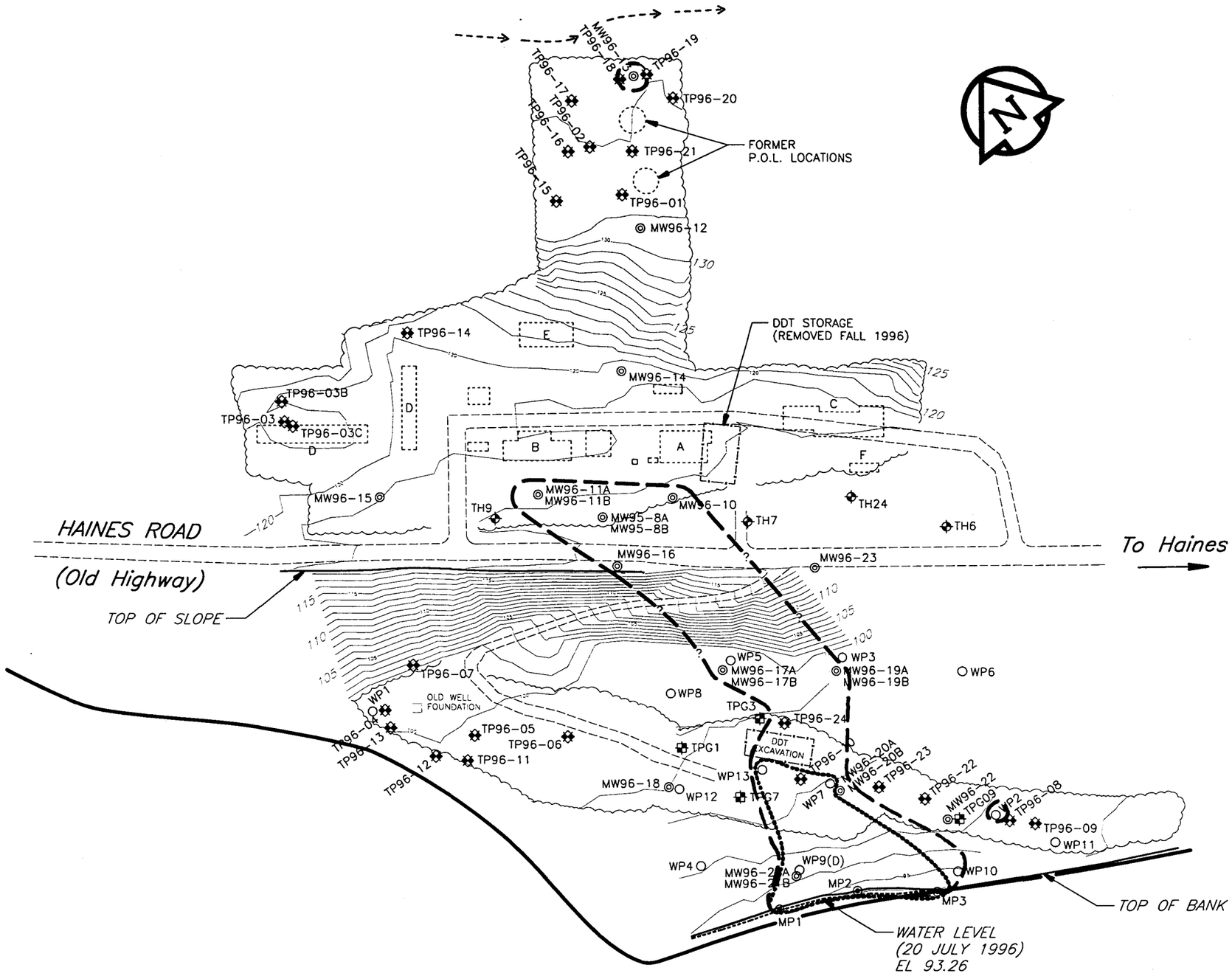
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Golder Associates

Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW AREAL EXTENT OF IMPACTED SOIL		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5-2
CHECKED:	AH		



LEGEND

- TEST HOLE
- MONITORING WELL (UMA 1995, 1996)
- MINI PIEZOMETER (UMA 1996)
- WELL POINT (Golder Associates 1994)
- TEST PIT (Golder Associates 1994)
- TEST PIT (UMA 1996)
- (D) DESTROYED

DESTROYED

AREAL EXTENT OF HYDROCARBONS (EXTRACTABLE, VOLATILE AND/OR NON-HALOGENATED COMPONENTS) EXCEEDING METHOD DETECTION LIMITS IN GROUNDWATER.

AREAL EXTENT OF DISSOLVED DDT ISOMERS EXCEEDING METHOD DETECTION LIMITS IN GROUNDWATER.

- EDGE OF ROAD
- TREE LINE
- GROUND ELEVATION CONTOUR
- CREEK
- A APPROX. LOCATION OF FORMER BUILDINGS
  - A - MAIN LINE PUMP BUILDING
  - B - UTILITY BUILDING
  - C - WAREHOUSE/SHOP/GARAGE
  - D - APARTMENT COMPLEX
  - E - DORMITORY
  - F - PUMP ISLAND

METHOD DETECTION LIMITS

EPH (C10-C31) — < 1 mg/L
BTEX — < 0.0005 to 0.001 mg/L
PAH — < 0.00001 to 0.0001 mg/L
DDT, DDE, DDD — < 0.0001 mg/L

NOTE:
DDT METHOD DETECTION LIMITS WERE LOWER FOR THE SAMPLES FROM THE MINI-PIEZOMETERS. BASED ON POSITIVE DETECTIONS AT THE MP's, THE DDT PLUME IS ASSUMED TO BE CONTINUOUS FROM THE EXCAVATION TO THE RIVER.

Scale 1:2000

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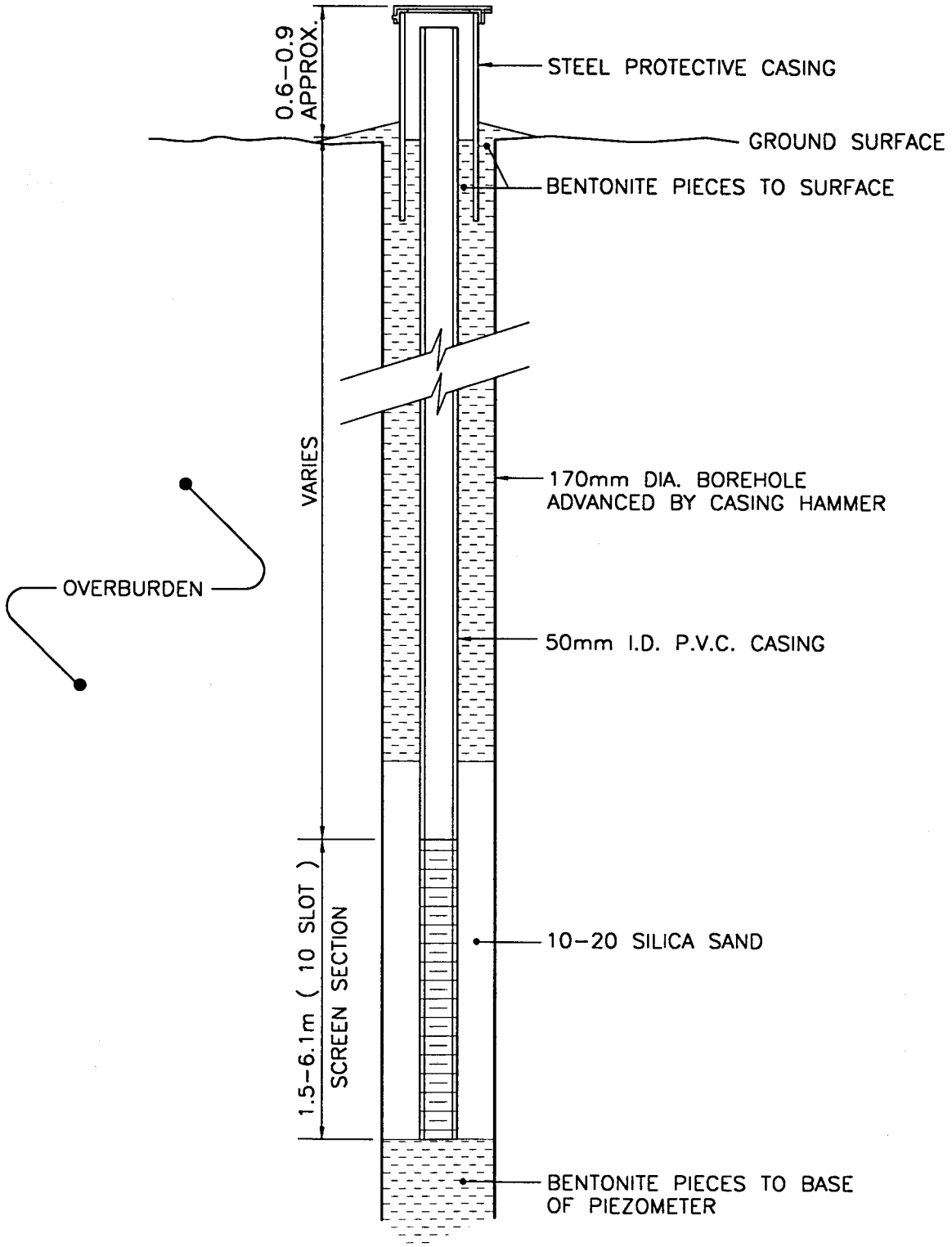
Golder Associates

Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE: RAINY HOLLOW
AREAL EXTENT OF IMPACTED GROUNDWATER

JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5-3
CHECKED:	AH		

NOTE : VERTICAL DIMENSIONS ARE SHOWN ON INDIVIDUAL WELL LOGS



NOTE:
MW96–15 CONSTRUCTED AS A 25mm DIAMETER PIEZOMETER.

NTS

ROYAL ROADS UNIVERSITY

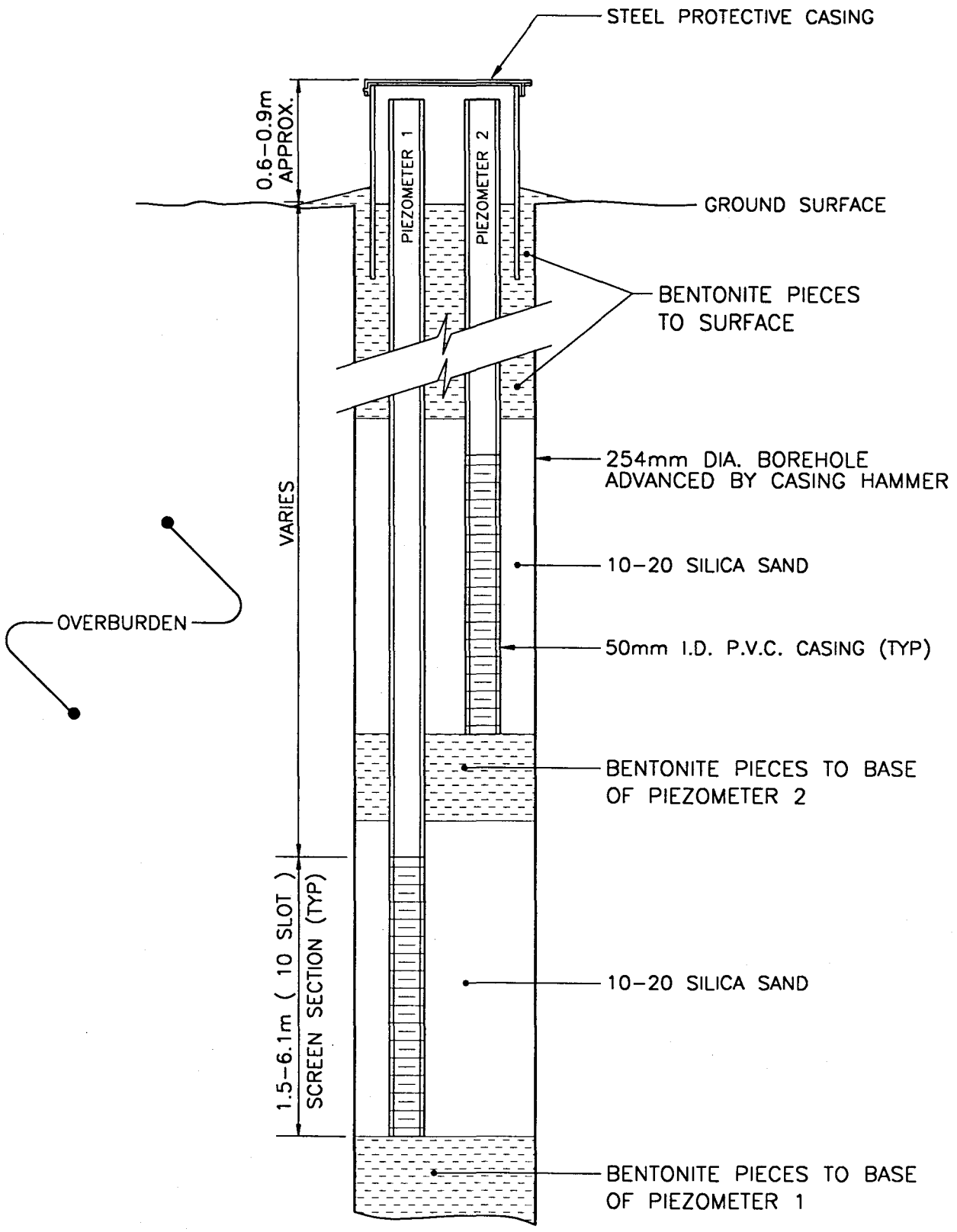
UMA Engineering Ltd. Engineers & Planners

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Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW SINGLE WELL INSTALLATION		
JOB No.	C799–001–01–02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5–4
CHECKED:	AH		

NOTE : VERTICAL DIMENSIONS ARE SHOWN ON INDIVIDUAL WELL LOGS



NTS

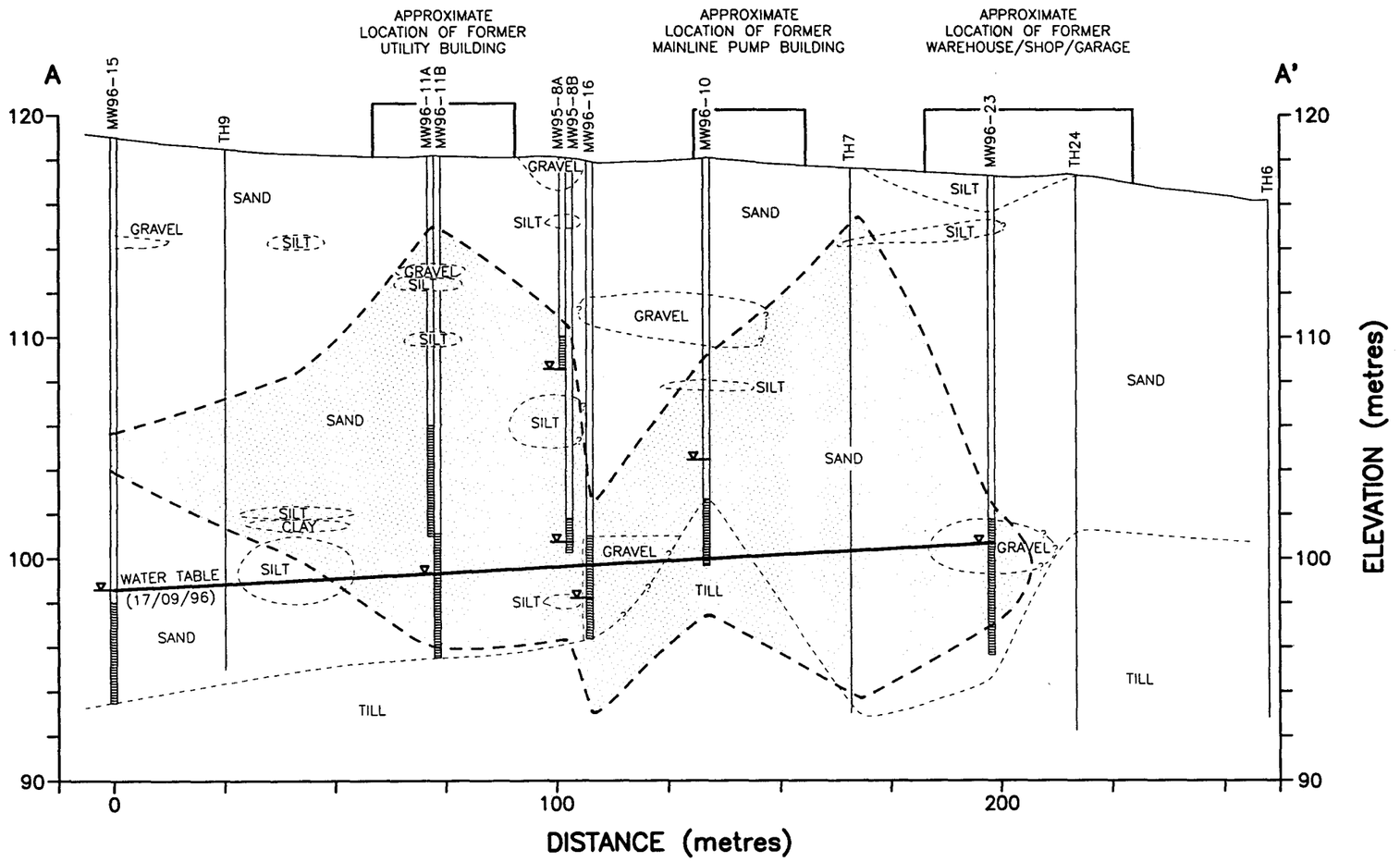
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Arctic Environmental Strategy

TITLE:	RAINY HOLLOW DOUBLE WELL INSTALLATION		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5–5
CHECKED:	AH		



LEGEND

GEOLOGICAL UNITS

GRAVEL	TYPICALLY 20–40mm DIAMETER PARTICLES. 20–40% MEDIUM TO VERY COARSE SAND; 0–20% SILT.
SAND	VARIES FROM FINE TO VERY COARSE. 20–40% GRAVEL (15–25mm DIAMETER); 0–20% SILT AND CLAY SIZED PARTICLES.
SILT	20–40% SAND (PREDOMINANTLY FINE GRAINED); 0–30% GRAVEL (40mm MAX. DIAMETER).
TILL	TYPICALLY SILT MATRIX (25mm MAX. DIAMETER) 20–30% GRAVEL; 20–30% CLAY; 0–10% SAND; OCCASIONAL SAND MATRIX.

- TEST HOLE – NO PIEZOMETER INSTALLED
- PIEZOMETER
- PIEZOMETER SCREEN SECTION
- GROUNDWATER ELEVATION
- AREAL EXTENT OF EXTRACTABLE HYDROCARBON IMPACTED SOIL
- GEOLOGIC CONTACT (ASSUMED)
- GEOLOGIC CONTACT (UNKNOWN)

SCALE
Horiz. 1:1250
Vert. 1:250

NOTE:
MW96–16 PROJECTED BACK TO SECTION A–A'.
WATER LEVEL LOWER IN MW96–16 AS IT IS DOWN GRADIENT OF SECTION A–A'.

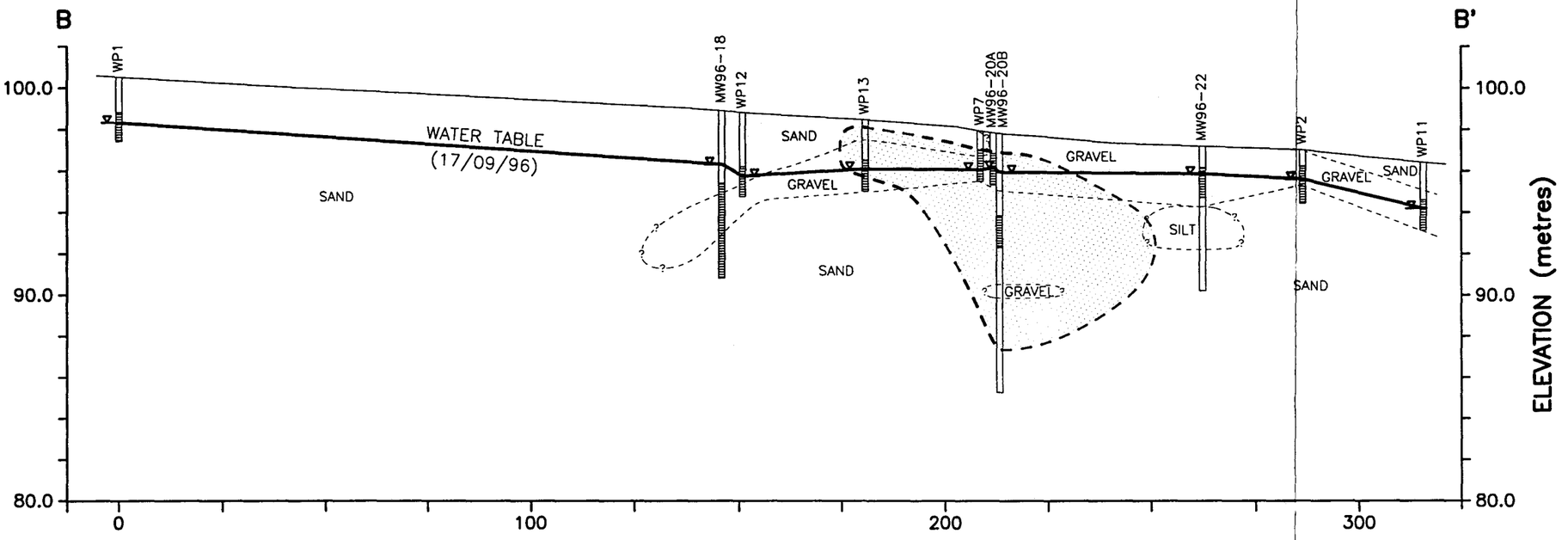
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TITLE:	RAINY HOLLOW SECTION A–A'		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5–6
CHECKED:	AH		



LEGEND

GEOLOGICAL UNITS

GRAVEL	TYPICALLY 20–40mm DIAMETER PARTICLES. 20–40% MEDIUM TO VERY COARSE SAND; 0–20% SILT.
SAND	VARIES FROM FINE TO VERY COARSE. 20–40% GRAVEL (15–25mm DIAMETER); 0–20% SILT AND CLAY SIZED PARTICLES.
SILT	20–40% SAND (PREDOMINANTLY FINE GRAINED); 0–30% GRAVEL (40mm MAX. DIAMETER).

AREAL EXTENT OF EXTRACTABLE HYDROCARBON IMPACTED SOIL

PIEZOMETER

PIEZOMETER SCREEN SECTION

GROUNDWATER ELEVATION

------- GEOLOGIC CONTACT (ASSUMED)

--?---?-- GEOLOGIC CONTACT (UNKNOWN)

SCALE
Horiz. 1:1250
Vert. 1:250

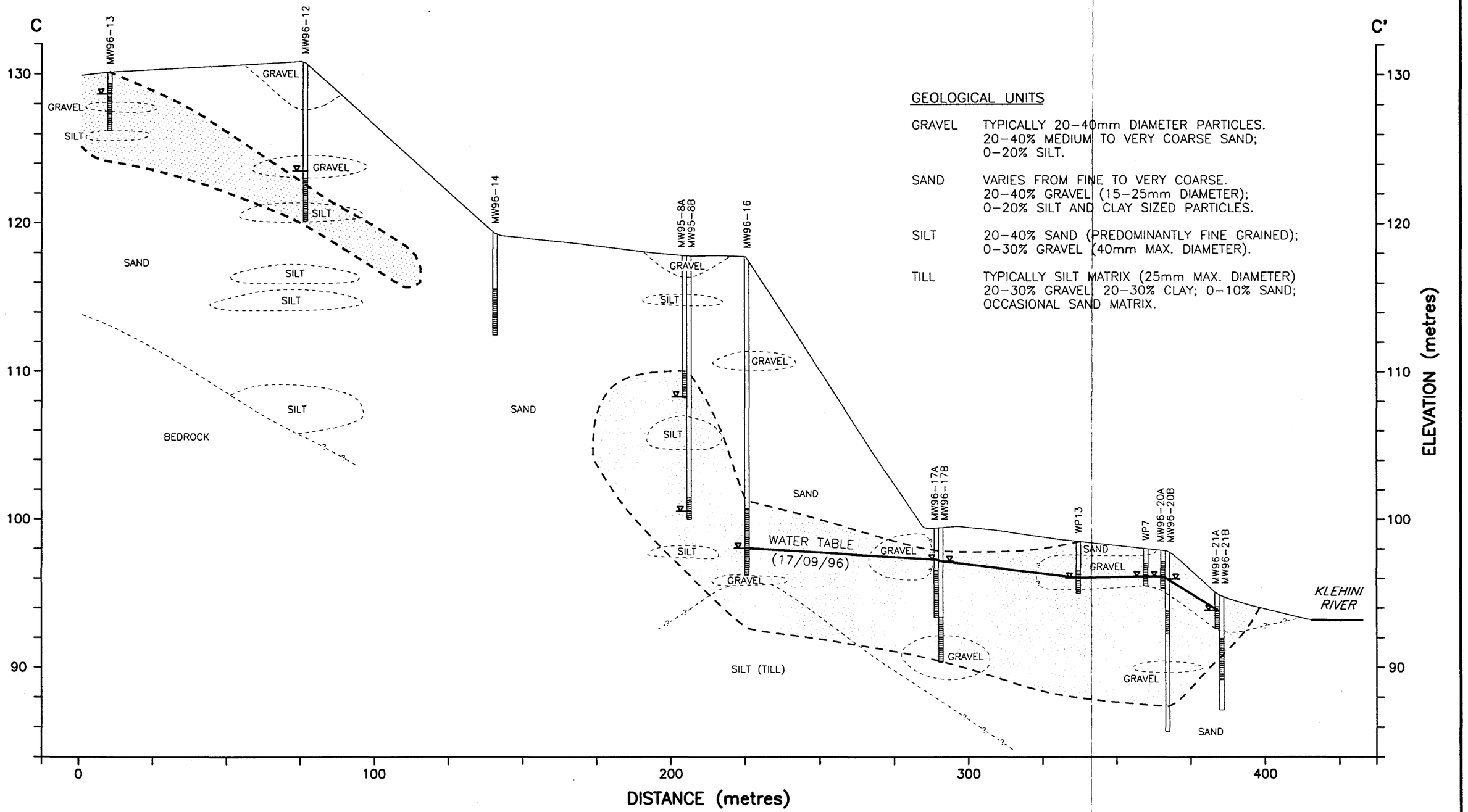
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Golder Associates

Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW SECTION B–B'		
JOB No.	C799–001–01–02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5–7
CHECKED:	AH		



GEOLOGICAL UNITS

GRAVEL	TYPICALLY 20–40mm DIAMETER PARTICLES. 20–40% MEDIUM TO VERY COARSE SAND; 0–20% SILT.
SAND	VARIES FROM FINE TO VERY COARSE. 20–40% GRAVEL (15–25mm DIAMETER); 0–20% SILT AND CLAY SIZED PARTICLES.
SILT	20–40% SAND (PREDOMINANTLY FINE GRAINED); 0–30% GRAVEL (40mm MAX. DIAMETER).
TILL	TYPICALLY SILT MATRIX (25mm MAX. DIAMETER) 20–30% GRAVEL; 20–30% CLAY; 0–10% SAND; OCCASIONAL SAND MATRIX.

LEGEND

- PIEZOMETER
- PIEZOMETER SCREEN SECTION
- GROUNDWATER ELEVATION
- AREAL EXTENT OF EXTRACTABLE HYDROCARBON IMPACTED SOIL
- GEOLOGIC CONTACT (ASSUMED)
- GEOLOGIC CONTACT (UNKNOWN)

SCALE
Horiz. 1:1250
Vert. 1:250

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Indian and Northern Affairs Canada
Arctic Environmental Strategy

TITLE:	RAINY HOLLOW SECTION C–C'		
JOB No.	C799-001-01-02	DATE:	DECEMBER 1996
DRAWN:	MAG	DWG. No.	5–8
CHECKED:	AH		

The water levels measured at 1 and 7 m below ground surface are not considered to be representative of the regional water table.

Beneath the lowermost bench, water levels in September were 1 to 3 m below ground. Table 5.4 summarizes water levels and groundwater elevations for September, 1996. The river level is expected to have a significant impact on the lower site groundwater levels. In July, the river level was surveyed at an elevation of 93.26 m. Drawing 5-1 shows groundwater levels in mid September, 1996, but river levels for July. The groundwater levels close to the river during mid September were actually lower than the July river water level shown in the drawings, as water levels in the river had dropped from July to September.

Horizontal gradients are steepest along the slope between the upper and lower sites and in the area closest to the river. These conditions are influenced by the topographic gradient along the slope and by the effect of groundwater discharge to the river. Finer grained soils were encountered in some of the test pits close to the river, which could affect the gradient. The highest gradients are in the order of 0.07 to 0.10 m/m. Gradients across the lower bench are smaller and in the order of 0.02. Vertical gradients were evaluated beneath the lower site in a series of three nested wells (with two piezometer installations per borehole). The change in water level with depth suggests that there is a slight downward gradient, however the predominant flow direction is lateral towards the river. At the river's edge, it is expected that there will be an upward hydraulic gradient associated with the discharge of groundwater to the river. The nested wells at site MW96-21 are the closest to the river. The lower piezometer has a water level 2 cm higher than the shallow well demonstrating a small component of upward groundwater flow.

Regionally, groundwater flow is towards the river, with groundwater discharging to the river. As the river valley is a significant topographic feature, it is unlikely that groundwater flows beneath the river to another discharge location. The base of the flow system was never determined; however, it was determined that the base of the impacted area at Rainy Hollow was only a few metres below ground surface. The hydraulic conductivity was evaluated through response tests in selected wells and by the assessment of grain size. The data from the response testing are summarized in Appendix D. **As the dominant material type at the lower bench is sand and gravel, the hydraulic conductivity is relatively high. The values determined from field response tests typically ranged from $1x10^{-3}$ to $1x10^{-4}$ cm/sec. Estimates of hydraulic conductivity based on grain size and Hazen's equation suggest values as high as $1x10^{-1}$ to $1x10^{-3}$.** Table 5.5 and 5.6 summarize the hydraulic conductivity calculated from field response tests and grain size, respecitvely. There are finer grained layers in the overburden which will influence the hydraulic conductivity measured over the entire length of the well screen. The Hazen calculations are based on gradations which will result in average conductivities for the soil mass tested.

Table 5.4: Summary of Water Level Data (Sept 17, 1996)

Well No.	TOC Elev (m)	Grd Elev (m)	Depth to water (m)	Groundwater Elevation (m)
MW96-8a	118.31	117.85	Dry to 9.76	NA (108.55)
MW96-8b	118.29	117.85	Dry to 17.61	NA (100.69)
MW96-10	118.55	117.88	14.22	104.35
MW96-11a	118.74	118.08	Dry to 18.65	NA (100.09)
MW96-11b	118.74	118.08	19.48	99.26
MW96-12	131.38	130.79	7.62	123.76
MW96-13	130.78	130.12	2.00	128.78
MW96-14	120.05	119.44	Dry to 7.08	NA (112.97)
MW96-15	119.34	118.77	20.78	98.56
MW96-16	118.37	117.69	20.17	98.20
MW96-17a	100.31	99.56	2.92	97.39
MW96-17b	100.18	99.56	2.89	97.29
MW96-18	99.65	99.04	3.35	96.30
MW96-19a	99.47	98.93	3.25	96.22
MW96-19b	99.47	98.93	3.24	96.23
MW96-20a	98.17	97.75	2.05	96.12
MW96-20b	98.17	97.75	2.18	95.99
MW96-21a	95.21	94.69	1.36	93.85
MW96-21b	95.21	94.69	1.34	93.87
MW96-22	97.61	97.08	1.86	95.75
MW96-23	117.53	116.97	16.94	100.60
WP-1	101.01	100.43	2.73	98.28
WP-2	98.17	96.97	2.49	95.68
WP-4	96.83	95.90	2.47	94.36
WP-7	98.80	97.91	2.69	96.11
WP-8	100.43	99.62	4.07	96.36
WP-10	94.55	93.64	1.89	92.66
WP-11	97.28	96.40	3.00	94.28
WP-12	99.46	98.82	3.69	95.77
WP-13	99.14	98.36	3.06	96.08

Using a calculated mean of 2.5×10^{-4} for hydraulic conductivity, a horizontal gradient of 0.075 m/m and an estimated porosity of 0.27, the average linear groundwater velocity could be estimated to be in the order of 20 metres per year (the trench where the DDT canisters were buried is approximately 80 m from the river). The effective velocity for the transport of hydrocarbons or DDT dissolved in groundwater would be reduced due to retardation. This information is used later in the estimate of contaminant loading to the river and in predicting future changes in contaminant transport. Little is known of quantitative changes in water level on the lower or upper sites. Both sites will be influenced by precipitation, in particular the recharge effects of spring melt of the winter

snow accumulation. In addition, the lower site water levels will also respond to fluctuations in the river water level. Quantifying seasonal water level variations would assist in improving the estimates of contaminant loading to the river and the predictions of future changes in contaminant concentration.

Table 5.5: Summary of Field Hydraulic Conductivity Result

Well No.	Test Type	Total Length of Screen (m)	Sat. Thickness of Aquifer (m)	Material Type	Hydraulic Conductivity (cm/s)
MW96-10	Rising Head	3.05	4.72	Gravel (Till)	9.36E-06
MW96-11b	Rising Head	4.57	3.76	Sand	8.80E-06
MW96-12	Rising Head	3.05	3.35	Sand & Silt	1.70E-06
MW96-16	Rising Head	4.57	1.85	Gravel	3.63E-04
MW96-17a	Rising Head	3.05	6.99	Sand	3.91E-04
MW96-17b	Rising Head	3.05	6.89	Sand & Gravel	3.00E-04
MW96-19a	Rising Head	3.05	2.12	Sand	2.52E-03
MW96-19b	Rising Head	1.52	2.23	Sand & Silt	1.47E-03
MW96-20a	Rising Head	1.52	0.82	Gravel	4.12E-03
MW96-20b	Rising Head	1.52	3.74	Sand	3.67E-04
MW96-21b	Rising Head	3.05	7.07	Sand	5.43E-04

Table 5.6: Hydraulic Conductivity Estimated from Grain Size Distribution

Well No.	Depth (m)	Material Type	Hydraulic Conductivity (cm/s)
MW96-16	17.68 - 18.29	Gravel	3.2E-02
	19.51 - 20.73	Gravel	1.6E-01
	21.34 - 21.94	Silt (Till)	1.1E-04
MW96-17	4.88 - 5.49	Sand	2.3E-03
	7.92 - 8.53	Gravel	2.0
	9.75 - 10.36	Gravel	2.6E-02
	11.58 - 12.19	Sand / Till (Till)	1.0E-04
MW96-18	2.44 - 3.05	Sand	1.6E-03
	4.88 - 5.49	Sand / Gravel	1.2E-03
	6.10 - 6.71	Gravel	4.2E-03
	7.92 - 8.53	Sand	6.4E-03
MW96-19	1.22 - 1.83	Sand	2.9E-02
	2.44 - 3.05	Sand	1.6E-01
	3.66 - 4.27	Sand	4.2E-03
	5.49 - 6.10	Silt / Sand	4.0E-04
MW96-20	0.61 - 1.22	Gravel	8.1E-01
	1.83 - 2.44	Gravel	2.0E-02
	3.05 - 3.66	Silty Sand	2.9E-04
	4.27 - 4.88	Silty Sand	4.0E-04
MW96-21	1.22 - 1.83	Gravel	5.2E-02
	1.83 - 2.44	Gravel	9.0E-01
	3.05 - 3.66	Sand	1.6E-03
	4.27 - 4.88	Sand	2.0E-02
MW96-22	1.22 - 1.83	Sand	1.7E-02
	1.83 - 2.44	Sand / Gravel	9.0E-01
MW96-23	15.85 - 16.64	Sand	5.6E-03
	18.29 - 18.90	Sand	9.6E-04
	21.95 - 22.56	Sand / Silt	1.6E-03
MW96-24	15.85 - 16.46	Sand / Silt (Till)	1.4E-04

5.3.3 Subsurface Distribution of Hydrocarbons

5.3.3.1 Hydrocarbons in Soil

Drawing 5-2 illustrates the interpreted areal extent of hydrocarbon impacted subsurface soils. There is a zone of impacted soil associated with the former AST facility. This area is believed to be a result of spillage of fuel from the tanks. Drawing 5-8 shows that the area toward the back of the POL containment dyke is contaminated from the

surface to a depth of about 6 m. Toward the front of the bench, the zone of hydrocarbon contamination from 8 to 10 m. below surface. This contamination may have resulted from migration of the source at the back of the tanks. An aerial oblique photograph shows a stained area near the back of the tanks which may be where surface spills ponded. Hydrocarbons may have flowed to the northeast as the ground surface drops off in this direction, however there is no sign of vegetation distress and hydrocarbons were not detected in samples collected from the small creek which passes near to this location. Hydrocarbons are typically in the range of light extractable petroleum hydrocarbons (C10-C18) with concentrations that range from less than the method detection limit of 250 ppm to as high as 9570 ppm.

There were two small areas of surface contamination near the former residences which extend to depths of a few millimetres to more than ten centimetres. Hydrocarbons were in the extractable range from C10 to C31 (primarily LEPHs: C10-C18) and concentrations were as high as 7650 ppm. Beneath the former pumping station facilities, hydrocarbons were not present at surface but were encountered at depths varying from 3 to 15 m. The contamination extended as deep as the till surface or 25 m below ground. The till surface seems to be a barrier to further vertical movement. Laterally, the hydrocarbons extended from below the shop to past the utility building. The fact that the hydrocarbons were not observed at surface at any location suggests that the source may have been product loss from the pipeline, possibly within the pumphouse itself, rather than other maintenance activities. The building foundations were buried during the Ministry of Forests cleanup, and the original spill point may have been obscured.

The shape of the impacted zone suggests some lateral spreading, however the outward extent of the impacted area is well defined by test holes MW96-15 and TH96-24. Hydrocarbons were primarily in the light end of the extractable range and concentrations range from < 250 ppm to a high of 968 ppm.

As indicated on Drawing 5-2, the hydrocarbons have migrated down the slope and traveled to the Klehini River. Drawings 5-7 and 5-8 show the vertical position of the hydrocarbons. The hydrocarbons are primarily below the water table and transport within the upper portion of the groundwater flow system is believed to be the major mechanism for the presence of hydrocarbons beneath the lower site. The lower site, however, was also used as an airstrip, at least for a short period during the early construction of the pumping station. Fuel storage and spills were probably common.

The areal extent of hydrocarbons at the lower bench (Rainy Hollow) is much smaller than at the upper site. The impacted soils extend from surface to a maximum depth of 10 m. Hydrocarbons were primarily the lighter extractable range with concentrations from < 250 ppm to a high of 1400 ppm. **An estimate of the size of the hydrocarbon source for the entire site (including both Border Station and Rainy Hollow) is 10,000 kg.**

5.3.3.2 Hydrocarbons in Groundwater

Drawing 5-3 illustrates the interpreted areal extent of hydrocarbons dissolved in groundwater. Drawings 5-6, 5-7 and 5-8 show the vertical position of the hydrocarbons below the water table. At the upper site, there was a small area of impacted groundwater below the POL storage site. A water sample from MW96-13 produced a result of 3.3 mg/L for extractable hydrocarbons. This is believed to be a perched condition on a silt layer a few metres below surface. Beneath the pump station, most of the impacted zone is above the water table. There are about 3 to 7 m of impacted soils below the water table. At TH-8, hydrocarbons in groundwater [7.6 mg/L EPH(C10-C18)] were observed in the shallow well (TH-8A) and are believed to be a result of a perched condition created by a local silt layer. The deeper well at this site, TH-8B had a few centimetres of free product in July, 1996. The water level in this well was slightly higher than the other deep wells and it is possible that this well also reflects a perched condition as there is a silt lens in the area of the well intake. This was the only well from the site investigation where free product was detectable using an interface probe, with the exception of MW96-16, which may have contained a thin layer (~ 1-3 mm) of free product barely detected using the interface probe on some occasions but not on others over the sampling period in July, 1996. The vast majority of the upper geologic section is sand and gravel and it would appear that hydrocarbons have migrated vertically to the regional water table through precipitation infiltration and then travelled laterally with the flow system down the slope and on to the Klehini River. Concentrations of extractable hydrocarbons in groundwater samples collected from wells beneath the pump station ranged from less than 1 mg/L to a high of 7.6 mg/L.

At the lower site, there was a layer of hydrocarbon-contaminated soil and groundwater up to 8 m thick beneath the water table. Near the river, this thickness was reduced to about 4 m. Hydrocarbon concentrations were primarily in the extractable range and vary from < 1 to 10 mg/L. There were also low but detectable concentrations of ethylbenzene and xylene in the groundwater.

Three mini-piezometers were driven to below the water table on the bank of the river. The middle of these piezometers (MP96-02) has a concentration of dissolved extractable hydrocarbons (LEPHs) of 5.9 mg/L. This data confirms the discharge of dissolved hydrocarbons to the river. The groundwater data derived from the mini-piezometers are discussed in greater detail in Section 5.6.

5.3.4 DDT Distribution

5.3.4.1 DDT in Soil

Drawing 5-2 shows the interpreted areal distribution of sumDDTs (DDTs+DDEs+DDDs) in soil beneath the lower site. The impacted zone surrounds the trench area where the drums were recovered and extends to the river. There are two satellite areas shown near the old pump house (WP-1) and near WP-11. These are shown as separate features. It is believed that there was never a source in these areas, but rather

that DDT was carried to these locations during the course of earth moving activities during 1994 or, in the case of WP-1 possibly at an earlier time. The DDT was primarily found below the surface with maximum concentrations occurring from 0.5 to 2.5 m depth. The maximum depth exceeded 4 m. **The highest soil concentrations were directly adjacent to the trench, and were in the range of 4 to 5 ppm. Further from the trench, concentrations were typically less than 2 ppm. Surface sampling around the trench has indicated areas of much higher concentrations, as discussed in Section 5.4. this is discussed elsewhere. An estimate of the total mass of DDT (all isomers) in subsurface soils based on the available soil chemistry data is 20 kg.** Review of the records of the number of damaged drums encountered during the 1994 emergency response suggests that the source term is probably lower, possibly closer to 5 kg DDTs.

5.3.4.2 DDT in Groundwater

Drawing 5-3 illustrates the interpreted areal extent of DDT dissolved in groundwater. There are only five wells where DDTs were detected as part of the 1996 detailed site investigation. Two of these are immediately below the trench (WP7 and WP13). The other three are the three mini-piezometers installed adjacent to the river. The groundwater samples collected from the mini-piezometers were extracted and analyzed using different methods than the other monitoring well or well point samples, with detection limits that were many orders of magnitude lower. In the immediate vicinity of the trench, the sum of all DDT isomers was 200 to 400 ng/L. At the river's edge, concentrations were from 1 to 8 ng/L. River water samples collected adjacent to the mini-piezometer MP96-02 also contained detectable DDT levels that were substantially higher than samples of river water from an upstream reference site, showing that DDT is introduced to the river from the groundwater flow system and that the flux is sufficient to produce measurable and elevated DDT concentrations in the river. This is discussed in more detail in Section 5.5.

The trench where the DDT canisters were buried was directly in line with the hydrocarbon plume migrating from the former pump station. The increased solubility of DDT in the presence of hydrocarbons has no doubt had an impact on the rate and concentration of DDT moving from the trench to the river in the groundwater flow system.

5.3.5 Predicted Fate of Subsurface Contaminants

This section summarizes the modeling exercise undertaken in order to predict the subsurface fate of DDT and hydrocarbons at Rainy Hollow: Specifically, calculation of the total mass flux of DDTs and hydrocarbons to the Klehini River are provided, along with statistical estimates of uncertainty and range.

5.3.5.1 Summary of Findings: Total DDT

The total mass flux [M/T] can be computed as follows:

$$J = v_c n C dA$$

where -

J is the mass flux (ignoring dispersion),
v_c is the average linear velocity of the contaminant in question,
n is the porosity,
C is the concentration of the contaminant and
dA is the surface area of flow.

The above assumes that the velocity is steady and uniform across dA. The concentration of DDT is known from analysis of three mini piezometers located near the river's edge.

Conservative contaminants move at the same rate as the groundwater flow system. However, DDT is significantly adsorbed onto any organic carbon present in the aquifer materials and is weakly attracted to clay. Consequently it moves more slowly than the prevailing groundwater. An approximate rate can be calculated as follows:

$$v_c = \frac{v_w}{R}$$

where -

v_w is the average linear groundwater velocity,
v_c is the average linear velocity
of the contaminant, and
R is the retardation coefficient.

This latter term is given by

$$R = 1 + \frac{\rho_b K_d}{n}$$

where -

ρ_b is the bulk density of the aquifer material (taken as 1.8 gm/cc),
n is the porosity, and
K_d is the distribution coefficient for sorption of DDT given by

$$K_d = f_{oc} K_{oc}$$

The values of K_d are linked by the organic carbon fraction in the aquifer and the octanol-water partition coefficient for DDT which is log (K_{oc}) - 5.77. The former f_{oc} values are not known with certainty.

The groundwater velocity is given by -

$$v_w = \frac{K\, dh}{n_e\, dl}$$

The gradient *dh/dl* is determined to be 0.075 at the outflow face and is assumed to be known for this exercise. n_e is the effective porosity, which is taken as being equal to the porosity n for granular materials. The hydraulic conductivity K is given by a log-normal pdf (*lnK*) with a mean of -8.27 and a standard deviation of 2.2 (K units cm/sec). The above translates into an average hydraulic conductivity of 2.56 x 10-4 cm/sec.

The statistics of K were determined from a statistical analysis of all the available piezometer test data. The values of porosity were taken from standard texts for sand and gravel mixtures. The value of f_{oc} was determined from lab tests of samples on the lower bench area and ranges from published sources. The summary of all the pertinent parameters and their associated pdf's are tabulated below:

Parameters and ranges for DDT mass flux

Quantity	Lower	Expected	Upper	σ	pdf type
ln (K)	-	-8.56	-	2.52	log-normal
n	0.20	0.27	0.35	-	uniform
dA (m^2)	300.	350.	400.	-	uniform
f_{oc}	0.00	0.0009	0.0015	-	truncated exponential
C (ng/L)	0.99	4.39	8.43	-	truncated exponential

The results of the Monte-Carlo runs are summarized below (see also Woodbury *et al.*, *Groundwater*, 33(4), 532-538, 1995). The units for the mass flux are in mg/year. **It can be concluded that there is a 95% probability that the mass flux lies within the range of 0.001 to 0.2488 mg/year. The probability of exceeding a value of 1.0 mg/year is 1.3%.**

Statistics for realizations of DDT mass flux (mg/year)

Statistic	Value
Mean	0.257
Median	0.0018
Mode	0.0100
Average Deviation	0.0375
Standard Deviation	0.0880
Skewness	6.456
Kurtosis	49.49
97.5 percentile	0.2488
2.5 percentile	0.0010
Null hypothesis	rejected

5.3.5.2 Summary of Findings: EPH(C10-C18)

The same method was followed as for DDT, except that the starting concentration of extractable petroleum hydrocarbons was assigned a uniform pdf between 0.0 and 5.9 mg/L. No retardation was assumed. The results of the Monte-Carlo runs are summarized below.

The data were highly skewed and a natural log transformation was found to be appropriate.

The units for the mass flux are in g/year. **It can be concluded from the above there is a 95% probability that the mass flux of hydrocarbons lies within the range of 14.6 and 806,129 g/year.**

Natural log transformed statistics for realization of mass flux of Extractable Petroleum Hydrocarbons (g/year)

In (EPH) statistic	Value
Mean	8.14
Median	8.17
Average Deviation	2.18
Standard Deviation	2.73
Skewness	-0.056
Kurtosis	0.100
97.5 percentile	13.60
2.5 percentile	2.68
Null hypothesis	accepted

5.3.5.3 Future Behavior of DDT

The above Monte Carlo runs suggest a median contaminant velocity of 0.018 m/year at the outflow face. However, the groundwater velocity in the main part of the aquifer is probably much higher than this value, considering that the burial of DDT was carried out in 1972 and DDT has already reached the outflow face about 80 m away from the Trench. This would suggest solute movement at a rate of about 3 m per year in the main part of the aquifer. However, this calculation does not account for dispersion which causes a zone of mixing and movement of mass away from the advective front. In addition, processes such as mass loss due to degradation of the DDT compounds is not accounted for in a purely advective calculation.

Limited modeling, utilizing a three dimensional analytic solution that accounts for the above processes, and crude calibration of that model suggests an average contaminant velocity of about 2 m/year in the lower bench area. It should also be noted that the there is an apparent hydraulic gradient increase (corresponding to a transmissivity decrease) near the river.

The computed mass flux for DDT is likely to increase with time at the outflow face, and this will be largely controlled by the in-situ decay rate of the DDT. The half-life of DDT in soils is in the range of 1 - 30 years. Our calibration runs of the above model suggest a half-life of about 15 years for total DDT. These runs were based on a strip source of dimensions 30 m by 2 m depth, dispersivities a_x = 10m, a_y = 5m, and a_z = 1m, with a source strength of 3,400 ng/L. This latter figure is the solubility limit for solid DDT in water. Based on these parameters, the model predicts a groundwater concentration of 7 ng/L at a distance of 80 m from the source after 20 years. This value corresponds well to the measured values in the mini-piezometer MP96-02 (8.4 ng/L total DDTS; Table 5.10). The calculated concentration at steady state that would be measured

in the mini piezometers would be approximately 37 ng/L. Assuming a dilution factor of about 20 between the concentrations measured in the river and the mini piezometers, a value of 2 ng/L is predicted to occur in the river immediately adjacent to the outflow face at some time in the future, when steady state conditions are established. Additional discussion of DDT inputs into the Klehini River is provided in section 5.5.

It is estimated from subsurface soil and groundwater concentrations that a maximum of 22 kg of DDT material remains in place in the trench area; however, estimates of loss from ruptured or damaged drums - up to 17.5 gallons of DDT and carrier solvent - suggest a residual mass of approximately 7 kg DDTs. This material is likely in the form of dissolved DDT in a kerosene or diesel carrier, trapped at residual saturation levels in the soil. Such a source is likely to continue to leach DDT material into the groundwater for a prolonged period.

The above results (and the high uncertainty in velocities and decay rates) suggest that further monitoring will be the key in determining whether concentrations will increase or decrease with time. A suggested monitoring program is detailed below.

5.3.5.4 Monitoring Phase

The above section indicates that DDT materials could continue to be generated and transported to the river for a prolonged period. Model results also show an increase of DDT concentrations near the river with time. A suggested monitoring program should be initiated as follows:

1. *Water level transients.* It is important to determine the average groundwater velocities and directions over a period of time. This enables us to revise and update our dispersion coefficients and refine our estimates of mass loading into the river. It is suggested that three wells be chosen for water level monitoring. One well should have a continuous recorder installed and the other two could be manually recorded at a frequency of twice per month.

2. *DDT concentration.* Our relatively simple model of the contaminant transport of DDT needs to be verified. Currently, we have only undertaken a crude calibration phase in which our model has been compared to observed DDT concentrations. We also need to carry out a verification phase to assess whether this model can reasonably predict the future behavior. Such a demonstration is needed to assure that the DDT loading will indeed not exceed previous predicted levels. Specific DDT chemicals should be monitored in the existing wells on a semi-annual basis for two years.

5.4 Surface Contaminant Distribution

Excluding DDT, DDE, or DDD, the concentrations of all chlorinated pesticides were less than the analyte-specific method detection limit in all 37 surface soil samples analyzed at ASL (<0.001 to <0.03 mg/kg).

The range of concentrations of DDT-type compounds (sumDDT = DDT + DDE + DDD) in surface soil samples collected in the vicinity of the excavated trench at Rainy Hollow was 0.014 to 173 mg/kg (ppm) (Table 5.7). Similarly, the range of sumDDT concentrations in surface soil samples collected within 100 m of the Temporary Storage Facility was <0.001 to 27 mg/kg. In contrast, the concentration of sumDDT in soil samples collected at distances greater than one km from the site was less than 0.05 mg/kg (Section 5.6, below). The DDT levels in these reference samples were probably attributable to inputs from Rainy Hollow/Border Station rather than long-range transport from more distant sources, since the major isomer present was the parent pesticide p,p'-DDT rather than the photo-degradation or microbial degradation products DDD and DDE. The maximum sumDDT concentrations found in surface soils from the site during this investigation actually exceeded the maximum concentration observed in soil samples from the Temporary Storage Facility (RRU, 1996c).

Figures 5.5 and 5.6 illustrate the spatial distribution of DDT compounds. Results based on DDT field test kits are also plotted. As noted above, the field test kits provided an over-estimate of the DDT soil concentrations for some soils relative to laboratory analyses, possibly due to an atypically good methanol extraction efficiency. The calibration standards provided with the kits may be designed for soil samples with greater organic carbon and moisture content, and - hence - a lower DDT extraction efficiency per unit of soil mass. The field test kit results, nonetheless, provide a good relative indication of the spatial distribution of DDT. Also, a failure of the DDT field test kits to detect DDT at concentrations exceeding 1 mg/kg can be taken as reliable evidence for the absence of high DDT soil concentrations, since no false negative results were observed for samples analyzed both in the lab and using field test kits.

At Rainy Hollow, sumDDT concentrations that exceeded 30 mg/kg occurred in samples collected from a small area immediately to the north of the trench; i.e., in samples collected along transect S96-L8, from the north-most end of the trench enclosure to a distance of between 10 and 20 m north. (S96-L8-1, -5, -10: Table 5.7). This area was probably used during the 1994 emergency response for the temporary placement of the most contaminated soils and perhaps the DDT canisters prior to removal either to the south in overpack barrels or to the Temporary Storage Facility. **In order to accurately define the spatial extent and mass of the most highly contaminated soil in this area (i.e., sumDDT > 10 mg/kg) additional confirmatory testing may be required. A reasonable rough-order-of-magnitude estimate of the amount of highly contaminated soil, however, is 15 m x 10 m x 0.2 m depth, for a total of 30 m^3 of soil or less.**

Soil samples collected from limited areas along access roads between the trench

and the Temporary Storage Facility exhibited sumDDT concentrations in the range 0.43 to 27 mg/kg. The higher concentrations were found in depressions along the road where water and fine particulates would tend to pool.

The total areal extent of surface soils with sumDDT concentrations in the range of 1-10 mg/kg can estimated from the present data and from an examination of Figures 5.5 and 5.6.

DDT concentrations along the major portion of access road surfaces were generally less than 2-3 mg/kg. In addition, a single test pit hand-excavated in the centre of the major access road to the east of the Temporary Storage Facility suggests that DDT-contaminated soils are confined to the upper ten centimeters or less of road surface, at least in some areas. The sumDDT concentrations in samples from S96-L7-70 were 2.6 mg/kg, 0.06 mg/kg amd 0.12 mg/kg at depths of 0, 10 and 20 cm respectively. Similarly, at sampling location L13-5 (N. of the trench at Rainy Hollow) the surface concentration was 2.4 mg/kg, while the sumDDT concentration at 10-15 cm depth was 0.36 mg/kg. It is possible that the vertical extent of contamination is greater than 5 to 10 cm depth in some areas where the surface soils are poorly consolidated, seasonally very dry, and especially prone to disturbance by vehicles and wind.

In addition to hotspots of DDT contamination, surface soil samples in the vicinity of the Rainy Hollow trench or the Temporary Storage Facility in areas of past vehicular traffic or passage by heavy equipment exhibited sumDDT concentrations in the range of approximately 0.1 to 3 mg/kg. All soil samples from areas of undisturbed vegetation, or areas not disturbed since before 1994, exhibited sumDDT concentrations that were less than 1 mg/kg. It is clear that, while some airborne redistribution of DDT has occurred since 1994 (see Section 5.6, below), the major mechanism of redistribution has been via tracking on heavy equipment and other vehicles. The redistribution was probably exacerbated during the 1994 emergency response by the adverse weather which caused the site to be extremely muddy.

Figure 5.5: Spatial distribution of DDT(mg/kg, or ppm) in surface soils in the vicinity of the Temporary Storage Facility, Border Station

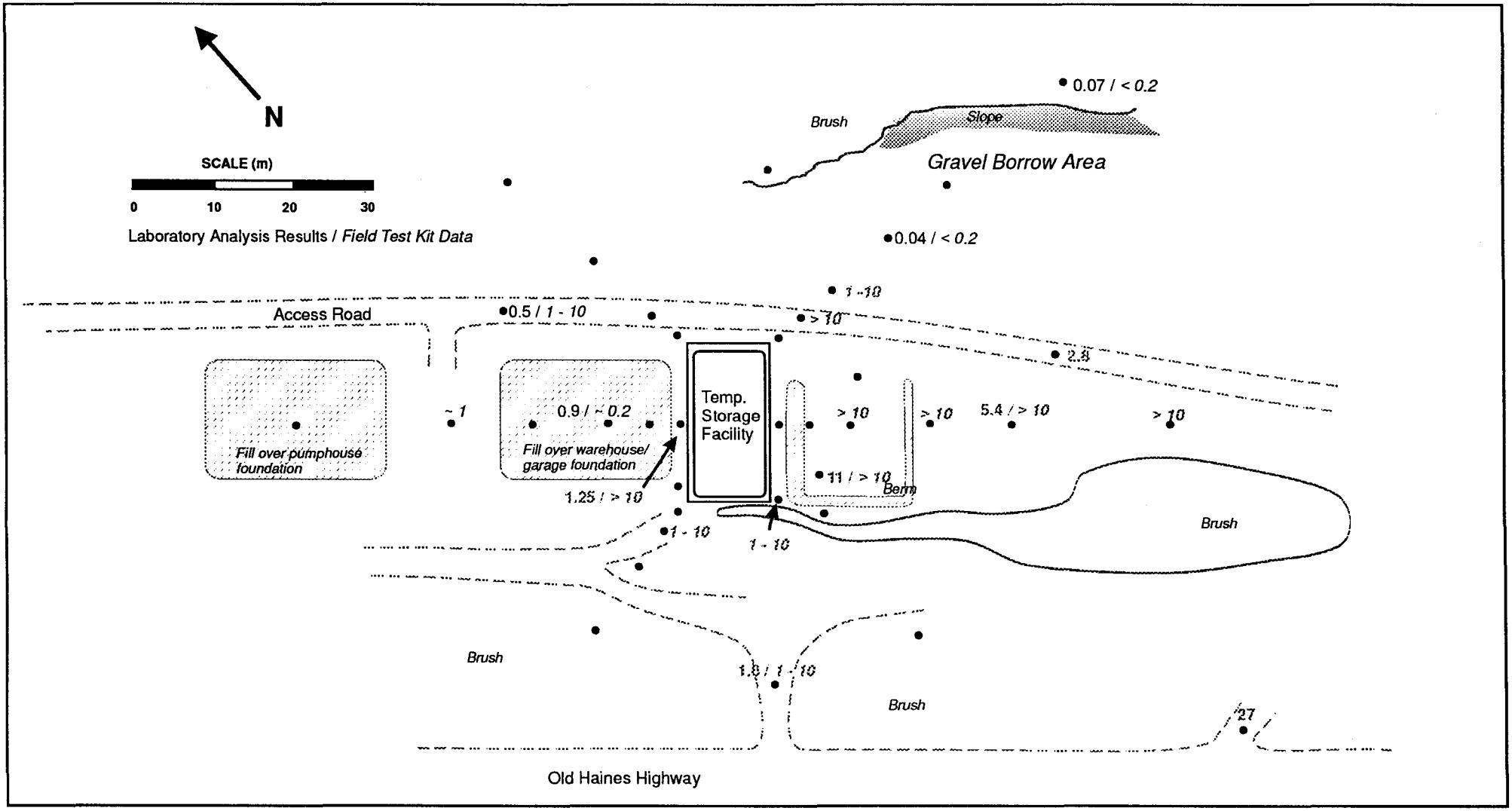


Figure 5.6: Surficial Soil Distribution of DDTs (mg/kg, or ppm) at Rainy Hollow

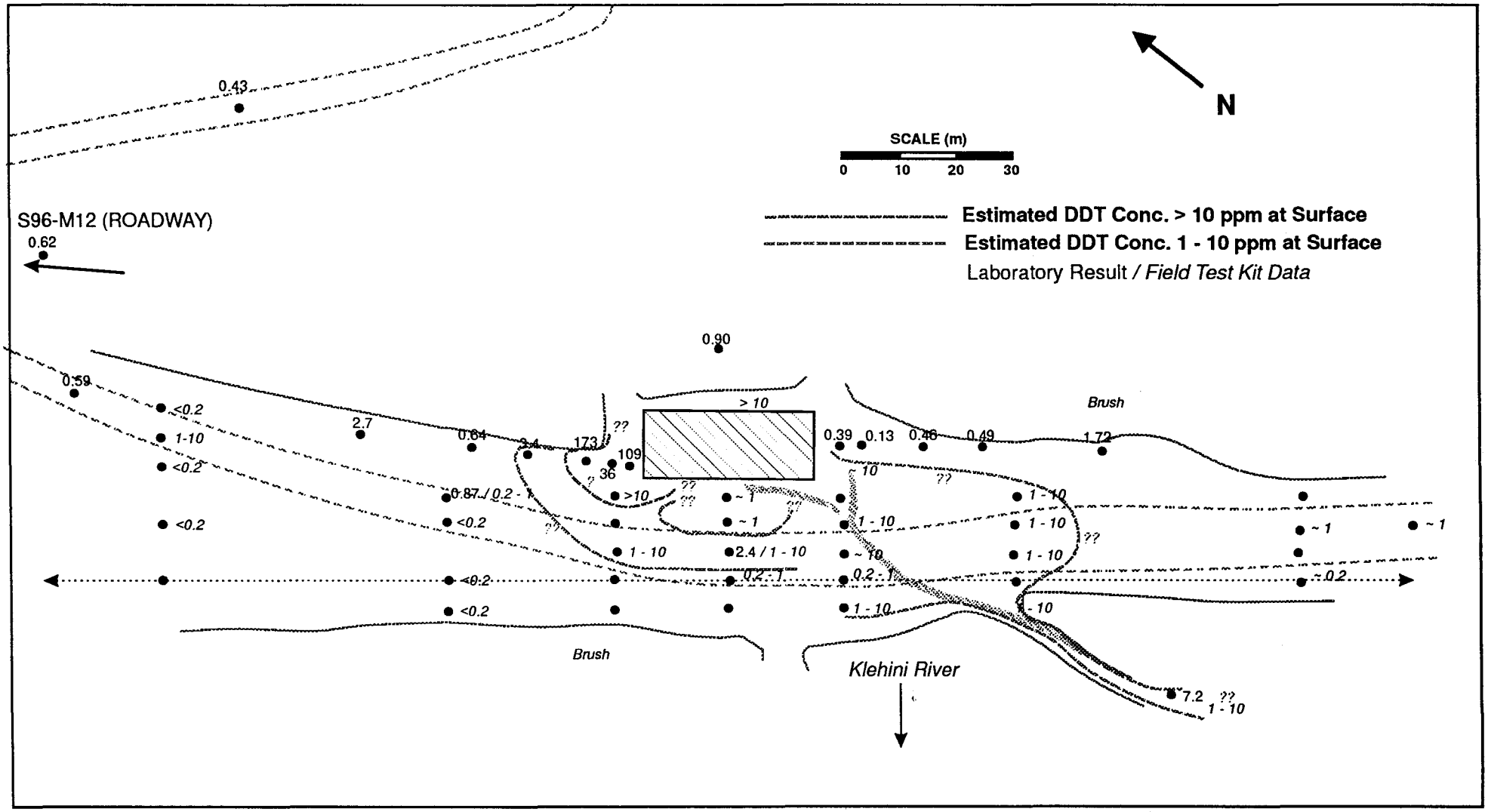


Table 5.7: *DDT Concentrations in Surface Soil Samples Collected in the Vicinity of the Rainy Hollow Trench or the Temporary Storage Facility at Border Station

	Depth from surface	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers
1) Vicinity of Temporary Storage Facility								
S96-01	surface	0.085	0.608	<0.002	0.024	0.222	0.663	**1.60**
S96-L1-1	surface	0.055	0.097	0.003	0.028	0.342	0.722	**1.25**
S96-L1-10	surface	0.002	0.003	<0.002	0.008	0.013	0.063	**0.09**
S96-L2-30	surface	0.131	0.34	0.014	0.856	0.993	3.05	**5.38**
S96-L4-20	surface	<0.001	<0.002	<0.002	0.006	0.007	0.03	**0.04**
S96-L4-48	surface	<0.001	<0.002	<0.002	0.014	0.008	0.05	**0.07**
S96-L6-0	surface	0.008	0.031	<0.002	0.016	0.07	0.407	**0.53**
S96-L6-70A	surface	0.108	0.359	0.003	0.173	0.478	1.69	**2.81**
S96-L6-70B	10 cm	0.002	0.005	<0.002	0.009	0.006	0.036	**0.06**
S96-L6-70C	20 cm	0.005	0.011	<0.002	0.013	0.018	0.069	**0.12**
S96-M1	surface							
S96-M3	surface	0.221	0.647	0.015	0.501	1.99	7.82	**11.2**
S96-M8	surface	0.038	0.109	0.005	0.124	0.3	1.21	**1.79**
S96-M10A	2 cm	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	**nd**
S96-M10B	10-12 cm	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	**nd**
S96-M10C	28-30 cm	<0.001	<0.001	<0.002	<0.001	0.001	0.005	**0.01**
S96-M14	surface	1.23	2.26	0.115	2.46	4.9	15.8	**26.8**
Border Station Area								
	Average of Surface Soil Samples							*4.68*
	St. Dev.							*8.03*
	Geometric Mean							*0.24*
2) Vicinity of Trench at Rainy Hollow (July, 1996)								
S96-L7-5	surface	0.025	0.132	<0.002	0.005	0.042	0.187	**0.39**
S96-L7-10	surface	0.007	0.043	<0.002	0.002	0.014	0.059	**0.13**
S96-L7-20	surface	0.044	0.146	<0.002	0.012	0.05	0.209	**0.46**
S96-L7-30	surface	0.022	0.139	<0.002	0.018	0.044	0.265	**0.49**
S96-L7-50	surface	0.065	0.257	<0.002	0.026	0.169	1.2	**1.72**
S96-L8-1	surface	4.06	5.91	0.222	1.06	28	69.4	**109**
S96-L8-5	surface	1.31	2.56	0.086	0.584	8.75	22.9	**36**
S96-L8-10	surface	3.6	7.75	0.286	1.67	35.9	124	**173**
S96-L8-20	surface	0.037	0.256	0.004	0.036	0.472	2.63	**3.44**
S96-L8-30	surface	0.02	0.061	<0.002	0.01	0.11	0.435	**0.64**
S96-L8-50	surface	0.156	0.293	0.005	0.058	0.704	1.46	**2.68**
S96-L8-100	surface	0.013	0.051	<0.002	0.006	0.106	0.413	**0.59**
S96-M10	surface	0.348	1.14	0.008	0.03	1.2	4.51	**7.24**
S96-M11	surface	0.005	0.03	0.004	0.014	0.119	0.732	**0.90**
S96-M12	surface	0.015	0.043	<0.002	0.018	0.127	0.412	**0.62**
S96-M13	surface	0.017	0.059	<0.002	0.008	0.065	0.283	**0.43**

*All other chlorinated pesticides < 0.001 to <0.03 mg/kg.

(continued next page)

Table 5.7 (cont'd):

	Depth from surface	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers
3) Vicinity of Trench at Rainy Hollow (September, 1996)								
L11-15	surface	0.033	0.151	<0.002	0.016	0.122	0.547	**0.87**
L13-5	surface	0.062	0.377	0.002	0.024	0.365	1.61	**2.44**
L15-15	surface	0.038	0.272	<0.002	0.01	0.125	0.589	**1.03**
L16-0	surface	0.008	0.064	<0.002	0.011	0.004	0.055	**0.14**
L13-5	(10-15 CM DEPTH)	0.015	0.088	<0.002	0.018	0.056	0.187	**0.36**
Rainy Hollow Vicinity								
	Average of Surface Soil Samples							*16.31*
	St. Dev.							*43.37*
	Geometric Mean							*1.54*

Another mechanism that has also contributed to the redistribution of DDT-contaminated soils is surface runoff. Topographic low areas tended to have higher sumDDT concentrations than high areas. Sample M10 was collected on the river side of the Rainy Hollow airstrip within a major rust-coloured drainage path, and within 10 m of well point WP10. The sumDDT concentration in this sample was 7.2 mg/kg.

The DDT concentrations in surface soils at Rainy Hollow and Border Station prompted a more critical evaluation of the associated risks to humans and/or other biological receptors. The risk assessment is provided in Chapter 6.

Eleven surface or subsurface soil samples collected from within the trench at Rainy Hollow (Tr96-01 to -11) were also analyzed for chlorinated pesticides. The DDT results are shown in Table 5.8. All other chlorinated pesticides were below the method detection limits.

Table 5.8: DDT Concentrations in Soil Samples from Beneath the Upper Tarp in the Backfilled Trench at Rainy Hollow.

	TR96-01	TR96-02	TR96-03	TR96-04	TR96-05	TR96-06	TR96-07	TR96-08	TR96-09	TR96-10	TR96-11
o,p'-DDD	0.57	0.27	0.072	0.021	0.123	0.926	0.068	0.007	0.027	0.042	0.028
p,p'-DDD	1.93	1.13	0.358	0.084	0.574	3.6	0.37	0.038	0.127	0.217	0.135
o,p'-DDE	0.01	0.003	<0.002	<0.002	<0.002	0.004	<0.002	<0.002	<0.002	<0.002	<0.002
p,p'-DDE	0.07	0.022	0.015	0.002	0.023	0.015	0.024	0.008	0.009	0.021	0.006
o,p'-DDT	0.768	0.058	0.007	0.013	0.009	<0.005	0.005	0.013	0.004	0.003	0.007
p,p'-DDT	2.96	0.521	0.02	0.059	0.057	0.005	0.018	0.067	0.033	0.045	0.038
Sum DDTs	**6.31**	**2.00**	**0.47**	**0.18**	**0.79**	**4.55**	**0.49**	**0.13**	**0.20**	**0.33**	**0.21**
EPH (C10-18)	<250	<250	<250	<250	<250	10700	516	<250	334	776	274
EPH (C19-31)	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250	<250
Benzene	-	<0.05	-	-	<0.05	<1	-	-	<0.05	-	-
Ethyl-benzene	-	<0.05	-	-	<0.2	14.1	-	-	<0.1	-	-
Toluene	-	<0.05	-	-	<0.1	<1	-	-	<0.05	-	-
meta- & para-Xylene	-	<0.05	-	-	<0.4	16.2	-	-	<0.3	-	-
ortho-Xylene	-	<0.05	-	-	<0.1	<1	-	-	<0.1	-	-
VPH	-	7.0	-	-	26	1030	-	-	37	-	-

The range of concentrations of sumDDTs was 0.13 to 6.3 mg/kg, while the arithmetic mean was 1.42 mg/kg (standard dev. = 2.04 mg/kg). The geometric mean was 0.60. If it is assumed that the DDT concentrations are normally distributed within the soils held between the upper and lower liners of the trench, then the upper 95th percentile sumDDT concentrations is estimated to be 5.4 mg/kg. Overall, the DDT levels were found to be considerably higher than stated in the report by Golder (1995); i.e., in the range of 0.22 to 0.62 mg/kg.

DDT-contaminated soil presently contained between the tarps in the backfilled trench could become bioavailable through two principle routes: (i) through direct ingestion of soils at the surface should the upper tarp be removed or compromised or indirectly via soil invertebrates or plants to higher trophic level animals; and (ii) via subsurface migration in groundwater followed by either surface emergence or drainage into the Klehini River. The second possible exposure route is addressed in Section 5.3 above as well as Section 5.5, immediately below. The first possible exposure route is examined as part of the detailed risk assessment (Chapter 6).

5.5 Contaminant Concentrations in Klehini River Sediment, Water and Biota Samples

There is little doubt that DDT and hydrocarbons in subsurface soils and groundwater are moving from the original input sources toward and into the Klehini River. The obvious next questions are: To what extent, and to what concentrations may aquatic biota may be exposed? As part of the ecological risk assessment, samples of river water, sediment and streambed invertebrates were collected from the Klehini River immediately adjacent to the site, as well as at upstream and downstream reference locations. The sampling locations and rationale are discussed in more detail in the Methods section, Chapter 3.

As mentioned previously, three mini-piezometers were installed on the bank of the Klehini River, within 1 m of the active flow. These intercept the groundwater immediately before entry into the Klehini River, and most closely represent the instantaneous contaminant input term for the Klehini River. The concentrations of hydrocarbons in groundwater samples collected from the mini-piezometers were measured as BETX, VPHs, LEPHs, HEPHs and PAHs. Inorganic elements were also determined by ICP. The data are provided in Table 5.9. Also included are results for the organic carbon concentration in the groundwater.

The samples collected from the mini-piezometers exceeded both the Criteria for the Protection of Freshwater Aquatic Life and the Drinking Water Standard for the metals chromium, iron, lead and zinc. Copper exceeded the Freshwater Aquatic Life Criteria but not the Drinking Water Standards. Finally, the method detection limits for arsenic, cadmium, selenium and silver were too high relative to the appropriate trigger levels to make any determination. It should be noted that there is no potential for the water mass characterized by the mini-piezometer samples to be consumed by humans, and the Drinking Water Standards are not directly relevant. Furthermore, the Freshwater Aquatic Life Criteria should be applied to water quality data for water at the immediate point of exposure by organisms; i.e., in surface waters. Given the close proximity of the mini-piezometers to the Klehini River, there is obvious concern with regard to the elveated metal levels in groundwater. It is necessary, however, to understand the geochemical origins of the metals as well as the predicted fate after infiltration of the groundwater into the Klehini River.

The elevated iron and manganese concentrations in ground water might, in some small part, be attributable to local mineral conditions. Their presence in dissolved form within groundwater, however, is directly attributable to dissolution from the solid phase of subsurface soils under anaerobic conditions. Iron and manganese form iron and manganese oxyhydroxides in well oxygenated environments, and have an extremely limited solubility in water. Under reducing conditions as found in suboxic or anaerobic environments, however, iron and manganese oxyhydroxides dissolve into the surrounding water moving through the interstices of the soil or sediment. Other metals such as copper, nickel, chromium, lead and zinc are known to adsorb to the abundant binding sites on iron and

manganese oxyhydroxides, expecially hydroxy- (OH-) groups. This latter group of metals will also react under highly anoxic conditions to form insoluble metal sulfide complexes provided that a large enough pool of free sulfides exist.

Overall, conditions that decrease the oxygen concentration in groundwater, and enhance the reducing conditions, favour the solubilization from mineral forms and movement in groundwater of several metals. Conversely, under well oxygenated conditions, iron and manganese will rapidly be removed from solution, as will some fraction of the other metals. At Rainy Hollow, the subsurface anoxia in shallow groundwater is enhanced by the hydrocarbon concentrations. Hydrocarbons provide a food substance for some groups of aerobic bacteria. The enhanced bacterial productivity in groundwater causes an oxygen depletion, with subsidiary effects on the mobilization into groundwater of iron and other metals. The same phenomenon undoubtedly accounts for the rust-coloured staining of surface soils near the Trench and down the surface drainage path leading away from the Trench. The expected fate of the metal-rich groundwater is as follows: Upon infiltration into the Klehini River, the groundwater will be rapidly re-oxidized and iron will be almost completely removed from solution. Visual observations of the rust-coloured staining on the river bed near mini-piezometer MP96-02 provide direct evidence of this. The rate of removal of other metals is expected to be slightly slower than for iron and manganese, depending on the kinetics of adsorption to particulates in the River; however, the process probably occurs with sufficient speed that the readily bioavailable dissolved forms are reduced by several orders of magnitude. It is unlikely that metal concentrations in Klehini River water collected dowstream from Rainy Hollow are distinguishable from upstream water levels.

No British Columbia or federal criterion or standard exists for hydrocarbons in surface water when measured as a group parameter (e.g., as VPHs or LEPHs), except that the presence of free product is an trigger for further action. The groundwater sample from mini-piezometers MP96-02 contained detectable hydrocarbons in the C10-C18 range (LEPHs) at a concentration of 5.9 mg/L, whereas samples from the other two mini-piezometers did not contain LEPHs at levels exceeding the detection limit of < 1.0 mg/L. The detectable HEPHs in MP96-01 (Table 5.10) are probably attributable to contamination from the mini-piezometer upriser, which appeared to contain a heavy oil coating introduced during the manufacture of the pipe. The BETX and naphthalene data are useful for delineating the linear extent of contaminated groundwater introduction to the river. If the HEPHs result for MP96-01 is discounted as unreliable, then the front of the groundwater contaminant plume where it intersects the river extends from a zone between MP96-01 and -02 to some undetermined distance downstream from MP96-03; however, the most contaminated extent of the river bank and adjacent river channel is very likely in the immediate vicinity of MP96-02 where a rust-coloured stain on the river bed was observed.

The concentration of naphthalene in the sample MP96-02 and anthracene in all three samples were equal to or higher than the criterion for the protection of aquatic life, whereas all other hydrocarbons constituents analytes were well below the Freshwater Aquatic Life Criteria. Even a minor dilution of the contaminated groundwater as it enters

the river would decrease the naphthalene concentration below the criterion for the protection of aquatic life. Naphthalene, ethylbenzene, xylenes and other light hydrocarbons with moderate aqueous solubility exhibit a very limited tendency to bioaccumulate. Furthermore, they have little persistence (or longevity) in the environment in surface water, sediment, or living organisms. The primary mode of toxicity is at the site of immediate exposure, to the organism directly exposed to contaminated water or sediment. Biological impacts tend to decrease rapidly away from the immediate point of contaminant input, and there is virtually no risk to other organisms in the ecosystem in association with the ingestion of contaminated organisms.

Table 5.9: Results of Analyses for Groundwater Samples from the Mini-piezometers, Installed on the Bank of the Klehini River.

	CCME Criterion for the Protection of Aquatic Life and/or B.C. Draft Reg.	Drinking Water Standards	MP96-01	MP96-02	MP96-03
Total Organic C (mg/L)			3.7	7.2	95
Metals (Total from field acidified sample, in mg/L)					
Aluminum	5 - 100 depending on pH	---	85	75	13
Antimony	---	---	<0.2	<0.2	<0.2
Arsenic	0.050	0.025	<0.2	<0.2	<0.2
Barium	---	1	0.62	0.54	0.13
Berylium	---	---	<0.005	<0.005	<0.005
Bismuth	---	---	0.20	0.10	<0.1
Boron	---	5	<0.1	<0.1	<0.1
Cadmium	0.0002 - 0.0018 depending on hardness	0.005	<0.01	<0.01	<0.01
Calcium	---	---	167	184	102
Chromium	0.002 - 0.02	0.05	0.24	0.22	0.04
Cobalt	---	---	0.10	0.06	0.01
Copper	0.002 - 0.004 depending on hardness	≤ 1 (aesthetic objective)	0.32	0.40	0.05
Iron	0.3	≤ 0.3	134	115	22
Lead	0.001 - 0.007 depending on hardness	0.01	0.09	0.27	0.07
Lithium	---	---	0.06	0.06	0.02
Magnesium	---	---	58	54	12
Manganese	---	≤ 0.05	2.0	3.6	1.4
Molybdenum	---	---	<0.03	<0.03	<0.03
Nickel	0.025 - 0.15 depending on hardness	---	0.13	0.10	<0.02
Phosphorus	---	---	2.4	3.5	0.80
Potassium	---	---	10	8.00	4.00
Selenium	0.001	0.01	<0.2	<0.2	<0.2
Silicon	---	---	76	70	22
Silver	0.0001	---	<0.01	<0.01	<0.01
Sodium	---	≤ 200	12	7.0	3.0
Strontium	---	---	0.46	0.48	0.24
Titanium	---	---	<0.1	<0.1	<0.1
Tin	---	---	<0.03	<0.03	<0.03
Vanadium	---	---	0.30	0.26	0.04
Zinc	0.03	≤ 5	5.1	26	6.0

(continued next page)

Table 5.9 (cont'd):

	CCME Criterion for the Protection of Aquatic Life and/or B.C. Draft Reg.		MP96-01	MP96-02	MP96-03
Hydrocarbon Constitutents (mg/L)					
VPHs	---	---	<0.1	**1.0**	**1.0**
LEPHs	---	---	<1.0	**5.9**	<1.0
HEPHs	---	---	**1.7**	<1.0	<1.0
Benzene	0.3	0.005	<0.0005	<0.0005	<0.0005
Ethyl-benzene	0.7	≤ 0.0024	<0.0005	**0.0041**	**0.0033**
Toluene	0.3	≤ 0.024	<0.001	<0.005	<0.001
meta- & para-Xylene	---	≤0.3 (total xylenes)	<0.0005	**0.0070**	**0.0039**
ortho-Xylene	---	as above	<0.0005	**0.0020**	**0.0009**
Acenaphthene	0.006	---	<0.0005	<0.0005	<0.0005
Acenaphthylene	---	---	<0.0005	<0.0005	<0.0005
Acridine	0.00005	---	<0.00005	<0.00005	0.00006
Anthracene	0.0001	---	**0.0001**	**0.0001**	**0.0001**
Benzo(a)anthracene	0.0001	---	<0.00001	<0.00001	<0.00001
Benzo(a)pyrene	0.00001	0.00001	<0.00001	<0.00001	<0.00001
Benzo(b)fluoranthene	---	---	<0.00001	<0.00001	<0.00001
Benzo(g,h,i)perylene	---	---	<0.0001	<0.0001	<0.0001
Benzo(k)fluoranthene	---	---	<0.00001	<0.00001	<0.00001
Chrysene	---	---	<0.0001	<0.0001	<0.0001
Dibenz(a,h)anthracene	---	---	<0.00001	<0.00001	<0.00001
Fluoranthene	0.0002	---	<0.0001	<0.0001	<0.0001
Fluorene	0.012	---	<0.0001	<0.0001	<0.0001
Indeno(1,2,3-c,d)pyrene	---	---	<0.00001	<0.00001	<0.00001
Naphthalene	0.001	---	<0.0002	**0.0011**	**0.0015**
Phenanthrene	0.0003	---	<0.0002	<0.0002	<0.0002
Pyrene	0.00002	---	0.00002	<0.00002	<0.00002
Chlorinated Pesticides (ng/L: Axys Data)					
o,p'-DDE	---	---	**0.01**	<0.01	<0.01
p,p'-DDE	---	---	**0.10**	**0.03**	**0.06**
o,p'-DDD	---	---	**0.07**	**2.0**	**0.79**
p,p'-DDD	---	---	**0.18**	**5.8**	**2.2**
o,p'-DDT	---	---	**0.15**	<0.18	**0.28**
p,p'-DDT	---	---	**0.48**	**0.6**	**0.43**
sumDDTs	1 ng/L as sumDDTs	*30,000*	*0.99*	*8.43*	*3.76*
Hexachlorobenzene	6.5	---	**0.08**	**0.09**	**0.08**
alpha HCH	---	---	0.02	0.03	0.08
beta HCH	---	---	<0.007	<0.009	<0.01
gamma HCH	---	4000	0.06	[1]ndr (0.03)	0.01
Heptachlor	10	300	<0.02	<0.005	<0.004
Aldrin	4	700	<0.003	<0.003	<0.003
Oxychlordane	---	---	<0.01	<0.01	<0.01
trans-Chlordane	6	7000	<0.04	<0.01	<0.008
cis-Chlordane	6	7000	<0.05	<0.02	<0.01
trans-Nonachlor	---	---	<0.04	<0.01	<0.008
cis-Nonachlor	---	---	<0.05	<0.01	<0.01
Mirex	---	---	<0.001	<0.001	<0.001
Heptachlor epoxide	10	300	<0.09	<0.03	<0.07
alpha-Endosulphan I	20	---	<0.10	<0.03	<0.06
Dieldrin	4	700	<0.12	<0.03	<0.08
Endrin	2.3	---	<0.28	<0.07	<0.16
Methoxychlor	---	900,000	<1.8	<0.15	<0.36

1: ndr - peak detected in chromatogram, but did not meet quantification criteria. The value in brackets is the maximum possible concentration.

The hazard to aquatic wildlife in the Klehini River or their predators was considered to be essentially zero, given the low concentrations of hydrocarbons in the groundwater introduced to the Klehini River, in conjunction with absence of sensitive or ecologically valuable receptor organisms in the immediate area of contaminated groundwater infiltration. Hydrocarbons, therefore, were eliminated from further scrutiny.

Groundwater samples (4 L each) from the mini-piezometers were analyzed for chlorinated pesticides, including DDTs, at Axys Analytical Services by high resolution gas chromatography/ high resolution mass spectrometry (HRGC/HRMS). The analytical methodology provides the best achievable analytical detection limits at the present time. The chlorinated pesticides hexachlorobenzene, gamma-HCH (hexachlorocyclohexane: lindane), and alpha-HCH were detected in all three samples, at concentrations exceeding that of the analytical blank. The presence of these compounds in the groundwater samples could either be attributable to (i) introduction from the mini-piezometer assemblies as manufacturing byproducts, or (ii) as impurities within the original DDT pesticidal formulation. Regardless of their origin, the apparent concentrations of HCB and the HCHs were many orders of magnitude below levels that could affect the health of any living organism.

The concentrations of DDTs (sumDDTs = DDT+DDE+DDD) in MP96-01, -02, and -03 were 0.99, 8.43 and 3.76 ng/L (parts-per-trillion) respectively. **DDT in groundwater samples from MP96-02 and -03 exceeded the criterion for the protection of aquatic life (1 ng/L). The predominant form was as p,p'-DDD and o,p'-DDD.** This is consistent with the fact that the principal biotransformation product of p,p'-DDT by microbes under anaerobic conditions is DDD. **The elevated concentration of DDTs in groundwater at sites immediately upgradient from areas of infiltration into the Klehini River initially suggested a possible hazard to aquatic wildlife within the Klehini River.**

Whereas the water-borne concentration of DDTs in the groundwater around the mini-piezometers approached or exceeded 1 ng/L, the maximum measured concentration water sampled from the Klehini River (Kle96-02), which was collected within 2-3 m from MP96-02, was 0.31 ng/L (Table 5.10a). Again, p,p'-DDD and o,p'-DDD were the major DDT-type isomers present. The parent compound p,p'-DDT was below the detection limit. Sample Kle96-02 undoubtedly represents the worst-case concentration for the river, at or near site where the maximum rate of DDD inflitration occurs, and where the river flow is minimal, providing much lower dilution factors than in the main channel of the river.

Given the low analytical detection limit employed, DDT and DDD were also detected in references samples Kle96-01 and -03, collected 1.0 km upstream and 1.6 km downstream from Rainy Hollow respectively. Only p,p'-DDT was detected in the travelling blank; therefore, the lower concentrations of p,p'-DDT in sample Kle96-01 and -03 were ignored as a probable sampling or analytical artifact. The three river water

samples differed in their organic carbon content (Table 5.10a), which directly influences the partitioning of hydrophobic organic compounds such as DDT into water as opposed to other environmental media; however, adjusting the data for organic C content would make the result for Kle96-02 even higher than the Kle96-01 sample. **The data clearly indicate that o,p'- and p,p'-DDD are elevated in river water adjacent to Rainy Hollow relative to the upstream reference, at concentrations that exceeds the background (upstream reference) by two orders of magnitude. It cannot be over-emphasized, however, that the concentration of DDTs in Kle96-02 is still very low; approximately 30% of the criterion for the protection of aquatic life.**

Table 5.10: DDT Concentrations in Aquatic Samples Collected for Risk Assessment
a) Klehini River Water (ng/L, or parts-per-trillion)

Sample	Kle96-01	Kle96-02	Kle96-03	Kle96-04 (trav. blank)
Batch (Axys Analytical Services)	CL-0840	CL-0840	CL-0866	CL-0840
Total Vol.	4 L	4 L	3 L	1 L
Total Organic C (mg/L)	68.7	20	2.2	not determined
o,p'-DDE	<0.001	<0.001	<0.003	<0.004
p,p'-DDE	<0.005	<0.004	0.006	<0.009
o,p'-DDD	<0.003	**0.08**	**0.005**	<0.005
p,p'-DDD	**0.004**	**0.23**	**0.01**	<0.006
o,p'-DDT	<0.02	<0.009	0.02	<0.05
p,p'-DDT	0.02	<0.02	0.04	0.06
Hexachlorobenzene	<0.01	<0.01	0.009	<0.03
alpha HCH	0.04	0.14	0.14	0.52
beta HCH	<0.002	<0.003	<0.004	0.04
gamma HCH	0.02	0.04	0.03	2.1
Heptachlor	<0.002	<0.002	<0.002	<0.004
Aldrin	<0.001	<0.001	<0.001	<0.001
Oxychlordane	<0.001	<0.002	<0.003	<0.006
trans-Chlordane	0.005	0.006	0.002	0.008
cis-Chlordane	0.002	0.004	<0.003	<0.004
trans-Nonachlor	0.004	0.005	<0.003	<0.006
cis-Nonachlor	<0.002	<0.001	<0.002	<0.002
Mirex	<0.001	<0.001	<0.001	<0.001
Heptachlor epoxide	<0.03	<0.02	<0.02	<0.12
alpha-Endosulphan I	<0.02	<0.02	<0.03	<0.12
Dieldrin	<0.03	<0.03	<0.03	<0.13
Endrin	<0.06	<0.06	<0.1	<0.27
Methoxychlor	<0.13	<0.13	<0.11	<0.6

Six river sediment samples were collected for DDT analysis: four in the vicinity of Rainy Hollow (Sed96-02 to -05), one reference sample collected 1.0 km upstream (Sed96-01) and one sample collected 1.6 km downstream (Sed96-06). The chlorinated

pesticide data are provided in Table 5.10b. The samples were extracted at Axys Analytical Services and analyzed by HRGC/HRMS. The sampling sites for Sed96-02, -03, and -04 corresponded directly to locations along the river of mini-piezometers MP96-01, -02, and -03 respectively: The sediment samples were collected in the relatively quiet stream channel within 2-4 m of the base of the mini-piezometers. Sample Sed96-05 was collected on the side of the gravel bar away from Rainy Hollow in a small back eddy off the main river channel.

Table 5.10b also includes for comparison the analytical data for two laboratory blanks run with the sample extracts from the Klehini River samples. All chlorinated pesticides were below the detection limit in one of the two blanks, but most of the DDTs were detected in the other blank. Results for the sediment samples should be interpreted accordingly.

Table 5.10b) Klehini River Sediment Samples (ng/g, or parts-per-billion)

Sample	Sed96-01	Sed96-02	Sed96-03	Sed96-04	Sed96-05	Sed96-06	Blank	Blank
Batch (Axys)	CL-0837	CL-0837	CL-0837	CL-0837	CL-0837	CL-0870	CL-0837	CL-0870
% moisture	26	26	24	23	25			
Total Organic C (%)	<0.05	<0.05	<0.05	<0.05	<0.05		<0.05	
o,p'-DDE	<0.003	<0.002	<0.002	<0.003	<0.003	<0.001	<0.002	<0.001
p,p'-DDE	<0.003	<0.002	<0.002	<0.003	**ndr (0.008)**	**0.006**	<0.003	<0.001
o,p'-DDD	[1]ndr (0.006)	<0.002	**0.01**	<0.002	<0.003	0.002	ndr (0.004)	<0.001
p,p'-DDD	**0.03**	<0.002	**0.05**	<0.002	<0.003	**0.006**	0.01	<0.001
o,p'-DDT	ndr (0.09)	<0.008	<0.02	<0.008	<0.02	**0.004**	ndr (0.03)	<0.001
p,p'-DDT	**0.14**	<0.009	<0.02	<0.02	<0.02	**0.02**	0.06	<0.002
Hexa-chlorobenzene	<0.009	<0.01	<0.006	<0.007	<0.007	0.007	0.04	0.002
alpha HCH	0.009	0.03	0.009	0.008	0.009	0.01	ndr (0.009)	<0.001
beta HCH	<0.004	<0.004	<0.004	<0.004	<0.005	<0.001	<0.004	<0.001
gamma HCH	0.006	0.009	<0.004	<0.004	ndr (0.006)	0.003	<0.004	<0.001
Heptachlor	ndr (0.001)	<0.001	ndr (0.001)	ndr (0.001)	ndr (0.001)	<0.001	<0.001	<0.001
Aldrin	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Oxychlordane	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
trans-Chlordane	<0.003	0.002	ndr (0.003)	0.002	<0.003	<0.002	0.002	<0.002
cis-Chlordane	ndr (0.001)	0.001	<0.001	ndr (0.002)	ndr (0.001)	<0.002	0.001	<0.002
trans-Nonachlor	0.001	0.001	ndr (0.001(	ndr (0.001)	ndr (0.001)	<0.002	0.001	<0.001
cis-Nonachlor	<0.002	<0.001	<0.001	<0.001	ndr (0.001)	<0.001	<0.001	<0.001
Mirex	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Heptachlor epoxide	<0.007	<0.007	<0.007	<0.007	<0.007	<0.02	<0.01	<0.03
alpha-Endosulphan I	<0.008	<0.008	<0.008	<0.01	<0.008	<0.02	<0.01	<0.08
Dieldrin	<0.008	<0.008	<0.008	<0.008	<0.008	<0.03	<0.01	<0.04
Endrin	<0.01	<0.01	<0.01	<0.01	<0.01	<0.1	<0.02	<0.15
Methoxychlor	<0.02	<0.02	<0.02	<0.02	<0.02	<0.13	<0.04	<0.20

1: ndr - peak detected in chromatogram, but did not meet quantification criteria. The value in brackets is the maximum possible concentration.

Hexachlorobenzene, lindane (gamma-HCH), heptachlor, trans-chlordane, cis-chlordane, and trans-nonachlor were detected in some or all of the samples. These are undoubtedly associated with inputs from long-range atmospheric transport. Based on the sampling locations, we expected that Sed96-03 had the greatest likelihood of having elevated DDT levels in association with local inputs from Rainy Hollow. This appears to be borne out by the detactable concentrations of p,p'-DDD (0.05 ng/g) and o,p'-DDD (0.01 ng/g) in this sample. Note, however, that the concentrations of p,p'-DDT (0.14 ng/g) and o,p'-DDT (~ 0.09 ng/g) were actually higher 1 km upriver, based on the results for reference sample Sed96-01, than in any of the other samples. The concentration of p,p'-DDD (0.03 ng/g) in the upstream reference sample was similar to that in sample Sed96-03. **Overall, there is no evidence for locally elevated concentrations of DDTs in sediment from the Klehini River that are attributable to local sources.**

Table 5.10c) Stream Invertebrates (Primarily Dragon Fly Nymphs) (ng/g wet wt., or parts-per-billion)

Sample	Sed96-01Bio	Sed96-03Bio	Sed96-05Bio	Sed96-06Bio	Blank	Blank
Batch (Axys)	CL-0842	CL-0842	CL-0842	CL-0897	CL-0842	CL-0897
% lipid	4.6	6.4	5.4	5.7		
o,p'-DDE	<0.10	<0.11	<0.12	<0.07	<0.06	<0.04
p,p'-DDE	0.98	0.34	0.26	0.47	<0.07	<0.04
o,p'-DDD	<0.22	<0.16	<0.18	<0.07	<0.10	<0.04
p,p'-DDD	0.41	<0.15	<0.17	<0.07	<0.10	<0.04
o,p'-DDT	<0.47	<0.37	<0.34	<0.12	<0.21	<0.04
p,p'-DDT	0.81	<0.35	<0.32	<0.12	<0.20	<0.04
Hexachlorobenzene	0.52	0.49	0.46	0.52	<0.1	<0.02
alpha HCH	<1.1	<1.1	<0.92	1.1	<0.77	<0.05
beta HCH	<1.6	<1.6	<1.4	<0.19	<1.2	<0.09
gamma HCH	<1.6	<1.6	<1.4	<0.17	<1.1	<0.08
Heptachlor	<0.84	<0.70	<0.90	<0.5	<0.51	<0.41
Aldrin	<0.37	<0.35	<0.39	<0.14	<0.20	<0.09
Oxychlordane	<3.6	<3.0	<4.3	<1.1	<1.8	<0.55
trans-Chlordane	<0.45	<0.36	<0.38	<0.12	<0.20	<0.08
cis-Chlordane	<0.50	<0.40	<0.43	<0.13	<0.23	<0.08
trans-Nonachlor	0.41	0.3	0.29	0.32	<0.11	<0.09
cis-Nonachlor	<0.15	<0.14	<0.15	<0.13	<0.10	<0.08
Mirex	<0.25	<0.25	<0.23	<0.11	<0.13	<0.04
Heptachlor epoxide	<0.04	0.08	0.08	0.21	<0.03	<0.02
alpha-Endosulphan I	<0.05	<0.10	<0.04	<0.05	<0.04	<0.02
Dieldrin	<0.08	0.19	0.29	0.28	<0.04	<0.02
Endrin	<0.13	<0.19	<0.11	<0.17	<0.10	<0.07
Methoxychlor	<0.27	<0.37	<0.22	<0.16	<0.19	<0.06

Stream invertebrates were also collected from five of the six locations where sediment samples were collected. Samples corresponding to sediment samples Sed96-02

and -03 were pooled since there was insufficient tissue mass to analyze them separately. Several chlorinated pesticides (p,p'-DDE, p,p'-DDD, p,p'-DDT, hexachlorobenzene, trans-Nonachlor, hepatchlor epoxide, dieldrin) were detected in the samples of pooled dragonfly nymphs (Table 5.10c). **The tissue concentrations of all pesticides including DDTs were either similar across all sampling locations or higher in the sample from the upstream reference location.**

Overall, the results obtained for groundwater immediately before it enters the Klehini River, river water, sediment, or stream bed invertebrates indicate the following:

- DDT has migrated in groundwater at the Rainy Hollow site from the Trench and is being introduced to the river, primarily as o,p'-DDD and p,p'-DDD;
- The maximum instantaneous concentration in July, 1996, of sumDDTs in contaminated ground water immediately before it entered the river was estimated to be 9 ng/L or more;
- Slightly elevated concentrations of DDTs were also measured in a 'worst-case' river water sample collected adjacent to the site - but the concentration (0.34 ng/L sumDDTs) was much lower than the criterion for the protection of aquatic life (1 ng/L);
- Sediment and streambed invertebrate samples collected in the Klehini River at Rainy Hollow contained concentrations of DDTs and other chlorinated pesticides that were either similar to or less than concentrations in reference samples. There was no evidence that local sources contribute to higher concentrations of DDT in either Klehini River sediments or stream bed biota;
- The streambed invertebrate concentrations of DDTs suggest that uptake from local sources at Rainy Hollow into lower trophic levels in the river is not significant; therefore, higher level predators are not at risk.

5.6 DDT in Terrestrial Soils, Plants and Small Mammals

Two major approaches were taken as part of the assessment of risk to terrestrial flora and fauna around Rainy Hollow/Border Station. The first approach involved the evaluation of the larger regional redistribution of DDT-type compounds in forest soils and in plants. The second approach involved the evaluation of DDT bioaccumulation in small mammals within the immediate vicinity (within 100 m) of the Trench or Temporary Storage Facility.

The volatility of DDT is sufficiently high that it may partition into the air from surface soils and water, and may be transported in the atmosphere within the gaseous

phase, as aerosols, and adsorbed onto larger particulates such as wind-blown soils. The volatility and persistence of many of the chlorinated pesticides and PCBs facilitate the local short range atmospheric transport from a point source, such that a halo of declining contaminant concentration is often observed around a point source.

Mobilization of DDT from soils or other sources into air, followed by deposition through adsorption onto plant surfaces is by far the most important route of uptake by herbivores, and - consequently - into their predators. The leaf surfaces of higher plants is covered with a waxy cuticle, which favours the adsorption from air of lipophilic substances, including DDT. The extremely low solubility of these compounds in water prevents them from being taken up into the roots of plants and then translocated to above-ground portions. While some adsorption of strongly hydrophobic organic contaminants tends to occur to the outside of root surfaces, transport into internal tissues is generally thought to be extremely limited. The high bush blueberriy (*Vaccinium* sp.) was used in this study as a model plant for food substances of larger herbivores such as moose around Border Station/Rainy Hollow.

A total of seven sites were established to investigate the regional redistribution from Rainy Hollow of DDT *via* the atmosphere. The locations of the sites are indicated in Chapter 3 (Map 3.4). The results for chlorinated pesticide concentrations in forest soil, and the roots, leaves and recent shoots, and fruit (ripe or partially ripe berries) of high bush blueberries (*Vaccinium* sp.) are provided in Table 5.11. The sites were located either within the immediate vicinity of the Trench as Rainy Hollow (RA96-01), within approximately 100 to 300 m from a DDT point source (RA96-02, -03, -04, and -07) or greater than one km away (RA96-05, -06). In Table 5.11, the chlorinated pesticide concentrations are expressed as mg/kg dry weight (ppm) in soils and as ng/g wet weight (ppb) in plant tissue samples.

Excluding DDT-type compounds, all other chlorinated pesticides were less than the detection limits in all soil and plant samples , with the exception of alpha-HCH in two root samples. The mean concentrations of sumDDTs (DDT+DDE+DDD) for all samples was 660 ng/g, 4.1 ng/g, 12 ng/g and 1.1 ng/g, in soil, leaves and shoots roots, and berries respectively. Similarly, the geometric mean concentration of sumDDTs was 130 ng/g, 2.0 ng/g, 6.8 ng/g and 0.86 ng/g in soil, leaves and shoots roots, and berries respectively.

The sumDDT concentration in blueberry plant shoots and leaves, and in blueberry roots declined with increasing distance from source areas, as shown in Figure 5.5. The observed results for shoot tissue and root tissue closely approximate a logarithmic decline as shown by the straight lines in the figure. The concentrations of DDTs in the fruit of the blueberry were above the detection limit but relatively uniform across all sampling sites. Overall, the data indicate the following:

- DDT concentrations were highest in forest soil samples, followed by roots, leaves and shoots, and fruit of *Vaccinium* sp. The relationship between distance from the point source and DDT concentrations was best for blueberry leaf and root tissue, poorer for forest soils, and not significant for the fruit (berries). The

relative concentrations of DDTs in different plant tissues may correspond to the age of the biomass; i.e., root tissues represent several years growth, leaves and shoots were produced in one summer growing season, and berries were produced only within the last two to three weeks prior to sampling. The low concentration of DDTs in berries relative to leaves, even in samples collected from the immediate vicinity of the Trench, suggest that equilibrium partitioning from soils and air onto plant surfaces is relatively slow.

- Other chlorinated pesticides that undergo long-range atmospheric transport were not detected in soil or plant samples collected either within close proximity to the site or at a distance of up to 1.6 km away. This and the fact that the parent compound p,p'-DDT comprised from 53-100% of the total DDT concentration even at the most distant sampling locations provide evidence that DDT is redistributed atmospherically from Rainy Hollow within a radius of 1.6 km or more.

Table 5.11: DDT and Other Chlorinated Pesticide Concentrations in Matched Samples of Soil, Roots, Shoots and Fruit of Blueberry (*Vaccinium* sp.)

Sample	RA96-01-4	RA96-02-4	RA96-03-4	RA96-04-4	RA96-05-4	RA96-06-4	RA96-07-4	Blank	RA96-01-01	RA96-02-01	RA96-03-01	RA96-04-01	RA96-05-01	RA96-07-01
Est. Distance from Closest Point Source (m.)	*0-10*	*130*	*110*	*300*	*1100*	*1600*	*50*		*0-10*	*130*	*110*	*300*	*1100*	*50*
Batch (Axys)	ASL	ASL	ASL	ASL	ASL	ASL	ASL	CL-0889	CL-0889	CL-0889	CL-0889	CL-0889	CL-0889	CL-0889
Type	Soil (mg/kg dry)	Soil (mg/kg dry)	Soil (mg/kg dry)	Soil (mg/kg dry)	Soil (mg/kg dry)	Soil (mg/kg dry)	Soil (mg/kg dry)		Leaves/ Shoots (ng/g wet)	Leaves/ Shoots (ng/g wet)	Leaves/ Shoots (ng/g wet)	Leaves/ Shoots (ng/g wet)	Leaves/ Shoots (ng/g wet)	Leaves/ Shoots (ng/g wet)
% lipid									1.1	1.0	0.9	0.91	0.72	0.84
% moisture	30.6	15.3	63.3	7.2	7.4	40.8	0.9							
o,p'-DDE	<0.002	<0.002	**0.002**	**0.007**	<0.002	<0.01	<0.002	<0.03	<0.03	<0.03	<0.02	<0.01	<0.02	<0.02
p,p'-DDE	**0.034**	**0.033**	**0.040**	**0.36**	<0.001	<0.01	**0.009**	<0.03	**0.92**	**0.33**	**0.13**	**0.47**	**ndr 0.05**	**0.47**
o,p'-DDD	**0.029**	**0.008**	**0.011**	**0.014**	0.001	**<0.01**	**0.001**	<0.05	**0.19**	**0.05**	<0.03	**0.08**	<0.03	<0.03
p,p'-DDD	**0.13**	**0.055**	**0.12**	<0.5	0.002	**<0.01**	**0.002**	<0.05	**1.2**	**0.01**	<0.05	**0.23**	<0.03	**0.16**
o,p'-DDT	<0.1	<0.08	<0.1	**0.52**	<0.001	<0.01	**0.007**	<0.06	**1.5**	**0.37**	**0.07**	**0.59**	<0.05	**0.37**
p,p'-DDT	**0.31**	**0.20**	**0.32**	**2.36**	**0**	<0.05	**0.028**	<0.05	**10**	**2**	**0.47**	**2.6**	**0.18**	**2.4**
alpha HCH	<0.05	<0.002	<0.005	<0.001	<0.05	<0.2	<0.001	<0.2	<0.15	<0.18	<0.15	<0.11	<0.13	<0.14
beta HCH	<0.005	<0.002	<0.005	<0.002	<0.05	<0.01	<0.002	<0.34	<0.25	<0.30	<0.25	<0.18	<0.22	<0.23
gamma HCH	<0.005	<0.001	<0.005	<0.001	<0.002	<0.05	<0.001	<0.30	<0.22	<0.26	<0.22	<0.16	<0.20	<0.20
Heptachlor	<0.005	<0.002	<0.005	<0.002	<0.005	<0.01	<0.002	<0.52	<0.32	<0.41	<0.35	<0.22	<0.30	<0.34
Aldrin	<0.005	<0.001	<0.005	<0.001	<0.001	<0.005	<0.001	<0.12	<0.07	<0.09	<0.08	<0.05	<0.07	<0.08
Oxychlordane	<0.005	<0.001	<0.005	<0.001	<0.001	<0.005	<0.001	<1.1	<0.68	<0.89	<0.75	<0.48	<0.6	<0.73
trans-Chlordane	<0.005	<0.001	<0.005	<0.001	<0.001	<0.002	<0.001	<0.11	<0.07	<0.09	<0.08	<0.05	<0.06	<0.07
cis-Chlordane	<0.005	<0.001	<0.005	<0.001	<0.001	<0.002	<0.001	<0.12	<0.07	<0.10	<0.08	<0.05	<0.07	<0.08
trans-Nonachlor	<0.005	<0.001	<0.005	<0.001	<0.001	<0.01	<0.001	<0.12	<0.07	<0.10	<0.08	<0.05	<0.07	<0.08
cis-Nonachlor	<0.005	<0.001	<0.005	<0.002	<0.001	<0.01	<0.001	<0.11	<0.06	<0.08	<0.07	<0.04	<0.06	<0.07
Mirex	<0.005	<0.001	<0.005	<0.001	<0.001	<0.01	<0.001	<0.04	<0.05	<0.04	<0.03	<0.02	<0.03	<0.03
Heptachlor epoxide	<0.005	<0.001	<0.005	<0.001	<0.001	<0.002	<0.001	<0.01	<0.01	<0.01	<0.008	<0.01	<0.008	<0.009
alpha-Endosulphan I	<0.005	<0.001	<0.005	<0.001	<0.001	<0.01	<0.001	<0.07	<0.04	<0.04	<0.03	<0.02	<0.02	<0.03
Dieldrin	<0.005	<0.001	<0.005	<0.001	<0.001	<0.01	<0.001	<0.01	<0.01	<0.02	<0.01	<0.01	<0.01	<0.01
Endrin	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.05	<0.05	<0.06	<0.03	<0.04	<0.03	<0.03
Methoxychlor	<0.005	<0.005	<0.005	<0.005	<0.005	<0.01	<0.005	<0.04	<0.04	<0.05	<0.03	<0.03	<0.03	<0.03

(continued on next page)

Table 5.11 (cont'd)

Sample	RA96-01-02	RA96-02-02	RA96-03-02	Blank	RA96-04-02	RA96-05-02	RA96-06-02	RA96-01-03	RA96-02-03	RA96-03-03	RA96-04-03	RA96-05-03	RA96-06-03	RA96-07-03
Est. Distance from Closest Point Source (m.)	*0-10*	*130*	*110*		*300*	*1100*	*1600*	*0-10*	*130*	*110*	*300*	*1100*	*1600*	*50*
Batch (Axys)	CL-0889	CL-0889	CL-0889	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896	CL-0896
Type	roots	roots	roots		roots	roots	roots	berries	berries	berries	berries	berries	berries	berries
	(ng/g wet)	(ng/g wet)	(ng/g wet)		(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)	(ng/g wet)
% lipid	0.16	0.18	0.26		0.16	0.17	0.19	0.59	0.38	0.41	0.54	0.72	0.21	0.23
% moisture														
o,p'-DDE	**0.04**	<0.02	**0.03**	<0.03	**0.04**	<0.04	<0.02	<0.02	<0.03	<0.02	<0.03	<0.02	<0.02	<0.03
p,p'-DDE	**2.8**	**3.6**	**2.5**	<0.04	**4.9**	**0.25**	**0.06**	**0.21**	**0.1**	**0.06**	**0.18**	**0.06**	**0.06**	**0.13**
o,p'-DDD	**0.13**	<0.03	**0.15**	<0.05	<0.04	<0.03	<0.04	**0.09**	<0.04	<0.03	<0.04	ndr 0.04	<0.03	<0.05
p,p'-DDD	**0.47**	**0.33**	**0.75**	<0.05	**0.33**	<0.05	<0.04	**0.13**	<0.05	<0.03	<0.04	<0.03	<0.04	<0.05
o,p'-DDT	**3**	**1.4**	**1.5**	<0.07	**0.74**	**0.16**	<0.09	**0.62**	**0.3**	<0.07	**0.2**	**0.12**	**0.18**	**0.16**
p,p'-DDT	**16**	**9.3**	**13**	<0.06	**6.9**	**1.1**	**0.35**	**1.3**	**0.62**	**0.17**	**0.47**	**0.39**	**0.47**	**0.33**
HCB	<0.05	<0.05	0.04	0.03	<0.05	<0.05	<0.05	<0.05	<0.04	<0.04	<0.04	<0.05	<0.05	<0.04
alpha HCH	<0.20	<0.16	<0.15	<0.01	<0.09	**0.14**	**0.35**	<0.07	<0.09	<0.07	<0.14	<0.08	<0.08	<0.13
beta HCH	<0.34	<0.27	<0.23	<0.16	<0.14	<0.15	<0.16	<0.11	<0.15	<0.12	<0.23	<0.13	<0.14	<0.21
gamma HCH	<0.30	<0.24	<0.20	<0.14	<0.13	<0.13	ndr 0.21	<0.10	<0.13	<0.10	<0.21	<0.11	<0.12	<0.19
Heptachlor	<0.42	<0.37	<0.32	<0.47	<0.38	<0.23	<0.32	<0.20	<0.37	<0.22	<0.31	<0.25	<0.24	<0.40
Aldrin	<0.10	<0.08	<0.07	<0.17	<0.13	<0.09	<0.12	<0.05	<0.10	<0.08	<0.12	<0.07	<0.08	<0.13
Oxychlordane	<0.91	<0.79	<0.69	<1.00	<0.85	<0.48	<0.69	<0.53	<0.78	<0.48	<0.61	<0.60	<0.52	<0.55
trans-Chlordane	<0.09	<0.08	<0.07	<0.12	<0.10	<0.07	<0.07	<0.06	<0.09	<0.06	<0.08	<0.07	<0.07	<0.09
cis-Chlordane	<0.10	<0.08	<0.07	<0.13	<0.01	<0.08	<0.07	<0.06	<0.09	<0.07	<0.08	<0.07	<0.07	<0.10
trans-Nonachlor	<0.10	<0.08	<0.07	<0.11	<0.10	<0.07	<0.08	<0.06	<0.09	<0.07	<0.09	<0.06	<0.07	<0.01
cis-Nonachlor	<0.09	<0.07	<0.06	<0.09	<0.09	<0.06	<0.06	<0.05	<0.07	<0.06	<0.08	<0.05	<0.06	<0.08
Mirex	<0.04	<0.04	<0.04	<0.06	<0.06	<0.05	<0.06	<0.06	<0.07	<0.05	<0.06	<0.06	<0.04	<0.06
Heptachlor epoxide	<0.01	<0.03	<0.01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
alpha-Endosulphan I	<0.1	<0.06	<0.03	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Dieldrin	<0.02	<0.04	<0.01	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Endrin	<0.04	<0.13	<0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Methoxychlor	<0.04	<0.11	<0.04	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

- If it is assumed that DDT adsorption to *Vaccinium* leaves and shoots is typical of other deciduous bushes in the vicinity of Rainy Hollow, then the maximum concentration of DDT, expressed as sumDDTs, available for consumption by medium to large herbivores is ≤ 11 ng/g (ppb) wet weight. The geometric mean concentration over the entire area influenced by short range transport of DDT from Rainy Hollow would be much less than this; i.e., ≤ 2 ng/g wet weight. Implications of the redistribution of DDT into the terrestrial environment is discussed in more detail in Chapter 6 as part of the risk assessment.

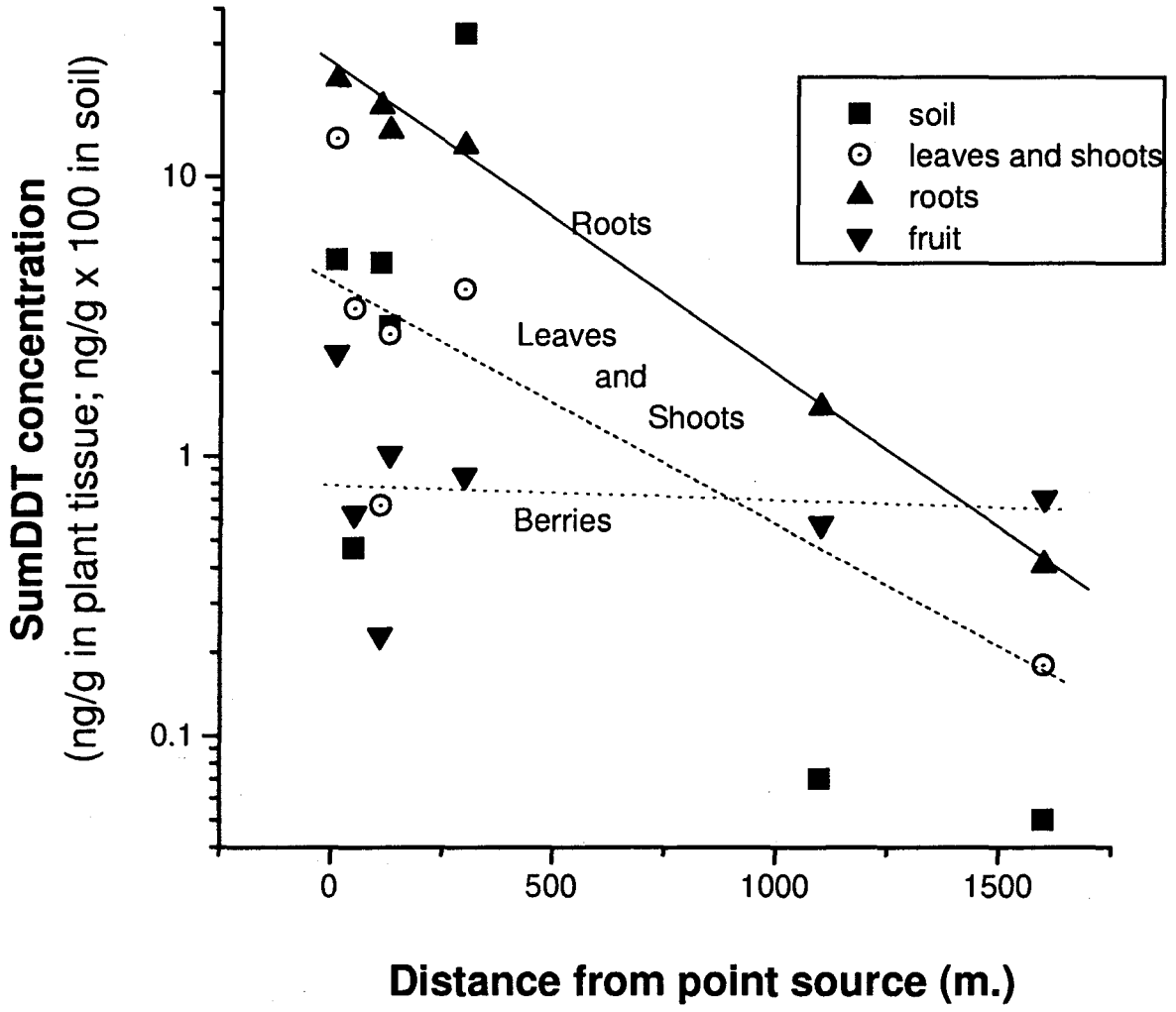


Figure 5.7: Decline away from the point source of total DDT concentration in forest soil and blueberry tissue

Small mammals were collected and analyzed for chlorinated pesticides in order to examine localized uptake of DDTs into terrestrial food chains, and implications for predators feeding in the vicinity of Border Station and Rainy Hollow. The data for chlorinated pesticide concentrations in the whole carcasses of shrews (*Sorex* sp.), deer mice (*Peromyscus maniculatus*) or voles (*Microtus* sp.) are presented in Table 5.12, immediately below. A detailed discussion of the implications of DDT bioaccumulation by small mammals at the site is provided in Chapter 6 as part of the ecological risk assessment.

Table 5.12: DDT Concentrations in Small Mammals from Rainy Hollow

Sample	Blank	RA96-100	RA96-101	RA96-102	RA96-103	RA96-104	RA96-105	RA96-106	RA96-107	RA96-108
Batch	CL-0897	CL-0897	CL-0897	CL-0897	CL-0897	CL-0897	CL-0897	CL-0898	CL-0899	CL-0900
		shrews[1]	deer[2] mouse	deer mouse	deer mouse	vole[3]	deer mouse (Temp. Storage Facility)	deer mouse	deer mouse	vole
% lipid		4.0	4.6	3.8	2.6	3.4	3.0	2.7	2.5	4.6
Chlorinated pesticides, ng/g wet weight										
o,p'-DDE	<0.04	<0.04	<0.03	<0.04	<0.03	<0.01	<0.07	<0.02	<0.03	<0.03
p,p'-DDE	<0.04	**3500**	**2.0**	**4.9**	**200**	**310**	**1.9**	**24**	**0.16**	**8.5**
o,p'-DDD	<0.04	**1.5**	**0.1**	**0.21**	**0.24**	**0.1**	<0.07	**0.09**	<0.03	<0.05
p,p'-DDD	<0.04	**480**	**0.67**	**1.9**	**17**	**20**	**0.32**	**6.0**	**0.04**	**0.69**
o,p'-DDT	<0.04	**3.7**	**0.49**	**1.1**	**1.8**	**0.27**	**0.21**	**0.19**	<0.06	**0.48**
p,p'-DDT	<0.04	**2500**	**3.3**	**7.5**	**100**	**120**	**1.2**	**11**	**0.25**	**5.6**
Hexachlorobenzene	<0.02	**0.05**	**0.08**	**0.15**	**0.4**	**0.05**	**0.15**	**0.07**	**0.08**	**0.18**
alpha HCH	<0.05	<0.09	<0.05	<0.05	<0.05	**0.08**	<0.16	**0.07**	<0.06	<0.07
beta HCH	<0.09	<0.12	<0.09	<0.08	<0.08	<0.04	<0.28	<0.06	<0.10	<0.12
gamma HCH	<0.08	<0.10	<0.08	<0.08	<0.07	<0.04	<0.24	<0.06	<0.09	<0.10
Heptachlor	<0.41	<0.33	<0.53	<0.15	<0.28	<0.10	<0.93	<0.20	<0.34	<0.32
Aldrin	<0.09	<0.15	<0.12	<0.07	<0.08	<0.02	<0.25	<0.07	<0.10	<0.11
Oxychlordane	<0.55	<0.63	<0.46	<0.30	<0.40	<0.15	<0.99	<0.30	<0.38	<0.31
trans-Chlordane	<0.08	<0.09	<0.12	<0.04	<0.06	<0.02	<0.20	<0.04	<0.07	<0.08
cis-Chlordane	<0.08	<0.09	<0.13	<0.04	<0.07	<0.03	<0.02	<0.05	<0.03	<0.08
trans-Nonachlor	<0.09	<0.12	<0.12	<0.05	<0.06	<0.03	<0.20	<0.05	<0.08	<0.07
cis-Nonachlor	<0.08	<0.15	<0.1	<0.04	<0.05	<0.02	<0.17	<0.04	<0.07	<0.06
Mirex	<0.04	<0.11	<0.06	<0.07	<0.06	<0.02	<0.12	<0.04	<0.07	<0.06
Heptachlor epoxide	<0.02	**0.18**	<0.03	**0.05**	ndr (0.15)	**0.04**	<0.04	**0.05**	**0.04**	<0.02
alpha-Endosulphan I	<0.02	**0.15**	<0.02	<0.02	<0.02	<0.02	<0.04	<0.01	<0.01	<0.02
Dieldrin	<0.02	**0.82**	**0.07**	**0.1**	<0.06	<0.02	<0.06	<0.02	<0.04	**0.18**
Endrin	<0.07	<0.09	<0.06	<0.08	<0.17	<0.07	<0.16	<0.05	<0.05	<0.08
Methoxychlor	<0.06	ndr (10)	<0.14	<0.07	<0.15	<0.06	<0.14	<0.04	<0.05	<0.07

1:shrews - *Sorex* sp.

2: Deer mouse - *Peromyscus maniculatus*

3: vole - *Microtus* sp.

The single sample made of of three pooled shrews (RA96-100) exhibited a sumDDT concentration of approximately 6,500 ng/g (wet weight). Individual deer mouse or voles contained sumDDT concentrations in the range of 0.45 to 450 ng/g. For all samples, the compounds p,p'-DDE and p,p'-DDT comprised the major portion of the body burden of chlorinated pesticides.

The very large range in whole body tissue concentrations in different small mammal samples (a range encompassing more than four orders of magnitude variation) is probably attributable in varying degrees to two factors:

- DDT is unevenly distributed in surface soils at Rainy Hollow and Border Station, and samples collected varied in concentration from <0.1 mg/kg to 137 mg/kg. These small mammals have very small home ranges, as discussed in Chapter 6. Small scale variation in DDT soil concentrations undoubtedly influence the extent of bioaccumulation.

- Different species, and individuals within a species, exhibit large differences in foraging behaviour - especially in the relative contribution of different food items to their diet. Shrews, being insectivores, are expected to have higher DDT levels than the primarily herbivorous moles and deer mice.

The small number of samples analyzed and sampling design precludes detailed conclusions about the quantitative relationship between DDT concentrations in surface soils and bioaccumulation in small mammals. The large range in tissue concentrations, however, suggests that higher tissue levels observed may be specifically associated with feeding in highly contaminated materials (e.g., < 10 mg/kg sumDDTs in soil) rather than areas with soils containing 0.5 to 2 mg/kg sumDDTs, which are more widely distributed around Rainy Hollow and Border Station.

5.7 Dioxins and Furans along the Pipeline Right-of-Way or Airstrip Clearing

Three soil samples were analyzed for 2,3,7,8-substituted tetra to octachlorinated dibenzo-p-dioxins and dibenzofurans (hereafter referred to as dioxins and furans). The sampling locations and descriptions are provided in Section 3.1.4.5. Samples ROW96-01 and -02 were collected along the right-of-way and ROW96-03 was collected from the south end of the airstrip in an area that has not been disturbed in the last decade. All sampling locations were chosen to represent worst-case scenarios; ie. in low areas that are recipients of surface runoff from larger adjacent areas likely to have been sprayed with 2,4,5-T The dioxin and furan data for these three samples is provided in Figure 5.8 as well as Table 5.13.

Overall, the concentrations of dioxins and furans were among the lowest recorded for surface soil samples in the Canadian Arctic, and provide no evidence for either the past application of 2,4,5-T in the vicinity of Border Station or of any

risks to humans or wildlife in association with dioxins and furans. None of the individual 2,3,7,8-substituted congeners that are considered to exhibit toxicity were detected (2,3,7,8-substituted PCDD/Fs with Ah receptor mediated toxicity were less than the analytical detection limits). It is possible that 2,4,5-T was not used on this portion of the Haines-Fairbanks Pipeline. The pipeline right-of-way within a short distance north of Border Station occurs above the tree line, in sub-alpine and alpine meadows. Re-vegetation of these areas was possibly sufficiently slow to preclude the local need for herbicide application.

Table 5.13: Dioxin and Furan Concentrations (pg/g) in Soil Samples Collected in the General Vicinity of Rainy Hollow

Analyte	ROW96-01	ROW96-02	ROW96-03
TeCDDs	2.3	1.4	0.3
PeCDDs	<0.3	<0.2	0.3
HxCDDs	0.4	<0.4	1.7
HpCDDs	3.1	2.0	5.6
OCDD	6.9	4.3	23
TeCDFs	2.6	1.1	3.4
PeCDFs	<0.3	<0.2	4.8
HxCDFs	<0.6	<0.6	0.9
HpCDFs	<0.8	<0.7	1.5
OCDF	<1.0	<1.0	1.2
2,3,7,8-TCDD	<0.2	<0.2	<0.1
1,2,3,7,8-PeCDD	<0.3	<0.2	<0.2
1,2,3,4,7,8-HxCDD	<0.4	<0.4	<0.3
12,3,6,7,8-HxCDD	<0.4	<0.4	<0.3
1,2,3,7,8,9-HxCDD	<0.4	<0.4	0.3
1,2,3,4,6,7,8-HpCDD	<0.6	<0.6	2.9
2,3,7,8-TCDF	0.2	<0.2	0.8
1,2,3,7,8-PeCDF	<0.3	<0.2	0.2
2,3,4,7,8-PeCDF	<0.3	<0.2	0.8
1,2,3,4,7,8-HxCDF	<0.6	<0.6	<0.5
1,2,3,6,7,8-HxCDF	<0.6	<0.6	<0.5
2,3,4,6,7,8-HxCDF	<0.6	<0.6	<0.5
1,2,3,7,8,9-HxCDF	<0.6	<0.6	<0.5
1,2,3,4,6,7,8-HpCDF	<0.8	<0.7	0.8
1,2,3,4,7,8,9-HpCDF	<0.8	<0.7	<0.6

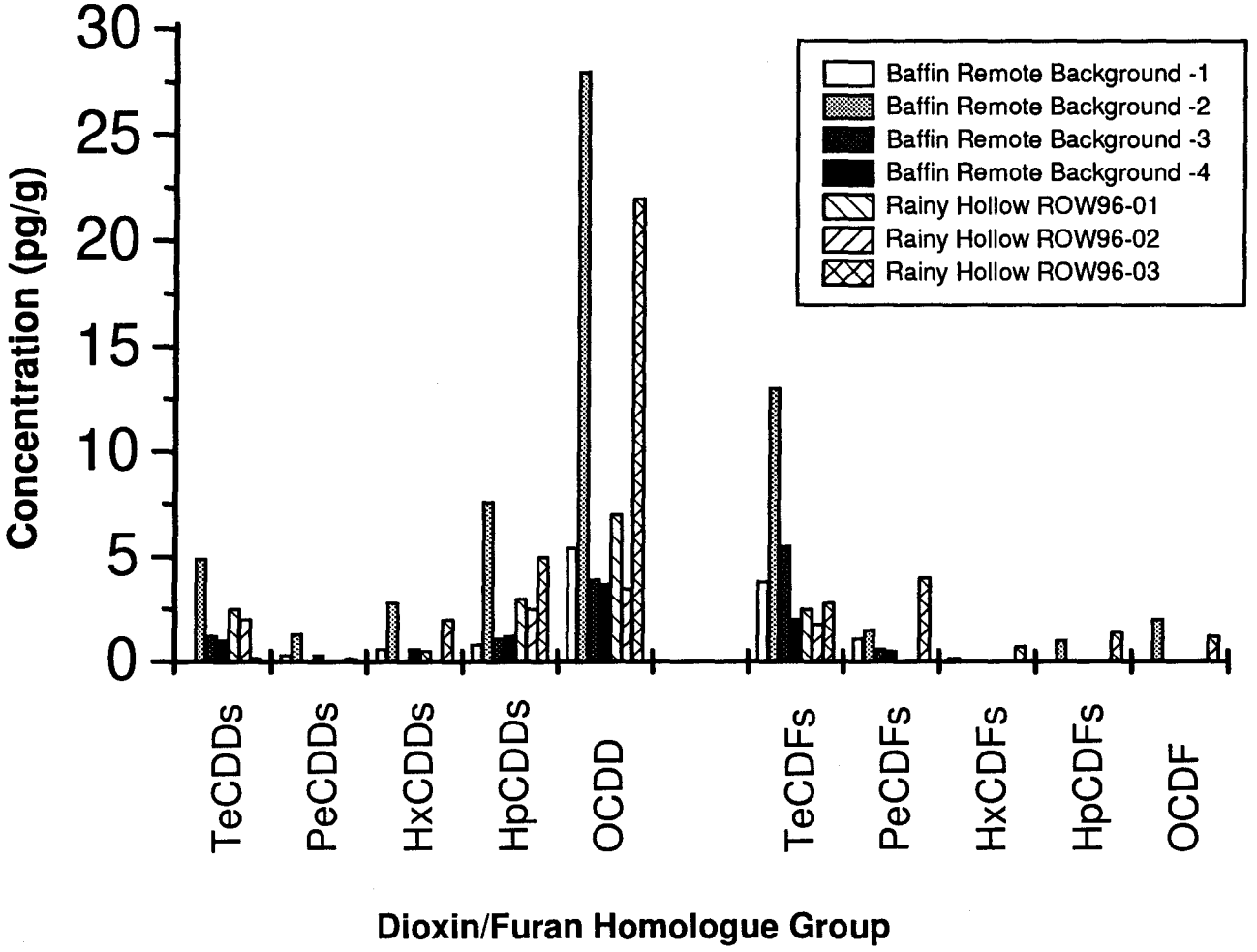


Figure 5.8: Dioxin and Furan Concentrations in Soil Samples from Rainy Hollow and other Uncontaminated Reference Locations in the Eastern Arctic

6. SCREENING LEVEL HUMAN HEALTH AND ECOLOGICAL RISK ASSESSMENT

6.1 Preliminary Considerations

6.1.1 General Considerations

The potential human and ecological health risks at the Rainy Hollow/Border Station were examined using a screening level risk assessment. This type of assessment allows for use of various conservative exposure assumptions in place of numerous site-specific values used for exposure parameters in a detailed risk assessment. For example, site-specific data were used to characterize contaminant source concentrations (e.g., soil contaminants, groundwater contaminants and soil particle size distribution), while conservative assumptions using professional judgment were employed to describe some aspects of contaminant fate and bioaccumulation, site usage and receptor ecology/behaviour.

Screening risk estimates conducted in this manner are likely to generate estimates of health risk that are greater than would otherwise be calculated using detailed site-specific data, since all assumptions made are intentionally conservative.

The objectives of the risk assessment were to address the following general questions:

i) Do the observed contaminant concentrations at Border Station and Rainy Hollow present concerns for human health and/or health of other living organisms?

ii) What are the relevant exposure pathways of concern?

iii) What are the magnitude of health risks based on conservative assumptions and potential health concerns for humans frequenting the site?

Our intent in providing information relevant to these questions is to provide a basis for addressing the basic risk management questions:

iv) Is there a need to implement further risk reduction measures at the Site?

And if so,

v) Where and in what manner should risk reduction measures be implemented?

6.1.2 Regulatory Considerations of Contaminant Levels

The contaminant concentrations and distribution at Rainy Hollow/Border Station have been discussed in detail in Chapter 5.0. The location of the site in the Province of B.C., within the Tatshenshini-Alsek Provincial Park, make B.C. Soil Criteria for Parkland (BC MELP Draft 3 Regulations; 1995) an applicable and relevant source of soil criteria, as discussed in Section 4.2. The federal CCME criteria for residential/parkland provide additional criteria and guidance. Finally, concerns about possible contaminant (i.e., deleterious substance) inputs to the Klehini River raise questions about the applicability of the Canada Fisheries Act at this site. The B.C. and CCME soil and water reference criteria or standards have been incorporated in the various contaminant data summary tables presented in Chapter 5.

6.1.3 Stakeholder Considerations

The views and concerns of stakeholders were sought and integrated into this assessment. The concerns helped guide the development of the conceptual exposure models. In broad terms, the primary stakeholders identified for the Rainy Hollow/Border Station included -

i) First Nations Residents and Land Users, including the Champagne and Aishihik First Nations, Haines Junction;

ii) Local Residents near Canada/U.S. Border (Canada Customs employees and their families);

iii) B.C. Ministry of Environment, Lands and Parks;

iv) Department of Indian Affairs and Northern Development (DIAND)

Informal discussions were conducted with representatives of the above stakeholder groups during the developmental stages and field sampling portion of the site investigation. In addition, reports were obtained from the Whitehorse office of DIAND which described typical dietary components of the local First Nations (i.e., food basket studies).

6.2 Problem Formulation

6.2.1 Introduction

Problem Formulation is the first phase in the risk assessment framework used herein. The goal of this phase is to examine the issues and unique aspects associated with a

contaminated site in order to develop an understanding of how the contaminant source may present health risks. A *screening level* health risk assessment is designed to be a conservative first round analysis of the upper bounds of potential health risks presented under specific exposure scenarios. This contrasts with *detailed* quantitative risk assessment in which the risk estimates are better defined by collecting and using additional field data or by using refined models and probabilistic methods for exposure and toxicity assessment. Guidance for conducting this screening risk assessment was obtained primarily from B.C. Environment's Recommended Framework for Risk Assessment (BCE, 1993) and the Health Canada draft document *Human Health Risk Assessment of Chemicals from Contaminated Sites: Volume 1 Risk Assessment Guidance Manual* (unpublished).

In general, three factors must be present for health risks from environmental contaminants to be realized:

i) there must be contaminant(s) at concentrations capable of causing health effects;

ii) there must be a receptor present, or one which makes use of the site, periodically; and

iii) there must be an exposure pathway by which the receptor comes into contact with the environmental contaminant.

These three factors are somewhat interdependent because both the environmental concentration and potential health effects of a contaminant depend upon the pathway by which exposure occurs. The exposure pathway in turn, is influenced by the nature of the receptor (for example, behaviour such as foraging and feeding ecology, lifestyle).

Preliminary conceptual exposure models were developed at an early stage, prior to conducting the supplemental site investigation, and communicated to BC Environment [Memorandum to G. Fox and M. MacFarlane from M. Rankin (July 8, 1996)]. These conceptual models assisted in defining the scope of the field sampling effort. Conceptual exposure models for both the human health and ecological risk assessment have since been modified to reflect new insights derived from the site investigation and discussions with Stakeholders. The problem formulation for human health and ecological risk assessments are discussed separately below.

6.2.2 Human Health Considerations

6.2.2.1 Contaminants of Concern

For the purpose of risk assessment, the contaminants of concern retained for consideration following the screening evaluation of soil and groundwater data (Chapter 5) were DDT and related isomers (DDE and DDD) (see also Chapter 4). Initially the presence of substantial petroleum hydrocarbon contamination of subsurface soils and

groundwater at the site; however, the field data for the detailed site investigation indicate that the substances were present at only low concentrations in surface soils or surface waters. This observation and previous work conducted by Golder (1995) concerning risks from petroleum hydrocarbons, suggested that the observed concentrations at this site do not warrant a further quantitative risk assessment.

Dioxins and furans were eliminated as contaminants of concern based on the analytical data (Section 5.7). The data did not provide any evidence for regionally- or locally-elevated dioxin or furan concentrations, and levels observed were similar to background concentrations in the Arctic that are reflective of long-range atmospheric transport from distant sources. Those dioxin/furan congeners known to exhibit Ah receptor mediated toxicity - the 2,3,7,8-substituted dioxins and furans - were generally below the analytical detection limits in the three soil samples analyzed. No new contaminants of concern were identified as part of the detailed site investigation.

6.2.2.2 Receptors

The anticipated use of the site by humans under present and future land use conditions (i.e., parkland) includes visits by First Nations people who potentially gather plants and berries, hunt and trap, as well as others who periodically use the site primarily for recreation. These people, therefore, would be the major receptors of any bioavailable contaminants.

The First Nations people potentially exposed are members of the Champagne and Aishihik in the vicinity of Haines Junction, and in surrounding areas. Visits to Rainy Hollow may be limited to a single day or perhaps longer in duration, and the visit could potentially include overnight camping. The remains of several recent campfires were evident at Rainy Hollow during July, 1996.

Individuals other than First Nations residents, for example residents near the local Canada/U.S. border crossing, have used the site in the past for recreational purposes such as day trips and overnight camping. Discussions with Canada Customs personnel suggested that most frequent users of the general area in the past tended to pass by the area enroute to areas farther north on the Old Haines Highway rather than spending extended periods of time (on a daily basis) in the immediate vicinity of Rainy Hollow and Border Station. Future recreational use of the area around the site and/or the site itself is likely. The site usage pattern of the above two user groups could in some cases be quite similar; however, an assumption was made that First Nations individuals may use the site more frequently and over a longer period of their life, given their potential interest in procuring traditional food items. The recreational users were hypothesized to use the site to a lesser extent in both frequency and duration over the long term. For these reasons, the risk characterization in this report focuses on First Nations 'receptors', with very conservative assumptions to maximize site usage (in other words, an intentional over-estimation of the period of time an individual would spend at the site within one year) and consequent exposure and risk. Risks to recreational and infrequent users, therefore, will actually be much lower than estimated here.

6.2.2.3 Exposure Pathways

Exposure pathways involve both environmental transport pathway and route(s) of uptake into the body. The three plausible routes of uptake include some form of ingestion (e.g., dietary or incidental), inhalation (breathing of vapours and airborne particulates), and absorption across the skin (dermal contact). Some contaminant uptake routes are more important than others for risk, depending on the chemical properties of the substance involved, and likely environmental fate. For the risk assessment, emphasis was placed on exposure pathways with a high likelihood of being operable and quantitatively significant, while pathways considered to be inoperable or of very minor significance were excluded. The important pathways of human exposure in the present case were deemed to include potential exposure from incidental soil ingestion, dermal contact and fugitive dust inhalation. Emphasis on soil ingestion and fugitive dust inhalation was considered important, based in part on observations during the July site visit. In spite of the large volume of rainfall that the site receives annually, the largely barren soils around the Trench at Rainy Hollow or the Temporary Storage Facility at Border Station (removed in October 1996) were extremely dry. The surface soils are made up of fine sand and silts with little organic matter, and were readily entrained in wind currents of even moderate strength. Vehicular traffic also creates large amounts of fugitive dust during dry conditions, at least in areas with minimal amounts of vegetative cover.

It is also recognized that dietary uptake of DDT through the consumption of local small and/or large game, plants or berries is possible, in light of interviews with First Nations members and local residents. The tissue residues of DDT and related compounds in small rodents or insectivorous shrews collected from the site indicate the potential for DDT accumulation in some local mammals. However, these small mammals are not likely to be representative of larger game (e.g., bears, rabbits, and especially moose) which may be hunted or trapped in this area. These larger species have much larger home ranges; therefore, the dietary component contributed by the foraging in the vicinity of Rainy Hollow is undoubtedly only a small portion of the total dietary intake. Therefore, tissue concentrations are expected to be much lower than those of resident small mammals.

Data on DDT concentrations in annual growth (leaves and shoots) or berries of blueberries were collected as one method for estimating the possible uptake into large herbivores such as moose. As noted in Chapter 5, the fruit of blueberries did not exhibit elevated DDT concentrations even in areas within 10 m of the Trench at Rainy Hollow (possible explanations are provided in Chapter 5). The uptake of DDT in association with the ingestion of blueberries can therefore be eliminated outright as a possible component of either human health or ecological risk. The sumDDT (DDT + DDE + DDD) concentrations in roots and shoots within a 1 to 2 km radius of Rainy Hollow, based on the analytical data provided in Table 5.8, exhibited a geometric mean concentration of 0.0013 mg/kg (wet weight basis), with a maximum and minimum concentration of 0.010 and 0.00018 mg/kg wet wt. respectively. The observed logarithmic decline in concentration away from the site suggests that blueberry foliage outside of the 2 km radius would exhibit sum DDT concentrations < 0.0003 mg/kg. While some reports exist for small rodents (e.g., voles, shrews, etc.), there are none that provide specific guidance on

bioaccumulation factors (BAFs) from terrestrial vegetation, especially woodland shrubs, to large transient herbivores such as moose, elk, deer or caribou. Mackay (1995), however, suggests that biomagnification factors (BMFs) in terrestrial food webs for highly hydrophobic organic substances such as DDT are around 10. This is probably an over-estimate. Assuming a BMF of 10 and a foliar concentation of 0.0013 mg/kg sumDDTs, the maximum whole body tissue concentration in a moose feeding 100% of the time within a 2 km radius of Rainy Hollow would be around 0.013 mg/kg or less. Based on the toxicity reference dose as described below, a 70 kg person would need to consume to an average of 2.6 kg moose meat per day, or approximately 980 kg per year in order obtain doses of sumDDT that approach the minimum levels estimated to be associated with elevated risk.

A diet-based DDT uptake estimate, however, was excluded from the human health risk assessment: The above-mentioned scenario is considered unreliable for the following reasons:

i) there is no scientific basis for estimating uptake (BAFs) of DDT from foliage by large herbivores including moose, since the scientific literature is essentially silent on this issue. Furthermore, the actual concentrations of DDT will undoubtedly vary from one tissue to the other, as well as between individual animals. These factors are difficult to predict at the present time;

ii) the foraging range of moose and other transient herbivores is much larger than the 2 km radius around Rainy Hollow, but an accurate estimate of the ranges of moose or other herbivores in the southern portion of Tatshenshini - Alsek Park/Chilkat River area of Alaska in not available; and

iii) The types of vegetation sampled and analyzed (one deciduous species only) preclude a reasonable estimation of DDT dietary intake by herbivores in the vicinity of the site. Blueberry and other deciduous foliage is limited in its availability both seasonally and geographically.

While resolution of items i) and ii) would tend to further lower the estimate of risk related to DDT from game consumption, better information with regard to item iii) could either elevate or lower the calculated risk in a presently unpredictable fashion. The assessment of risk for any contaminant for which toxic effects are mediated by food web transfer is strongly influenced by the food-to-consumer bioaccumulation factor(s) (BAFs) used in deriving estimates of risk. A BAF from plants to moose, for example, of 1 instead of 10 - an estimate that is well within the realm of possibility - would imply that a 70 kg person would need to consume an average of 26 kg moose meat per day to be at risk (instead of 2.6 kg/day; see above). We were unable to obtain samples of moose or other herbivore tissue for the direct analysis of DDT concentrations in game. Therefore, it is necessary to acknowledge some small untested potential for exposure via this pathway. This is further discussed in Section 6.3.1.

6.2.2.4 Conceptual Exposure Model for Humans

In light of the previous considerations, the preliminary conceptual exposure model was edited appropriately to signify those exposure pathways which are either of minimal importance or inoperable, considered significant and retained for further assessment, or considered operable but lacking adequate data for assessment (e.g., dietary intake from local game). This is illustrated in Figure 6.1

PRELIMINARY CONCEPTUAL EXPOSURE MODEL - HUMAN RECEPTORS

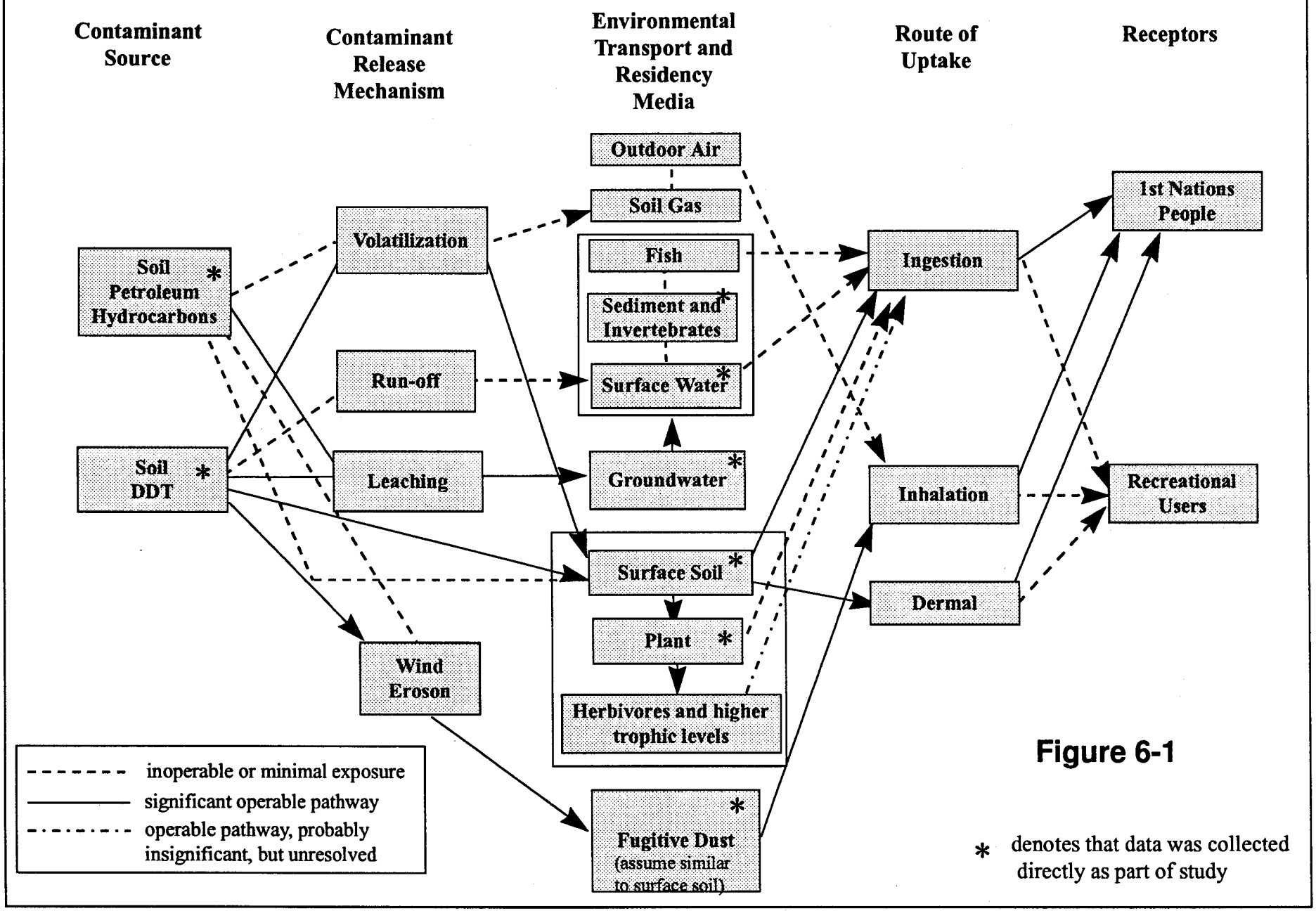


Figure 6-1

6.2.3 Ecological Problem Formulation

6.2.3.1 Contaminants of Concern

The contaminants of concern retained for further consideration with regard to ecological receptors following the screening evaluation and detailed site investigation are largely dependent on the pathway of interest. Ecological receptors potentially include all living organisms at the site, excluding humans. For all pathways, inorganic constituents (e.g. various metals and other inorganic constituents) were not considered further based on low observed concentrations and/or low inherent toxicity.

Earlier concerns by site managers focused on possible movement of DDT and hydrocarbons toward and into the Klehini River *via* groundwater or surface run-off. The analytical data (Chapter 5) demonstrate that this is not a major concern at the present time. DDT, DDE or DDD concentrations in sediments, stream invertebrates or river water samples collected within the Klehini River and adjacent to Rainy Hollow could not be distinguished from concentrations at reference sites upstream or downstream. Given the high persistence and strong tendency of DDT to accumulate in both biota and organic components of sediments, this data indicates that DDT is not a contaminant of concern for either aquatic receptors in the Klehini River, or predators on aquatic biota such as bald eagles. Possible risk pathways for contamination of the Klehini River and its inhabitants could be confidently ruled out, since the dose to aquatic organisms contributed from contaminated areas at Rainy Hollow *via* sediment or river water was essentially zero. All aquatic ecological risk pathways were excluded for further risk assessment. The same conclusion with similar rationale was made for petroleum hydrocarbons and aquatic receptors.

For terrestrial receptors, DDT levels in surficial soil were sufficiently high to warrant further consideration. The concern is exemplified by isolated soil samples collected in the vicinity of the Rainy Hollow trench (Table 5.7), and tissue residues of small rodents collected at the site (Table 5.12).

The analyses of petroleum hydrocarbons, as group parameters, and as specific PAHs, (Table 5.2), did not indicate that excessive levels were present in surface soils at the site, other than in a single confined area of soil staining (TP96-03-1). As this is easily managed through facile removal or remediation, it was concluded that petroleum hydrocarbon are not contaminants of concern for terrestrial biota at Rainy Hollow or Border Stations.

Analysis of soil samples collected in the right-of-way and near the end of the airstrip did not indicate elevated levels of dioxins or furans which were previously contemplated in association with historical application of 2, 4, 5-T (Section 5.7). As the observed values were among the lowest recorded for surface soils in the Canadian Arctic, the substances were excluded from further consideration.

6.2.3.2 Ecological Receptors

A possible list of ecological receptors was provided previously in the preliminary conceptual exposure model provided to BCE (July 8, 1996, Memorandum to G. Fox and M. MacFarlane from M. Rankin, Golder Associates); further comments are provided here. It is necessary to define a subset of living organisms for ecological risk assessment based on a number of factors, including -

- their perceived importance to Stakeholders;
- their known presence around the site either habitually or as transient migrants through the area;
- inclusion of sensitive, rare, and/or endangered species;
- a reasonable understanding of the organism's physiological and population ecology; and
- inclusion of keystone or highly influential species that have substantially larger than average influence on the surrounding ecosystem.

The aquatic receptors considered initially included benthic insect invertebrates and juvenile Dolly Varden char that are routinely present in the Klehini River, adjacent to Rainy Hollow. Of particular concern was bald eagle populations, particularly downstream within the Chilkat Bald Eagle Reserve, which might bioaccumulate DDT from eating contaminated salmonids. Larger fish such as longnose sucker, mountain whitefish, grayling, or sea-run salmon have not been observed this far up the Klehini River either during the 1994, 1995 and 1996 site visits or by long term residents of the area. This is consistent with the general view that this section of the Klehini River is generally low in productivity, typical of many silty glacier fed rivers. As noted earlier, the analysis of stream bed invertebrates and sediment for chlorinated pesticides, including DDTs, did provide not any evidence for locally elevated contaminant concentrations. This infers that these theoretical receptors are not receiving DDT exposure in association with inputs from Rainy Hollow, in spite of DDT's persistence and bioaccumulative properties. The evidence infers that aquatic receptors such as fish do not contribute to potential trophic transfer to piscivorous raptors or mammals in the area.

Potential terrestrial receptors, as discussed in Chapter 2, include soil invertebrates and other insects, plants, small herbivores (e.g., voles, mice, hare, small birds) or insectivores/omnivores (shrews and small birds) and larger mammals which are either herbivores (e.g., moose), carnivores (e.g., foxes and coyotes) or omnivores (e.g., grizzly or black bear). The possibility of risks to insects or insect larvae, other soil invertebrates or plants, is rarely embraced as being of direct concern during ecological risk assessments unless the species involved are either rare or endangered, of commercial importance, or are useful as bioindicators of possible effects to other species. Rather, plants and invertebrates are usually considered in light of their role as vectors of exposure and risk to

larger, often vertebrate species including herbivores and predators.

General observations of the site indicated vegetative cover to be significant (Chapter 2) with poorly vegetated areas essentially limited to areas of past disturbance by heavy equipment and/or vehicles. There is considerable use of the site by small wild life, and an impressive diversity of plants, birds and mammals around the site (anecdotal observations: formal wildlife and resource surveys were not carried out). The riparian habitat between the old airstrip clearing at Rainy Hollow and the Klehini River, in particular, may support a large number of small birds, mammals and other flora and fauna.

Limited areas of isolated hydrocarbon-stained soils in the northern portion of Rainy Hollow showed signs of phytotoxity wherein vegetative cover was eliminated or scarce. Confirmatory evidence of small mammal exposure to DDTs was obtained through tissue analysis, as previously presented in Chapter 5 (Table 5.12). These small mammals represented both herbivores and omnivores, and substantiate the consideration of small mammals occupying similar niches. Additionally, these animals are prey for larger predators and implicate them as receptors through trophic level transfer (e.g., to fox).

The territorial range of these small mammals is fairly small, on the order of less than a 50 m radius (US EPA 1994) (Table 6.1). Therefore, the population of small mammal receptors considered as site-associated receptors (i.e., maximally exposed) is also expected to be relatively small and localized. With regard to population level effects for small mammals, therefore, any possible population-level impacts associated with adverse effects on individuals would undoubtedly be offset by immigration from healthy sub-populations outside of the immediate zone of high DDT contamination.

Table 6.1: Estimated life history parameters and other characteristics of small mammal species sampled at Rainy Hollow or closely related species (after Sample and Suter, 1996; Burt and Grossheider, 1976)

Parameter	Species					
	Short-Tailed Shrew (*Blarina brevicauda*)	**Masked Shrew** (*Sorex cinereus*)	**Meadow Vole** (*Microtus pennsylvanicus*)	**White Footed Mouse** (*Peromyscus leucopus*)	**Deer Mouse** (*Peromyscus maniculatus*)	**Red Fox** (*Vulpes vulpes*)
• Avg. Body Wt (adult).	0.015 kg (0.011 - 0.022 kg)	0.003 - 0.006 kg	0.044 kg	0.022 kg	0.018 - 0.035 kg	4.5 kg
• Size	76-102 mm long (head and body)	51-57mm long (head and body)	89-127 mm (head and body)	91-107 mm long (head and body)	71-102 mm long (head and body)	
• Food Consumption Rate • (estimated)	mean = 0.009kg/d	Eats >> own weight/d (up to 3x own wt/d)	0.005 kg/d	0.0034 kg/d		mean = 0.45 kg/d
• Water Consumption Rate (estimated)	0.0033 L/d		0.006 L/d	0.0066 L/d		0.38 L/d
• Soil Consumption Rate	0.00117 kg/d (13% of diet)		0.00012 kg/d (2.4% of diet)	< 2% of diet		0.0126 kg/d (2.8%)
• Diet	earthworms: 31.4% slugs, snails: 27.1% soil and litter invertebrates: 13.2% fungi: 8.4% misc. animals: 8.1%	mostly insects, but includes many other small animals	herbivorous; predominantly monocot and dicot shoots; lesser amounts of seeds and roots (esp. in winter); minimal fungi and insects	omnivorous and opportunistic: stores seeds and nuts. arthropods: 30-57% vegetation: 34-67% seeds, fruit	seeds, acorns, insects; stores food.	small mammals: 69% birds: 12% plants: 10.4% insects: 0.9% misc: 5.5%
• Home Range	0.39 ha (Manitoba bog)		Approx. 0.04 to 0.4 ha	0.059 ha	0.2 - 1.2 ha.	700 - 720 ha
• Habitat Requirements	Variable; requires > 50% veg. Cover. Most abundant in hardwood forests with deep litter and humus.	Moist situations in forest, open country, brushland	Grassy fields, marshes and bogs. Near streams, lakes, swamps; nests above or below ground	wooded, brushy areas. Occasionally in the open	Occupies virtually every dryland habitat type within its range. Nests in burrow in ground, trees, stumps and buildings.	wide and diverse: prefer mixture of forest and open habitat
• Population Density	2.3 to 8.1/ha (seasonally variable)	"Concentrations of these shrews have been observed..."	2 - 128/ha	6 - 57/ha	25 - 37/ha in summer; less in winter	0.046 - 0.077/ha
• Behaviour	nocturnal; semifossorial; spends little time above surface. Active year round - does not hibernate	active day or night; nest of dry leaves or grass in stumps of under logs and debris piles	either diurnal or nocturnal depending on local and amount of vegetative cover; active year round: does not hibernate	semi-arboreal, but spends most of time on ground. Primarily nocturnal. Enters torpor to overwinter and during bouts of low food availability		active year round
• Other	Apparently unpalatable to most predators	Breeding season Mar. - Oct.; 2-10 young/litter; probably more than 1 litter/season	Extremely high fecundity relative to many small mammals. Gestation period of 21 d.; 1-9 young/litter; several litters/y. Where they co-occur, vole populations tend to decrease as short-tailed shrew populations increase. 3-4 y population cycle. Lives 1-3 yr in wild	Expected longevity 2-3 y.	Breeding season Feb. - Nov. (but varies with latitude); 1-8 young/litter, but typically 3-5; breed at 5-6 weeks. Rarely lives more than 2 y in wild, but 5-8 years in captivity.	

6.2.3.3 Exposure Pathways

Several exposure pathways were excluded from further quantitative risk assessment based on results from the detailed site investigation and/or direct observations made during the field investigation in July 1996. In particular, all pathways associated with exposure to aquatic organisms and subsequent trophic transfers were considered to have minimal significance or be virtually inoperable. Pathways associated with groundwater contamination by petroleum hydrocarbons were also excluded, since they were of minor significance.

6.2.3.4 Conceptual Ecological Exposure Model

The conceptual ecological exposure model is provided in Figure 6.2. This schematic diagram integrates insights from the detailed site investigation and ecological considerations for the site and was updated from the earlier preliminary ecological conceptual exposure model.

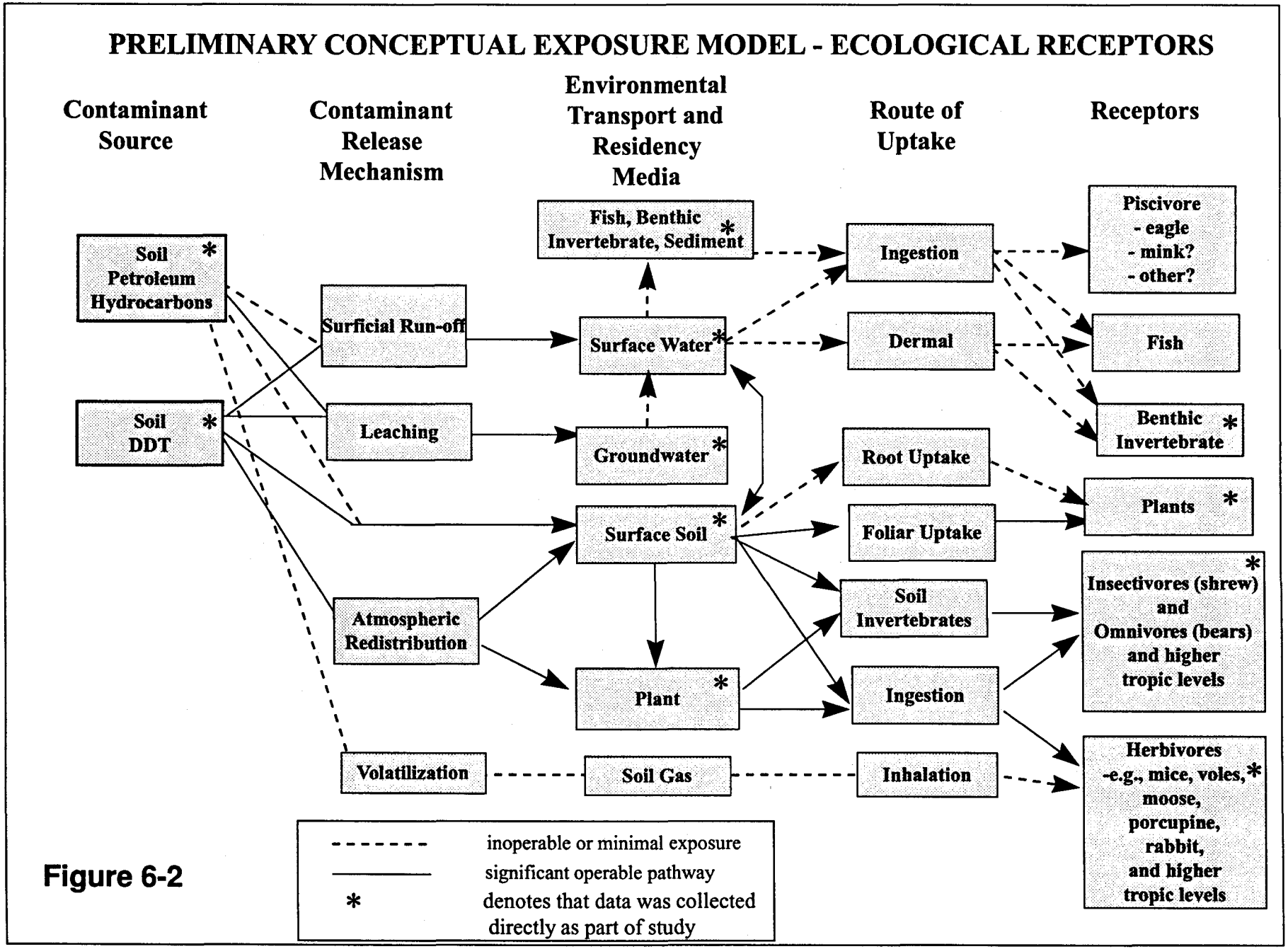

PRELIMINARY CONCEPTUAL EXPOSURE MODEL - ECOLOGICAL RECEPTORS
Contaminant Source
Contaminant Release Mechanism
Environmental Transport and Residency Media
Route of Uptake
Receptors
Soil Petroleum Hydrocarbons *
Soil DDT *
Surficial Run-off
Leaching
Atmospheric Redistribution
Volatilization
Fish, Benthic Invertebrate, Sediment *
Surface Water *
Groundwater *
Surface Soil *
Plant *
Soil Gas
Ingestion
Dermal
Root Uptake
Foliar Uptake
Soil Invertebrates
Ingestion
Inhalation
Piscivore - eagle - mink? - other?
Fish
Benthic Invertebrate *
Plants *
Insectivores (shrew) and Omnivores (bears) and higher tropic levels *
Herbivores -e.g., mice, voles, moose, porcupine, rabbit, and higher tropic levels *
inoperable or minimal exposure
significant operable pathway
* denotes that data was collected directly as part of study

Figure 6-2

6.3 Screening Level Risk Assessment

6.3.1 Human Health Risk Assessment

6.3.1.1 Exposure Assessment for Human Receptors

The exposure assessment for the Rainy Hollow land use was comprised of three primary components; i.e.-

i) determination of receptor and exposure assumptions;

ii) estimation of exposure concentrations using observed contaminant concentrations in soil and predictive modelling of environmental fate and transport where necessary; and

iii) estimation of chemical intake rate.

The exposure assessment was conducted for the scenarios of interest as per the conceptual exposure model for the site (Section 6.2), and is described in the next sections.

Note that the following exposure assessment does not address the potential human exposure via dietary consumption of small or large game that may be obtained from this area. While the conceptual exposure model recognizes this to be a possible but likely minor exposure pathway, pre-existing information cannot be used to provide a reliable estimate of DDT concentrations in relevant game species. Additionally, the lack of tissue residue data for local game confers too much uncertainty for purposes of exposure and risk analysis. Therefore, this exposure pathway remains unquantified.

6.3.1.2 Receptor and Exposure Assumptions

For the Rainy Hollow land-use, the most representative receptor was considered to be a First Nations adult and child hunting/camping at the Site. The exposure pathways quantified were:

i) ingestion of soils;

ii) dermal contact with soil; and

iii) inhalation of fugitive dust.

Exposure factors used to characterize the receptor behaviour (e.g., soil ingestion rate), and physical or physiological parameters (e.g., weight) were primarily derived from CCME (1996). Receptor characteristics are provided in the Table 6.2, below.

Table 6.2: Assumed Characteristics of Human Receptors

Parameter	Child (aged 12-19 years)	Adult (20+ years)
Body Weight	57 kg	70 kg
Soil Ingestion Rate	20 mg/day	20 mg/day
Breathing Rate	21 m^3/day	23 m^3/day
Body Surface Area Exposed	0.43 m^2	0.43 m^2
Soil Dust Adherence Factor	10 g/m^2	10 g/m^2
Duration of Exposure	7 years	60 years
Averaging Time (non-carcinogen)	7 years	60 years

6.3.1.3 Assumptions for Estimation of Exposure Concentrations

Estimation of exposure concentrations was conducted for the three possible exposure pathways noted above. For soil ingestion and dermal contact, no environmental fate and transport models were required. For the dust inhalation pathway, the US EPA RAGS (1991) model for rapid assessment of exposure via fugitive dusts was used. The model used for the dust inhalation pathway is further described in Appendix E.

The primary release mechanisms for fugitive dust emissions is wind erosion. The model requires that a particulate emission factor (PEF) be calculated. The PEF relates the contaminant concentration in soil with the concentration of respirable particles (less than 10 microns, PM10) in the air due to fugitive dust emissions caused by wind erosion. The relationship is derived by Cowherd (1985). The default assumptions provided by EPA (1991) assume that there is no vegetative cover and the surface has "unlimited erosion potential". The model and input variables are described in greater detail in Appendix E. However, in brief, it was assumed that: i) an area of 100 m by 100 m of the site lacked vegetative cover; ii) the mode of the soil particle size distribution was 100 μm (silty soils); and iii) the surface roughness was 1 m (representative of a mountainous area). These assumptions were considered conservative for the Site, resulting in a bias towards higher exposure and risk levels.

An additional key aspect of the model is that dust emissions, and hence exposure,

are assumed to occur periodically for four months of the year when there is no precipitation or snow cover. Therefore, the calculations take into account the number of days when the surficial dust is wet and not amenable to wind erosion.

For calculation purposes, it is assumed the soil concentration for sumDDT was either 173 mg/kg (maximum) or 1.54 mg/kg (geometric mean).

6.3.1.4 Estimation of Intake Rates

The exposure equations used for determination of incidental soil ingestion, dermal contact with soils and inhalation of fugitive dust are defined by the US EPA (1991) and are summarized below.

Note that the *bioavailability* factors for DDT via each exposure pathway are discussed in concert with the toxicity assessment of this substance (Section 6.3.2).

Ingestion of Soil

$$\text{Dose Rate}_{ing} = \frac{IR_{ing} \times C_s \times EF \times ED \times BF \times UCF_1 \times FI}{BW \times AT \times UCF_2}$$

where:

Dose Rate$_{ing}$ = dose rate via soil ingestion (mg/kg-day);
C_s = DDT concentration in soil(dust) (mg/kg);
IR_{ing} = soil ingestion rate (mg/day);
EF = exposure frequency (day/year);
ED = exposure duration (year);
BF = bioavailability factor (unitless);
UCF_1 = unit conversion factor to convert mg soil to kg soil;
FI = fraction of daily soil ingestion derived from site (1.0, conservative);
BW = body weight (kg);
AT = averaging time (year).
UCF_2 = unit conversion factor to convert years to days.

Dermal Absorption of Soil

$$\text{Dose Rate}_d = \frac{C_S \times SDAF \times SA \times BF \times EF \times ED \times UCF_1 \times FI}{BW \times AT \times UCF_2}$$

where all variables as noted for soil ingestion apply, and:

Dose Rated = dose rate via dermal contact (mg/kg-day);
SDAF = soil/dust adherence factor (mg/m^2-day);
SA = body surface area exposed (m^2);
BF = bioavailability factor (unitless);
FI = fraction of daily dermal contact derived from site.

Inhalation - Fugitive Dust

$$\text{Dose Rate}_{inh} = \frac{IR_{inh} \times ET \times C_{FD} \times C_{C\text{-}FD} \times UCF_1 \times EF \times ED \times BF}{BW \times AT \times UCF_2}$$

where:

Dose Rate_{inh} = dose rate via inhalation of fugitive dust (mg/kg-day);
IR_{inh} = inhalation rate (m^3/hr);
ET = exposure time outside (hr/day);
C_{FD} = concentration of fugitive dust in air (mg/m^3);
$C_{C\text{-}FD}$ = concentration of DDT in fugitive dust (mg/kg);
UCF_1 = unit conversion factor to convert mg of dust to kg of dust;
EF = exposure frequency (day/year);
ED = exposure duration (year);
BF = bioavailability factor (unitless);
BW = body weight (kg);
AT = averaging time (year);
UCF_2 = unit conversion factor to convert years to days.

Using the above equations, dose rates were computed for DDTs for human receptors at the Rainy Hollow site. Concentrations of DDT in soil for estimation purposes include the maximum and geometric mean observed values in the vicinity of the Rainy Hollow trench. Sample calculations are provided in Appendix E. Dose rates for these receptors are summarized in the following section.

6.3.1.5 Exposure Assessment Results

The estimated dose rates for receptors potentially exposed to DDT detected in soil (maximum of 173 ppm, and geometric mean of 1.54 ppm) are shown in Table 6.3 for the various exposure pathways.

Table 6.3: Dose Rates for Humans Exposed to DDT in Soils at Rainy Hollow (assuming maximum and geometric mean DDT in soils)

Exposure Pathway	Dose Rate (mg/kg body wt./day)	
	Rainy Hollow	
	maximum (173 ppm)	geometric mean (1.54 ppm)
Child Receptor (12-19 years)		
inhalation of fugitive dust	2.2×10^{-5}	1.9×10^{-7}
ingestion of soils	5.3×10^{-6}	4.7×10^{-8}
dermal contact with soils	1.1×10^{-5}	1.0×10^{-7}
Adult Receptor (20+ years)		
inhalation of fugitive dust	1.9×10^{-5}	1.7×10^{-7}
ingestion of soils	4.3×10^{-6}	3.9×10^{-8}
dermal contact with soils	9.3×10^{-6}	8.3×10^{-8}

6.3.1.6 Toxicity and Bioavailability Assessment

Toxicity assessment involves classification of the potential toxic effects of a chemical or class of chemicals, followed by the estimation of the amount of chemical exposure which can be received by human receptors without the inducement of adverse health effects. Toxicity assessment is conducted for all chemicals of concern, and considers possible modes of toxicity associated with different routes, durations of exposure, and sensitivities of receptors. The toxicity assessment provides an estimate of how much chemical exposure may occur without any adverse health effects (for threshold chemicals), or unacceptable degree of risk (for non-threshold chemicals). For substances exhibiting a threshold for toxicity, the exposure limit, or toxicity reference value, is expressed in the same units as the estimated exposure from the site (e.g., mg/kg body weight-day) and is called a reference dose. For non-threshold chemicals (e.g., some carcinogens), the exposure limit is expressed as a rate of change of risk of cancer associated with a specified rate of exposure and is called a slope factor or potency factor (units of $[\text{mg/kg body weight-day}]^{-1}$).

The International Association for Research on Cancer (IARC) considers DDT to be in Class 2B - Possibly Carcinogenic to Humans as opposed to Class 2A - Probable Human Carcinogen, or Class 1 - Proven Human Carcinogen. The BCE policy for contaminated sites is to employ risk assessment methods for carcinogens for only Groups 1 and 2A.. Therefore this risk assessment employed methods for DDT as a threshold acting chemical.

6.3.1.7 Toxicity Reference Values

The reference dose (RfD) is the exposure limit used to characterize a safe exposure rate to a threshold-acting compounds. The reference dose has been developed based on a concept that a threshold dose exists, below which adverse effects are unlikely to occur. For each of these chemicals, a no-observed-adverse-effect level (NOAEL) or lowest-observed-adverse-effect level (LOAEL) is identified from laboratory animal studies or, in some cases, available human data. An RfD for a chemical is derived by multiplying the NOAEL or LOAEL values by a series of safety factors to ensure protection of sensitive receptors (i.e., safety factors take into account interspecies and intraspecies differences). The reference dose identified for DDT is discussed below.

6.3.1.8 DDT Toxicity Reference Value

DDT has been reported to cause effects on the central nervous system and liver in humans (WHO, 1984). DDT has been shown to cause cancer in some laboratory animals; however, it has not been implicated in human carcinogenicity (WHO, 1984). DDT is not regulated as a carcinogen in Canada and for these reasons, DDT was treated as a threshold chemical for this assessment. Presently, there is active research being conducted on new modes of toxic action for DDT. The interest focuses on DDT's potential to be an endocrine disrupter with anti-androgenic properties. However, no data are available yet to derive a dose-response relationship for this endpoint. Therefore, the threshold effect employed here was based primarily on liver toxicity. A more definite risk assessment may also consider bioaccumulation and residues in breast milk.

A chronic RfD of 5×10^{-4} mg/kg body weight-day was established for DDT by the US EPA (1996) based on a subchronic (27-week) dietary study in rats (Laug et al., 1950). Histopathological effects in the liver (i.e., liver lesions) were reported in rats fed 5 ppm, which were dose-related, with no effects at 1 ppm (expressed as 0.05 mg/kg body weight-day by the US EPA, 1996). The RfD was calculated by applying an uncertainty factor of 100 to the NOEL to account for interspecies and intraspecies variability (e.g., 0.05 mg/kg body weight-day / 100 = 0.0005 mg/kg BW-day). A LOEL of 0.5 mg/kg body weight-day determined from a 2-year dietary rat study (Fitzhugh, 1948) provides the same RfD as that obtained from the subchronic study, assuming an uncertainty factor of 1000 to account for interspecies and intraspecies variability and use of a LOEL rather than a NOEL.

The U.S. Environmental Protection Agency (USEPA, 1996) also considers DDT, DDE and DDD to be probable human carcinogens, and have designated a slope factor for

DDT of 0.34/μg/kg-day. This can be used to calculate a risk-specific dose of 0.03 μg DDT/kg-day (or 3 x 10^{-5} mg DDT/kg-day) for a hypothetical carcinogenic risk of 1 in 100,000 (10^{-5}). This is a more conservative toxicity reference value than the USEPA sub-chronic reference dose by a factor of about 17, as well as the Allowable Daily Intake (ADI) proposed by the World Health Organization (WHO, 1979) by a factor of about 170.

The risk to humans was calculated using the chronic RfD as discussed above since this was considered to be the best available toxicity reference value; however, the risk-specific dose for a 10^{-5} risk based on a hypothetical cancer endpoint can also be substituted as an even more conservative reference dose. The net result is an increase in the Risk Quotient by approximately one order of magnitude (see below).

6.3.1.9 Bioavailability

DDT can be absorbed into the body via ingestion and inhalation; however, it is poorly absorbed through the skin (WHO, 1984). Furthermore, in humans, less than 1% of DDT in soil was absorbed from soil containing 10 ppm radiolabeled DDT placed onto the skin for a 24-hour period (Wester *et al.*, 1990). For the purpose of this assessment, it was conservatively assumed that 100% of DDT inhaled or ingested is bioavailable, and that 1% of DDT is bioavailable following dermal contact.

6.3.1.10 Risk Characterization

Risk characterization is the final step in the risk assessment process where the results of the exposure and toxicity assessments are integrated to provide risk estimates. The process of risk characterization conducted in this assessment reflects the conservative approach used to generate deterministic risk estimates. The process and interpretation of these steps are discussed below.

6.3.1.11 Estimation of Hazard Quotients for Risk Assessment

The hazard quotient is defined as:

$$\text{Hazard Quotient (unitless)} = \frac{\text{Dose Rate (mg/kg-day)}}{\text{Reference Dose (mg/kg-day)}}$$

For contaminants which demonstrate threshold effects, the hazard quotient is the current and conventional approach for characterizing human health risks. A hazard index is the sum of the hazard quotients calculated for exposure pathways of concern for each chemical. The nature of this estimate (i.e., quotients of the estimated exposure divided by the accepted toxicity reference value) provides a basis by which to judge the acceptability or unacceptability of health risks by comparing the hazard quotient to a value of unity. A hazard quotient which exceeds unity is generally regarded as being indicative of an unacceptable exposure scenario which may potentially result in health effects (i.e.,

estimated exposure exceeds the accepted safe toxicity reference value). Conversely, a hazard quotient less than unity is generally regarded as being indicative of an acceptable exposure scenario (i.e., estimated exposure does not exceed the toxicity reference value). When evaluating the magnitude of hazard quotients, especially ones which are marginally equivalent to unity, it is important to consider the sources of uncertainty which may have influenced the calculations.

The hazard quotients were calculated for each exposure route, using the maximum and geometric mean DDT soil concentrations of 173 ppm and 1.54 ppm, respectively. The hazard quotients are summarized in Table 6.4.

Table 6.4:Risk Estimates for Humans Exposed to DDT in Soils at Rainy Hollow (assuming maximum and geometric mean DDT concentrations in soils)

Exposure Pathway	Hazard Quotients	
	Rainy Hollow	
	maximum (173 ppm)	geometric mean (1.54 ppm)
Child Receptor (12-19 years)		
inhalation of fugitive dust	4.3×10^{-2}	3.8×10^{-4}
ingestion of soils	1.1×10^{-2}	9.5×10^{-5}
dermal contact with soils	2.3×10^{-2}	2.0×10^{-4}
HAZARD INDEX	**7.7×10^{-2}**	**6.8×10^{-4}**
Adult Receptor (20+ years)		
inhalation of fugitive dust	3.8×10^{-2}	3.4×10^{-4}
ingestion of soils	8.7×10^{-3}	7.7×10^{-5}
dermal contact with soils	1.9×10^{-2}	1.7×10^{-4}
HAZARD INDEX	**6.6×10^{-2}**	**5.9×10^{-4}**

As shown in the above Table, the calculated hazard quotients and the respective

hazard indices for DDT are substantially less than 1 via all exposure pathways in spite of the conservative assumptions employed. **The evidence indicates, therefore, that in the context of the exposure scenarios considered for this site there is no undue risk to humans from exposure to DDT and its related compounds at Rainy Hollow.**

6.3.1.12 Uncertainty Associated with Risk Estimates

The present risk assessment was conducted using a "worst-case" deterministic approach for the contaminants of concern. Using this approach, neither a quantitative uncertainty analysis, nor a sensitivity analysis is possible, since the variability in the input parameters is not defined. However, inherent in the present approach is the use of conservative assumptions for both the exposure and toxicity components of the assessment. These conservative assumptions collectively generate risk estimates that are likely to be "worst-case" estimates, and any error associated with them is likely to overestimate the risk relative to the risks that are associated with the potential exposure scenarios.

The Human Health Soil Quality Objective (HHSQO) for tDDT (sumDDT) of 6 mg/kg was based on similar concepts to those provided specifically for Rainy Hollow in Section 6.2. The primary differences were the inclusion of some exposure via diet (soil to produce to small mammals) in the HHSQO and use of a risk-specific dose of 0.03 μg DDT/kg-day based on a *cancer endpoint*, as opposed to the sub-chronic RfP used herein. Note that whereas the human health risk assessment included herein predicts no risk at concentrations of sumDDT in soil up to 173 mg/kg, the HHSQO suggests that human health risks are at least marginally possible at concentrations of tDDT in soil exceeding 6 mg/kg. Note however that this is a consequence of both a different toxicity endpoint together with different exposure assumptions.

6.3.2 DDT in Surficial Soils and Associated Risk to Terrestrial Biota

As mentioned in Section 6.1, the ultimate goal for conducting risk assessment is to enable informed decisions regarding risk management. The results of the detailed field investigation allowed a narrowing of issues regarding the immediate and long-term management of Rainy Hollow/Border Station.

The major problem at the site is the contamination of surficial soils by DDTs (Section 5.4 and Chapter 7). Three zones of DDT distribution may be defined, based on the magnitude of contamination:

i) a small area approximately 10 m x 20 m in size, immediately to the north of the Trench at Rainy Hollow, with *total DDT concentrations in surface soils in the range of approximately 30 to 170 mg/kg*;

ii) larger areas of approximately 100 m x 20 m at Rainy Hollow and approximately 80 m x 20 m at Border Station, to the south of the former location of the Temporary Storage Facility, *with total DDT concentrations in the range 1 to*

10 mg/kg; and

iii) isolated and as yet poorly defined areas along access roads and surface drainage channels with *total DDT concentrations in the range of 5 to 30 mg/kg.*

Unlike the situation for humans, where exposure to DDT and the associated worst-case risk was estimated through simplified models, the concentrations of DDTs in the whole body tissues of three species of small mammals was measured directly. The concentration of DDT in small mammals from Rainy Hollow strongly suggests that the present surficial soil contamination is associated with bioaccumulation [up to ~ 6 mg/kg wet wt. in the whole carcasses (pooled) of shrews]. Undoubtedly the tissue concentrations are attributable to several sources, including diet (i.e., plants and invertebrates), direct soil ingestion, and possibly indirect soil ingestion from grooming of fur. However, several questions remain unanswered with regard to the associated ecological risk, and - ultimately - the informed establishment of remedial goals for the site. The questions include the following:

i) To what extent are the observed DDT tissue burdens in small mammals, especially shrews, attributable to restricted areas of highly contaminated soils as opposed to larger, slightly less contaminated areas?

ii) What is the actual health risk to individual populations/sub-populations of exposed small mammals in association with DDT bioaccumulation at the site?

iii) What is the risk to sub-populations of small mammal predators?

iv) Finally, do any other birds, mammals or other important species have a tendency to bioaccumulate DDTs based on exposure scenarios not considered during this study?

6.3.2.1 Constraints on Estimating Ecological Risks from Food-Chain Mediated Uptake of DDT

A common aspect of all of the aforementioned questions is that answering them requires a confident understanding of the fate and effects of DDT associated with transfer through the food chain. More specifically, the quantification of ecological risk based on soil contamination for this portion of the conceptual model would require the use of accurate bioaccumulation factors (BAFs: estimates of DDT transfer from one species to another) and bioconcentration factors (BCFs: estimates of DDT transfer from soil or water to an organism). **The following section does not provide detailed estimates of ecological risk based on DDT-contaminated soils; rather, it informally explores the factors that heavily influence possible answers to the four aforementioned questions.**

Teed (1996) recently provided in draft form guidance on "Canadian Soil Quality Guidelines for DDT: Environmental". The document, prepared for CCME

with support from the Arctic Environmental Strategy-Action on Waste (Whitehorse) office of DIAND, reviewed the sources and emissions of DDT to the Canadian Environment, environmental fate, and toxicological effects. The report lists guidelines for DDT in soils designed to protect a broad range of environmental receptors according to protocols for the derivation of environmental and human health soil quality guidelines, as outlined by CCME (1996). **The draft soil quality guidelines for DDT have not been critically reviewed to the present time; however, they are included in Table 6.5 and are discussed here, since their derivation is directly relevant to the Rainy Hollow investigation.**

Table 6.4: Draft Environmental Guidelines of Total DDT in Soil - DO NOT QUOTE OR CITE

Guidelines (in mg tDDT[2]/kg)	Land Use	
	Agricultural / Residential- / Parkland	Commercial-Industrial [1]
SQG_{SC}: soil quality guideline for soil contact (vascular plants and soil invertebrates)	25	
Nutrient and Energy Cycle Check: disruption of microbial processes	547	
SQG_I: (Herbivores) - Food and soil ingestion by grazing herbivores	100	
SQG_I: (3rd level predators) - Soil→soil invertebrates→birds→predators	0.8	
Groundwater check (Aquat. Life using criterion of 1 ng/L)	0.12	
SQG_E	0.8	
HHSQO-Human Health Soil Quality Objective (non-residential areas of northern Canada)	6	

1: A single soil quality guideline is provided, since DDT is persistent, subject to long-range transport, and highly bioaccumulative. The concept of land use as envisioned in the Protocol, therefore, would not provide adequate protection for ecological or human receptors.
2: tDDT = total DDT; i.e., o,p'-DDT + p,p'-DDT. Since the available literature generally indicates that the toxicity of DDT is greater than DDE or DDD, a guideline based on DDT would also be protective for data as sumDDTs (DDT+DDE+DDD)

With regard to ecological risk assessment, the lowest soil quality guideline for tDDT was derived from consideration of a risk pathway as follows:

(1) soil → soil invertebrates→ song birds → predators (e.g., raptors)

The risk pathway used to calculate the SQG_I (herbivores) was as follows:

(2) soil → plants→ grazing herbivores

Both of these risk scenarios are instructive with regard to Rainy Hollow. However, the SQGs for both of these is very strongly influenced by the bioaccumulation factors (BAFs) and BCFs used to estimate food-chain related contaminant transfer - probably more so than by the toxicity reference values for which slightly more reliable data exist.

Teed (1996) provides an excellent overview of the existing studies on bioaccumulation and toxicity to a wide variety of biota. Documented bioconcentration factors (BCFs) for tDDT from soils to soil invertebrates (primarily earth worms) range from 0.10 to 10.6, although the best available estimates derived from a U.S. superfund site by Menzie *et al.* (1992) is 0.10 to 0.35. Few published estimates exist for the bioaccumulation of tDDT from dietary items to shrews or other insectivores. Laug *et al.* (1950) estimated the bioaccumulation factor (BAF) from soil invertebrates to shrews to be 29. Conversely, Menzie *et al.* (1992) estimated BAFs from food to shrews or voles, expressed on a dry weight basis for the food and a wet weight basis for small mammal whole tissues to be 0.2 and 0.3, respectively.

Given a weight tissue concentration in whole carcass wet weight of approximately 6 mg/kg sum DDTs in the shrews (*Sorex* sp.) collected from Rainy Hollow, could the documented BCFs and BAFs be used to back-calculate sumDDT concentrations in soils? **In other words, can the available information adequately resolve whether the high DDT concentrations in shrews are due to only the most highly contaminated soils, or rather the larger mass of soils with sumDDTs in the low mg/kg range?**

A concentration of 6 mg/kg wet wt. in shrews, along with a BAF (food dry weight to whole body wet weight) of 0.2 (Menzie *et al.*, 1992) would require a concentration in the food (primarily soil invertebrates) of 30 mg/kg dry wt. Assuming a moisture content in the food of ~70%, this would require a wet weight concentration in food of ~100 mg/kg. If a soil to soil invertebrate BCF of 0.1 to 0.35 is then assumed, the soils would require a sumDDT concentration of 286 to 1000 mg/kg - values that are clearly too high relative to the known soil concentrations at Rainy Hollow. If a BCF of 10.6 is used instead, then the back-calculated soil concentration would be 9.4 mg/kg.

If a diet to shrew BAF of 29 is assumed (Laug *et al.*, 1950), which is the highest documented value, along with a soil to soil invertebrate BCF encompassing the range of published values (0.1 to 11) then the estimates of soil concentration required to achieve the actual measured sumDDT concentration in the pooled shrew samples vary from 0.019 to 2.1 mg/kg, values that are probably too low relative to actual soil concentrations of sumDDT to which the shrews and their food substances were exposed. **The main point is that any assertion about concentration thresholds for DDT in soils designed to minimize ecological risk will be highly influenced by the assumptions made regarding contaminant transfer through the food chain.** The actual BCFs at Rainy Hollow might be higher than observed in other studies, since the organic carbon content of the surface soils in extremely low on average. Hydrophobic contaminants like DDT, therefore, might more readily desorb from soil particles and partition into living organisms.

6.3.2.2 Hazard to the Individual Organism

In order to further examine whether the environmental soil concentrations of DDT at Rainy Hollow are hazardous to small mammal individuals, the estimated DDT exposure rates for several small rodent mammals were developed and compared to laboratory derived no-observed-effect-levels (NOELS) and lowest-observed-effect-levels (LOELS) for rats. The NOELS and LOELS considered were the same as those used to derive the human reference dose related to protection from histopathological effects.

The simple calculations presented here consider only direct ingestion of soil and do not consider DDT contributions from vegetation, or more importantly insect and other dietary invertebrates that are important components of the shrew's diet (i.e., no food chain considerations). Table 6.6 provides a summary of the underlying assumptions and calculated hazard quotients based on soil ingestion. Note that two surrogate species have been considered. The Dusky Shrew, however is indigenous to the Rainy Hollow area.

Table 6.5: Summary of Soil Ingestion-Based Hazard Quotients

Mammal	Dose rate		Hazard Quotient[1]			
	Maximum DDT in soil (173 ppm)	Geometric mean DDT in soil (1.54 ppm)	Maximum DDT in soil (173 ppm)		Geometric Mean DDT in soil (1.54 ppm)	
			LOEL	NOEL	LOEL	NOEL
Deer mouse[2]	8.65	0.08	17.3	173	0.15	1.54
Dusky shrew[3]	3.84	0.03	7.69	77	0.07	0.68
White-footed mouse[4]	1.56	0.01	3.12	31	0.03	0.28

1) LOEL of 0.5 mg/kg-day, and NOEL of 0.05 mg/kg-day (discussed in Toxicity section of report)
2) dose rate assumes mean body weight of 0.02 kg (US EPA, 1993) and soil ingestion rate of 0.001 kg/day (conservatively assumed 5% of mean body weight)
3) dose rate assumes mean body weight of 0.0063 kg (Smith, 1993) and soil ingestion rate of 0.00014 kg/day (based on data for white-footed mouse from Beyer et al., 1994)
4) dose rate assumes mean body weight of 0.0251 kg (Millar, 1975) and soil ingestion rate of 0.000226 kg/day (Beyer et al., 1994)

The calculated hazard quotients suggest that an elevated hazard exists for liver tissue effects in all three species considered, in association with the *maximally* contaminated soils. This assumes a similarity in toxicity response between rats in the laboratory and other species of rodents or insectivores in a northern Canadian ecosystem . The hazard quotient derived from the site *geometric mean* DDT concentration in soil and the threshold LOEL was << 1, suggesting that soil ingestion of soils from the vast majority of locations at Rainy Hollow or Border Station do not increase the risk of liver tissue abnormalities. Additional intake via plant and especially soil invertebrates, however

- especially in the case of the shrew - would elevate the estimated hazard.

6.3.2.3 Consideration of Population Level Effects

The inferences made with regard to liver effects in the previous section apply only to sub-populations that would frequent the area around the Rainy Hollow Trench, or the portion of Border Station immediately to the south of the Temporary Storage Facility location. This is because the small mammals studied here have a small home range of ≤40 m radius (U.S. EPA, 1993) (Table 6.1). Sub-populations at distances significantly greater than this are unlikely to experience similar hazards due to the rapid decrease in soil DDT as one moves away from the trench. Thus on the basis of the nature of the effect (i.e., liver pathology) and the relevant exposure zone, it is unlikely this hazard is significant to the greater population of these mammals.

A more recent focus of interest in the mode of toxicity for DDT and other related chlorinated organics, is their ability to disrupt endocrine functions. Unfortunately information was not available to facilitate consideration of this effect endpoint, although active endocrine-related research on DDT in laboratory mammals is in progress.

Potential implications of this effect endpoint are relevant not only to the individual organism, but may also have a bearing on reproductive success and therefore the population level. Furthermore, this health effect endpoint appears to be far more sensitive than the liver effects previously discussed. This is especially relevant in terms of the bioaccumulative nature of DDT and long-term partitioning to lipid compartments. The implications of this combination of endpoint sensitivity and potential for long-term internal exposure through re-mobilization from fat stores requires substantial research but may be a more relevant population hazard for areas facilitating chronic low level exposure to DDT-like endocrine disruption. Recommendations concerning these perspectives are provided in Section 8.0.

6.3.2.4 Risk to Predators of Small Mammals

One final question is whether the documented DDT concentrations in small mammals cause elevated DDT concentrations in their predators, at levels sufficiently high to impair health. Teed (1996) provided estimates for toxicity reference values enroute to deriving soil quality guidelines (Table 6.6).

Table 6.6: Selected toxicity reference values for tDDT in wildlife.

• Soil Contact: vascular plants and soil invertebrates - **NPER:** no potential effects range (25th percentile of effects and no effects data distribution)	**25 mg/kg in soil**
• SQG_I (Herbivores) - **DTED**: Daily threshold Effects Dose (= lowest observed adverse effects dose/uncertainty factor)	**10 mg/kg body wt./ day (in diet)** (rabbits)
• SQG_I (Predators) - **$DTED_{PB}$**: : Daily threshold Effects Dose for predatory birds (egg-shell thinning endpoint)	**0.87 mg/kg bw/day (in prey)**

No formal risk assessment was attempted; however, the available toxicological studies suggest that the occasional ingestion of prey items containing approximately 0.5 to 5 mg/kg wet weight DDTs by predatory birds should not result in either acute toxicity or adverse effects such as increased incidence of cancer or obvious reproductive effects. The toxicological information on mid-sized to large predatory mammals is extremely sparse, so no determination can be made. The spatial extent of DDT contamination at Rainy Hollow and Border Station, however, is probably sufficiently limited that it comprises a virtually insignificant portion of the feeding range of raptors, large predatory mammals, or large herbivores. For example, the home range of the meadow vole is estimated to be 0.04 to 0.4 ha (Table 6.1) whereas the range of a red fox is roughly 700 ha. If it is assumed that more than one sub-population of vole exhibits elevated DDT concentrations, and therefore assume an affected area of 1-2 ha, this would still comprise less than 0.3% of the fox's foraging range. The estimated percent of foraging range conservatively assumed to be affected locally-elevated DDT for various carnivores is shown in Table 6.7.

Table 6.7: Percent Contribution of a 2 or 10 Ha. Area to the Total Foraging Area of Some Carnivores Found Around Rainy Hollow.

Species	Home Range	2 ha.	10 ha.
Red Fox (*Vulpes vulpes)*	700 - 720 ha	0.29%	1.4%
Gray Wolf (*Canis lupus*)	≥ 48 km radius	< 0.0005%	0.0014%
Coyote (*Canis latrans*)	≥ 10 km radius	0.0064%	0.032%
Black Bear (*Ursus americanus*)	≥ 24 km radius	0.0011%	0.0055%
Grizzly Bear (*Ursus horribilis*)	≥ 40-80 km radius	<0.0005%	0.002%
Mink (*Mustela vison*)	770 ha, linear along streams	0.26%	1.3%
Red-Tailed Hawk (*Buteo jamaicensis*)	233 ha	0.86%	4.3%

7. SYNOPSIS OF MAJOR ISSUES AT RAINY HOLLOW/BORDER STATION

This study was conducted on behalf of Arctic Environmental Strategy - Action on Waste, Whitehorse, in cooperation with the Rainy Hollow Working Group. The study included two closely interrelated components: a detailed site investigation of the Border Station/Rainy Hollow site in the Tatshenshini-Alsek Wilderness Provincial Park, and a human health and screening level ecological risk assessment. The study was preceded in 1994 and 1995 by preliminary site investigations conducted by various members of the research team assembled for this project. A detailed sampling program was carried out in July and September 1996. **The sampling and analytical program for the detailed site investigation comprised -**

- Drilling using an air rotary drill of 14 new boreholes, and installation of piezometers (monitoring wells) in all but one. Nested wells (two piezometers/borehole) were installed in four of the bore holes.

- Analysis of more than 100 soil subsurface samples collected from boreholes for BETX, extractable petroleum hydrocarbons (EPHs), PAHs, chlorinated pesticides, inorganic elements, and/or PCBs.

- Installation by hand of three mini-piezometers at the site along the bank of the Klehini River.

- Collection of groundwater samples from all newly installed monitoring wells and mini-piezometers, as well as from nine of the fifteen well points or piezometers installed during preliminary site investigations during late July, 1996.

- Re-sampling of seven monitoring wells during mid-September, 1996.

- Calculation of soil permeabilities in the vicinity of most monitoring wells using data from rising head response tests.

- Analysis of all groundwater samples for BETX and EPHs, and all groundwater samples collected from Rainy Hollow wells and mini-piezometer samples for chlorinated pesticides.

- Excavation of 24 test pits using a backhoe to depths of 1 to 3 m for the investigation of suspected areas of subsurface contamination or past burial of debris.

- Collection of 4 soil/sediment and 2 water samples from the creek environment adjacent to the upper clearing where the above-ground storage tanks (ASTs) were formerly located.

- Collection of 87 surface soil samples in the vicinity of the DDT trench at Rainy Hollow, Temporary Storage Facility at Border Station, or access roads between the two.

- Analysis of surface and subsurface soils samples for DDT and other chlorinated pesticides,

Additional data were obtained for the purpose of conducting a screening level risk assessment of human health and ecological receptors. The sampling and analytical program included -

- Collection of three surface soil samples along right-of-ways and analysis for 2,3,7,8-substituted dioxins/furans.

- Collection at seven sites located up to 1.6 km from Rainy Hollow of forest soil and plant samples (high-bush blueberry, *Vaccinium* sp., leaves and shoots, roots, berries).

- Trapping of small mammals (eight individual or pooled whole carcass samples in total) in the immediate vicinity of the Trench at Rainy Hollow, or the Temporary Storage Facility at Border Station.

- Collection of river water (n = 3), sediment (n = 6), and streambed invertebrate (n = 4) samples from the Klehini River upstream, adjacent to and downstream from Rainy Hollow.

- Analyses of chlorinated pesticides, including DDT-type compounds, in soil, sediment, water and biological tissues by GC/ECD or HRGC/HRMS.

A summary of the major conclusions drawn from the detailed site investigation is as follows:

i) The major contaminant sources of interest at Rainy Hollow and Border Station were confirmed to be (a) subsurface soils and groundwater at Border Station and Rainy Hollow contaminated with light hydrocarbons, primarily diesel; (b) DDTs in subsurface soils and groundwater, arising from the earlier burial of DDT-containing canisters in a trench at Rainy Hollow; and (c) DDTs in surface soils at Rainy Hollow near the trench, at Border Station near the Temporary Storage Facility, and on access roads and tracked areas between them. The vertical and areal extent of DDT and hydrocarbon contamination were estimated.

ii) A separate zone of subsurface hydrocarbon contamination was discovered at the upper-most bench at Rainy Hollow, where the above-ground storage tanks (ASTs) were previously located. The contaminated soil and groundwater volume, however, is limited and contamination is probably not linked to

subsurface contamination closer to the Klehini River. Hydrocarbons may have flowed to the northeast toward a localized wetland and creek as the ground surface drops off in this direction; however there is no sign of vegetation distress and hydrocarbons were not detected in samples collected from the small creek which passes near to this location.

iii) Inorganic elements, PCBs, dioxins and furans and chlorinated pesticides other than DDTs were investigated as part of a larger contaminant suite and subsequently dismissed as contaminants of concern. Subsurface anomalies identified near the pumphouse foundation at Rainy Hollow during 1994 were attributable to small amounts of iron and other metal containing debris scattered throughout soils reworked at some time after 1980. The anomalies were not dumps; nor was there any evidence of the burial of hitherto undiscovered hazardous debris or contaminating materials.

The original burial of 40 cannisters containing DDT in an area that is virtually in the centre of the pathway of subsurface migration of hydrocarbons from the upper bench toward the Klehini river represents an extremely unfortunate circumstance. Two main issues emerge: the subsurface movement of hydrocarbons into the Klehini River, and the migration of DDT along the same path.

There appears to be a regional water table beneath the upper site (Border Station), at a depth of 16 to 20 m below ground surface. The groundwater flow is towards the river, and there is compelling evidence, especially based on the mini-piezometer data, that groundwater contaminated with both hydrocarbons and DDTs is discharging to the river. Using a calculated mean of 2.5×10^{-4} for hydraulic conductivity, a horizontal gradient of 0.075 m/m and an estimated porosity of 0.27, the average linear groundwater velocity could be estimated to be in the order of 20 metres per year (the trench where the DDT canisters were buried is approximately 80 m from the river). The effective velocity for the transport of hydrocarbons or DDT dissolved in groundwater would be reduced due to retardation associated with a very limited aqueous solubility.

Beneath the former pumping station facilities, hydrocarbons were not present at surface but were encountered at depths varying from 3 to 15 m. Approximately 4 cm of free product was encountered in one well (TH-8B). The contamination extended as deep as the till surface or 25 m below ground. The till surface seems to be a barrier to further vertical movement. Laterally, the hydrocarbons extended from below the shop to past the utility building. The areal extent of hydrocarbons at the lower bench (Rainy Hollow) is much smaller than at the upper site. The impacted zone comprises a layer of hydrocarbon-contaminated soil and groundwater up to 8 m thick beneath the water table. Near the river, this thickness was reduced to about 4 m. There is a 95 % probability that the mass flux to the Klehini River of light extractable petroleum hydrocarbons, i.e. - diesel, lies within the range of 4,819 to 486,778 g/year.

For DDTs, the contaminated subsurface area surrounds the trench area where the drums were recovered and extends to the river. The highest soil concentrations were

directly adjacent to the trench, and were in the range of 4 to 5 ppm. Further from the trench, subsurface soil concentrations were typically less than 2 ppm. . At the river's edge, concentrations of sumDDTs in groundwater were from 1 to 8 ng/L. There is a 95 % probability that the mass flux for DDTs to the Klehini River lies within the range of 0.0183 to 0.3497 mg/year. Modeling efforts were undertaken in order to assess whether hydrocarbon and DDT inputs into the Klehini River are likely to change in the future. The conclusions were deemed to be unreliable: Further monitoring will be the key in determining whether concentrations will increase or decrease with time.

The presence of DDT in shallow surface soils at the site is a separate issue, both in terms of its underlying cause and possible ecotoxicological implications. Three zones of DDT distribution were defined, based on the magnitude of contamination:

i) a small area approximately 10 m x 20 m in size, immediately to the north of the Trench at Rainy Hollow, with *total DDT concentrations in surface soils in the range of approximately 30 to 170 mg/kg*;

ii) larger areas of approximately 100 m x 20 m at Rainy Hollow and approximately 80 m x 20 m at Border Station, to the south of the former location of the Temporary Storage Facility, *with total DDT concentrations in the range 1 to 10 mg/kg*; and

iii) isolated and as yet poorly defined areas along access roads and surface drainage channels with *total DDT concentrations in the range of 5 to 30 mg/kg.*

Prior to the initiation of the detailed site investigation, the major concern at the site revolved around the possible introduction of hydrocarbons and DDT into the Klehini River, and subsequent toxicity to and/or bioaccumulation by aquatic organism or their predators. It became evident in the time leading up to and during the field component of the study that risk to terrestrial flora and fauna, or to humans due to DDT contamination of surface soils required careful consideration.

The screening risk assessment included an evaluation of risks to non-human receptors in the Klehini River due to DDT inputs *via* contaminated groundwater, and to small mammals and their predators in the terrestrial and riparian habitat within ~ 100 m of the Rainy Hollow Trench. The human health risks associated with ingestion of DDT-contaminated soil, inhalation of DDT in the gaseous phase, or dermal absorption were also assessed. The human health risk assessment indicated that in the context of the exposure scenarios considered for this site, there is no risk to humans from exposure to DDT and its related compounds at Rainy Hollow.

The water-borne concentration of DDTs in the groundwater samples from mini-piezometers installed on the river bank approached or exceeded the Criterion for the Protection of Freshwater Aquatic life of 1 ng/L; however, the maximum measured concentration in a water sample from the Klehini River was 0.31 ng/L. p,p'-DDD and

o,p'-DDD were the major DDT-type isomers present, while the parent compound p,p'-DDT was below the detection limit. This sample undoubtedly represents the worst-case concentration for the river, at or near the location where the maximum rate of DDD infiltration occurs, and where the river flow is minimal, providing much lower dilution factors than in the main channel of the river. Samples of river sediment or stream bed invertebrates (primarily dragonfly nymphs) collected from areas of the Klehini River adjacent to Rainy Hollow did not exhibit elevated DDT concentrations relative to reference samples collected 1.1 km upstream or 1.6 km downstream. The streambed invertebrate DDT concentrations indicate that uptake from local sources at Rainy Hollow into lower trophic levels in the river is not significant; therefore, higher level predators such as fish or bald eagles are probably not at risk.

Possible risk pathways for contamination of the Klehini River and its inhabitants could be confidently ruled out, since the dose to aquatic organisms contributed from contaminated areas at Rainy Hollow *via* sediment or river water was essentially zero. All aquatic ecological risk pathways were excluded for further risk assessment. The same conclusion, with a similar rationale, was made for petroleum hydrocarbons and aquatic receptors. Given the low concentrations of hydrocarbons in the groundwater introduced to the Klehini River as of July 1996, the hazard to aquatic wildlife in the Klehini River or their predators was considered to be essentially zero.

With regard to the terrestrial environment and ecological risk, the analytical data for forest soils and high-bush blueberry tissues show that DDT has been redistributed atmospherically from Rainy Hollow within a radius of 1.6 km or more. If it is assumed, however, that DDT adsorption to *Vaccinium* leaves and shoots is typical of other deciduous bushes in the vicinity of Rainy Hollow, then the maximum concentration of DDT, expressed as sumDDTs, available for consumption by medium to large herbivores would be $\leq$ 11 ng/g (ppb) wet weight. The geometric mean concentration over the entire area influenced by short range transport of DDT from Rainy Hollow would be much less than this; i.e., $\leq$ 2 ng/g wet weight.

Small mammals were collected and analyzed for chlorinated pesticides in order to examine localized uptake of DDTs into terrestrial food chains, and implications for predators feeding in the immediate vicinity of Border Station and Rainy Hollow. A single sample made up of three pooled shrews (RA96-100) exhibited a sumDDT concentration of approximately 6,500 ng/g (wet weight). Individual deer mouse or voles contained sumDDT concentrations in the range of 0.45 to 450 ng/g. For all samples, the compounds p,p'-DDE and p,p'-DDT comprised the major portion of the body burden of chlorinated pesticides.

The accurate assessment of ecological risk for exposure to a lipophilic, highly bioaccumulative substance such as DDT requires knowledge of the magnitude of transfer through the food web. Our analysis suggested that ecological risk assessments, as well as any assertion about concentration thresholds for DDT in soils designed to minimize ecological risk, will be highly influenced by the validity of assumptions regarding contaminant bioconcentration and bioaccumulation.

Hazard quotients based on soil ingestion alone, without additional exposure through diet, suggested that an elevated hazard exists for liver tissue effects in all three species of small mammals considered, at least in association with highly contaminated soils. The adverse effects to individuals foraging within the immediate vicinity of Rainy Hollow would undoubtedly be of negligible consequence at the population level, given the size of the contaminated area.

Overall, in spite of the demonstrated subsurface contamination at Rainy Hollow by hydrocarbons and DDT, there is little if any evidence for elevated risks to humans or aquatic receptors based on past and current contaminant inputs. The prediction of future contaminant fluxes into the Klehini River which was conducted as part of the detailed site assessment should be verified, as discussed in Chapter 8. The future monitoring of groundwater conditions is advocated, at least over the short term. The sumDDT concentration in one sample of pooled shrew tissue (*Sorex* sp.) provide some cause for concern with regard to the contamination with DDTs of surface soil at Rainy Hollow. It is conceivable that some small mammals and song birds may exhibit elevated risk due to extended foraging in areas were highly contaminated soils occur. It remains unclear, however, whether the most extreme cases of DDT bioaccumulation in small mammals were associated with exposure to only the most contaminated soils (e.g., sumDDTs > 10 mg/kg) or to DDT concentrations that were less than 10 mg/kg. This issue is directly relevant to the establishment of protective remediation goals, as discussed in Chapter 6. In any event, the limited spatial extent of DDT contamination at Rainy Hollow as compared to vast feeding ranges of larger animal, or in light of the size of most populations of smaller animals and plants in the Tatshenshini-Alsek Wilderness Park suggests that the ecological risks to populations, communities and the ecosystem as a whole are insignificant.

8. IMPLICATIONS, REMEDIAL OPTIONS AND RECOMMENDATIONS

Some of the options for remediation of the site clearly emerge from the detailed investigation and risk assessment. With regard to contaminants at Border Station/Rainy Hollow, there are two major issues:

i) subsurface migration of hydrocarbons and DDT toward and into the river, and

ii) contamination of surface soils in the vicinity of the Trench at Rainy Hollow as well as the former location of the Temporary Storage Facility.

8.1 Implications of Subsurface Contamination

There is clear evidence that both DDT and hydrocarbons are being introduced to the Klehini River through the discharge of contaminated groundwater; however, the actual instantaneous concentrations of these substances in sediment, river water, or stream invertebrates is presently so low as to preclude any possibility of deleterious biological effects. DDT levels were indistinguishable from background concentrations for sediment and stream invertebrates. The concentration of DDTs was elevated in groundwater samples from mini-piezometers installed along the bank of the Klehini River, as well as in the river water samples collected within a few metres of mini-piezometer MP96-02. Measured concentrations of DDTs in the mini-piezometers were in very good agreement with estimates using groundwater models of the flux of DDT toward the river from the Trench area and concentrations of DDT likely to be found in groundwater at the outflow face by the river (i.e., a predicted concentration of 7 ng/L DDTs compared with a measured concentration of 8.4 ng/L in MP96-02). The modeling of hydrocarbon or DDT fluxes in groundwater beneath the lower terrace at Rainy Hollow provide the following estimates:

- There is a 95% probability that the mass flux of hydrocarbons lies within the range of 15 to 806,000 g/year. An estimate of the size of the hydrocarbon source for the entire site (including both Border Station and Rainy Hollow) is 10,000 kg.

- There is a 95% probability that the mass flux of DDTs lies within the range of 0.001 to 0.25 mg/year. The probability of exceeding a value of 1.0 mg/year is 1.3%. An estimate of the total mass of DDT (all isomers) in subsurface soils is 20 kg.

One question that remains with regard to groundwater contamination is whether the flux of contaminants to the river will increase or decrease over time. The estimated mass of hydrocarbons and DDTs present in subsurface soils and groundwater along with estimated fluxes suggests that contaminant migration toward the Klehini River will occur for the foreseeable future, with a decline in overall contaminant concentrations in the

absence of intervention controlled primarily by in situ rates of degradation. The estimated half-life for DDT in subsurface environments is 15 - 30 years. The aforementioned modeling calculations suggest that at steady state, i.e. some time in the future, the groundwater concentration of DDTs at the river outflow face could increase to 37 ng/L. The data from the analysis of river water samples and groundwater suggests that a dilution factor of at least 25 fold occurs within a very short distance from the point of groundwater discharge (over a distance of 2 m or less into the river based on data from MP96-02 and the river water sample Kle96-02). Assuming a dilution factor of 20 to 30 fold for groundwater discharged to the small channel inside the gravel bar of the Klehini River, there is a possibility that the local concentrations of DDTs in the slower flowing river water in the immediate vicinity of the outflow face of the contaminant plume could exceed 1 ng/L, the CCME criterion and B.C. standard for the protection of freshwater aquatic life. It is important to note, however, that dilution factors for introduction of DDTs into the main flow of the Klehini River are undoubtedly much larger than 100-fold. The maximum estimated input of DDTs from Rainy Hollow would not result in concentrations of DDT greater than 1 ng/L across the majority of the river.

Overall, the results indicate that the past and present levels of DDT discharge to the Klehini River from Rainy Hollow are lower than concentrations expected to cause deleterious biological effects. Predicted future fluxes will probably also be sufficiently low to preclude risks to aquatic biota and their consumer; however, these predictions should be verified, as discussed below.

A second question regards the presence of free hydrocarbons on the groundwater surface in the vicinity of monitoring well TH-8A, at the upper terrace (Border Pump Station). If a large volume of non-aqueous phase hydrocarbons is present beneath the upper terrace, this could represent a substantial source for the lower terrace at Rainy Hollow, and possibly a greater rate of flux of DDT in the future. A major objective of the drilling and subsurface sampling program was the identification of the original source of hydrocarbons as well as size (volume and concentration distribution) of the contaminant plume. Free product was detected at the water surface only in two wells: TH-8A (up to 4 mm thickness hydrocarbons) and MW96-16 (near limit of detection for interface probe: ~ 1 to 2 mm). Free product was not observed in any other well. Given the small amount of free product observed, remediation through the direct removal of hydrocarbons using a pump and recovery system would probably be ineffective in terms of the percentage of hydrocarbons recovered relative to effort and costs.

Although the original source of hydrocarbon input was not determined with complete certainty, the vertical and lateral distribution of contaminated soils and groundwater strongly suggest that the original point of discharge was in the vicinity of the pump house, in the vicinity of and slightly upgradient from wells TH-8 and MW96-11. We estimate that MW96-16, at the southwest edge of the old Haines-Fairbanks highway is located within the approximate centre laterally of the contaminated area, and along with MW96-11 and TH-8, provide a good indication of the hydrocarbon plume characteristics at the present time. The maximum concentrations of extractable petroleum hydrocarbons (EPH(C10-C18)) or some of the polycyclic aromatic hydrocarbons (PAHs) such as

naphthalene observed in groundwater samples occurred in monitoring well MW96-17, at the base of the slope between the upper an lower terrace. This provides some evidence that the most concentrated portion of the hydrocarbon plume has already migrated to the lower terrace.

Separate historical spillage of hydrocarbons from the above-ground storage tanks (ASTs) previously located on a third terrace above the pump station have resulted in limited areas of subsurface contamination. The absence of any signs of vegetative stress, high biological productivity of the wetland and absence of hydrocarbons or other contaminants in surface soils, creek water or sediment indicate that the historical spill(s) from the ASTs have not resulted in any biological impacts; nor is any risk likely in the future. The overall subsurface investigation indicated that the hydrocarbon contamination beneath the AST area is not the primary source of contamination to subsurface soils further down the slope toward the river.

8.2 Implications of DDT Contamination of Surface Soils

The presence of DDT in shallow surface soils at the site is a separate issue, both in terms of its underlying cause and possible ecotoxicological implications. Three zones of DDT distribution were defined, based on the magnitude of contamination:

i) a small area approximately 10 m x 20 m in size, immediately to the north of the Trench at Rainy Hollow, with *total DDT concentrations in surface soils in the range of approximately 30 to 170 mg/kg*;

ii) larger areas of approximately 100 m x 20 m at Rainy Hollow and approximately 80 m x 20 m at Border Station, to the south of the former location of the Temporary Storage Facility, *with total DDT concentrations in the range 1 to 10 mg/kg*; and

iii) isolated and as yet poorly defined areas along access roads and surface drainage channels with *total DDT concentrations in the range of 5 to 30 mg/kg*.

Soils containing less than 1 mg/kg DDTs comprise a fourth category. These soils were deemed to pose no risk to either human health or other living organisms.

The screening-level risk assessment clearly indicated that there are no expected human health risks at Rainy Hollow in association with the ingestion of DDT-contaminated soils, inhalation of contaminated particulates or vapour, or absorption of DDT through the skin. We were not able to reliably model human exposure via food-chain related uptake (in the diet), but suggest that this is probably insignificant given that the contaminated area around Rainy Hollow represents a minute portion of the expected feeding range of most animals that might be eaten by humans, and that DDT concentrations in the plants analyzed were very low ($\leq$ 14 ng/g wet weight in above-

ground portions). The component of DDT uptake into humans due to consumption of wildlife and other food items could be ascertained through the analyses of representative samples of country food. We note that the draft CCME recommendations included a soil DDT concentration of 6 ppm, below which risk to humans would be negligible. The apparent discrepancy between this and the study conducted for CCME in the estimated concentration of DDT in soil that could lead to elevated risk is due primarily to use of a much more conservative toxicological end point in the CCME study based on a cancer end point (DDT is a suspected carcinogen only; not a known carcinogen) as well as estimates of the duration of site use that are unrealistically high for Rainy Hollow.

The most contaminated soils, those falling in the concentration range for DDTs of ~10 to > 170 ppm, were estimated to comprise a total volume of ≤ 40 m^3. The removal, therefore, of these soils from contact with the environment would impose a minimal clean up cost, and strongly minimize any unforeseen effects on flora and fauna within the immediate vicinity of the site. There is no compelling evidence that the remaining contaminated soils, those with DDTs in the range of 1 to 10 ppm, constitute a hazard to either humans or wildlife. As precautionary measures, however, two things might be considered: (i) capping of the soils containing 1-10 ppm DDTs using clean soil to eliminate entirely any operable exposure pathway; and/or (ii) re-evaluation of the DDT bioaccumulation in small mammal populations and associated health effects before and after removal of the most contaminated soils (> 10 ppm DDTs) in order to determine if lower remediation triggers are warranted. Several ecological and physiological characteristics of the small mammals occurring at Rainy Hollow would allow a good experimental determination of the relationship between concentrations of DDT in soils and both the bioavailability and ecological risk. Such characteristics include the foraging range, longevity, and high fecundity of the shrews, deer mice and voles.

The Draft CCME DDT Soil Quality Guidelines (SQGs) kindly provided by Mr. Scott Teed were reviewed by us, given the obvious relevance to this project. The derivation of the generic SQGs for the protection of wildlife has not to the best of our knowledge been successfully accomplished for situations where the main exposure pathway is mediated by food web transfer. The major issue is a lack of confidence in the estimates of exposure concentration (dose) since the existing knowledge on bioconcentration and bioaccumulation factors for most species and contaminants is weak. Application of a SQG_I (soil quality guideline for ingestion pathways) for third level predators of 0.8 ppm DDTs in soil at Rainy Hollow/Border Station would not be relevant, since the derivation of this guideline does not include any consideration of the geographic scale of contamination. The guideline does not account for dilution of prey item or predator body burden of DDTs in association with feeding in non-contaminated areas of the foraging range.

8.3 Summary of Recommendations

The recommendations for site restoration provided below include measures designed to address the two major issues discussed above, as well as a number of smaller

items. These include removal of the snow fence and upper tarp from the Trench facility, re-contouring of the lower site to prevent erosion of surface soils and runoff toward the river, and remediation of the discrete hydrocarbon stain located at the surface in the vicinity of the now demolished residence locations at Border Station.

The entire range of remedial options for removing hydrocarbon and/or DDT contamination at any site in either surface or subsurface soils includes combinations of -

- massive excavation and either removal from the site for treatment; or on site treatment
- in-place isolation and encapsulation;
- capture and recovery of contaminants borne in groundwater; and
- *in situ* remediation using a variety of biological, mechanical (soil venting) and chemical treatments.

For Border Station/Rainy Hollow, several of these can be eliminated as viable options as likely to be ineffective or inefficient given the site condition, or anticipated to be prohibitively expensive. For example removal of the subsurface hydrocarbon contamination at the upper site is precluded due to the depth of the contaminated material from the surface. The capture and recovery of hydrocarbons in groundwater is not likely to produce a substantial decrease in the size of the contaminant source due to the very limited amount of free product present and the hydrophobicity of the majority of hydrocarbon constituents present; the major portion of the contaminant mass will be adsorbed to subsurface soil particles at any given time as opposed to being found in the groundwater. In place encapsulation involving a slurry cut-off wall tied into the silt till is technically feasible for controlling the lateral movement of groundwater given the area and depth impacted.

There are a few more viable options for the remediation of DDT in surface or subsurface soils at the lower terrace near the river. All possible solutions, however, should be evaluated in the context of *risk management*. The following recommendations are based on the premise that the need for any action arises only in situations were there is a possibility of risk to humans and/or other living organisms at present, or some reasonable expectation that risks could occur in the future. The direct objective of remedial actions is to eliminate any possibility of risk. This includes interventions to eliminate demonstrated risk potential as well as precautionary measures where there is some uncertainty regarding the risks. Other actions may be warranted at any site based on other considerations; for example aesthetic or other stakeholder concerns. The following recommendations, however, are based only on environmental risk management.

Should the flux of DDT or hydrocarbons to the Klehini River increase in the future beyond the predicted levels (i.e., >>37 ng/L DDTs at the outflow face to the river) it might be necessary to either design a method of groundwater interception or to remove a

relatively large volume of DDT-contaminated soil from the area between the Rainy Hollow trench and the River.

Based on the detailed site investigation and screening-level risk assessment of Border Station/Rainy Hollow, the following are some suggestions appropriate within the context of risk management:

i) **Continuation of groundwater monitoring program to validate and improve predictions of contaminant fate:** It is important to determine the average groundwater velocities and directions over an extended period of time. This enables us to revise and update our dispersion coefficients and refine our estimates of mass loading into the river. It is suggested that three wells be chosen for water level monitoring, with emphasis on wells installed on the lower terrace. One well should have a continuous recorder installed and the other two could be manually recorded at a frequency of twice per month. This would only be necessary over the spring, summer and fall months in 1997 and 1998.

The relatively simple model of the contaminant transport of DDT used for this study needs to be verified. Currently, we have only undertaken a crude calibration phase in which our model has been compared to observed DDT concentrations. A verification phase is needed to assess whether this model can reasonably predict the future behavior. Such a demonstration is needed to assure that the DDT loading will indeed not exceed previous predicted levels. Specific DDT chemicals should be monitored in the existing wells on a semi-annual basis for at least two years. The data derived from the mini-piezometers installed on the river bank were particularly instructive. It is likely that the mini-piezometers will be destroyed through river ice damage over the course of the year; however replacement of the wells as required would be a relatively simple and inexpensive task.

The monitoring program could be relatively simple to carry out and inexpensive. Local people could be trained to take readings of water levels in the wells and to sample monitoring wells and the river at regular intervals for the analysis of DDT concentrations. An appropriate QA/QC component would ensure the reliability of the resulting data. Some consideration must be given to appropriate sample collection and analytical techniques for determination of DDTs in groundwater and surface water: A two to four litre composite water sample is sufficient to achieve an analytical detection limit much lower than 1 ng/L, the criterion for the protection of freshwater aquatic life, provided that an appropriately sensitive analytical method is employed, which involves a more detailed clean up procedure. Axys Analytical Services and a small number of other commercial laboratories specialize in the analysis of low level organochlorine concentrations.

ii) **Removal or isolation of DDT-contaminated surface soils:** The most contaminated soils, those falling in the concentration range for sumDDTs of >

10 to ~ 170 ppm were localized and relatively small; therefore, the removal of these soils from contact with the environment would impose a minimal clean up cost, and strongly minimize any unforeseen effects on flora and fauna within the immediate vicinity of the site. The important principal is that possible exposure pathways for DDT in surface soils to wildlife need to be curtailed. This could be accomplished either by the removal of the soils from the site or through the use of an appropriate physical barrier (partial encapsulation). Immunoassay-based field test kits for DDT appear to be sufficiently reliable to be used in confirmatory testing of any removal or isolation activities.

There is no compelling evidence that the remaining contaminated soils, those with sumDDTs in the range of 1 to 10 ppm, constitute a hazard to either humans or wildlife. As precautionary measures, however, capping of the soils containing 1-10 mg/kg sumDDTs using a 0.5 to 1 m thick layer of clean granular material excavated from nearby will eliminate entirely any operable exposure pathway. Clean fill is available at the upper site as well as further east along the old Haines-Fairbanks Highway in the form of an existing gravel borrow area.

iii) **Removal of the snow fence and upper tarp from the Rainy Hollow Trench area:** Confirmatory testing of the soils within the upper one metre of the backfilled trench indicated that the range of concentrations of sumDDTs was 0.13 to 6.3 mg/kg, while the arithmetic mean was 1.42 mg/kg (standard dev. = 2.04 mg/kg). The geometric mean was 0.60. If it is assumed that the DDT concentrations are normally distributed within the soils held between the upper and lower liners of the trench, then the upper 95th percentile sumDDT concentrations is estimated to be 5.4 mg/kg. The DDT and hydrocarbon concentrations, therefore, were within the range observed in several surface soil samples outside of the backfilled trench, and the associated estimation of risk is similar. As for other surface soils with DDT concentrations in the 1-10 mg/kg range, capping with 0.5 to1 m of clean fill after removal of the upper tarp and snow fence is recommended as a precautionary measure.

Removal of the upper tarp will also have the effect of increasing the local infiltration of surface water from rain fall and snow melt. This should not, however, increase the flux of DDTs away from the source area since the major portion of the DDT source is either beneath the lower tarp in the backfilled trench placed at or near water table depth, or in subsurface soils lateral to the trench.

iv) **Initiation of a small rodent study to ascertain the validity of DDT remediation triggers at Rainy Hollow:** There is some uncertainty regarding the ecological risks associated with DDT soil contamination in the range of 1 to 10 mg/kg. Furthermore, it is not possible to ascertain with absolute confidence the source area for the DDT bioaccumulation measured in a pooled sample of shrews from the site. As discussed above, the possible ecological risks would be

eliminated by the complete removal of exposure pathways by capping with clean fill. The re-evaluation of the DDT bioaccumulation in small mammal populations and associated health effects (especially effects on fecundity) before and after removal of the most contaminated soils (> 10 ppm sumDDTs) is an option that could be undertaken in order to determine if lower remediation triggers are warranted at this or other DDT-contaminated sites.

v) **Analysis of DDT concentrations in relevant food substances for terrestrial wildlife likely to inhabit the area around Rainy Hollow** (e.g., moose): The assessment of human health risk described herein did not include incorporation of an ingestion estimate for the consumption of food. The existing scientific information and data did not allow us to predict with any confidence the concentrations likely to be found in moose meat or other food substance in association with local areas of DDT contamination at Rainy Hollow. It is extremely unlikely that the source of DDT at Rainy Hollow results in any measurable increase relative to background levels in the DDT tissue concentrations in either large herbivorous mammals or larger carnivores and omnivores; this is due to the low DDT concentrations analyzed in blueberry tissue near the site, in conjunction with the extremely small size of the contaminated area relative to the feeding range size of most animals. The possibility of food-chain related risks to humans, however, could be examined directly through the analysis of DDT in a limited number of country food samples.

vi) **Re-contouring and regrading of Rainy Hollow**: As a precautionary measure, recontouring of the lower terrace at Rainy Hollow in the area of the Trench should be considered to eliminate substantial surface runoff toward the Klehini River, and - hence - the erosion and entrainment of surface soil particles exhibiting low-level DDT contamination. Some re-contouring to limit vehicular access would also enhance re-vegetation of the area and, in the absence of a cap of clean fill, minimize the potential for mobilization of contaminated surface soils as wind-blown dust.

vii) **Remediation of localized surface hydrocarbon stains**: two discrete hydrocarbon stains were confirmed at the upper site to the northwest, an irregular shaped stain approximately 5 x 10 m in size (vicinity of TP96-03) where the original source was probably a small heating oil or diesel tank; and a tar-like stain a short distance away that is limited to a depth of a few millimeters. The former of these two stains will undergo natural remediation within a few decades or less. Hydrocarbon concentrations at a depth of 1 m or more were lower than the B.C. Draft soil standards. Test pits excavated laterally to the stain indicated that no subsurface lateral migration of hydrocarbons has occurred. The degradation of hydrocarbons in the uppermost soils could be enhanced through in place reworking of the soils, which would enhance volatilization, sunlight-mediated photolysis and microbial degradation. This may not be necessary, since no impacts to wildlife populations are likely to

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10. APPENDICES

A: Analytical Data

B: Hydrocarbon Signatures for Soil and Water Samples

C: Borehole Logs and Soil Gradational Analysis

D: Estimation of Groundwater Permeability, Including Response Tests

E: Modeling of Human Exposure to DDT via Inhalation of Dust

Appendix A: Analytical Data

Appendix A-1: Soil Samples Moisture Content (%)

	Moisture %		Moisture %		Moisture %		Moisture %
BH96-10-1	15.3	BH96-20-2	8.7	S96-L8-1	0.9	TP96-11-1	22.5
BH96-10-2	10.6	BH96-21-1	3.6	S96-L8-5	0.1	TP96-11-1B	11.7
BH96-10-3	6.6	BH96-21-1D	3.2	S96-L8-10	0.2	TP96-11-2	17
BH96-10-4	7.5	BH96-21-2	4.4	S96-L8-20	0.1	TP96-11-2B	18.8
BH96-10-5	8.7	BH96-21-3	9.6	S96-L8-30	1.4	TP96-14-1	1.9
BH96-11-1	7.4	BH96-21-4	11.3	S96-L8-50	0.1	TP96-14-2	9.1
BH96-11-2	6.3	BH96-21-5	9.8	S96-L8-100	0.2	TP96-14-3	8.8
BH96-11-3	6.2	BH96-22-1	8.4	S96-M10	32.8	TP96-16-1	7.5
BH96-11-4	6.1	BH96-22-2	6.2	S96-M10A	2.4	TP96-16-2	9.3
BH96-12-1	5.0	BH96-22-3	8.4	S96-M10B	4.8	TP96-17-1	13.8
BH96-12-2	6.2	BH96-23-1	4.5	S96-M10C	7.0	TP96-17-2	16.2
BH96-12-3	6.9	BH96-23-2	7.0	S96-M11	23	TP96-19-1	16.2
BH96-13-1	7.7	BH96-23-3	7.8	S96-M12	1.2	TP96-19-2	20.7
BH96-13-1B	"	BH96-23-4	5.8	S96-M13	0.2	TP96-22-1	
BH96-13-2	9.4	BH96-23-5	12	S96-M14	0.2	TP96-22-2	24.6
BH96-13-3	8.4	BH96-23-6	7.0	S96-M3	2.4	TP96-23-1	
BH96-14-1	6.0	BH96-23-7	6.9	S96-M8	3.1	TP96-23-2	18.7
BH96-14-2	5.2	BH96-24-1	5.8			TP96-24-1	14
BH96-14-3	3.8	BH96-24-2	5.4	Sed96-01	26.8	TP96-24-2	4.5
BH96-14-4	7.7	BH96-24-3	6.7	Sed96-02	25.9	TP96-24-2B	4.7
BH96-15-1	4.8	BH96-24-4	6.7	Sed96-03	26.5	TR96-01	17.8
BH96-15-2	6.2	BH96-24-5	6.6	Sed96-04	23.3	TR96-02	14.3
BH96-15-3	2.9			Sed96-05	22.5	TR96-03	14.2
BH96-15-4	3.7	RA96-01-4	30.6	Sed96-6	27.9	TR96-04	13.8
BH96-16-1	3.1	RA96-02-4	15.3			TR96-05	15.4
BH96-16-2	3.1	RA96-03-4	63.3	SS96-01	81.7	TR96-06	13.4
BH96-16-3	3.5	RA96-04-4	7.2	SS96-02	68.1	TR96-07	15.4
BH96-16-4	-	RA96-05-4	7.4	SS96-03	83.7	TR96-08	15.7
BH96-16-5	5.8	RA96-06-4	40.8	SS96-04	40.4	TR96-09	16.7
BH96-16-5D	5.8	RA96-07-4	0.9	TH96-8B-FP	-	TR96-10	16.7
BH96-16-6	7.3			TP96-02-1	15.1	TR96-11	16.5
BH96-16-6D	7.7	S96-01	10.1	TP96-02-2	11.6		
BH96-16-7	10.4	S96-L1-1	1.6	TP96-02-3	6.7		
BH96-16-7D	8.7	S96-L1-10	2.5	TP96-03-1	35.7		
BH96-17-1	4.4	S96-L2-30	0.6	TP96-03-2	4.8		
BH96-17-2	3.6	S96-L4-20	3.3	TP96-03-3	5.3		
BH96-17-3	3.6	S96-L4-48	0.9	TP96-03-4	4.9		
BH96-18-1	5.3	S96-L6-0	2.0	TP96-03B	6.4		
BH96-18-2	3.7	S96-L6-70A	0.7	TP96-03C	1.9		
BH96-18-3	6.9	S96-L6-70B	4.1	TP96-04-1	5.0		
BH96-18-4	7.2	S96-L6-70C	5.9	TP96-04-2	13.4		
BH96-19-1	6.4	S96-L7-10	0.6	TP96-05-2	13.2		
BH96-19-2	4.0	S96-L7-20	2.8	TP96-06-2	10.1		
BH96-19-3	14.3	S96-L7-30	2.7	TP96-10-1	13.1		
BH96-19-4	10.7	S96-L7-5	1.6	TP96-10-2	5.5		
BH96-20-1	4.3	S96-L7-50	2.4	TP96-10-3	11.5		

Appendix A-2: Subsurface Soil Metal Content (mg/kg, or ppm dry wt)

	BH96-15-2	BH96-15-4	TP96-03-1	TP96-11-1B	TP96-11-2B
Al	16600	17200	20100	17100	16500
Sb	<20	<20	<20	<20	<20
As	<100	<100	<100	<100	<100
Ba	160	139	94	77	81
Be	<0.5	<0.5	<0.5	<0.5	<0.5
Bi	<10	<10	40	22	28
Cd	<2	<2	<2	<2	<2
Ca	24900	9010	10700	9710	11100
Cr	27	43	42	51	57
Co	9	10	7	12	11
Cu	24	28	56	22	16
Fe	23600	25700	41500	28500	29600
Pb	<50	<50	<50	<50	<50
Li	15	11	14	10	9
Mg	8670	10600	10200	9110	9570
Mn	397	416	459	456	476
Mo	<4	<4	<4	<4	<4
Ni	16	20	11	17	17
P	181	321	1980	624	656
K	2910	1840	2800	992	953
Se	<50	<50	<50	<50	<50
Ag	<2	<2	<2	<2	<2
Na	910	656	343	477	535
Sn	<10	<10	<10	<10	<10
Ti	464	294	1040	996	1340
V	60	66	135	88	98
Zn	60	51	97	60	61

Appendix A-3: Concentration of Extractable and Volatile Hydrocarbons in soil (mg/kg, or ppm)

Final Report	Extractable Hydrocarbons					Non-halogenated Volatiles				
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene
BH96-10-1	-	681	<250	-	-	-	-	-	-	-
BH96-10-2	-	281	<250	-	-	-	-	-	-	-
BH96-10-3	-	<250	<250	-	-	-	-	-	-	-
BH96-10-4	-	<250	<250	-	-	-	-	-	-	-
BH96-10-5	-	<250	<250	-	-	-	-	-	-	-
BH96-11-1	-	594	<250	-	-	-	-	-	-	-
BH96-11-2	-	900	<250	-	-	-	-	-	-	-
BH96-11-3	-	849	<250	-	-	-	-	-	-	-
BH96-11-4	-	<250	<250	-	-	-	-	-	-	-
BH96-12-1	-	<250	<250	-	-	-	-	-	-	-
BH96-12-2	-	<250	<250	-	-	-	-	-	-	-
BH96-12-3	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-13-1	43	838	<250	-	-	<0.3	<0.3	<0.3	<0.05	<0.3
BH96-13-2	-	<250	<250	-	-	-	-	-	-	-
BH96-13-3	-	<250	<250	-	-	-	-	-	-	-
BH96-14-1	-	<250	<250	-	-	-	-	-	-	-
BH96-14-2	-	<250	<250	-	-	-	-	-	-	-
BH96-14-3	-	<250	<250	-	-	-	-	-	-	-
BH96-14-4	-	<250	<250	-	-	-	-	-	-	-
BH96-15-1	-	<250	<250	-	-	-	-	-	-	-
BH96-15-2	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-15-3	-	<250	<250	-	-	-	-	-	-	-
BH96-15-4	-	<250	<250	-	-	-	-	-	-	-
BH96-16-1	-	<250	<250	-	-	-	-	-	-	-
BH96-16-2	-	<250	<250	-	-	-	-	-	-	-
BH96-16-3	40	968	<250	-	-	<0.05	<0.05	<0.05	<0.1	<0.05
BH96-16-4	-	<250	<250	-	-	-	-	-	-	-
BH96-16-5	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-16-6	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-16-7	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-17-1	-	<250	<250	-	-	-	-	-	-	-
BH96-17-2	-	<250	<250	-	-	-	-	-	-	-
BH96-17-3	-	<250	<250	-	-	-	-	-	-	-
BH96-18-1	-	<250	<250	-	-	-	-	-	-	-
BH96-18-2	-	<250	<250	-	-	-	-	-	-	-
BH96-18-3	-	<250	<250	-	-	-	-	-	-	-
BH96-18-4	-	<250	<250	-	-	-	-	-	-	-

Notes: 1, 2 - values include PAH; not corrected through subtraction of light or heavy PAH concentrations as per B.C. Draft Regs.

Appendix A-3: Concentration of Extractable and Volatile Hydrocarbons in soil, continued (mg/kg, or ppm)

Final Report	Extractable Hydrocarbons					Non-halogenated Volatiles				
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene
BH96-19-1	<10	<250	<250	<250	<250	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-19-2	97	778	<250	-	-	<0.05	<0.1	<0.1	<0.2	<0.2
BH96-19-3	-	<250	<250	-	-	-	-	-	-	-
BH96-19-4	-	<250	<250	-	-	-	-	-	-	-
BH96-20-1	369	629	<250	<250	629	<1	<0.3	<0.4	<3	<0.6
BH96-20-2	-	<250	<250	-	-	-	-	-	-	-
BH96-21-1	<10	-	-	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-21-1Dup	<10	<250	<250	<250	<250	<0.05	<0.05	<0.05	<0.05	<0.05
BH96-21-2	-	<250	<250	-	-	-	-	-	-	-
BH96-21-3	-	<250	<250	-	-	-	-	-	-	-
BH96-21-4	-	<250	<250	-	-	-	-	-	-	-
BH96-21-5	-	<250	<250	-	-	-	-	-	-	-
BH96-22-1	-	<250	<250	-	-	-	-	-	-	-
BH96-22-2	-	<250	<250	-	-	-	-	-	-	-
BH96-22-3	-	<250	<250	-	-	-	-	-	-	-
BH96-23-1		<250	<250							
BH96-23-2		<250	<250							
BH96-23-3		<250	<250							
BH96-23-4		<250	<250							
BH96-23-5		<250	<250							
BH96-23-6		<250	<250							
BH96-23-7		<250	<250							
BH96-24-1		<250	<250							
BH96-24-2		<250	<250							
BH96-24-3		<250	<250							
BH96-24-4		<250	<250							
BH96-24-5		<250	<250							
Sed96-01	-	<250	<250	-	-	-	-	-	-	-
Sed96-02	-	<250	<250	-	-	-	-	-	-	-
Sed96-03	-	<250	<250	-	-	-	-	-	-	-
Sed96-04	-	<250	<250	-	-	-	-	-	-	-
Sed96-05	-	<250	<250	-	-	-	-	-	-	-
Sed96-06	-	<250	<250	-	-	-	-	-	-	-

Appendix A-3: Concentration of Extractable and Volatile Hydrocarbons in soil, continued (mg/kg, or ppm)

Final Report	Extractable Hydrocarbons					Non-halogenated Volatiles				
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene
S96-01	<10	<250	<250	<250	<250	<0.05	<0.05	<0.05	<0.05	<0.05
SS96-02	-	<250	<250	<250	<250	-	-	-	-	-
SS96-03	-	<250	<250	<250	<250	-	-	-	-	-
SS96-04	-	<250	<250	-	-	-	-	-	-	-
TP96-02-1	<10	<250	<250	<250	<250	<0.05	<0.05	<0.05	<0.05	<0.05
TP96-02-2	-	<250	<250	-	-	-	-	-	-	-
TP96-02-3	-	<250	<250	-	-	-	-	-	-	-
TP96-03-1	151	5910	1740	1730	5890	<0.05	<0.4	<0.2	11.2	7.6
TP96-03-2	-	<250	<250	-	-	-	-	-	-	-
TP96-03-3	-	<250	<250	-	-	-	-	-	-	-
TP96-03-4	-	<250	<250	-	-	-	-	-	-	-
TP96-03B	-	<250	<250	-	-	-	-	-	-	-
TP96-03C	-	<250	<250	-	-	-	-	-	-	-
TP96-04-1	-	<250	<250	-	-	-	-	-	-	-
TP96-04-2	-	<250	<250	-	-	-	-	-	-	-
TP96-05-2	-	<250	<250	-	-	-	-	-	-	-
TP96-06-2	-	<250	<250	-	-	-	-	-	-	-
TP96-10-1	-	<250	<250	-	-	-	-	-	-	-
TP96-10-2	-	<250	<250	-	-	-	-	-	-	-
TP96-10-3	-	899	<250	-	-	-	-	-	-	-
TP96-11-1	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
TP96-11-2	<10	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
TP96-14-1	<10	<250	2490	2490	<250	<0.05	<0.05	<0.05	<0.05	<0.05
TP96-14-2	-	<250	<250	-	-	-	-	-	-	-
TP96-14-3	-	<250	<250	-	-	-	-	-	-	-
TP96-16-1	-	<250	<250	-	-	-	-	-	-	-
TP96-16-2	-	<250	<250	-	-	-	-	-	-	-
TP96-17-1	-	9570	<250	-	-	-	-	-	-	-
TP96-17-2	-	8670	<250	-	-	-	-	-	-	-
TP96-19-1	178	-	-	-	-	<0.05	<0.2	<0.1	<2	<0.6
TP96-19-2	-	3370	<250	-	-	-	-	-	-	-
TP96-22-2	-	<250	<250	-	-	-	-	-	-	-
TP96-23-2	-	463	<250	-	-	-	-	-	-	-
TP96-24-1	-	1410	<250	-	-	-	-	-	-	-
TP96-24-2	694	1420	<250	-	-	<0.5	<2	<2	<4	<2

Appendix A-3: Concentration of Extractable and Volatile Hydrocarbons in soil, continued (mg/kg, or ppm)

Final Report	Extractable Hydrocarbons					Non-halogenated Volatiles				
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene
TR96-01	-	<250	<250	-	-	-	-	-	-	-
TR96-02	7	<250	<250	-	-	<0.05	<0.05	<0.05	<0.05	<0.05
TR96-03	-	<250	<250	-	-	-	-	-	-	-
TR96-04	-	<250	<250	-	-	-	-	-	-	-
TR96-05	26	<250	<250	-	-	<0.05	<0.2	<0.1	<0.4	<0.1
TR96-06	1030	10700	<250	-	-	<1	14.1	<1	16.2	<1
TR96-07	-	516	<250	-	-	-	-	-	-	-
TR96-08	-	<250	<250	-	-	-	-	-	-	-
TR96-09	37	334	<250	-	-	<0.05	<0.1	<0.05	<0.3	<0.1
TR96-10	-	776	<250	-	-	-	-	-	-	-
TR96-11	-	274	<250	-	-	-	-	-	-	-

Appendix A-4: Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in soil (mg/kg, or ppm)

	Acenaphthene	Acenaphthylene	Anthracene	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene	Chrysene	Dibenz(a,h)anthracene	Fluoranthene	Fluorene	Indeno(1,2,3-c,d)pyrene	Naphthalene	Phenanthrene	Pyrene
BH96-19-1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
BH96-20-1	0.02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01	0.11	<0.01	<0.01
BH96-21-1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
S96-01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
SS96-01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	<0.01	<0.01
SS96-02	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.18	<0.01	<0.01
SS96-03	0.02	<0.01		<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.03	<0.01	0.04	0.06	<0.01
TP96-02-1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
TP96-03-1	3.5	0.8	1.2	0.2	<0.1	<0.1	<0.1	<0.1	0.4	<0.1	0.4	3.6	<0.1	20.2	8.7	1.2
TP96-14-1	<0.1	<0.1	0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1

Appendix A-5: Concentration of Chlorinated Pesticides including DDT in soil (mg/kg, or ppm)

	Total PCBs	Aldrin	alpha-BHC	beta-BHC	delta-BHC	cis-Chlordane (alpha)	trans-Chlordane (gamma)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers	Dieldrin	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Endrin	Heptachlor	Heptachlor Epoxide	Lindane (gamma-BHC)	Methoxychlor	Mirex	cis-Nonachlor	trans-Nonachlor	Oxychlordane	Toxaphene
BH96-10-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-11-2	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-12-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-15-2	<0.05	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-15-4	<0.05	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-16-3	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-16-5D	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-16-6D	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-16-7D	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-17-3	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-18-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	0.003	<0.002	0.002	0.012	0.039	0.056	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-18-2	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	0.002	<0.002	0.001	0.006	0.023	0.032	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-19-1		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-19-2		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-20-1		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-21-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.003	0.008	<0.002	<0.001	<0.001	<0.002	0.011	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-21-2	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	0.002	<0.002	<0.001	<0.001	<0.002	0.002	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-21-3	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-21-4	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-21-5	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
BH96-22-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030

Appendix A-5: Concentration of Chlorinated Pesticides including DDT in soil, continued (mg/kg, or ppm)

	Total PCBs	Aldrin	alpha-BHC	beta-BHC	delta-BHC	cis-Chlordane (alpha)	trans-Chlordane (gamma)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers	Dieldrin	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Endrin	Heptachlor	Heptachlor Epoxide	Lindane (gamma-BHC)	Methoxychlor	Mirex	cis-Nonachlor	trans-Nonachlor	Oxychlordane	Toxaphene
RA96-01-4	-	<0.005	<0.05	<0.005	<0.02	<0.005	<0.005	0.029	0.13	<0.002	0.034	<0.1	0.314	0.507	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.5
RA96-02-4	-	<0.001	<0.002	<0.002	<0.001	<0.001	<0.001	0.008	0.055	<0.002	0.033	<0.08	0.198	0.294	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
RA96-03-4	-	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.011	0.120	0.002	0.040	<0.1	0.321	0.494	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.5
RA96-04-4	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.014	<0.5	0.007	0.357	0.521	2.360	3.259	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.002	<0.001	<0.001	<0.030
RA96-05-4	-	<0.001	<0.05	<0.05	<0.05	<0.001	<0.001	0.001	0.002	<0.002	<0.001	<0.001	0.004	0.007	<0.001	<0.001	<0.001	<0.005	<0.005	<0.005	<0.001	<0.002	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
RA96-06-4	-	<0.005	<0.2	<0.01	<0.01	<0.002	<0.002	<0.01	<0.01	<0.01	<0.01	<0.01	<0.05	< d.l.	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.002	<0.05	<0.01	<0.01	<0.01	<0.01	<0.005	<0.5
RA96-07-4		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.001	0.002	<0.002	0.009	0.007	0.028	0.047	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-01	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.085	0.608	<0.002	0.024	0.222	0.663	1.60	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.002	<0.001	<0.001	<0.030
S96-L1-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.055	0.097	0.003	0.028	0.342	0.722	1.25	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L1-10	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.002	0.003	<0.002	0.008	0.013	0.063	0.089	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L2-30	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.131	0.340	0.014	0.856	0.993	3.050	5.38	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L4-20	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.002	<0.002	0.006	0.007	0.030	0.043	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L4-48	-	<0.001	<0.05	<0.05	<0.05	<0.001	<0.001	<0.001	<0.002	<0.002	0.014	0.008	0.050	0.072	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.05	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L6-0	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.008	0.031	<0.002	0.016	0.070	0.407	0.532	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L6-70A	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.108	0.359	0.003	0.173	0.478	1.690	2.81	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L6-70B	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.002	0.005	<0.002	0.009	0.006	0.036	0.058	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L6-70C	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.005	0.011	<0.002	0.013	0.018	0.069	0.116	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L7-10		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.007	0.043	<0.002	0.002	0.014	0.059	0.125	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L7-20		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.044	0.146	<0.002	0.012	0.050	0.209	0.461	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L7-30		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.022	0.139	<0.002	0.018	0.044	0.265	0.488	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L7-5		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.025	0.132	<0.002	0.005	0.042	0.187	0.391	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L7-50		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.065	0.257	<0.002	0.026	0.169	1.2	1.72	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030

Appendix A-5: Concentration of Chlorinated Pesticides including DDT in soil, continued (mg/kg, or ppm)

	Total PCBs	Aldrin	alpha-BHC	beta-BHC	delta-BHC	cis-Chlordane (alpha)	trans-Chlordane (gamma)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers	Dieldrin	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Endrin	Heptachlor	Heptachlor Epoxide	Lindane (gamma-BHC)	Methoxychlor	Mirex	cis-Nonachlor	trans-Nonachlor	Oxychlordane	Toxaphene
S96-L8-1		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	4.06	5.91	0.222	1.06	28.0	69.4	109	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-5		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	1.31	2.56	0.086	0.584	8.75	22.9	36.2	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-10		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	3.60	7.75	0.286	1.67	35.9	124	173	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-20		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.037	0.256	0.004	0.036	0.472	2.630	3.44	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-30		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.020	0.061	<0.002	0.010	0.110	0.435	0.636	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-50		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.156	0.293	0.005	0.058	0.704	1.460	2.68	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-L8-100		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.013	0.051	<0.002	0.006	0.106	0.413	0.589	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M10		<0.001	<0.001	<0.002	<0.001	<0.005	<0.005	0.348	1.14	0.008	0.030	1.20	4.510	7.24	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.01	<0.001	<0.030
S96-M10A	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M10B	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M10C	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	0.001	0.005	0.006	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M11		<0.01	<0.01	<0.002	<0.001	<0.001	<0.005	0.005	0.030	0.004	0.014	0.119	0.732	0.90	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M12		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.015	0.043	<0.002	0.018	0.127	0.412	0.615	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M13		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.017	0.059	<0.002	0.008	0.065	0.283	0.432	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M14		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	1.23	2.26	0.115	2.46	4.90	15.8	26.8	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M3	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.221	0.647	0.015	0.501	1.99	7.82	11.2	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
S96-M8	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.038	0.109	0.005	0.124	0.300	1.21	1.79	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-04-2	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	0.002	<0.002	<0.001	0.003	0.018	0.023	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-10-1	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.003	0.004	<0.002	<0.001	<0.001	<0.002	0.007	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-10-2	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.093	0.301	<0.002	<0.001	<0.001	<0.002	0.394	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-10-3	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.931	2.750	0.002	0.006	<0.02	0.014	3.703	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.02	<0.001	<0.001	<0.030

Appendix A-5: Concentration of Chlorinated Pesticides including DDT in soil, continued (mg/kg, or ppm)

	Total PCBs	Aldrin	alpha-BHC	beta-BHC	delta-BHC	cis-Chlordane (alpha)	trans-Chlordane (gamma)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers	Dieldrin	Endosulfan I	Endosulfan II	Endosulfan Sulfate	Endrin	Heptachlor	Heptachlor Epoxide	Lindane (gamma-BHC)	Methoxychlor	Mirex	cis-Nonachlor	trans-Nonachlor	Oxychlordane	Toxaphene
TP96-11-1B	<0.05	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.002	0.028	<0.002	0.013	0.017	0.132	0.192	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-11-2B	<0.05	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	0.002	0.002	0.010	0.014	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TP96-24-2B	-	<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	<0.001	<0.001	<0.002	<0.001	<0.001	<0.002	< d.l.	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TR96-01		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.570	1.93	0.010	0.070	0.768	2.96	6.31	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.001	<0.001	<0.030
TR96-02		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.270	1.13	0.003	0.022	0.058	0.521	2.00	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.001	<0.001	<0.030
TR96-03		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.072	0.358	<0.002	0.015	0.007	0.020	0.472	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.001	<0.001	<0.030
TR96-04		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.021	0.084	<0.002	0.002	0.013	0.059	0.179	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TR96-05		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.123	0.574	<0.002	0.023	0.009	0.057	0.786	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.001	<0.001	<0.030
TR96-06		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.926	3.60	0.004	0.015	<0.005	0.005	4.55	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.04	<0.001	<0.001	<0.030
TR96-07		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.068	0.370	<0.002	0.024	0.005	0.018	0.485	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.01	<0.001	<0.001	<0.030
TR96-08		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.007	0.038	<0.002	0.008	0.013	0.067	0.133	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TR96-09		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.027	0.127	<0.002	0.009	0.004	0.033	0.200	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TR96-10		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.042	0.217	<0.002	0.021	0.003	0.045	0.328	0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030
TR96-11		<0.001	<0.001	<0.002	<0.001	<0.001	<0.001	0.028	0.135	<0.002	0.006	0.007	0.038	0.214	<0.001	<0.001	<0.001	<0.001	<0.005	<0.002	<0.001	<0.001	<0.005	<0.001	<0.001	<0.001	<0.001	<0.030

Appendix A-6: Groundwater or Surface Water Metal Content (mg/L, or ppm)

	MP96-01	MP96-02	MP96-03	Cr96-01	Cr96-02
Al	85	75	13	0.069	0.042
Sb	<0.2	<0.2	<0.2		
As	<0.2	<0.2	<0.2	0.0001	0.0001
Ba	0.62	0.54	0.13	<0.01	<0.01
Be	<0.005	<0.005	<0.005	<0.005	<0.005
Bi	0.2	0.1	<0.1		
B	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	<0.01	<0.01	<0.01	<0.0002	<0.0002
Ca	167	184	102	12.8	12.6
Cr	0.24	0.22	0.04	<0.001	<0.001
Co	0.10	0.06	0.01	<0.02	<0.02
Cu	0.32	0.40	0.05	0.003	0.003
Fe	134	115	22	0.12	0.08
Pb	0.09	0.27	0.07	<0.001	<0.001
Li	0.06	0.06	0.02	<0.02	<0.02
Mg	58	54	12	1.4	1.44
Mn	2.0	3.6	1.4	0.017	0.007
Hg	-	-	-	<0.00005	<0.00005
Mo	<0.03	<0.03	<0.03	<0.03	<0.03
Ni	0.13	0.10	<0.02	<0.02	<0.02
P	2.4	3.5	0.8		
K	10	8.0	4.0		
Se	<0.2	<0.2	<0.2	<0.0005	<0.0005
Si	76	70	22		
Ag	<0.01	<0.01	<0.01	<0.0001	<0.0001
Na	12	7.0	3.0	<2	<2
Sr	0.46	0.48	0.24		
Tl	<0.1	<0.1	<0.1		
Sn	<0.03	<0.03	<0.03		
Ti	6.6	4.3	0.94		
V	0.30	0.26	0.04	<0.03	<0.03
Zn	5.1	26	6.0	<0.005	<0.005

Appendix A-7: Concentration of Extractable and Volatile Hydrocarbons in Groundwater or Surface Water (mg/L, or ppm)

	Extractable Hydrocarbons					Non-halogenated Volatile Organics					
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene	total xylenes
Samples Collected in July 1996											
TH-8A	<0.1	7.6	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-10	<0.1	<1.0	<1.0	-	-	0.0008	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-12	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-13	<0.1	3.3	<1.0	-	-	<0.0005	<0.0005	0.002	<0.0005	<0.0005	< d.l.
BH96-15	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-16	0.5	6.7	<1.0	-	-	<0.0005	0.0011	<0.001	0.0011	0.0016	0.0027
BH96-17A	-	1.5	<1.0	-	-	-	-	-	-	-	-
BH96-17B	-	1.7	<1.0	-	-	-	-	-	-	-	-
BH96-18	-	<1.0	<1.0	-	-	-	-	-	-	-	-
BH96-19A	0.8	1.9	<1.0	-	-	<0.005	<0.005	<0.005	<0.005	<0.005	< d.l.
BH96-19B	-	<1.0	<1.0	-	-	-	-	-	-	-	-
BH96-20A	1.2	1.3	<1.0	-	-	<0.0005	0.0226	0.002	0.058	0.0111	0.0691
BH96-20B	-	<1.0	<1.0	-	-	-	-	-	-	-	-
BH96-21A	0.2	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-21B	<0.1	<1.0	<1.0	-	-	0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
BH96-21C	-	1.2	<1.0	-	-	-	-	-	-	-	-
BH96-22	-	<1.0	<1.0	-	-	-	-	-	-	-	-
BH96-23	-	<1.0	<1.0	-	-	-	-	-	-	-	-
BH96-26	-	<1.0	<1.0	-	-	-	-	-	-	-	-
WP96-1	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-2	0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-4	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-6	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-7	2.8	10	<1.0	-	-	<0.005	0.024	0.010	0.054	0.012	0.0660
WP96-8	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-10	<0.1	<1.0	<1.0	-	-	<0.0005	0.001	<0.001	<0.0005	<0.0005	< d.l.
WP96-11	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
WP96-13	0.4	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	0.0006	<0.0005	0.0006
WP96-14	-	<1.0	<1.0	-	-	-	-	-	-	-	-
MP96-01	<0.1	<1.0	1.7	1.7	<1.0	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
MP96-02	1	5.9	<1.0	<1.0	5.9	<0.0005	0.0041	<0.005	0.0070	0.0020	0.0090
MP96-03	1	<1.0	<1.0	<1.0	<1.0	<0.0005	0.0033	<0.001	0.0039	0.0009	0.0048
Cr96-01	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.
Cr96-02	<0.1	<1.0	<1.0	-	-	<0.0005	<0.0005	<0.001	<0.0005	<0.0005	< d.l.

Notes: 1, 2 - values include PAH; not corrected through subtraction of light or heavy PAH concentrations as per B.C. Draft Regs.

Appendix A-7: Concentration of Extractable and Volatile Hydrocarbons in Groundwater or Surface Water, continued (mg/L, or ppm)

	Extractable Hydrocarbons					Non-halogenated Volatile Organics					
	VPHs	EPH[1] (C10-18)	EPH[2] (C19-31)	HEPHs	LEPHs	Benzene	Ethyl-benzene	Toluene	meta- & para-Xylene	ortho-Xylene	total xylenes
Samples Collected in September 1996											
BH96B-10		0.97	0.13	0.13	0.97						
BH96B-11		0.1	<0.10	<0.10	0.1						
BH96B-17A		1.92	0.41	0.41	1.9						
BH96B-17B		2.08	0.11	0.11	2.06						
BH96B-19A		0.52	<0.10	<0.10	0.52						
BH96B-20A		1.31	<0.10	<0.10	1.31						
BH96B-21A		0.39	<0.10	<0.10	0.39						

Appendix A-8: Concentration of Polycyclic Aromatic Hydrocarbons (PAHs) in Groundwater or Surface Water (mg/L, or ppm)

	Acenaphthene	Acenaphthylene	Acridine	Anthracene	Benzo(a)anthracene	Benzo(a)pyrene	Benzo(b)fluoranthene	Benzo(g,h,i)perylene	Benzo(k)fluoranthene	Chrysene	Dibenz(a,h)anthracene	Fluoranthene	Fluorene	Indeno(1,2,3-c,d)pyrene	Naphthalene	Phenanthrene	Pyrene
MP96-01	<0.0005	<0.0005	<0.00005	0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	<0.0002	<0.0002	0.00002
MP96-02	<0.0005	<0.0005	<0.00005	0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0011	<0.0002	<0.00002
MP96-03	<0.0005	<0.0005	0.00006	0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0015	<0.0002	<0.00002
BH96B-10	<0.0005	<0.0005	<0.00005	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0002	<0.0002	<0.00002
BH96B-11	<0.0005	<0.0005	0.00009	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0003	<0.0002	<0.00002
BH96B-17A	0.001	<0.0005	<0.00005	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	0.0008	<0.00001	0.0211	<0.0002	<0.00002
BH96B-17B	0.0008	<0.0005	<0.00005	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	0.0008	<0.00001	0.0231	<0.0002	<0.00002
BH96B-19A	<0.0005	<0.0005	0.00006	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0028	<0.0002	<0.00002
BH96B-20A	<0.0005	<0.0005	<0.00005	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	0.0002	<0.00001	0.0055	<0.0002	<0.00002
BH96B-21A	<0.0005	<0.0005	<0.00005	<0.0001	<0.00001	<0.00001	<0.00001	<0.0001	<0.00001	<0.0001	<0.00001	<0.0001	<0.0001	<0.00001	0.0007	<0.0002	<0.00002

Appendix A-9: Concentration of Chlorinated Pesticides including DDT in Groundwater (mg/L, or ppm)

	Aldrin	alpha-BHC	beta-BHC	delta-BHC	cis-Chlordane (alpha)	trans-Chlordane (gamma)	o,p'-DDD	p,p'-DDD	o,p'-DDE	p,p'-DDE	o,p'-DDT	p,p'-DDT	Sum DDT Isomers	Dieldrin	Endo-sulfan I	Endo-sulfan II	Endo-sulfan Sulfate	Endrin	Endrin Aldehyde	Hepta-chlor	Heptachlor Epoxide	Lindane (gamma - BHC)	Methoxy-chlor	Mirex	cis-Nonachlor	trans-Nonachlor	Oxychlordane	Toxaphene
TH-8A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-15	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-16	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-17A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-17B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-19A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-19B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-20A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-20B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-21A	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-21B	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-21C	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
BH96-22	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-2	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-4	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-6	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-7	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	0.0004	<0.0001	<0.0001	<0.0001	<0.0001	0.0004	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-8	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-10	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-11	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-13	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030
WP96-14	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	< d.l.	<0.001	<0.002	<0.0005	<0.010	<0.001	<0.001	<0.0005	<0.010	<0.001	<0.010	<0.010	<0.010	<0.010	<0.010	<0.030

Appendix B: Hydrocarbon Signatures for Soil and Water Samples

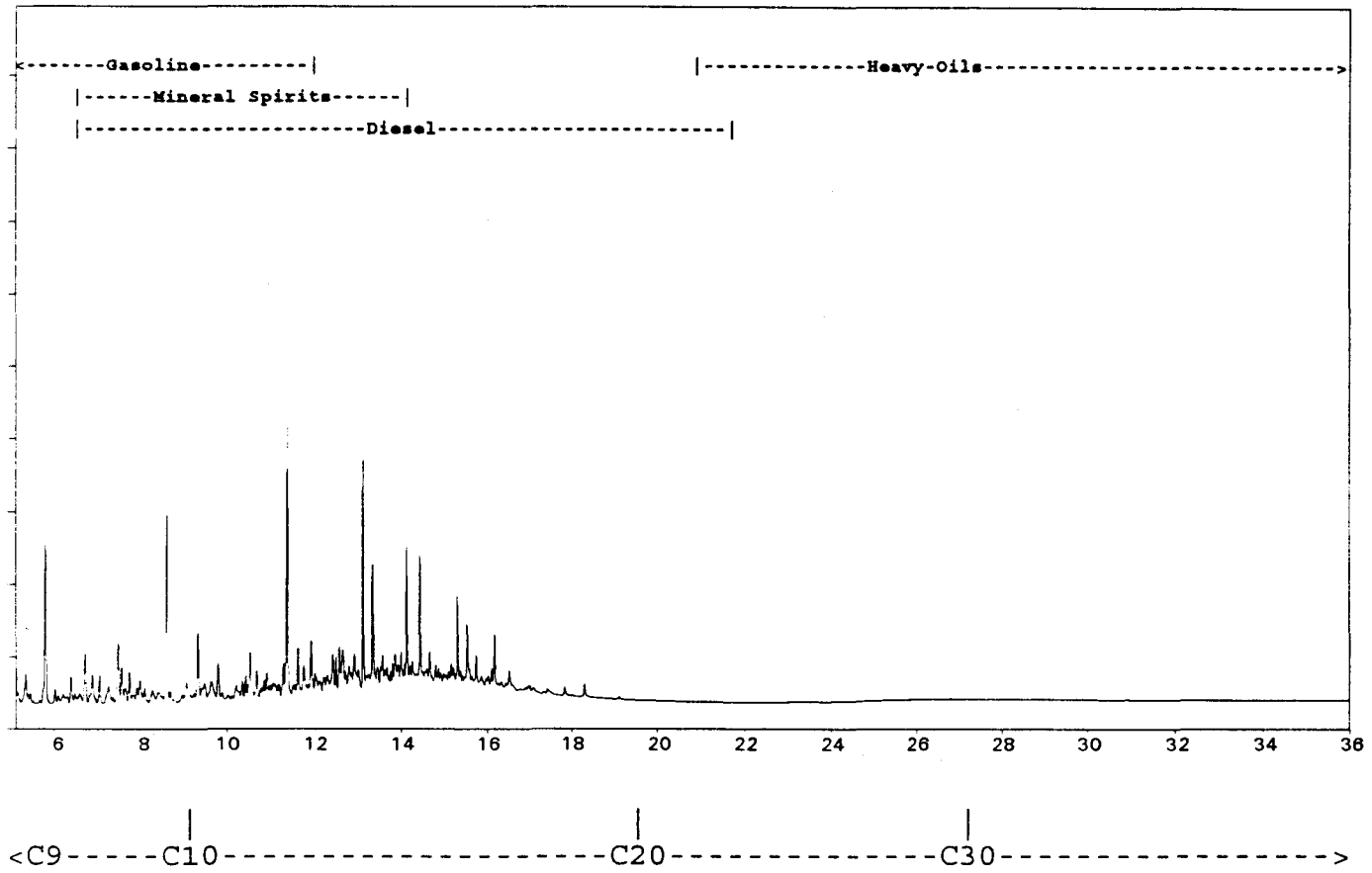
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-10-01 July 11, 1996

Sample acquired: JUL 21, 1996 16:12:58

File Name: c:\TEH\TEHJUL21.11R , Sample Name: G3053 1

Sequence file: TEHJUL21



ASL Sample ID: G3053 1* 8.0Dilution

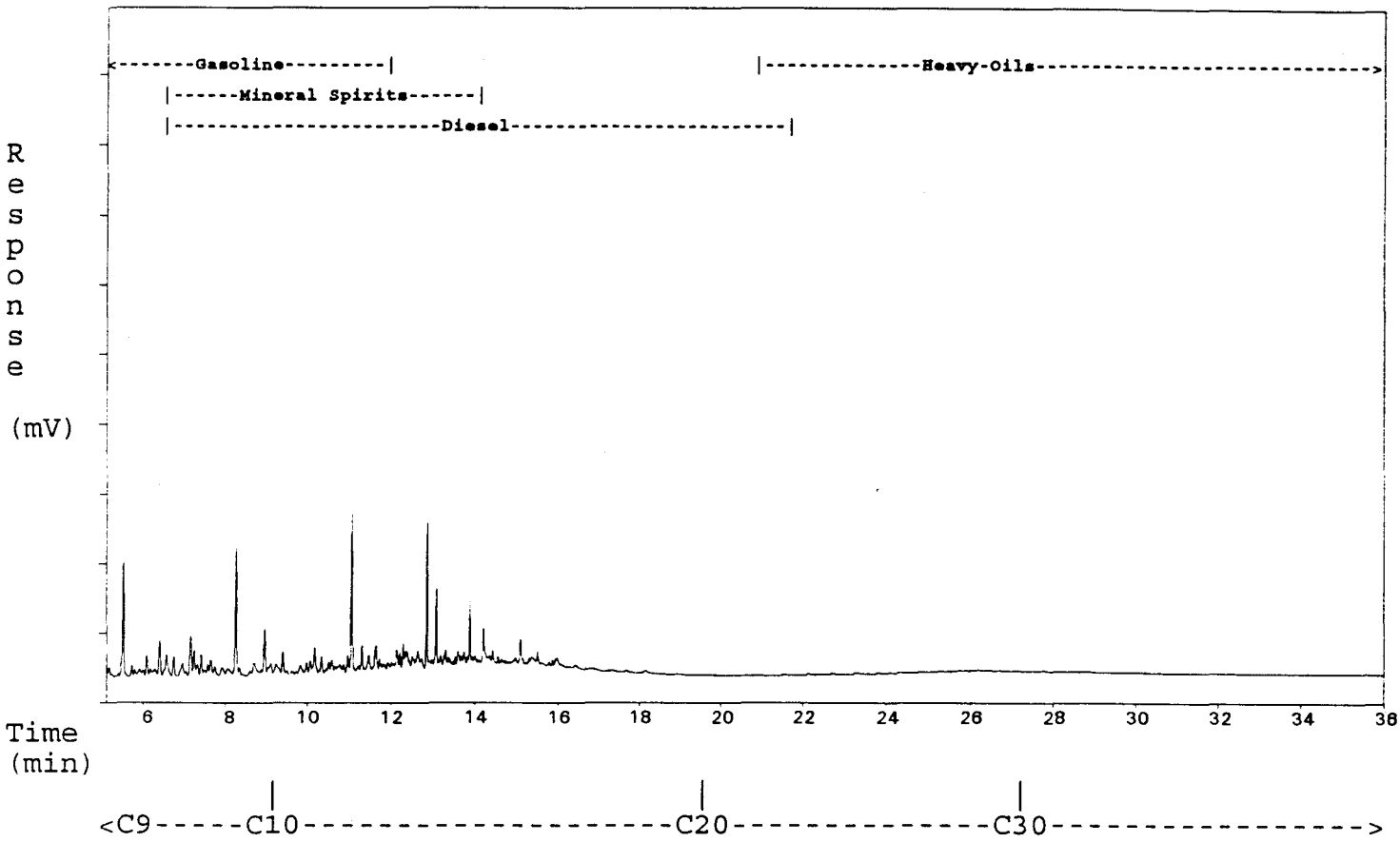
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.8
Carbon 10 to Carbon 20	(C10-C20)	79.0
Carbon 20 to Carbon 30	(C20-C30)	0.6
Greater than Carbon 30	(>C30)	0.7

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-10-02 July 11, 1996 16:00

Sample acquired: JUL 21, 1996 16:12:58
File Name: c:\TEH\TEHJUL21.12R , Sample Name: G3053 2
Sequence file: TEHJUL21



ASL Sample ID: G3053 2* 8.0Dilution

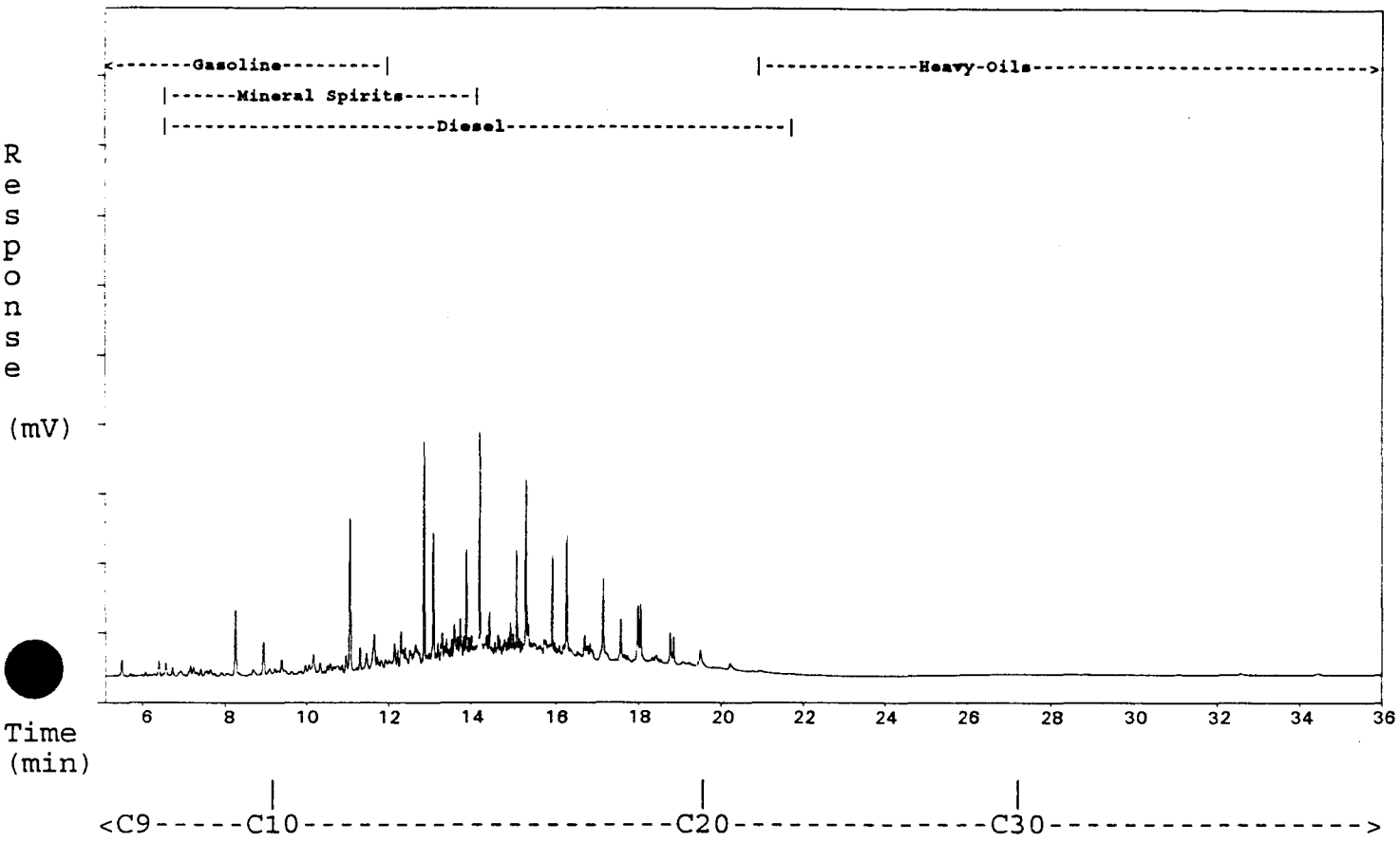
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	23.1
Carbon 10 to Carbon 20	(C10-C20)	70.0
Carbon 20 to Carbon 30	(C20-C30)	4.1
Greater than Carbon 30	(>C30)	2.8

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-11-01 July 12, 1996

Sample acquired: JUL 21, 1996 17:50:43
File Name: c:\TEH\TEHJUL21.16R , Sample Name: G3053 6
Sequence file: TEHJUL21



ASL Sample ID: G3053 6* 8.0Dilution

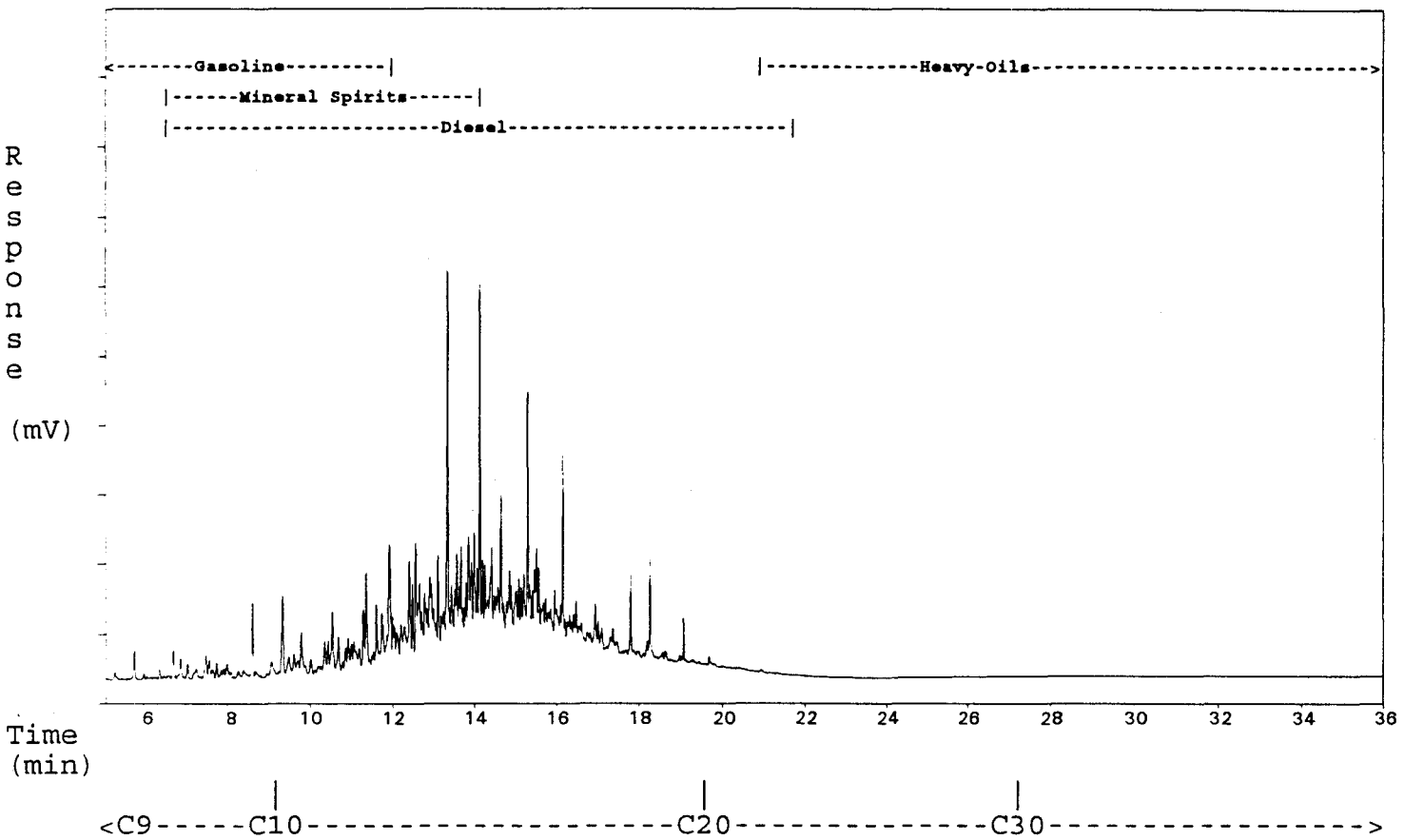
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	4.6
Carbon 10 to Carbon 20	(C10-C20)	92.9
Carbon 20 to Carbon 30	(C20-C30)	1.3
Greater than Carbon 30	(>C30)	1.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-11-02 July 12, 1996

Sample acquired: JUL 21, 1996 18:39:38
File Name: c:\TEH\TEHJUL21.17R , Sample Name: G3053 7
Sequence file: TEHJUL21



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	4.0
Carbon 10 to Carbon 20	(C10-C20)	95.1
Carbon 20 to Carbon 30	(C20-C30)	0.8
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

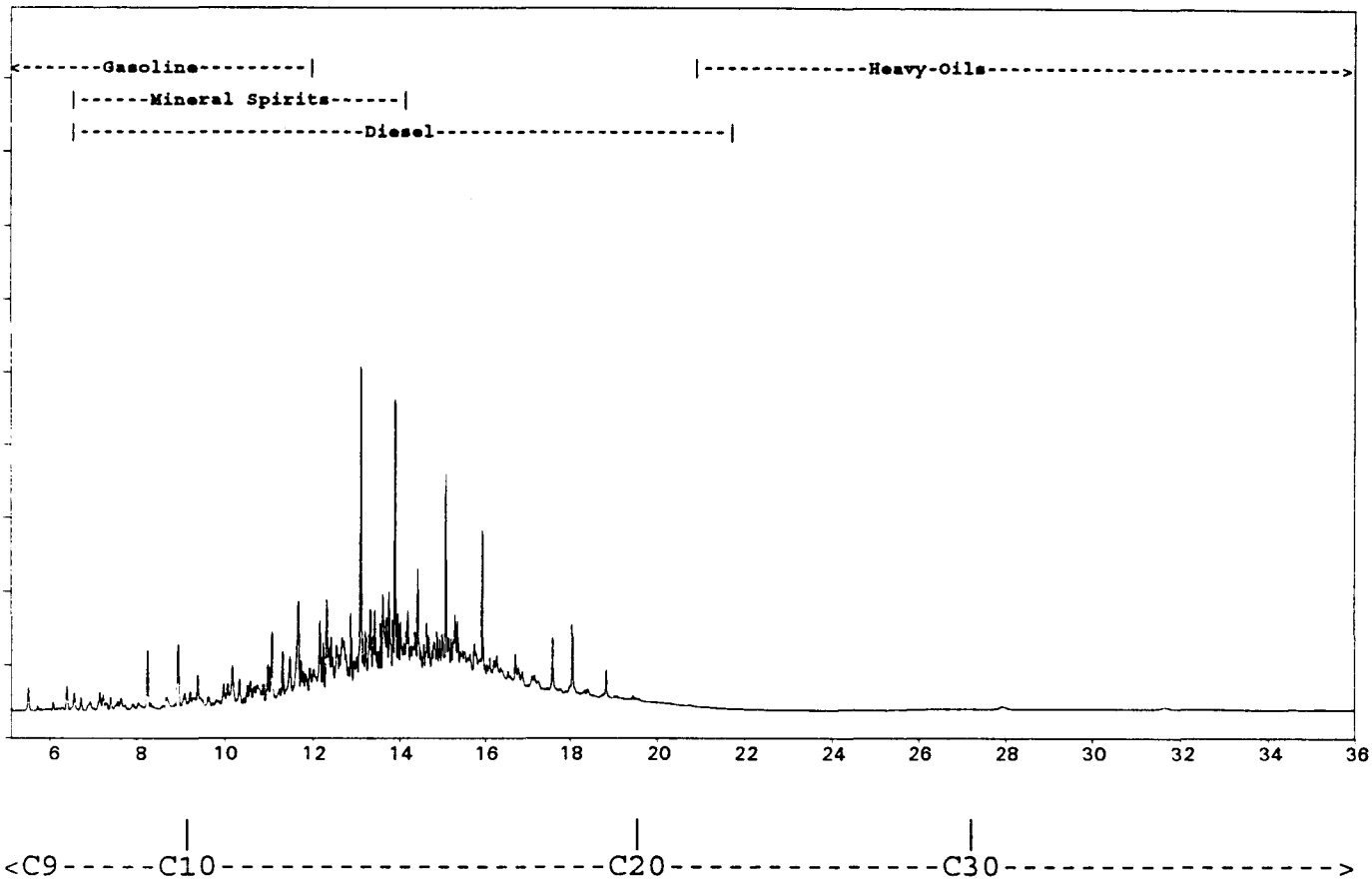
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-11-02 Laboratory Replicate July 12, 1996

Sample acquired: JUL 21, 1996 18:39:38

File Name: c:\TEH\TEHJUL21.18R , Sample Name: QC 67587#G3053 7DUP

Sequence file: TEHJUL21



ASL Sample ID: QC 67587#G3053 7DUP* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	4.3
Carbon 10 to Carbon 20	(C10-C20)	94.6
Carbon 20 to Carbon 30	(C20-C30)	0.3
Greater than Carbon 30	(>C30)	0.9

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

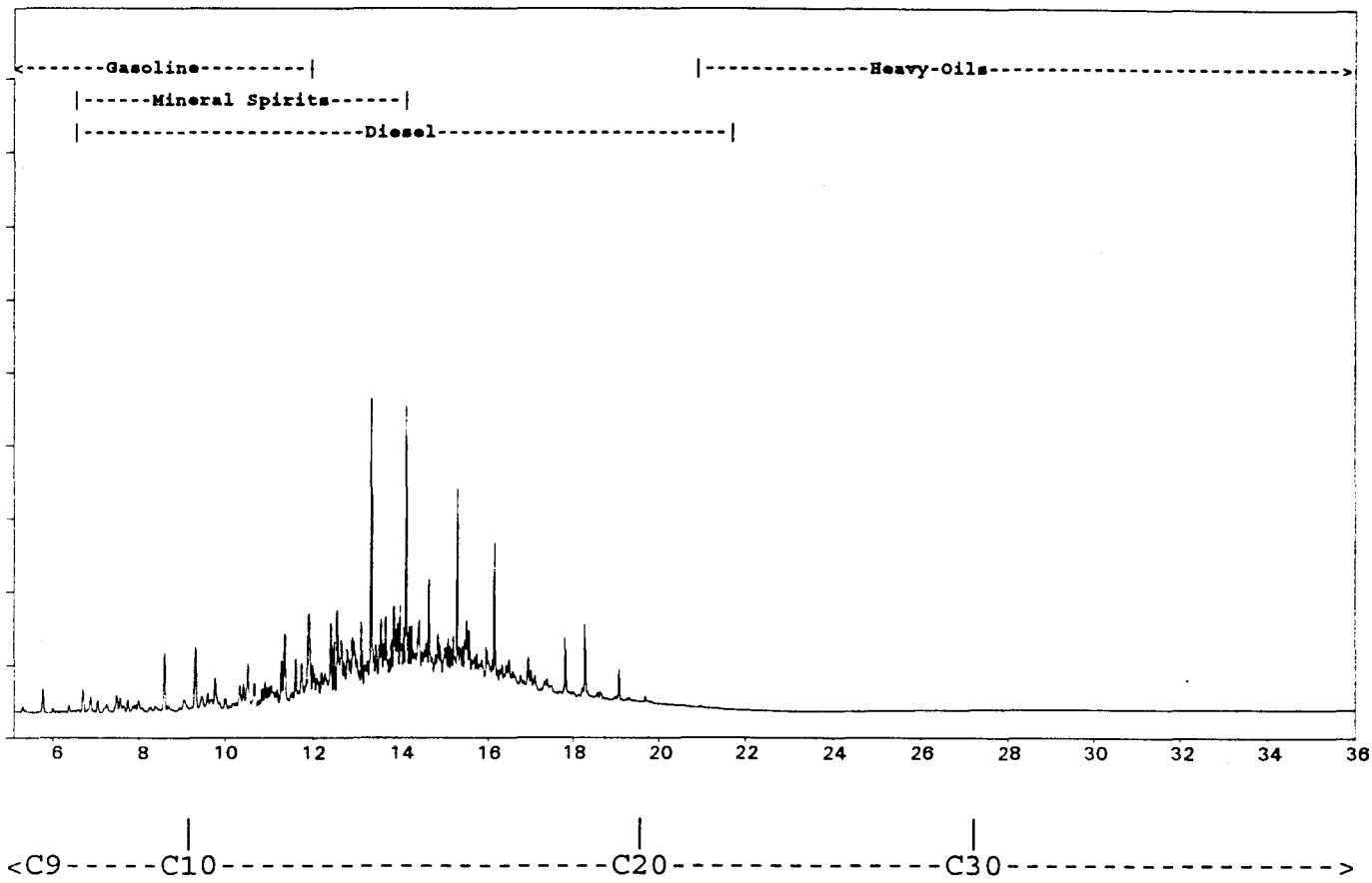
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-11-03 July 12, 1996

Sample acquired: JUL 21, 1996 19:28:33

File Name: c:\TEH\TEHJUL21.19R , Sample Name: G3053 8

Sequence file: TEHJUL21



ASL Sample ID: G3053 8* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	4.1
Carbon 10 to Carbon 20	(C10-C20)	95.1
Carbon 20 to Carbon 30	(C20-C30)	0.7
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

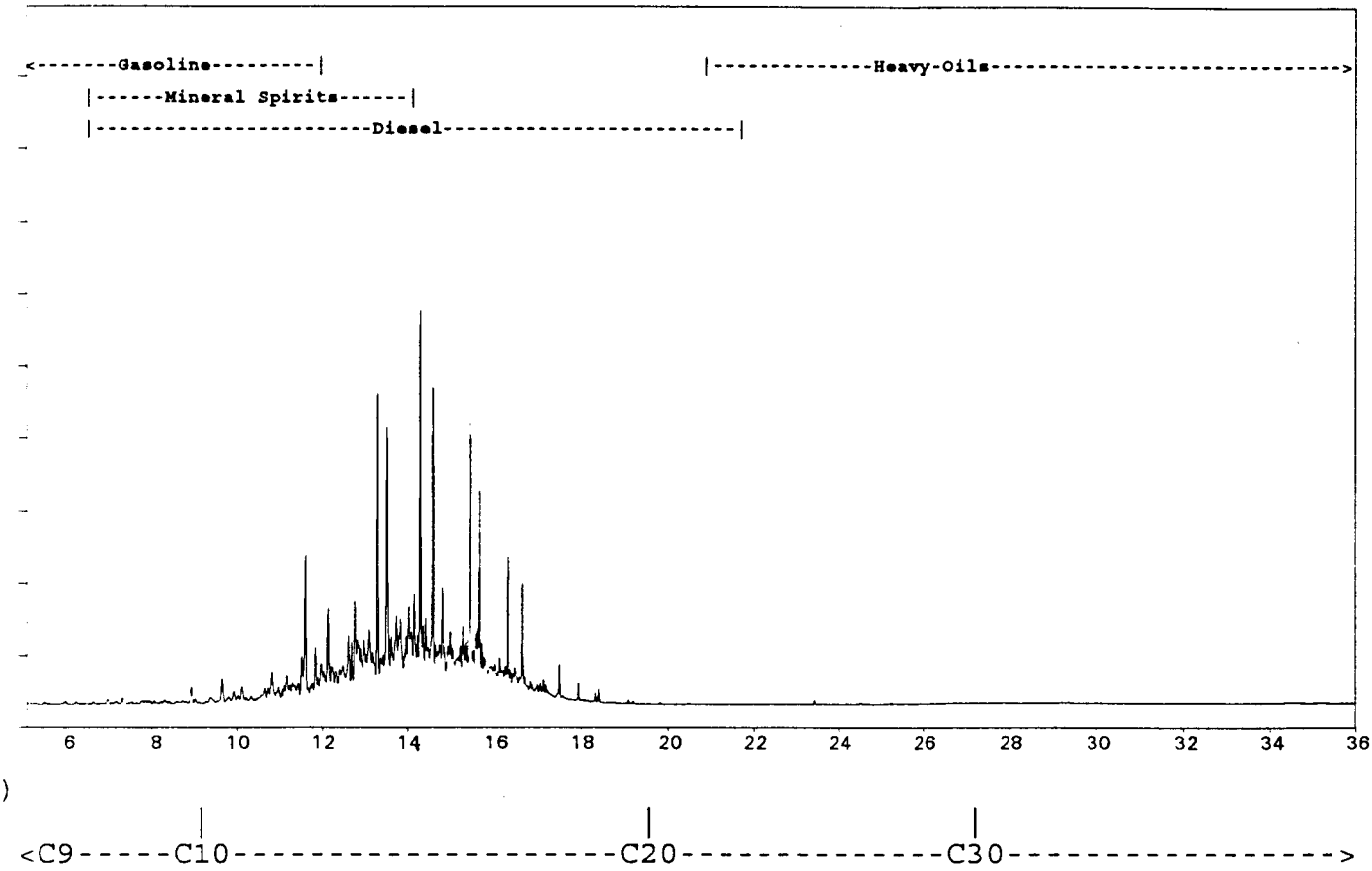
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-13-01 July 14, 1996

Sample acquired: JUL 31, 1996 02:39:51

File Name: c:\TEH\TEH30JUL.14R , Sample Name: G3347 31

Sequence file: TEH30JUL



ASL Sample ID: G3347 31* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	1.5
Carbon 10 to Carbon 20	(C10-C20)	98.2
Carbon 20 to Carbon 30	(C20-C30)	0.2
Greater than Carbon 30	(>C30)	0.2

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

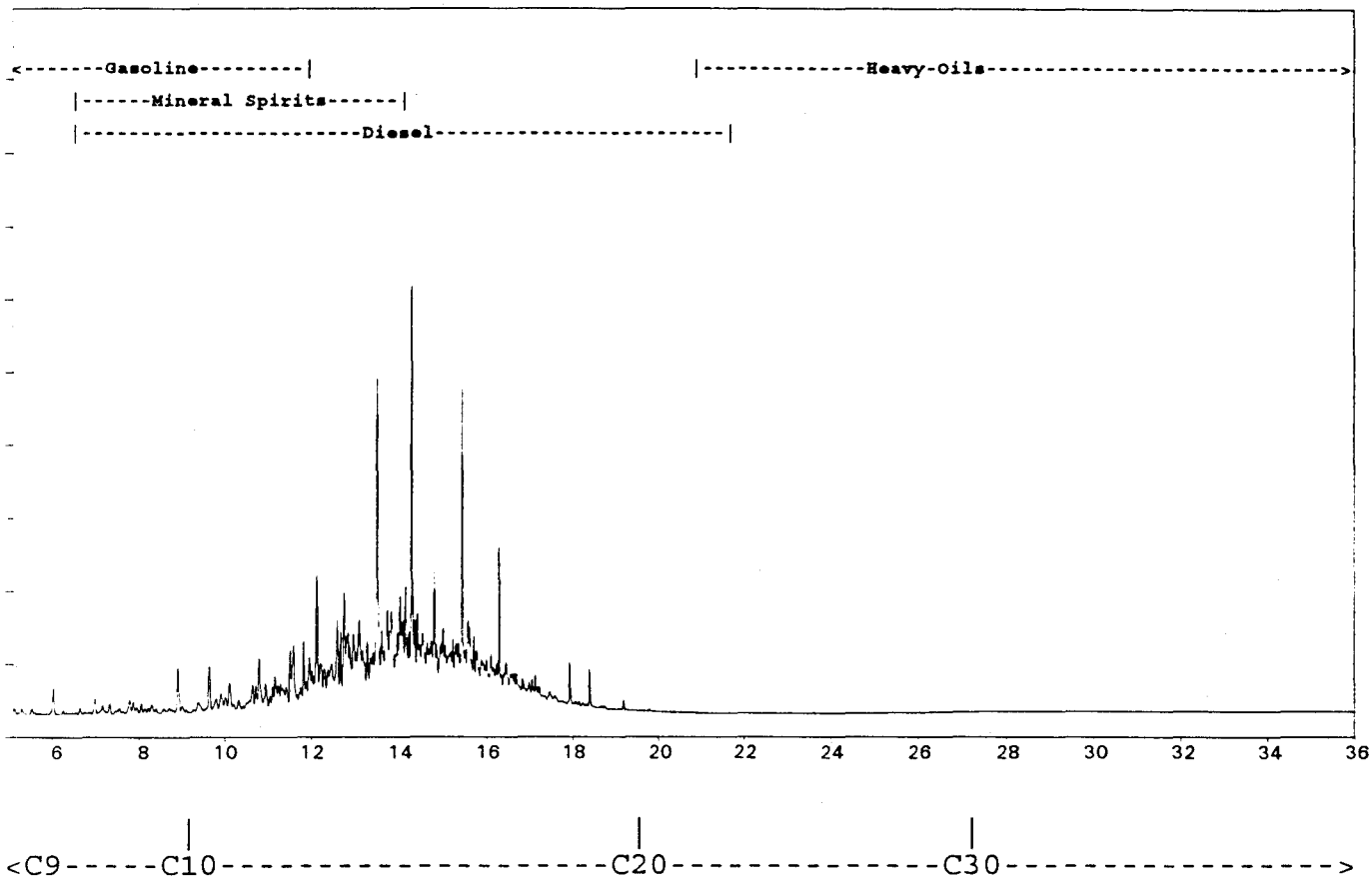
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-16-03 July 16, 1996

Sample acquired: JUL 31, 1996 14:49:05

File Name: c:\TEH\TEH30JUL.29R , Sample Name: G3347 44

Sequence file: TEH30JUL



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	3.1
Carbon 10 to Carbon 20	(C10-C20)	96.8
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

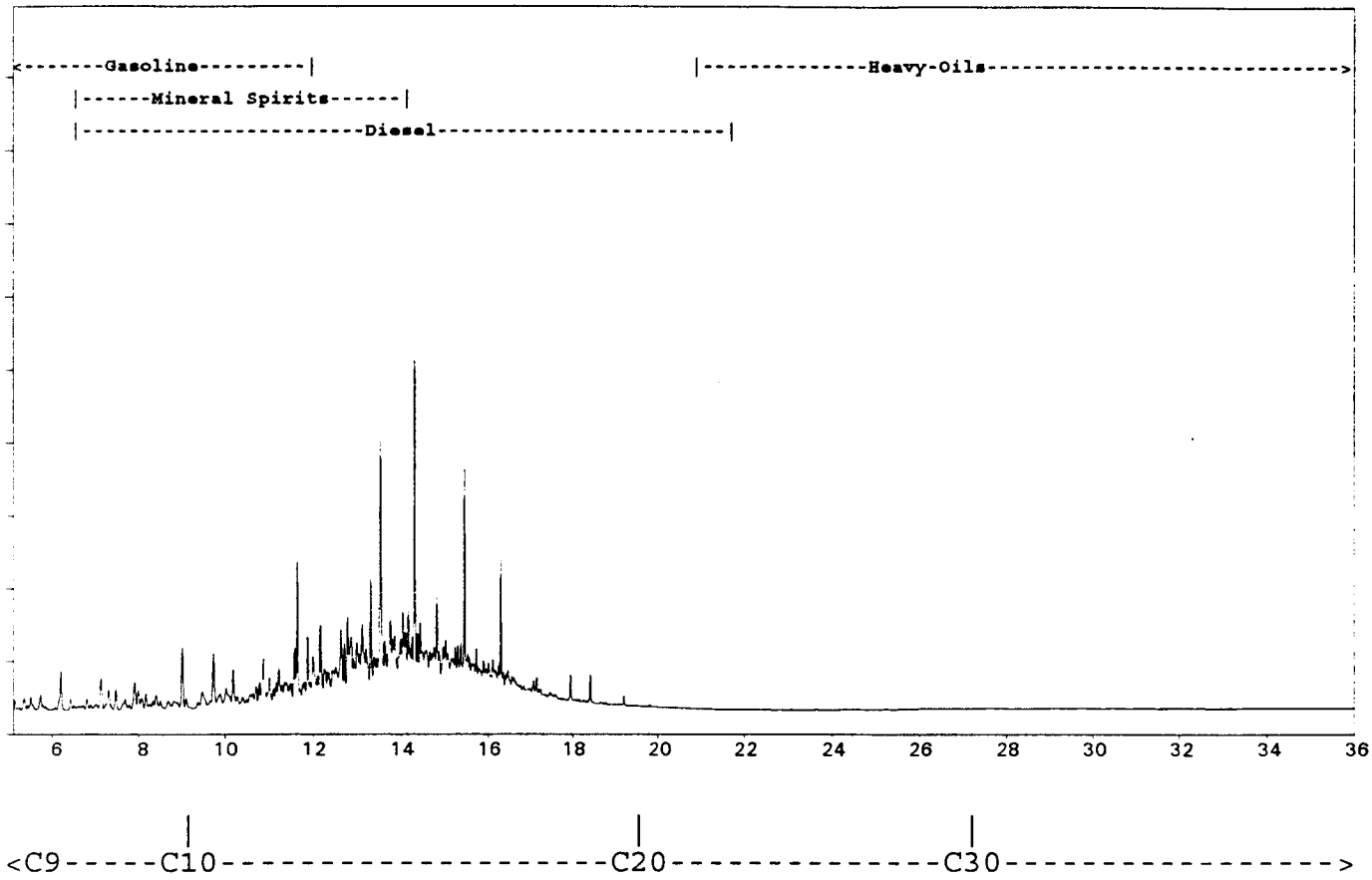
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-19-02 July 19, 1996

Sample acquired: JUL 29, 1996 07:13:15

File Name: c:\TEH\TEH28JUL.23R , Sample Name: G3345 30

Sequence file: TEH28JUL



ASL Sample ID: G3345 30* 8.0Dilution

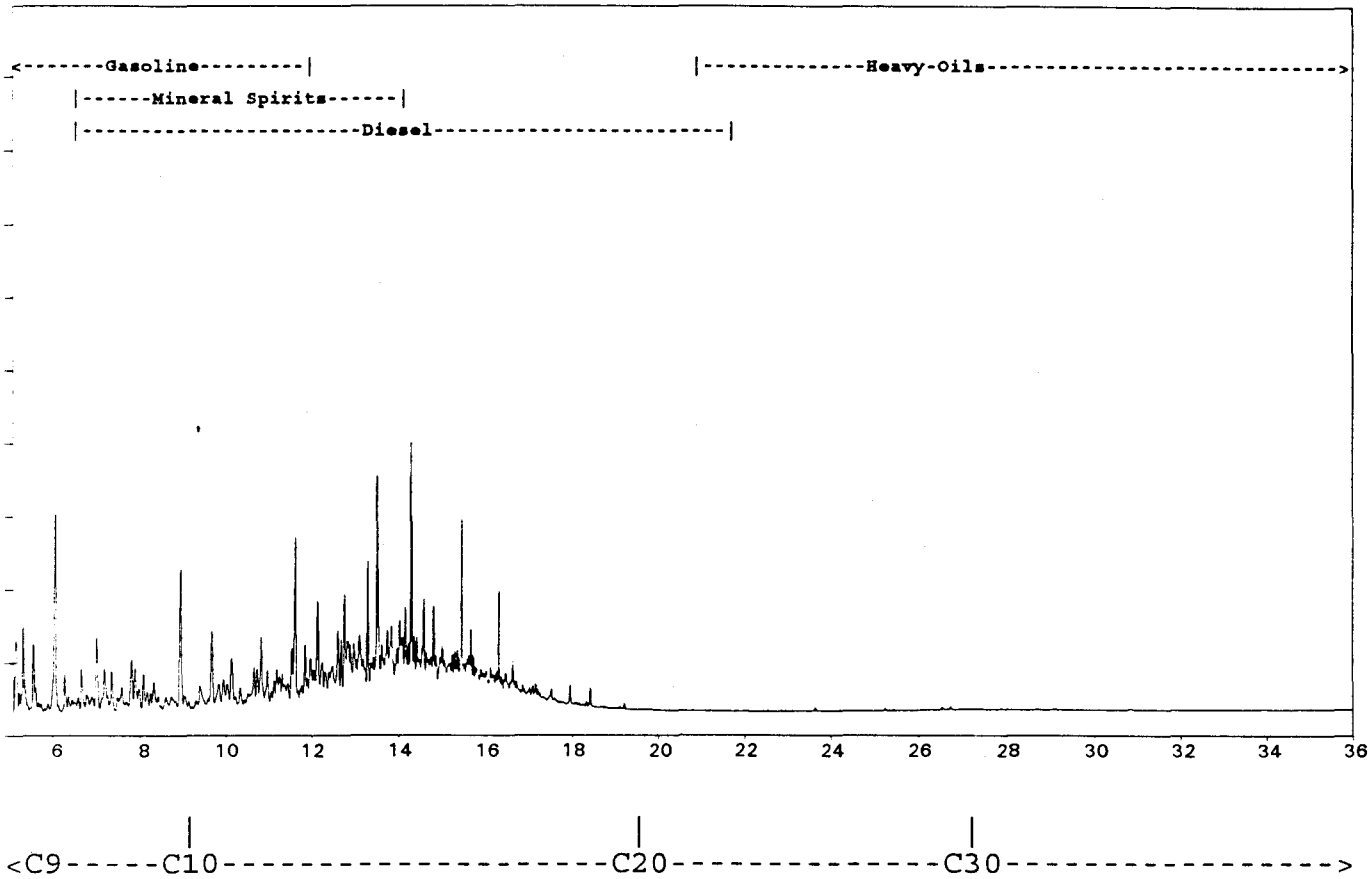
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	6.7
Carbon 10 to Carbon 20	(C10-C20)	92.9
Carbon 20 to Carbon 30	(C20-C30)	0.2
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-20-01 July 19, 1996

Sample acquired: JUL 29, 1996 09:39:35
File Name: c:\TEH\TEH28JUL.26R , Sample Name: G3345 33
Sequence file: TEH28JUL



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.0
Carbon 10 to Carbon 20	(C10-C20)	80.4
Carbon 20 to Carbon 30	(C20-C30)	0.2
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

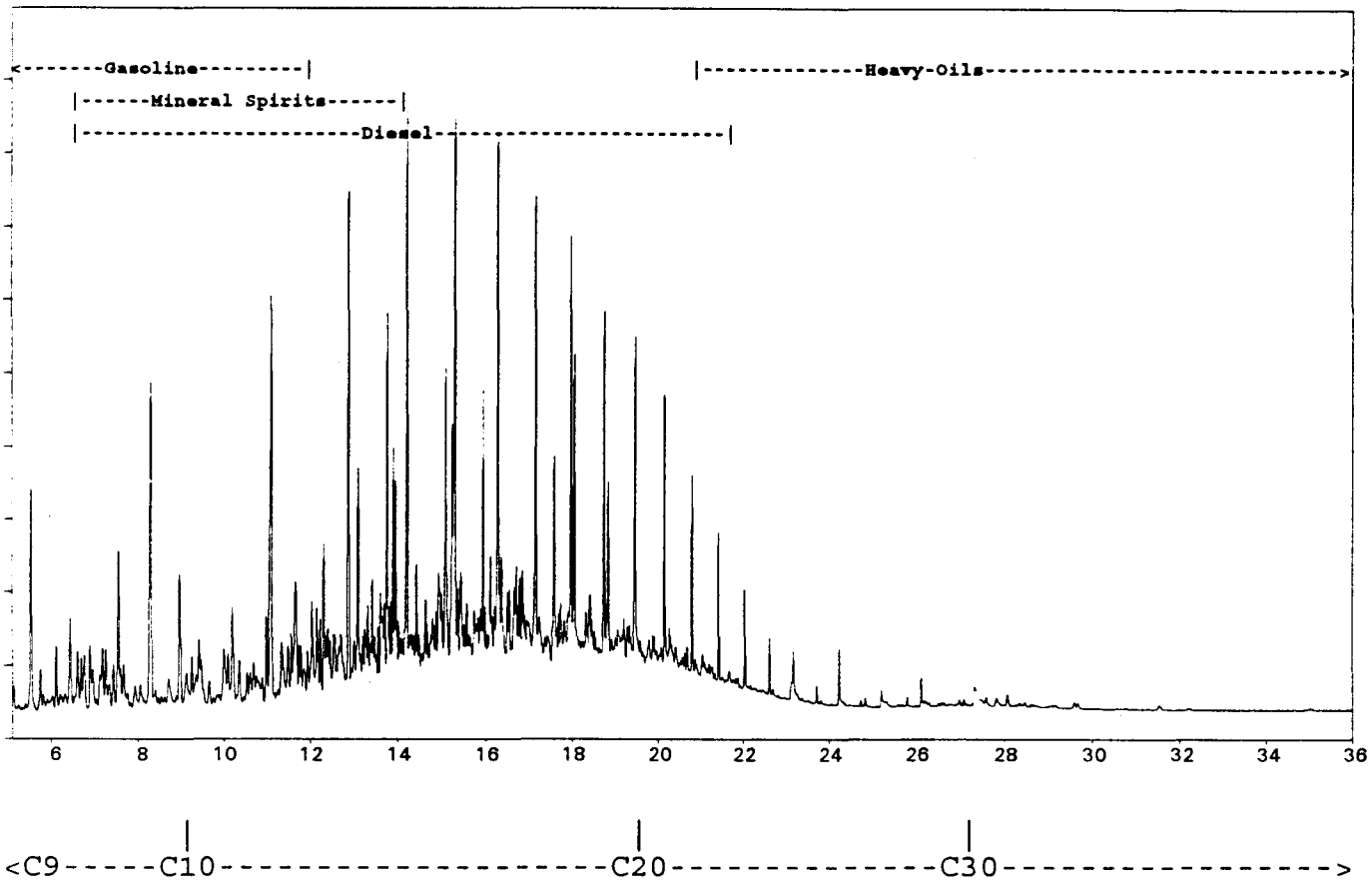
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-03-01 July 11, 1996 15:05

Sample acquired: JUL 22, 1996 08:21:32

File Name: c:\TEH\TEHJUL21.52R , Sample Name: G3053 41

Sequence file: TEHJUL21



ASL Sample ID: G3053 41* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	9.2
Carbon 10 to Carbon 20	(C10-C20)	79.3
Carbon 20 to Carbon 30	(C20-C30)	9.6
Greater than Carbon 30	(>C30)	1.9

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

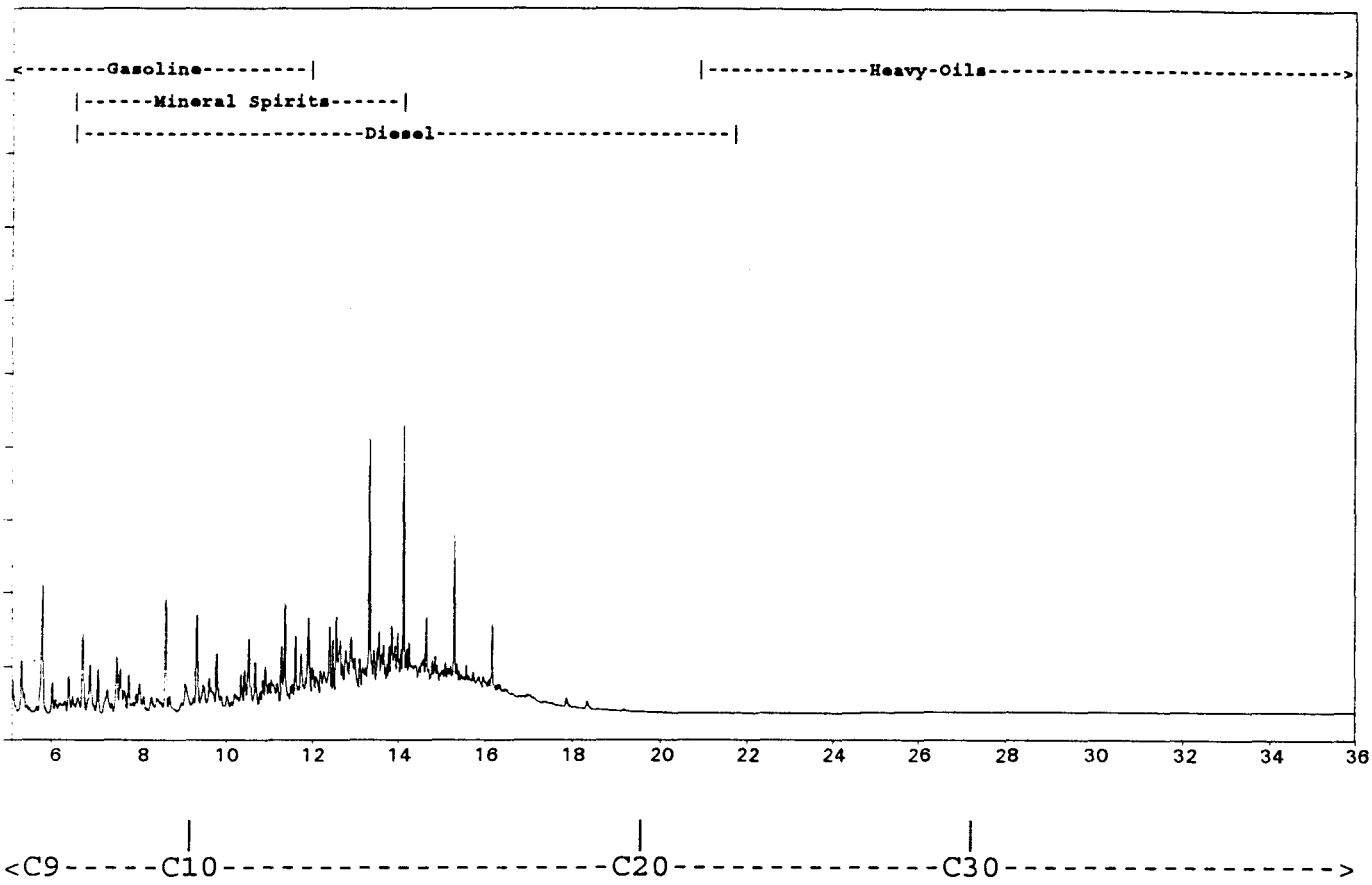
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-10-03 July 11, 1996

Sample acquired: JUL 23, 1996 00:02:39

File Name: c:\TEH\TEHJUL22.21R , Sample Name: G3053 52

Sequence file: TEHJUL22



ASL Sample ID: G3053 52* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.8
Carbon 10 to Carbon 20	(C10-C20)	79.8
Carbon 20 to Carbon 30	(C20-C30)	0.2
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

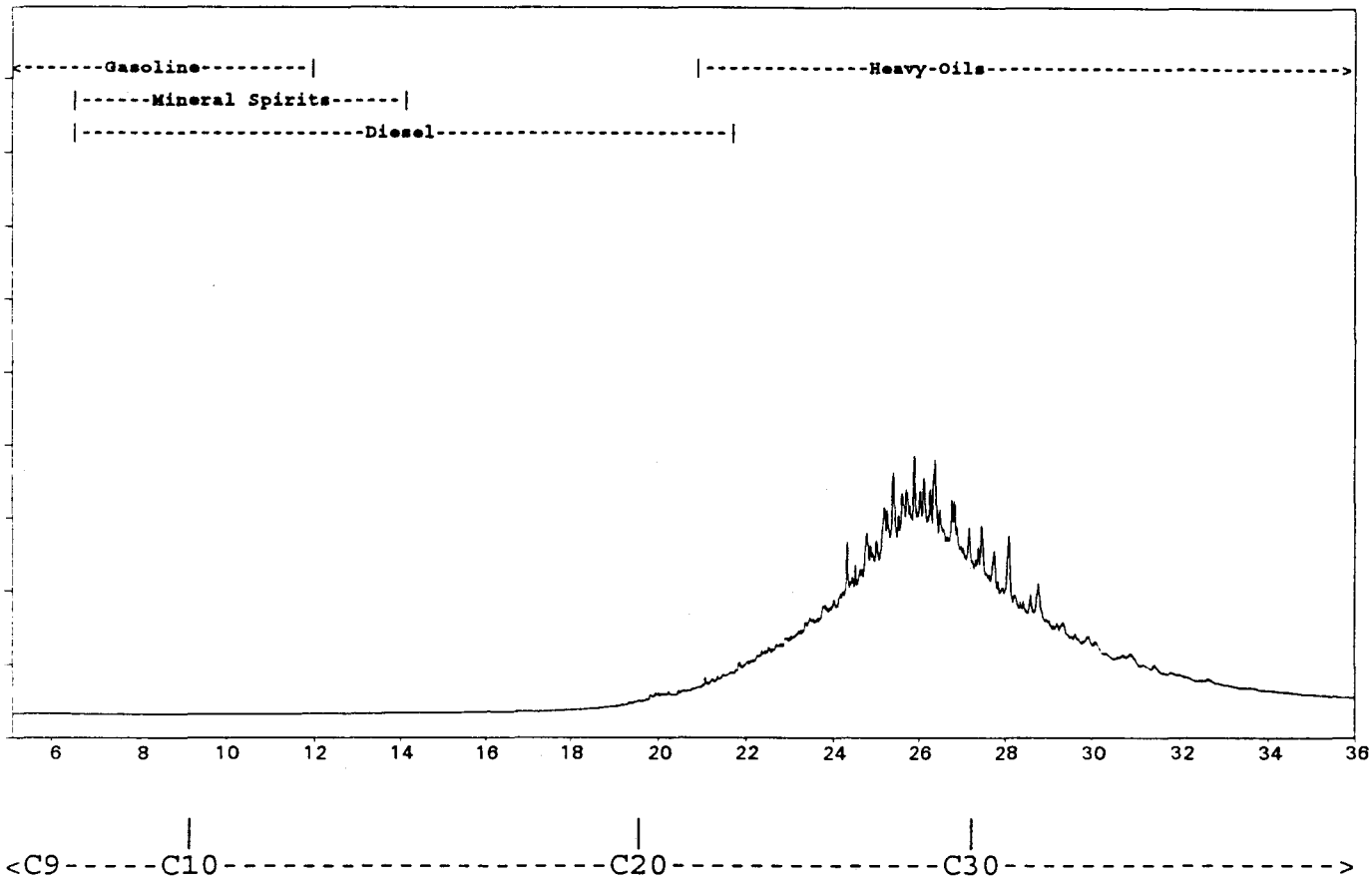
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-14-01 July 13, 1996 12:00

Sample acquired: JUL 22, 1996 18:20:00

File Name: c:\TEH\TEHJUL22.07R , Sample Name: G3053 12#Rx5

Sequence file: TEHJUL22



ASL Sample ID: G3053 12#Rx5* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	0.0
Carbon 10 to Carbon 20	(C10-C20)	1.6
Carbon 20 to Carbon 30	(C20-C30)	48.0
Greater than Carbon 30	(>C30)	50.3

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

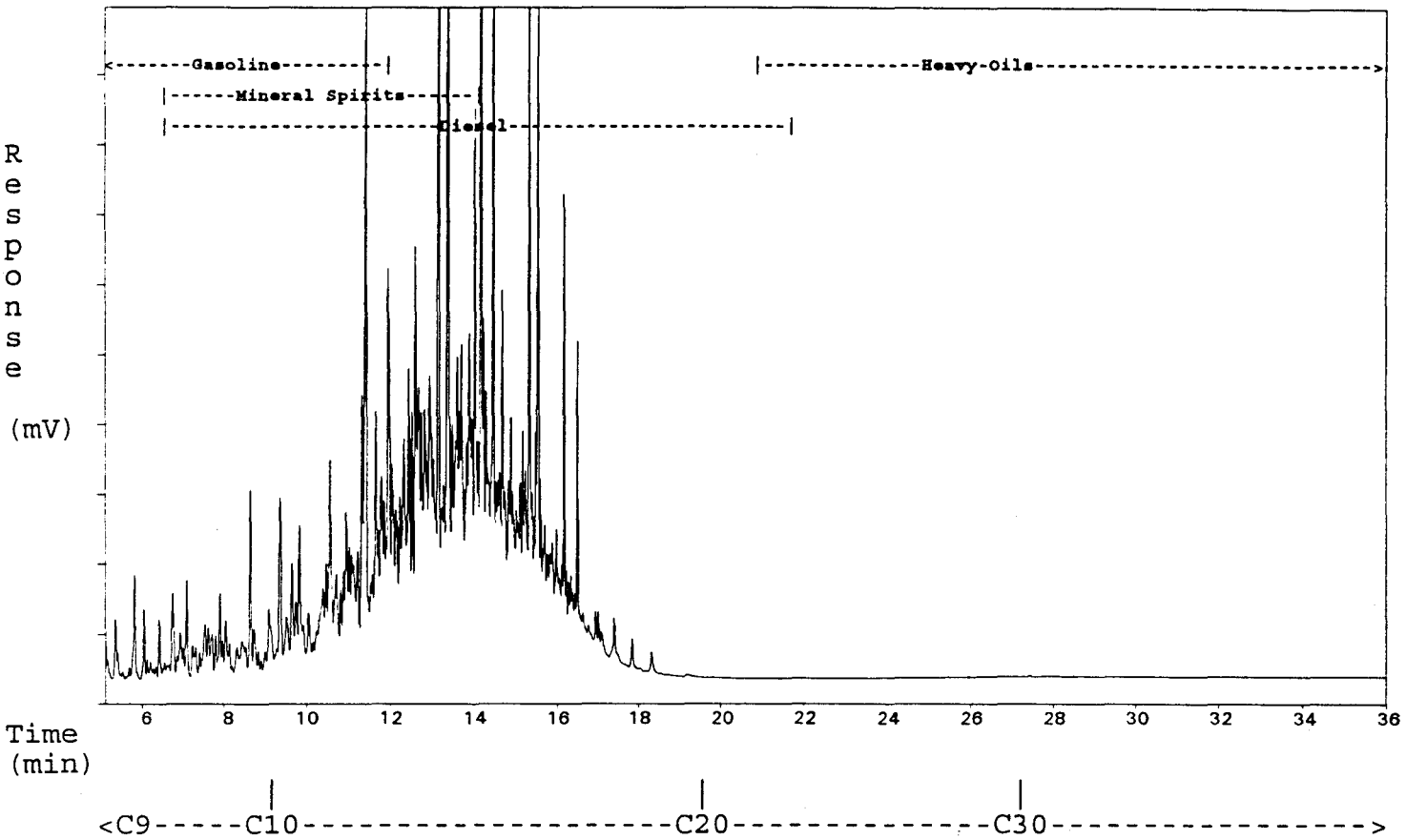
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-17-01 July 13, 1996 14:30

Sample acquired: JUL 22, 1996 02:45:12

File Name: c:\TEH\TEHJUL21.37R , Sample Name: G3053 24

Sequence file: TEHJUL21



ASL Sample ID: G3053 24* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	7.6
Carbon 10 to Carbon 20	(C10-C20)	92.2
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

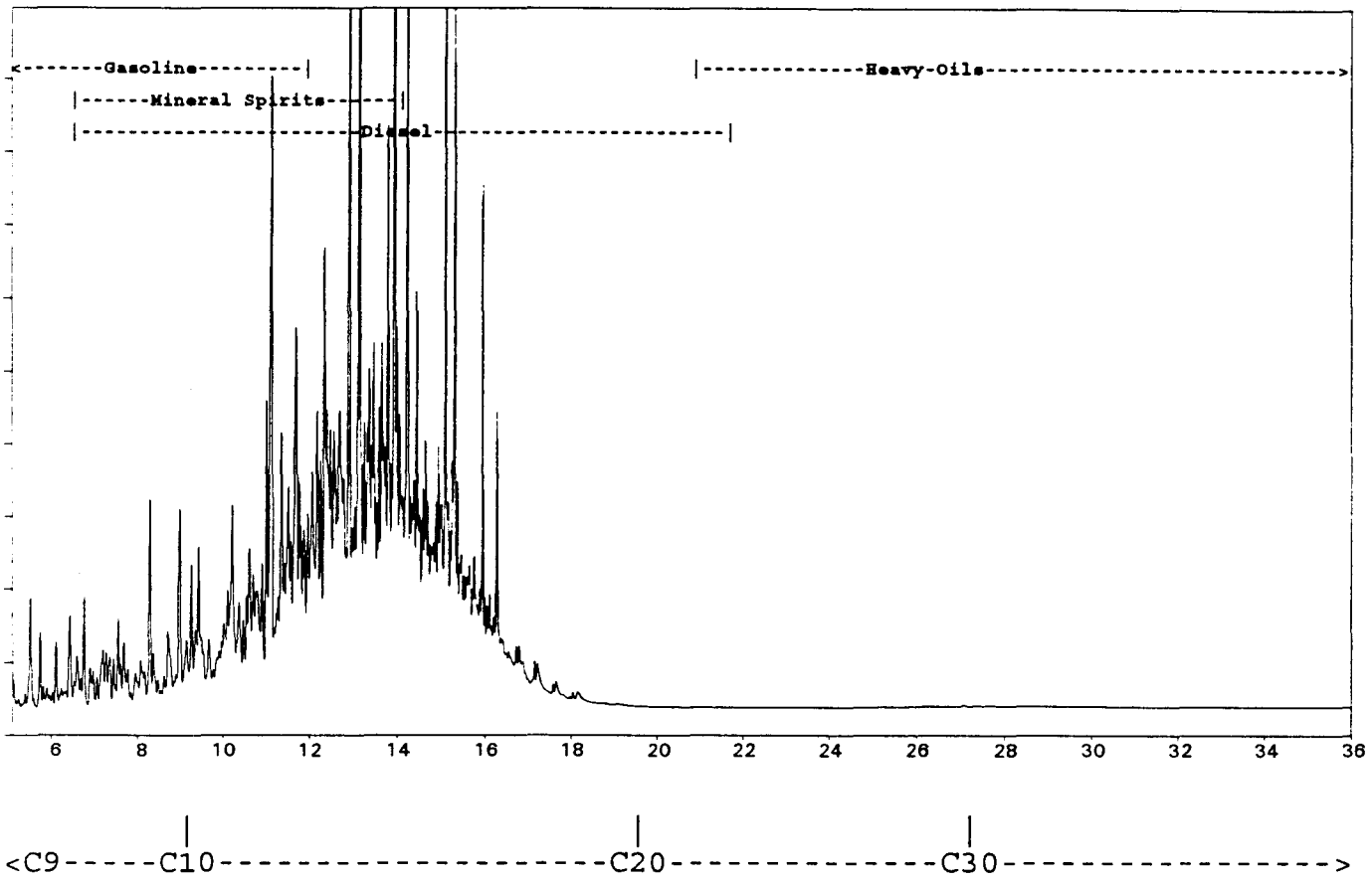
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-17-02 July 13, 1996

Sample acquired: JUL 22, 1996 02:45:12

File Name: c:\TEH\TEHJUL21.38R , Sample Name: G3053 25

Sequence file: TEHJUL21



ASL Sample ID: G3053 25* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	8.0
Carbon 10 to Carbon 20	(C10-C20)	91.8
Carbon 20 to Carbon 30	(C20-C30)	0.0
Greater than Carbon 30	(>C30)	0.2

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

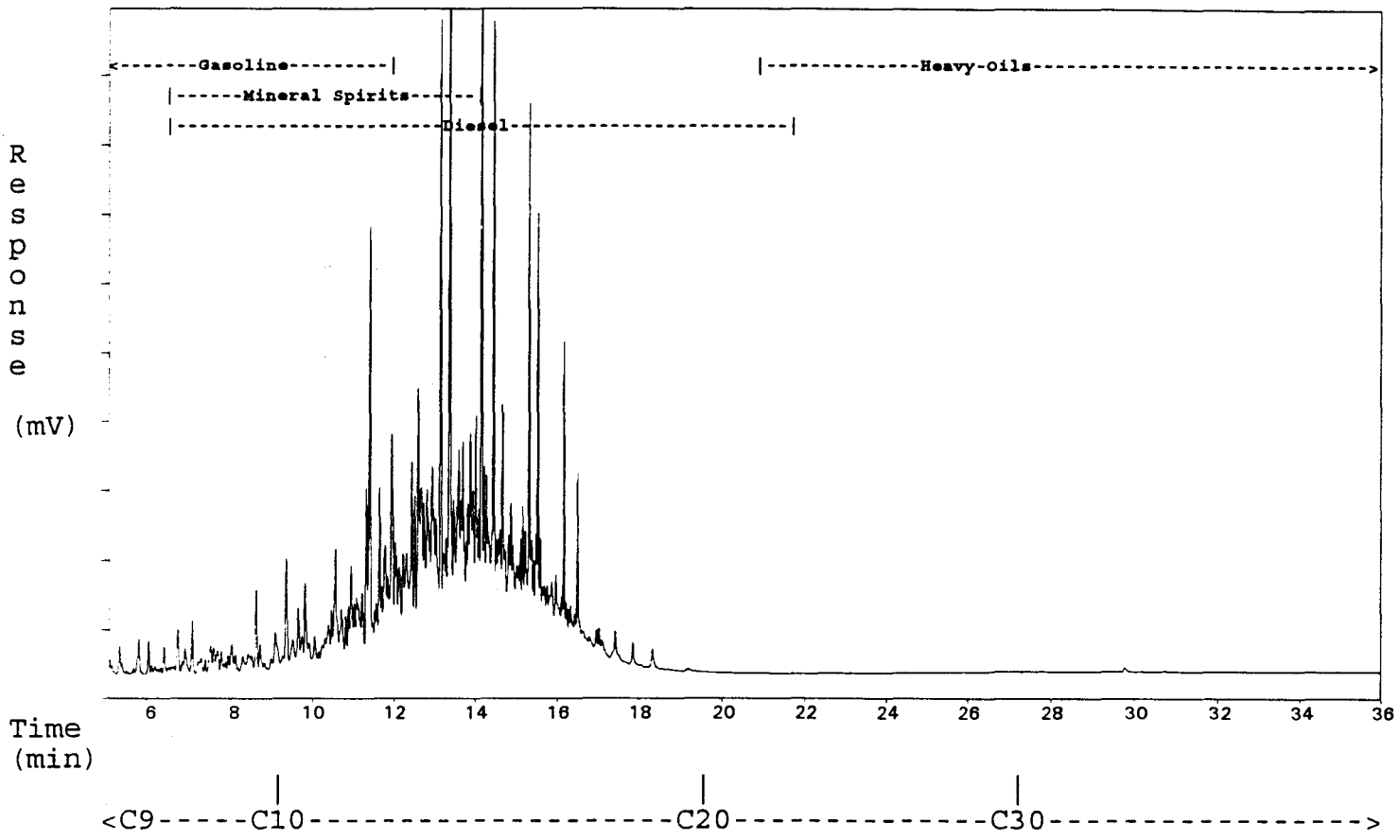
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-19-02 July 13, 1996 15:35

Sample acquired: JUL 22, 1996 03:33:21

File Name: c:\TEH\TEHJUL21.39R , Sample Name: G3053 27

Sequence file: TEHJUL21



ASL Sample ID: G3053 27* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	5.5
Carbon 10 to Carbon 20	(C10-C20)	94.1
Carbon 20 to Carbon 30	(C20-C30)	0.0
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

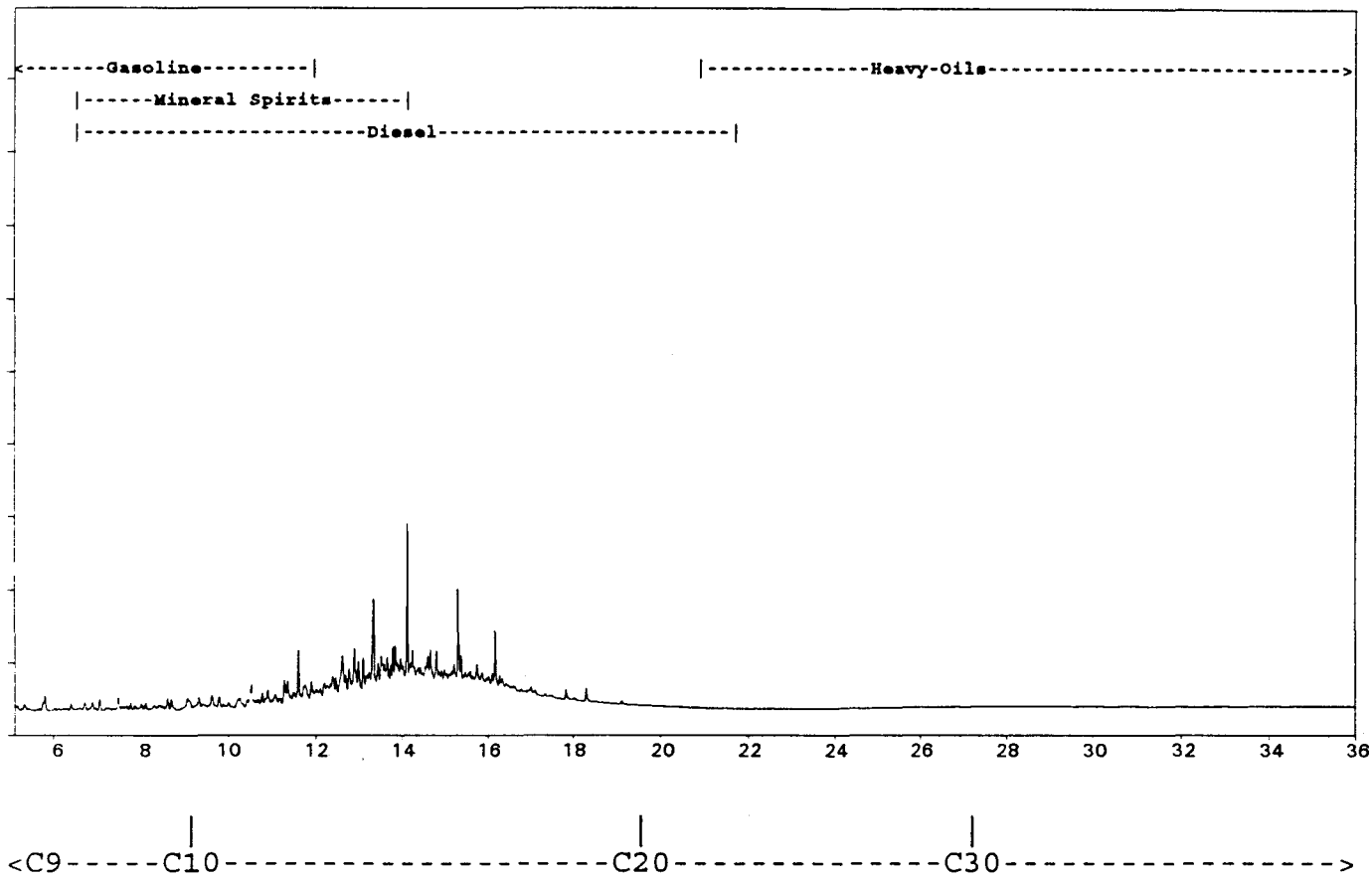
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-23-02 July 13, 1996

Sample acquired: JUL 22, 1996 00:20:36

File Name: c:\TEH\TEHJUL21.31R , Sample Name: G3053 18

Sequence file: TEHJUL21



ASL Sample ID: G3053 18* 8.0Dilution

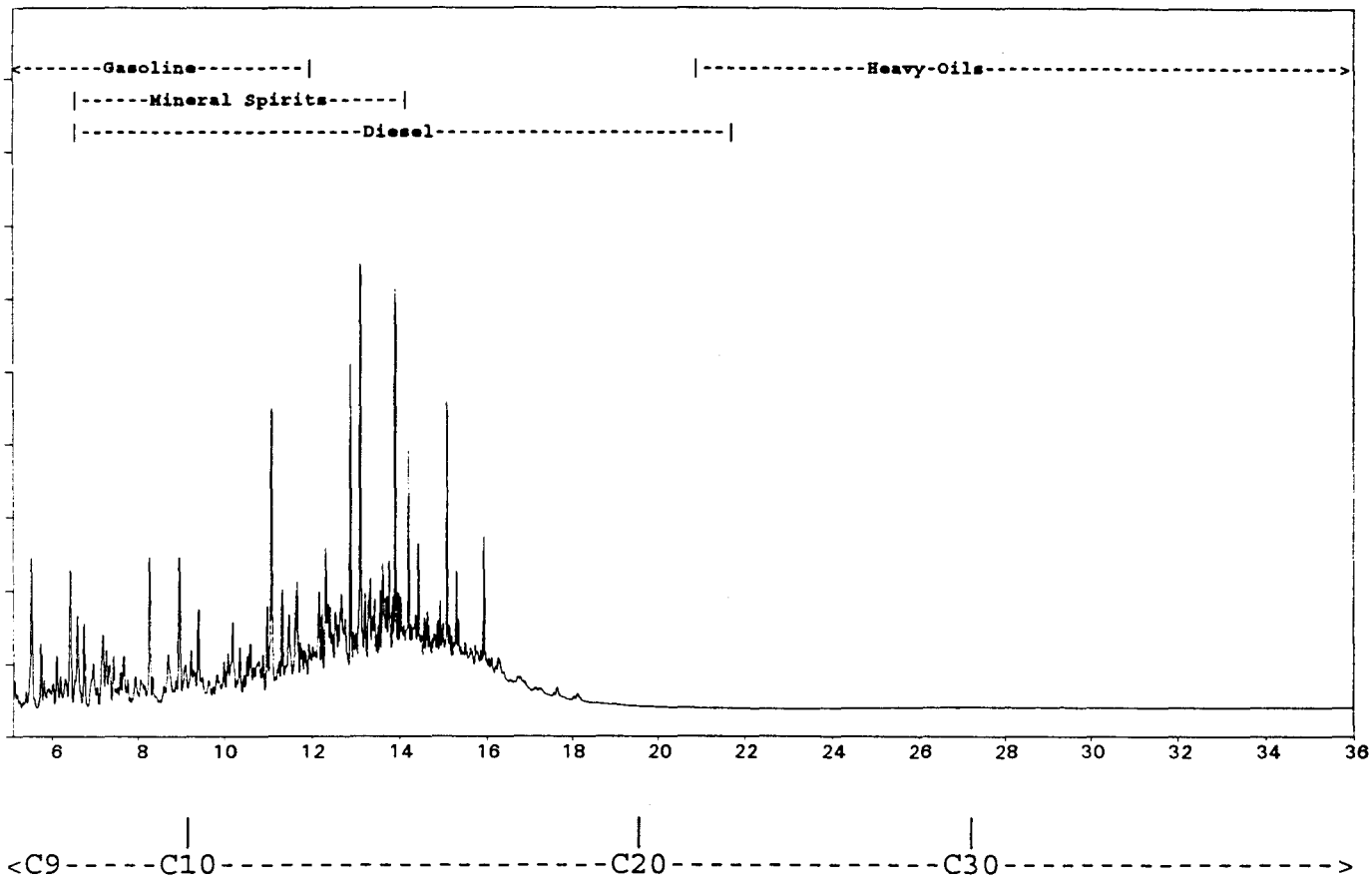
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	5.1
Carbon 10 to Carbon 20	(C10-C20)	94.6
Carbon 20 to Carbon 30	(C20-C30)	0.2
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-24-01 July 13, 1996

Sample acquired: JUL 22, 1996 00:20:36
File Name: c:\TEH\TEHJUL21.32R , Sample Name: G3053 19
Sequence file: TEHJUL21



ASL Sample ID: G3053 19* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.1
Carbon 10 to Carbon 20	(C10-C20)	80.6
Carbon 20 to Carbon 30	(C20-C30)	0.0
Greater than Carbon 30	(>C30)	0.3

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

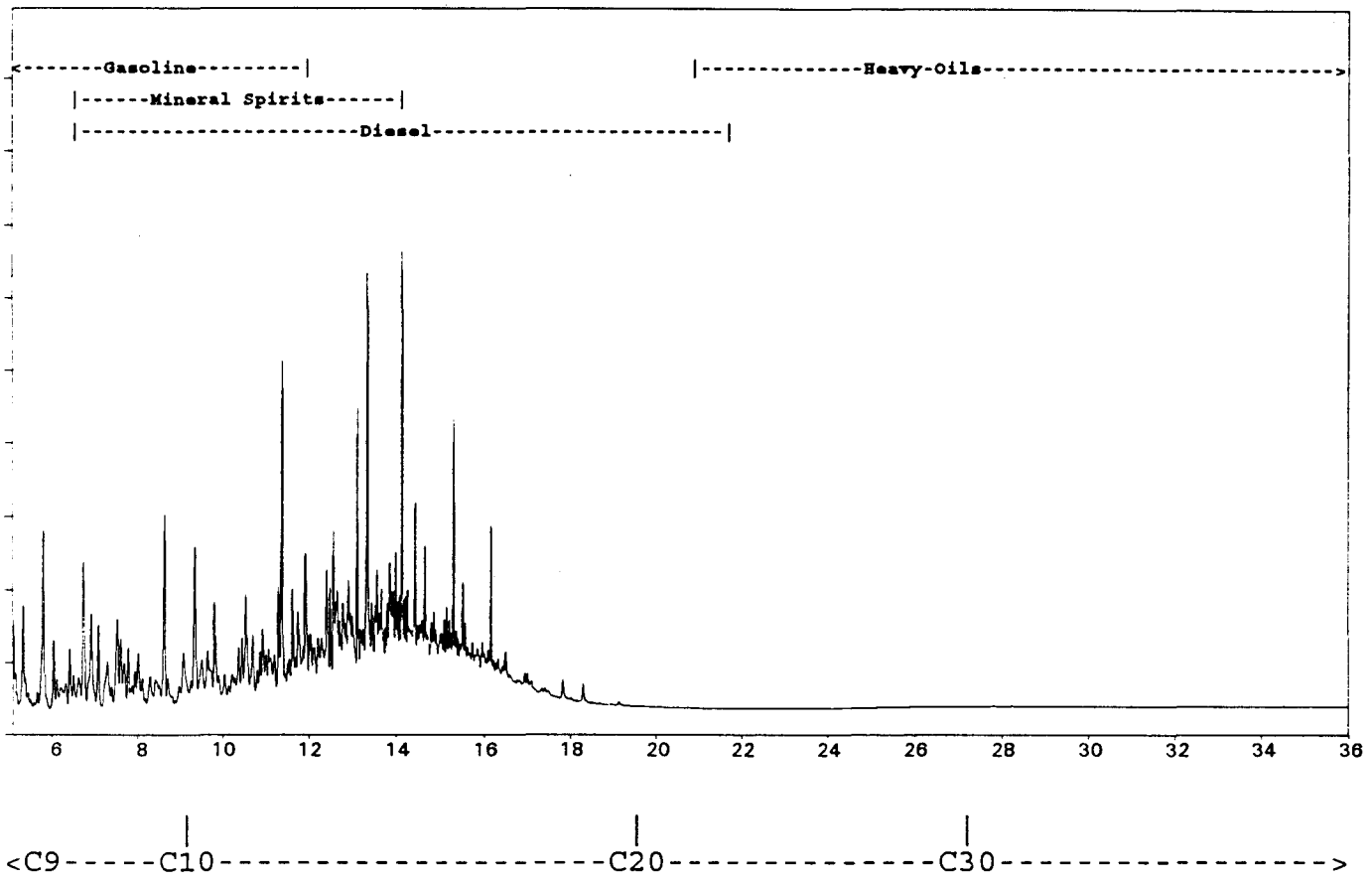
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-24-02 July 13, 1996

Sample acquired: JUL 22, 1996 01:08:52

File Name: c:\TEH\TEHJUL21.33R , Sample Name: G3053 20

Sequence file: TEHJUL21



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	20.6
Carbon 10 to Carbon 20	(C10-C20)	79.2
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

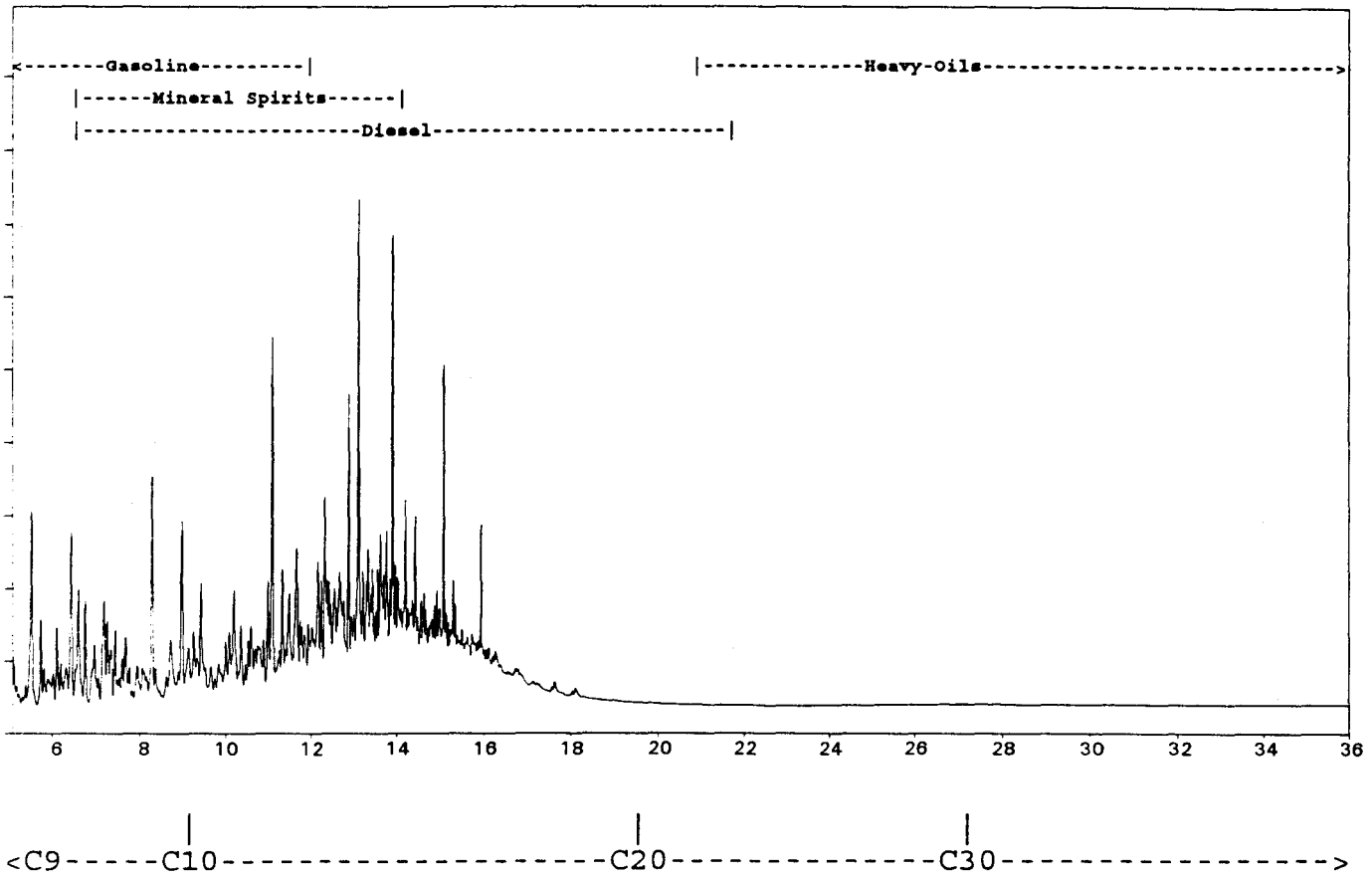
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-24-02 Laboratory Replicate July 13, 1996

Sample acquired: JUL 22, 1996 01:08:52

File Name: c:\TEH\TEHJUL21.34R , Sample Name: QC 67588#G3053 20DUP

Sequence file: TEHJUL21



ASL Sample ID: QC 67588#G3053 20DUP* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	21.6
Carbon 10 to Carbon 20	(C10-C20)	78.3
Carbon 20 to Carbon 30	(C20-C30)	0.0
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

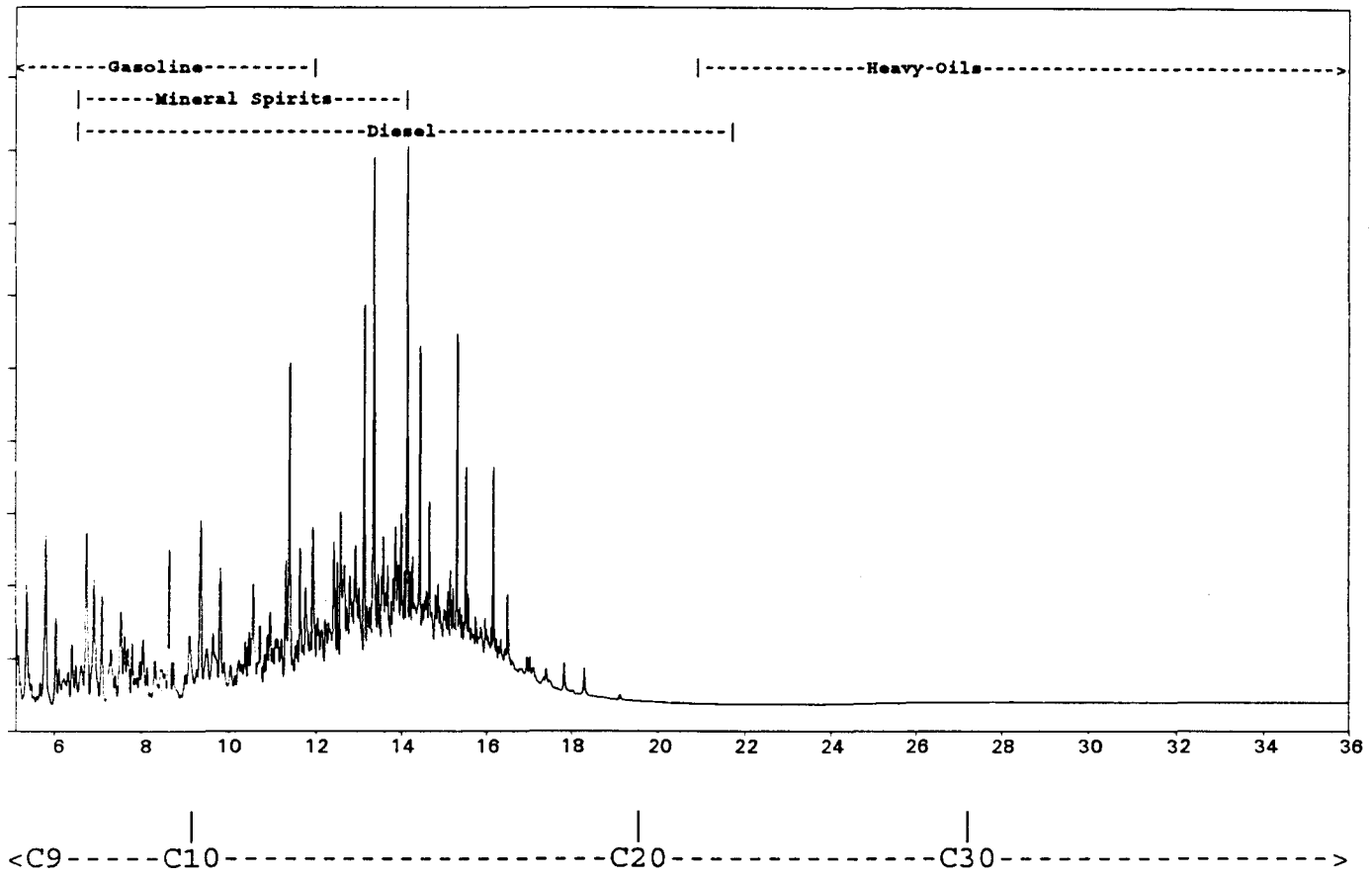
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TP96-24-03 July 13, 1996

Sample acquired: JUL 22, 1996 01:56:59

File Name: c:\TEH\TEHJUL21.35R , Sample Name: G3053 22

Sequence file: TEHJUL21



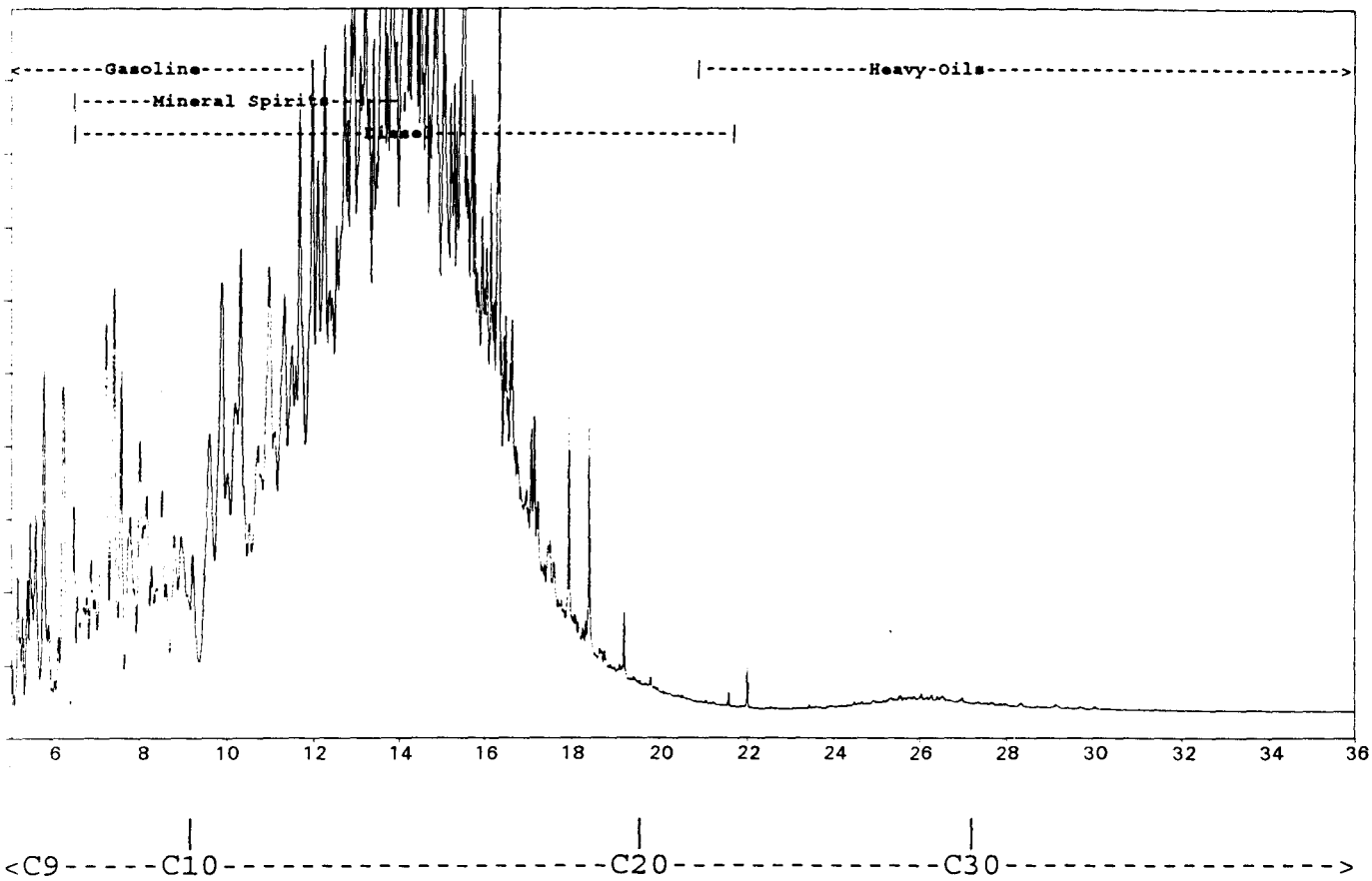
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.9
Carbon 10 to Carbon 20	(C10-C20)	80.0
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-06 July 19, 1996

Sample acquired: JUL 28, 1996 23:49:26
File Name: c:\TEH\TEH28JUL.14R , Sample Name: G3345 6
Sequence file: TEH28JUL



ASL Sample ID: G3345 6* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	12.7
Carbon 10 to Carbon 20	(C10-C20)	86.2
Carbon 20 to Carbon 30	(C20-C30)	0.7
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

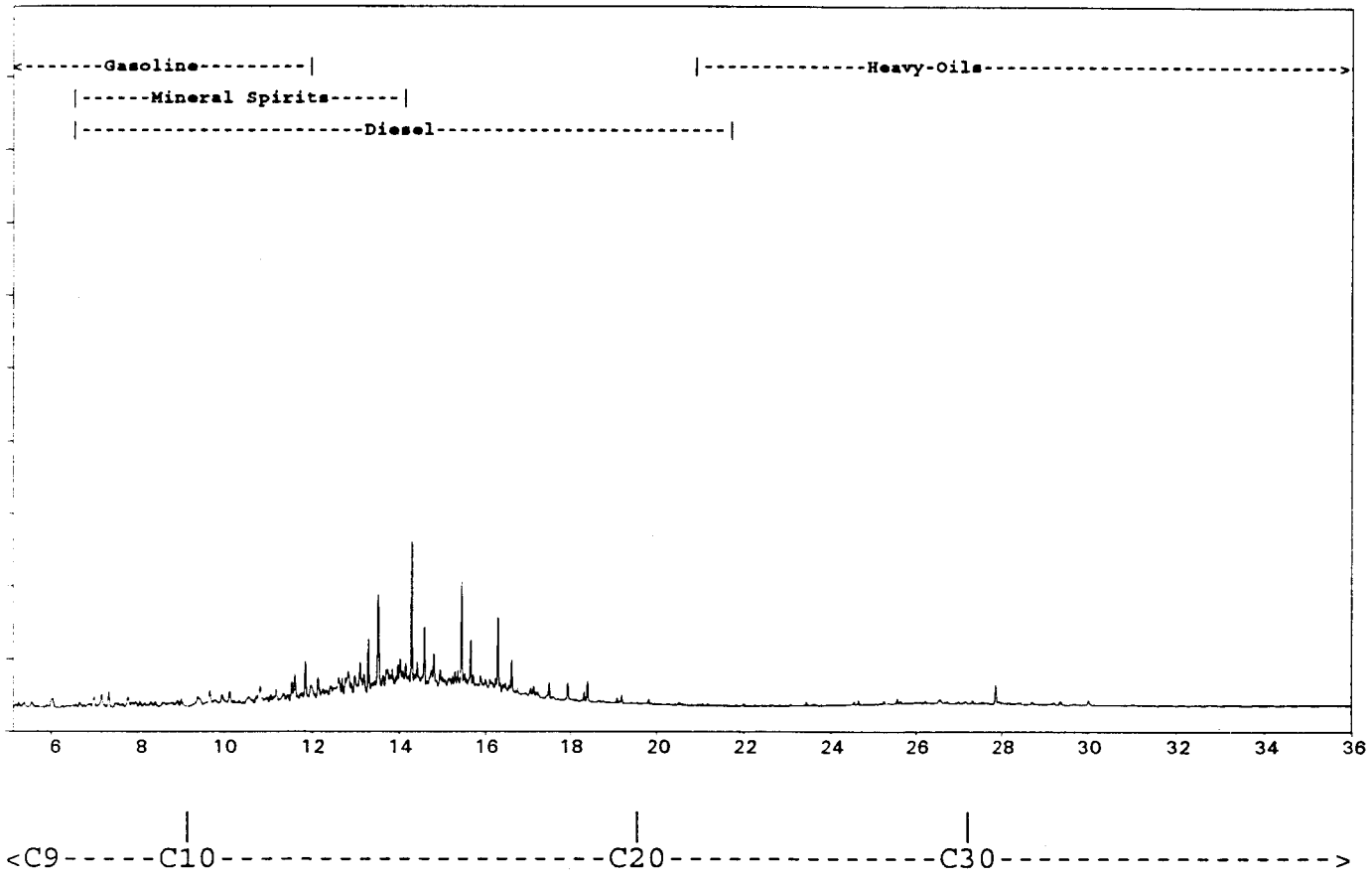
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-07 July 19, 1996

Sample acquired: JUL 29, 1996 01:29:25

File Name: c:\TEH\TEH28JUL.16R , Sample Name: G3345 7

Sequence file: TEH28JUL



ASL Sample ID: G3345 7* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	6.0
Carbon 10 to Carbon 20	(C10-C20)	85.8
Carbon 20 to Carbon 30	(C20-C30)	3.4
Greater than Carbon 30	(>C30)	4.7

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

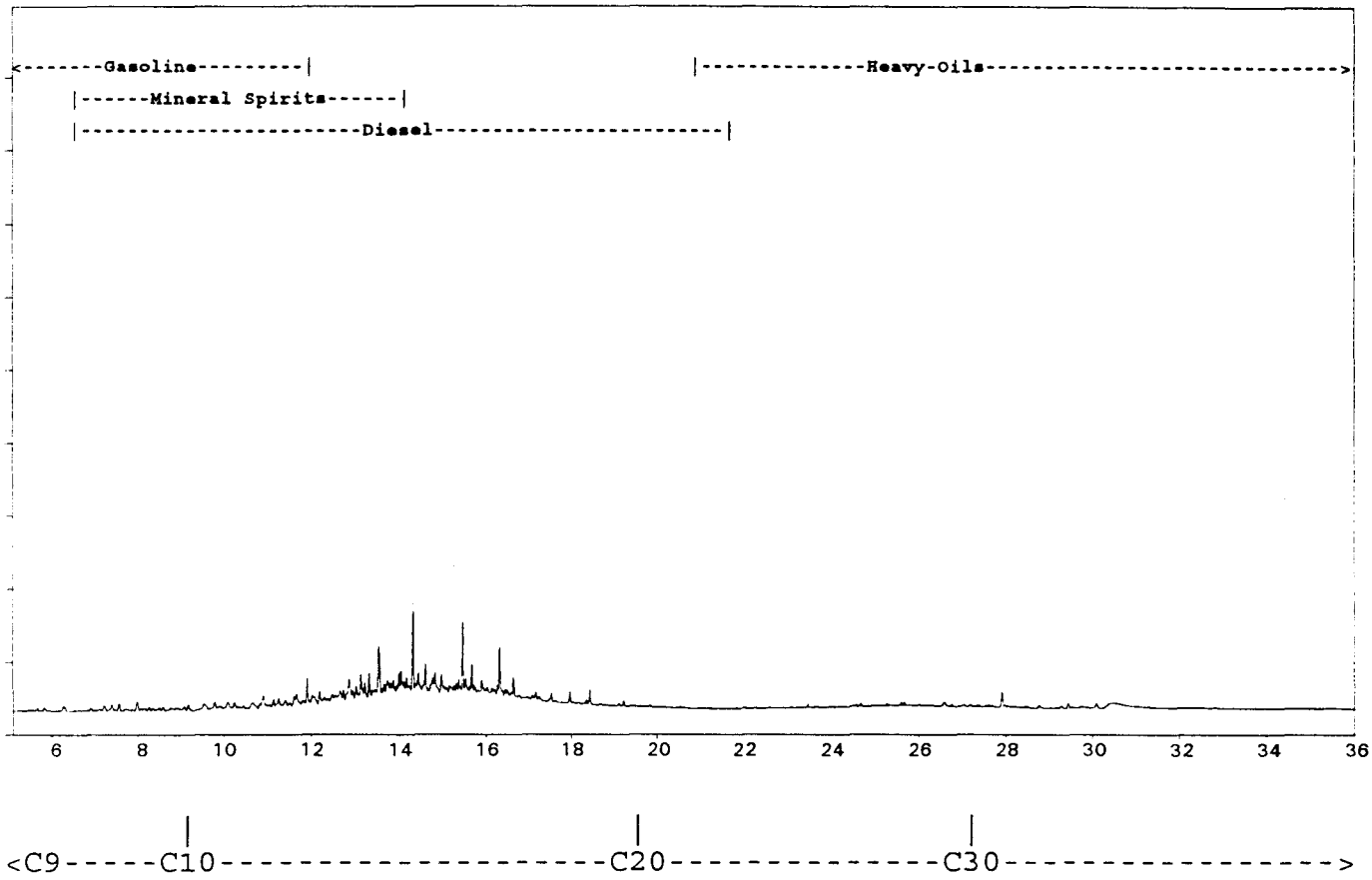
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-09 July 19, 1996

Sample acquired: JUL 29, 1996 03:07:27

File Name: c:\TEH\TEH28JUL.18R , Sample Name: G3345 9

Sequence file: TEH28JUL



ASL Sample ID: G3345 9* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	3.7
Carbon 10 to Carbon 20	(C10-C20)	85.1
Carbon 20 to Carbon 30	(C20-C30)	5.1
Greater than Carbon 30	(>C30)	6.2

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

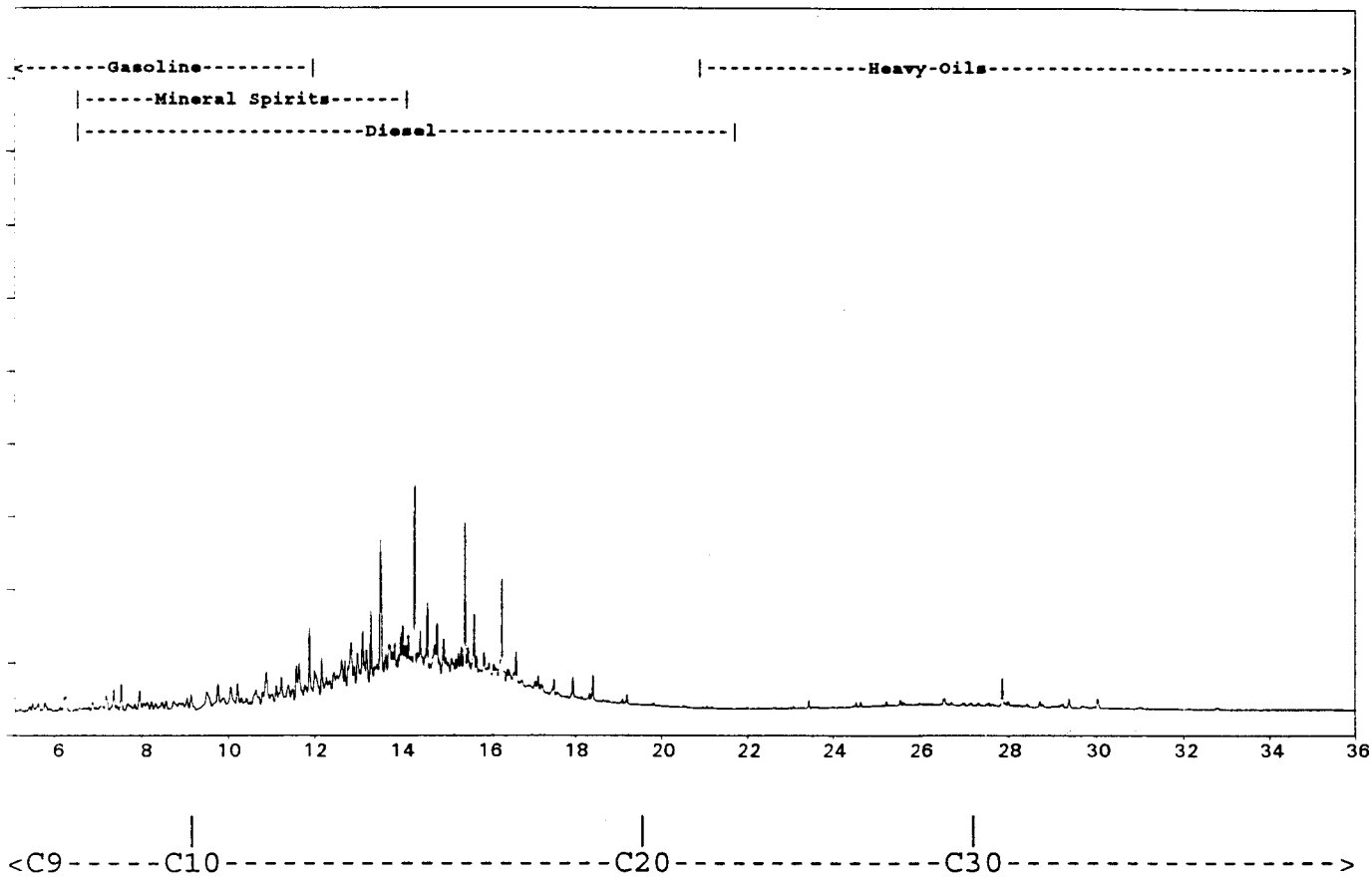
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-10 July 19, 1996

Sample acquired: JUL 29, 1996 03:55:26

File Name: c:\TEH\TEH28JUL.19R , Sample Name: G3345 10

Sequence file: TEH28JUL



ASL Sample ID: G3345 10* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	5.1
Carbon 10 to Carbon 20	(C10-C20)	85.5
Carbon 20 to Carbon 30	(C20-C30)	4.3
Greater than Carbon 30	(>C30)	5.1

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

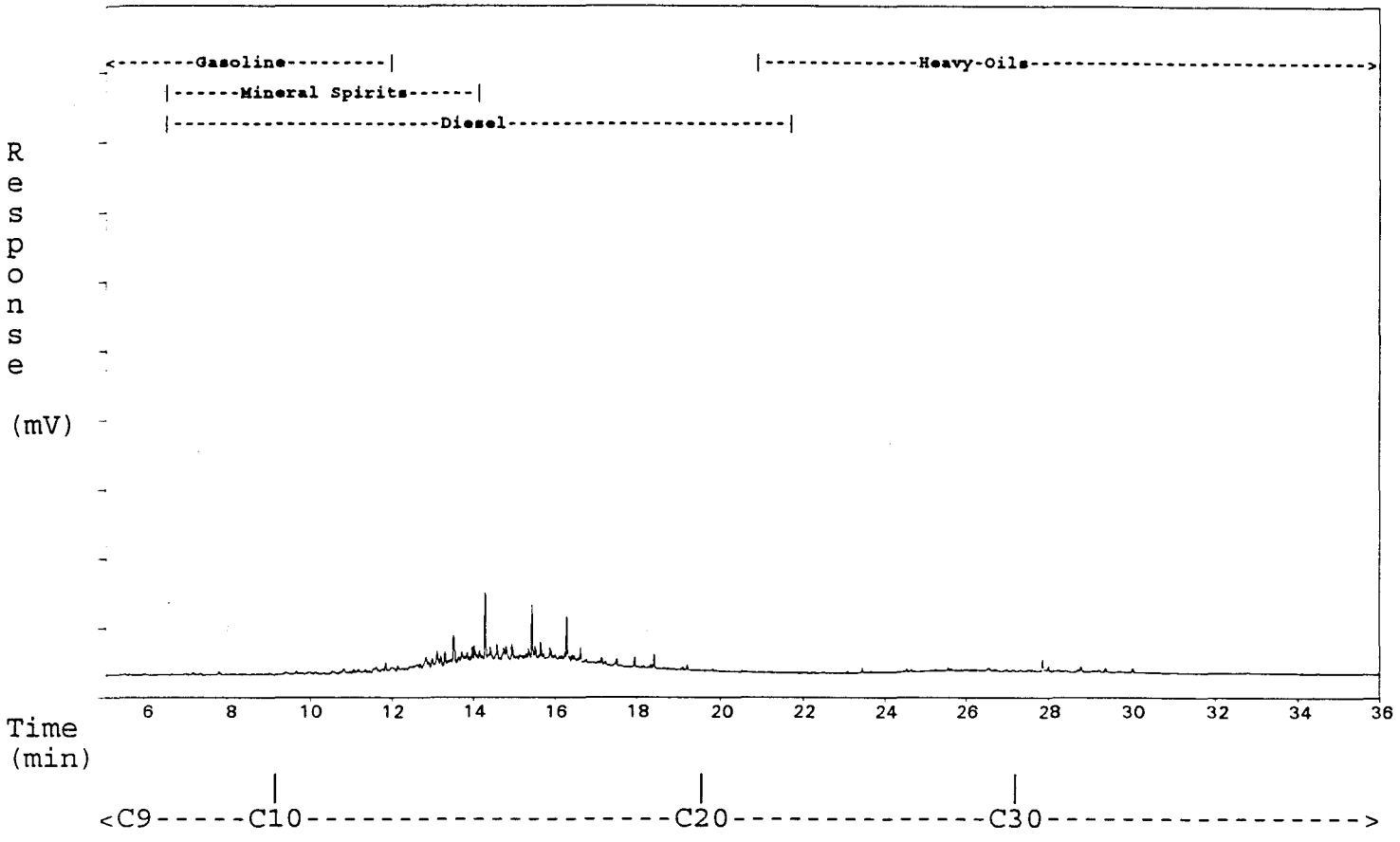
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-11 July 19, 1996

Sample acquired: JUL 29, 1996 04:45:23

File Name: c:\TEH\TEH28JUL.20R , Sample Name: G3345 11

Sequence file: TEH28JUL



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	1.4
Carbon 10 to Carbon 20	(C10-C20)	84.2
Carbon 20 to Carbon 30	(C20-C30)	6.1
Greater than Carbon 30	(>C30)	8.3

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

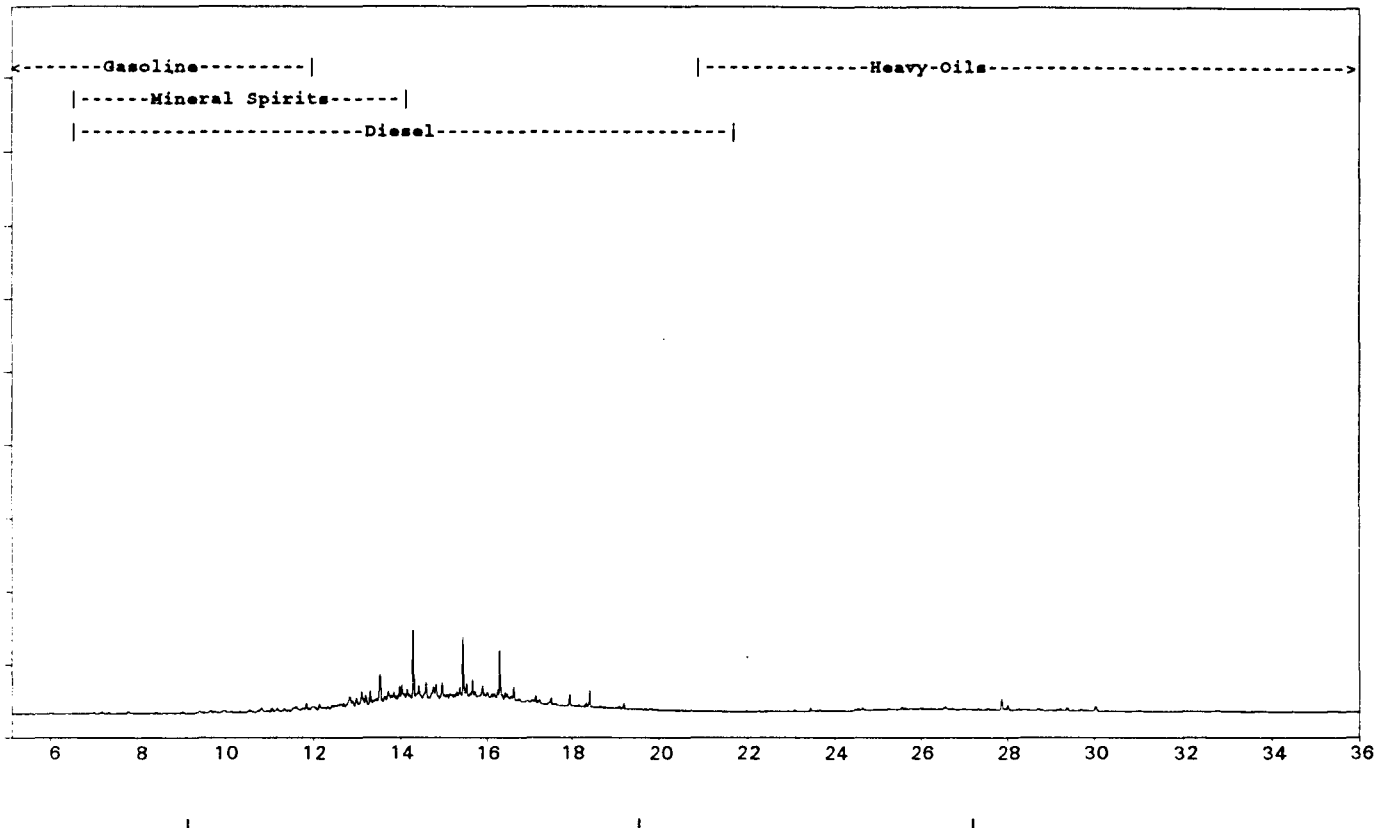
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TR96-11 Laboratory Replicate July 19, 1996

Sample acquired: JUL 29, 1996 05:34:59

File Name: c:\TEH\TEH28JUL.21R , Sample Name: QC 68506#G3345 11'

Sequence file: TEH28JUL



ASL Sample ID: QC 68506#G3345 11'* 8.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	1.2
Carbon 10 to Carbon 20	(C10-C20)	83.8
Carbon 20 to Carbon 30	(C20-C30)	6.5
Greater than Carbon 30	(>C30)	8.6

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

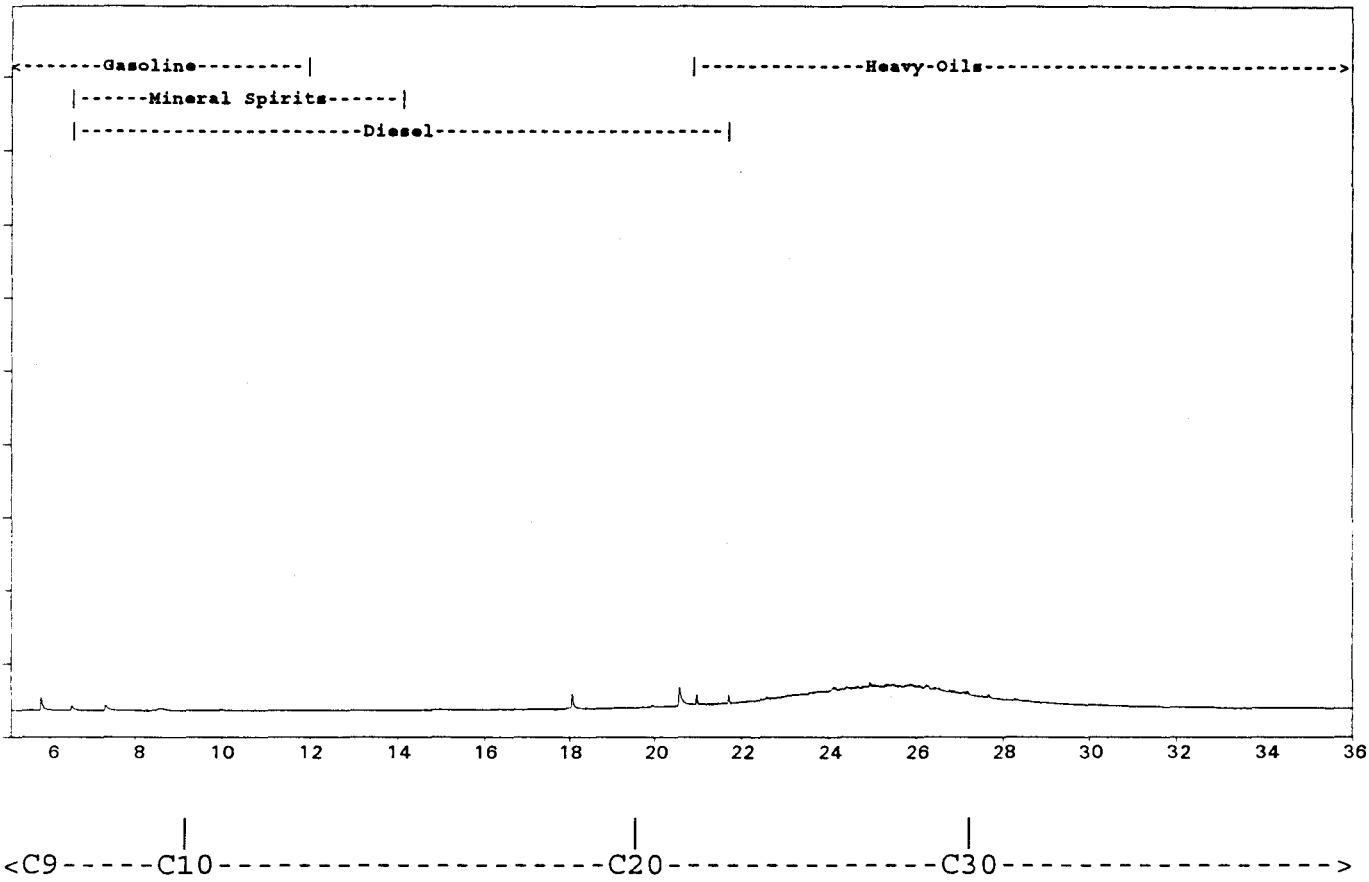
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: MP96-01 July 20, 1996

Sample acquired: AUG 9, 1996 06:50:35

File Name: c:\TEH\TEHAUG08.48R , Sample Name: G3361 1

Sequence file: TEHAUG08



ASL Sample ID: G3361 1* 1.0Dilution

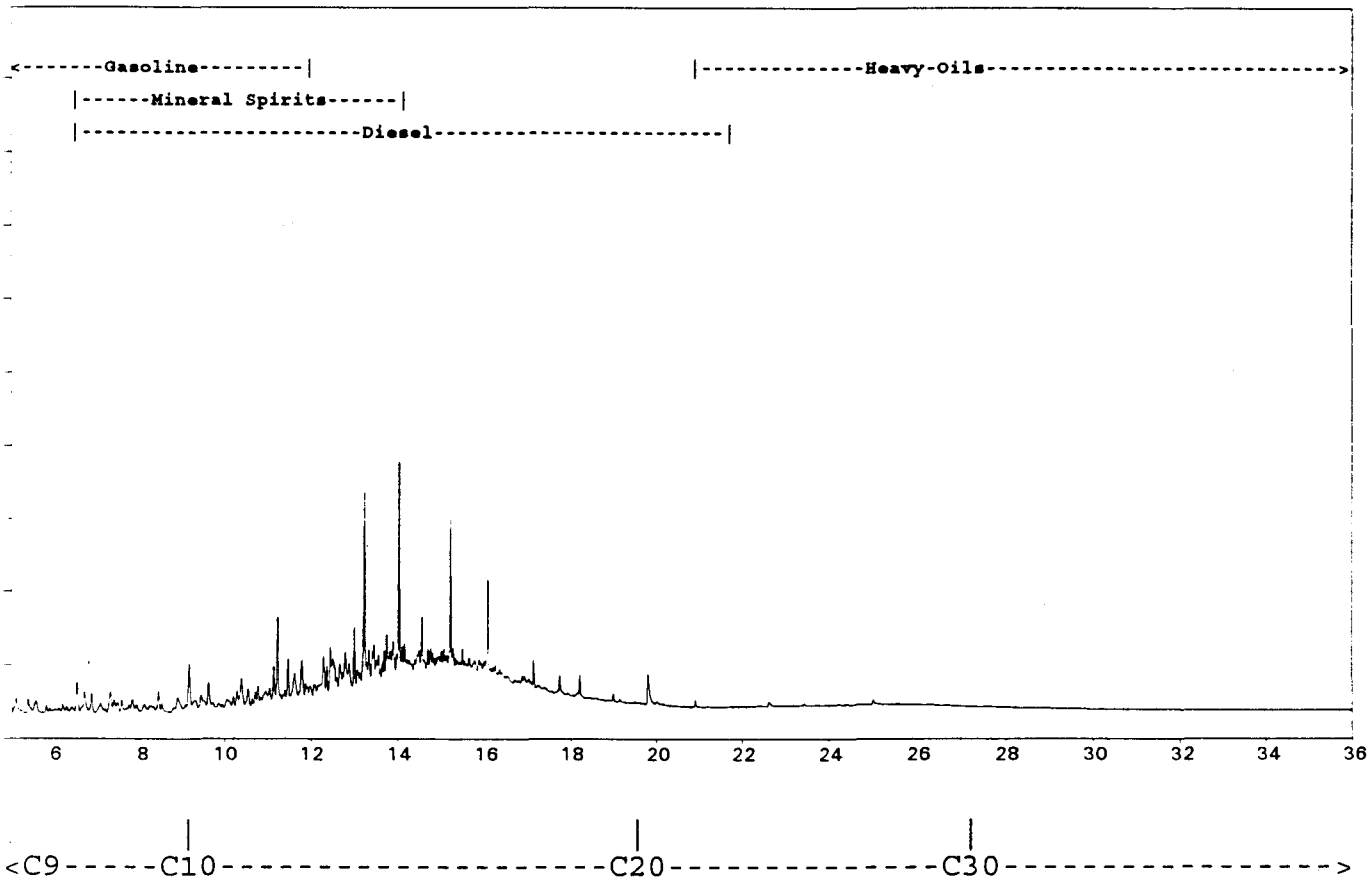
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	3.0
Carbon 10 to Carbon 20	(C10-C20)	3.9
Carbon 20 to Carbon 30	(C20-C30)	73.6
Greater than Carbon 30	(>C30)	19.5

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: MP96-02 July 20, 1996

Sample acquired: AUG 9, 1996 07:37:46
File Name: c:\TEH\TEHAUG08.49R , Sample Name: G3361 2
Sequence file: TEHAUG08



ASL Sample ID: G3361 2* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	6.7
Carbon 10 to Carbon 20	(C10-C20)	88.6
Carbon 20 to Carbon 30	(C20-C30)	4.3
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

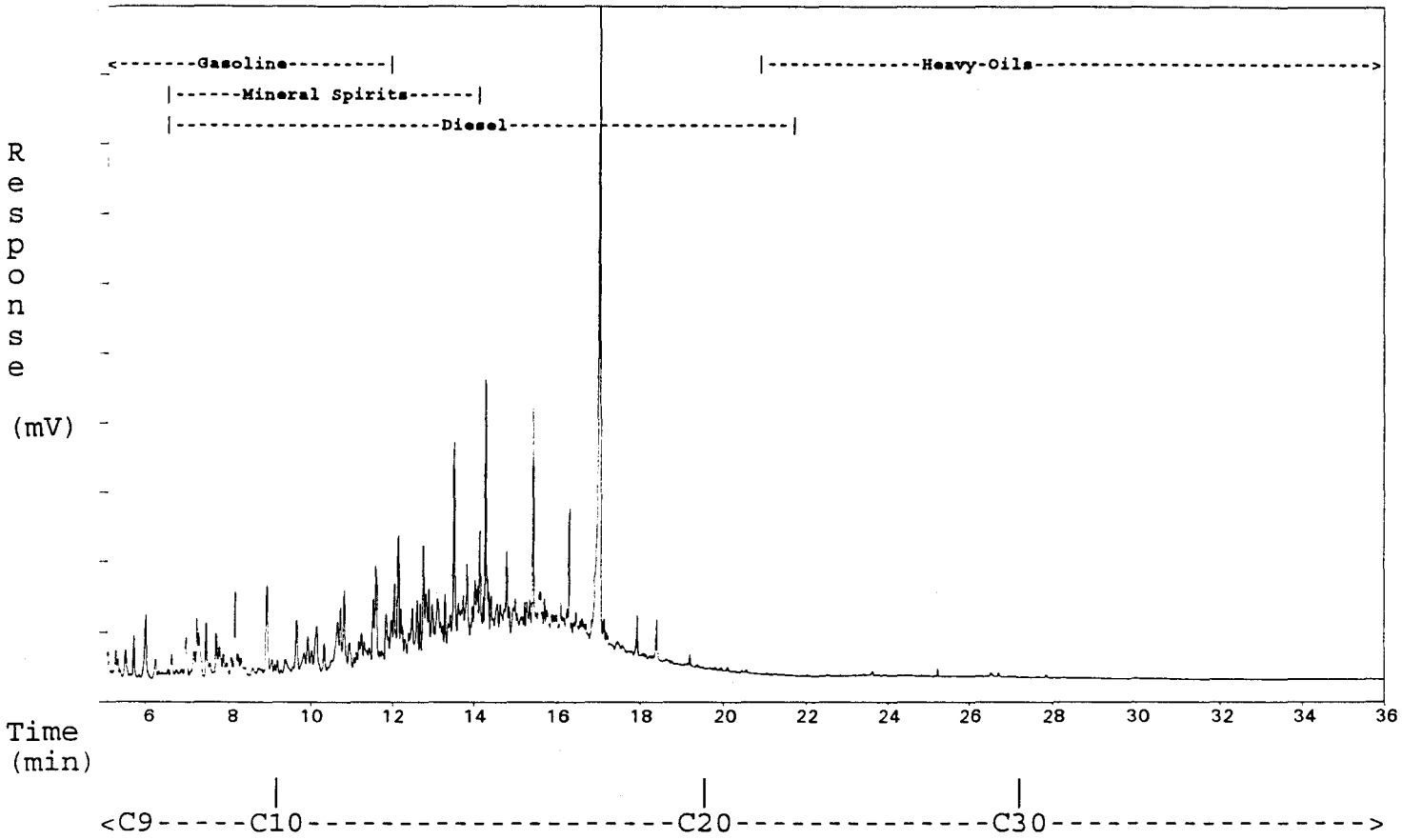
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: WP-96-7 July 20, 1996

Sample acquired: JUL 31, 1996 18:54:08

File Name: c:\TEH\TEH30JUL.34R , Sample Name: G3361 8

Sequence file: TEH30JUL



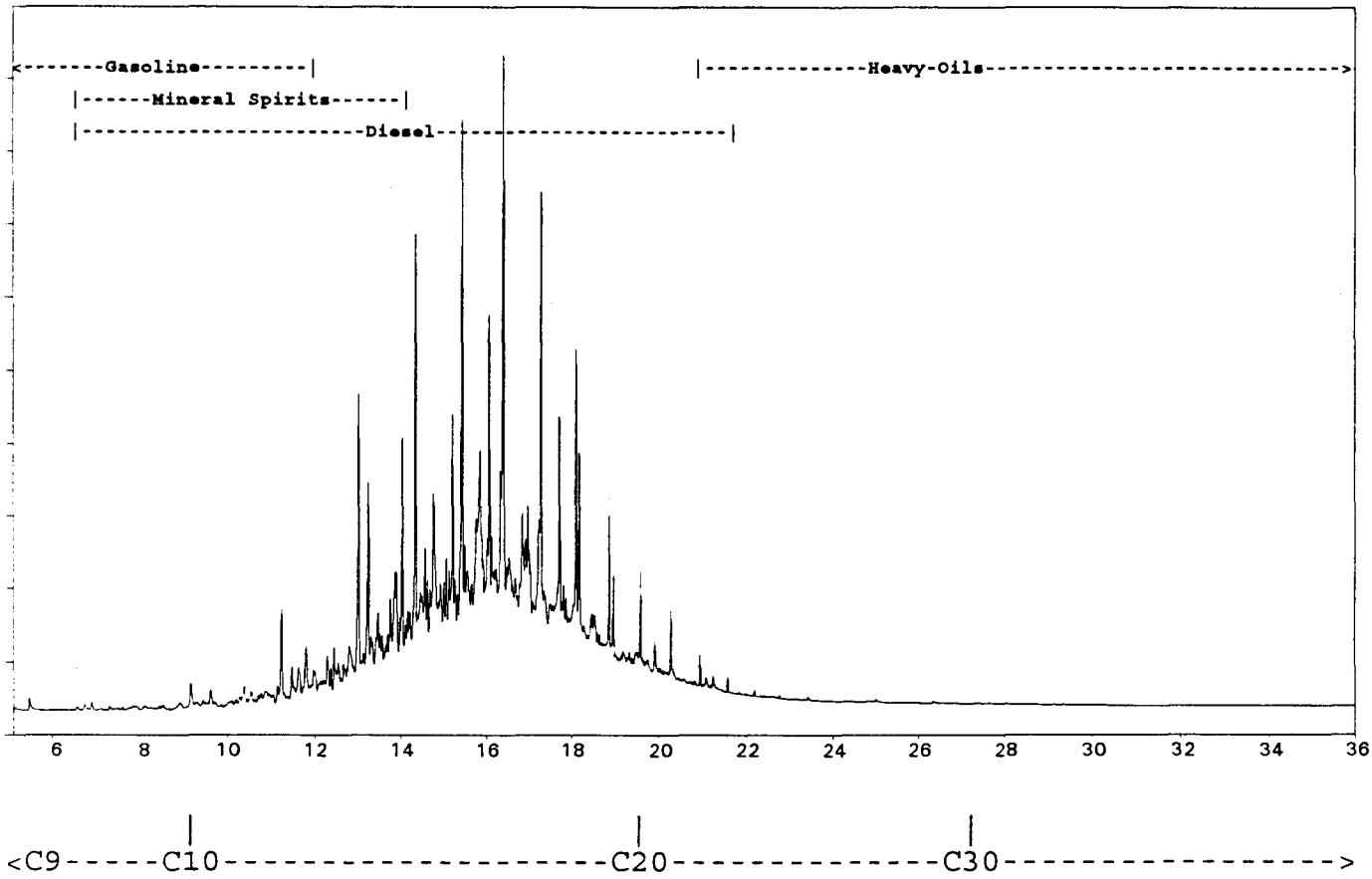
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	10.2
Carbon 10 to Carbon 20	(C10-C20)	86.1
Carbon 20 to Carbon 30	(C20-C30)	2.8
Greater than Carbon 30	(>C30)	0.9

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: TH-8A July 21, 1996

Sample acquired: AUG 9, 1996 08:25:04
File Name: c:\TEH\TEHAUG08.51R , Sample Name: G3361 17
Sequence file: TEHAUG08



ASL Sample ID: G3361 17* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	0.7
Carbon 10 to Carbon 20	(C10-C20)	93.0
Carbon 20 to Carbon 30	(C20-C30)	5.7
Greater than Carbon 30	(>C30)	0.6

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

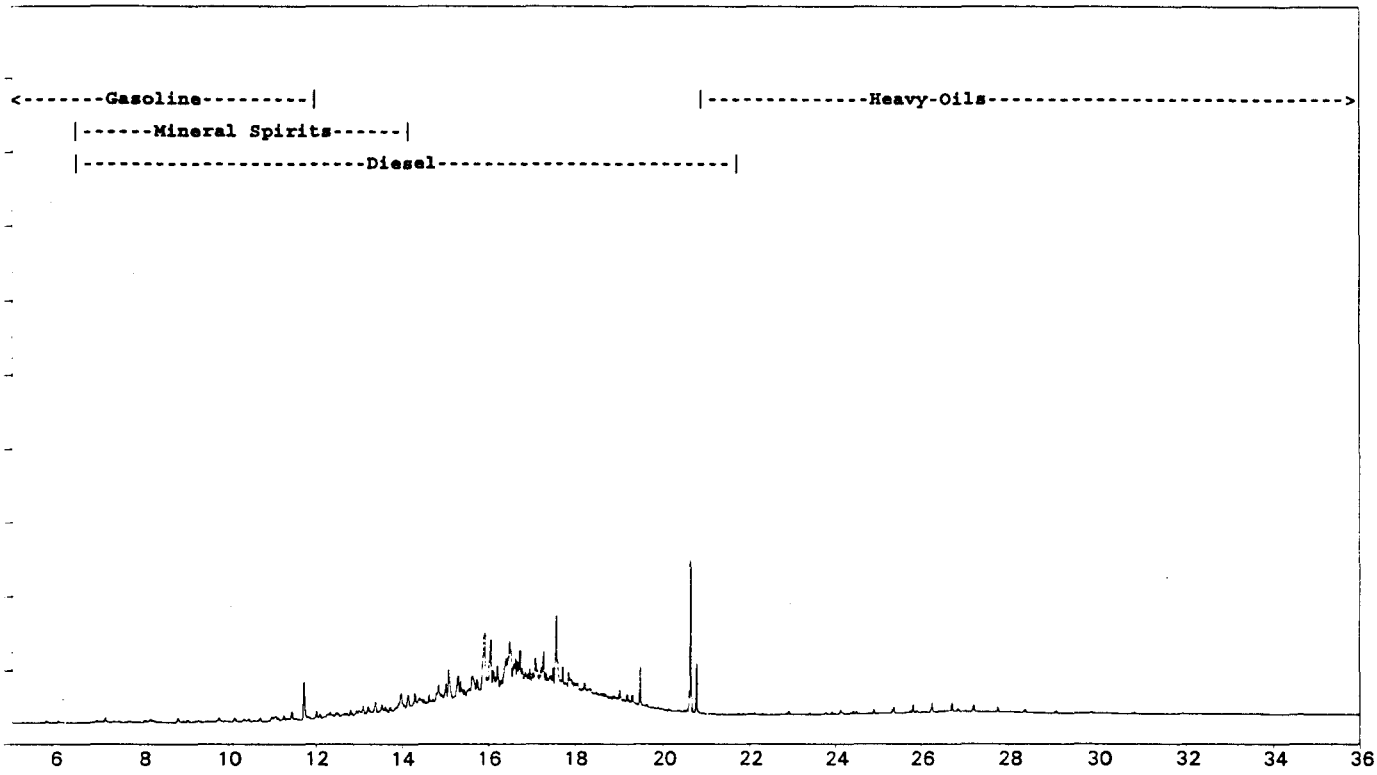
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-10**

Sample acquired: SEP 28, 1996 21:34:10

File Name: c:\TEH\TEHSEP27.78R , Sample Name: G5283 2

Sequence file: TEHSEP27



ASL Sample ID: G5283 2* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	1.4
Carbon 10 to Carbon 20	(C10-C20)	83.6
Carbon 20 to Carbon 30	(C20-C30)	9.2
Greater than Carbon 30	(>C30)	5.8

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

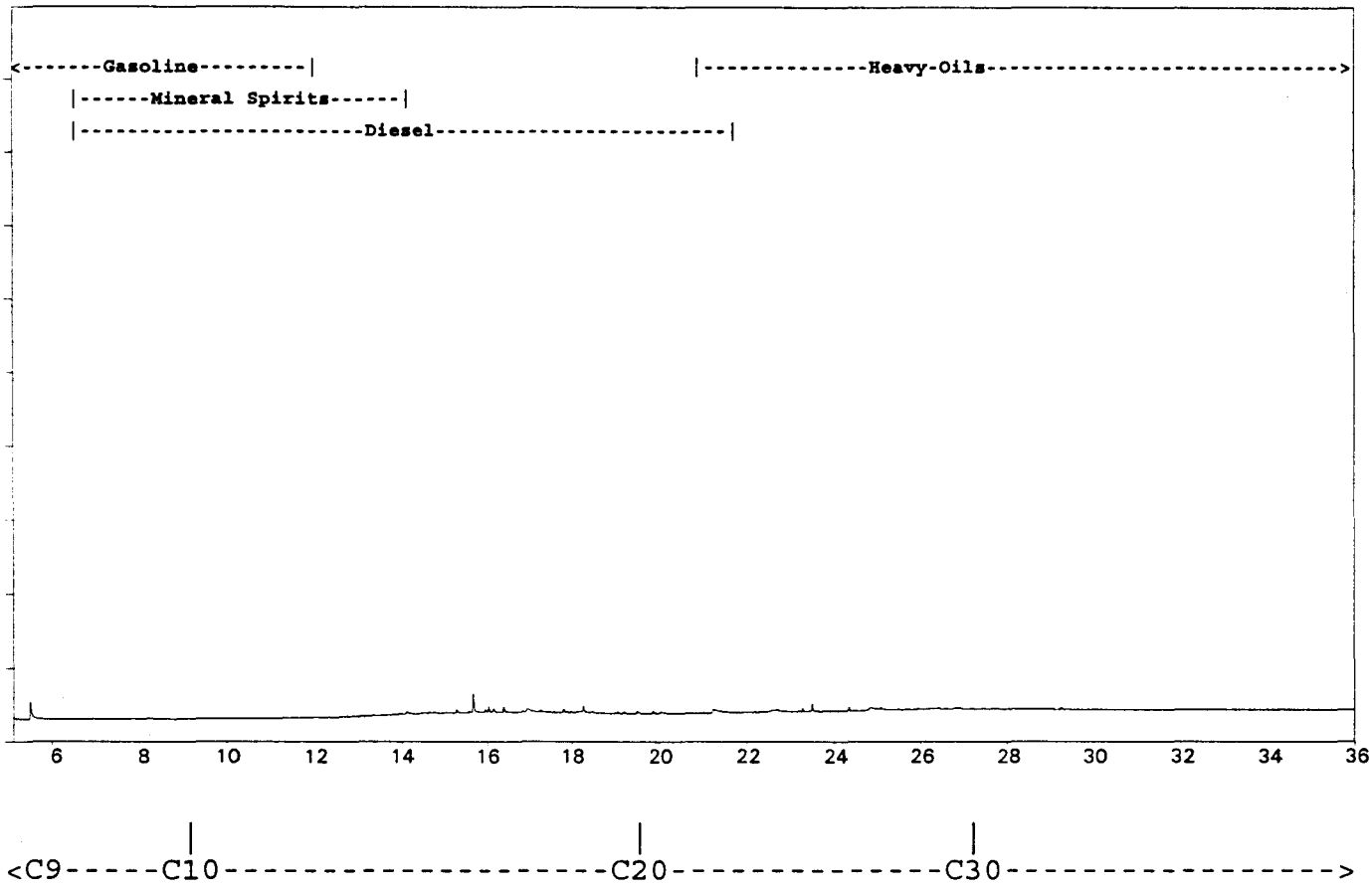
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-11 B**

Sample acquired: SEP 28, 1996 22:20:47

File Name: c:\TEH\TEHSEP27.79R , Sample Name: G5283 3

Sequence file: TEHSEP27



ASL Sample ID: G5283 3* 1.0Dilution

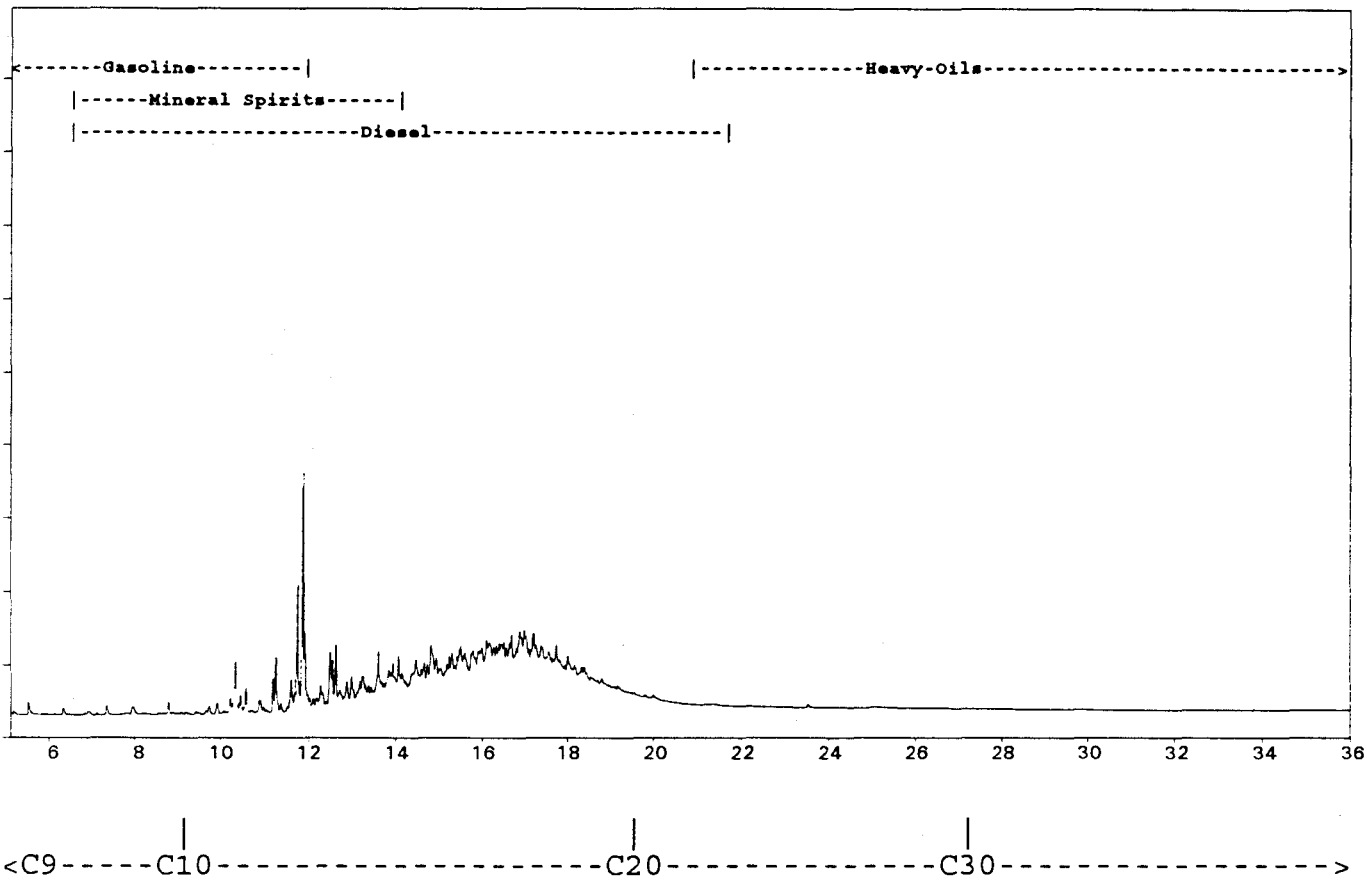
HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	6.1
Carbon 10 to Carbon 20	(C10-C20)	51.7
Carbon 20 to Carbon 30	(C20-C30)	22.1
Greater than Carbon 30	(>C30)	20.5

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-13 July 20, 1996

Sample acquired: AUG 5, 1996 06:05:26
File Name: c:\TEH\TEHAUG04.45R , Sample Name: G3361 20
Sequence file: TEHAUG04



ASL Sample ID: G3361 20* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	1.4
Carbon 10 to Carbon 20	(C10-C20)	96.5
Carbon 20 to Carbon 30	(C20-C30)	1.9
Greater than Carbon 30	(>C30)	0.2

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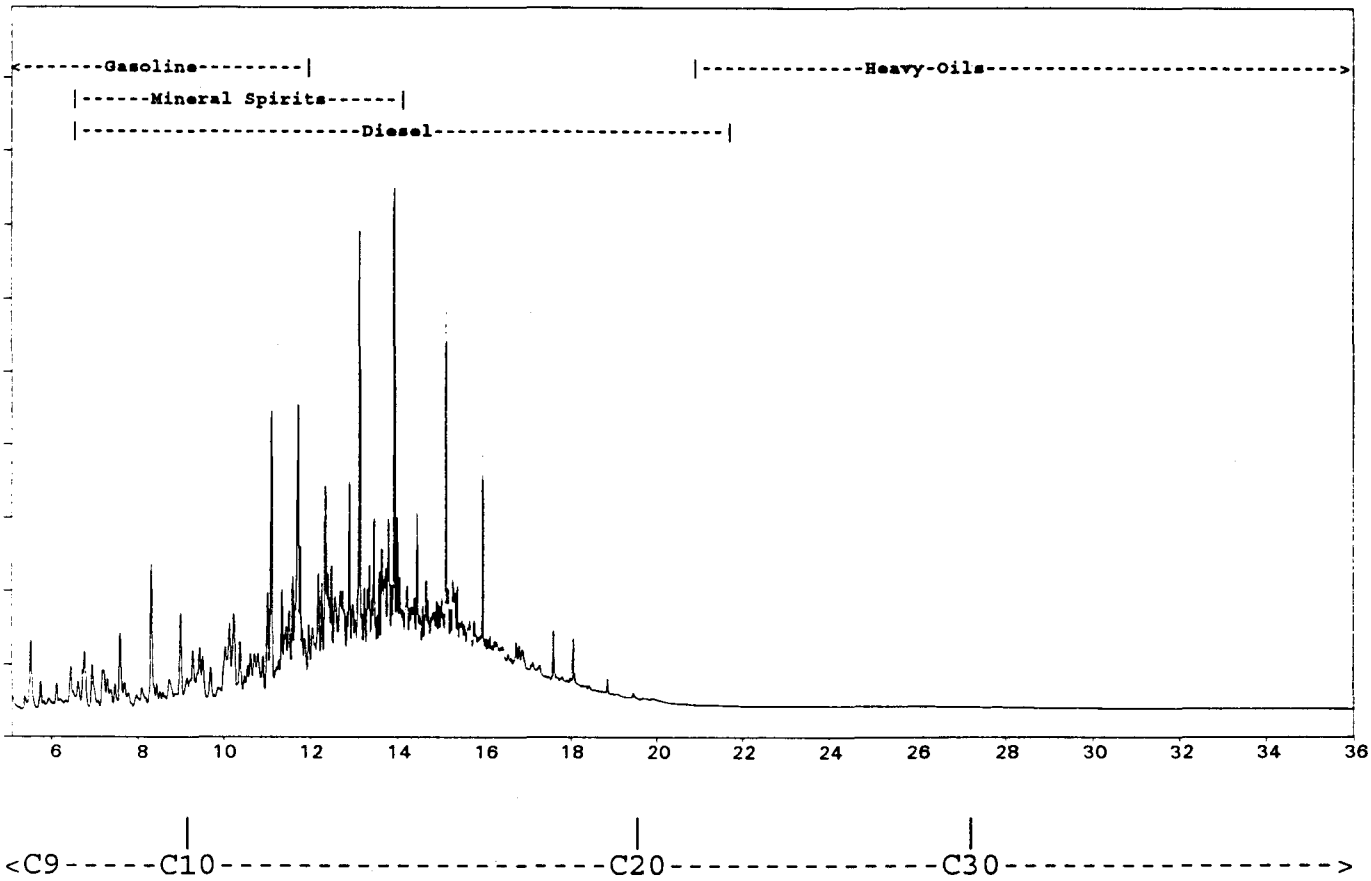
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-16 July 20, 1996

Sample acquired: AUG 5, 1996 06:05:26

File Name: c:\TEH\TEHAUG04.46R , Sample Name: G3361 22

Sequence file: TEHAUG04



ASL Sample ID: G3361 22* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	9.3
Carbon 10 to Carbon 20	(C10-C20)	90.6
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

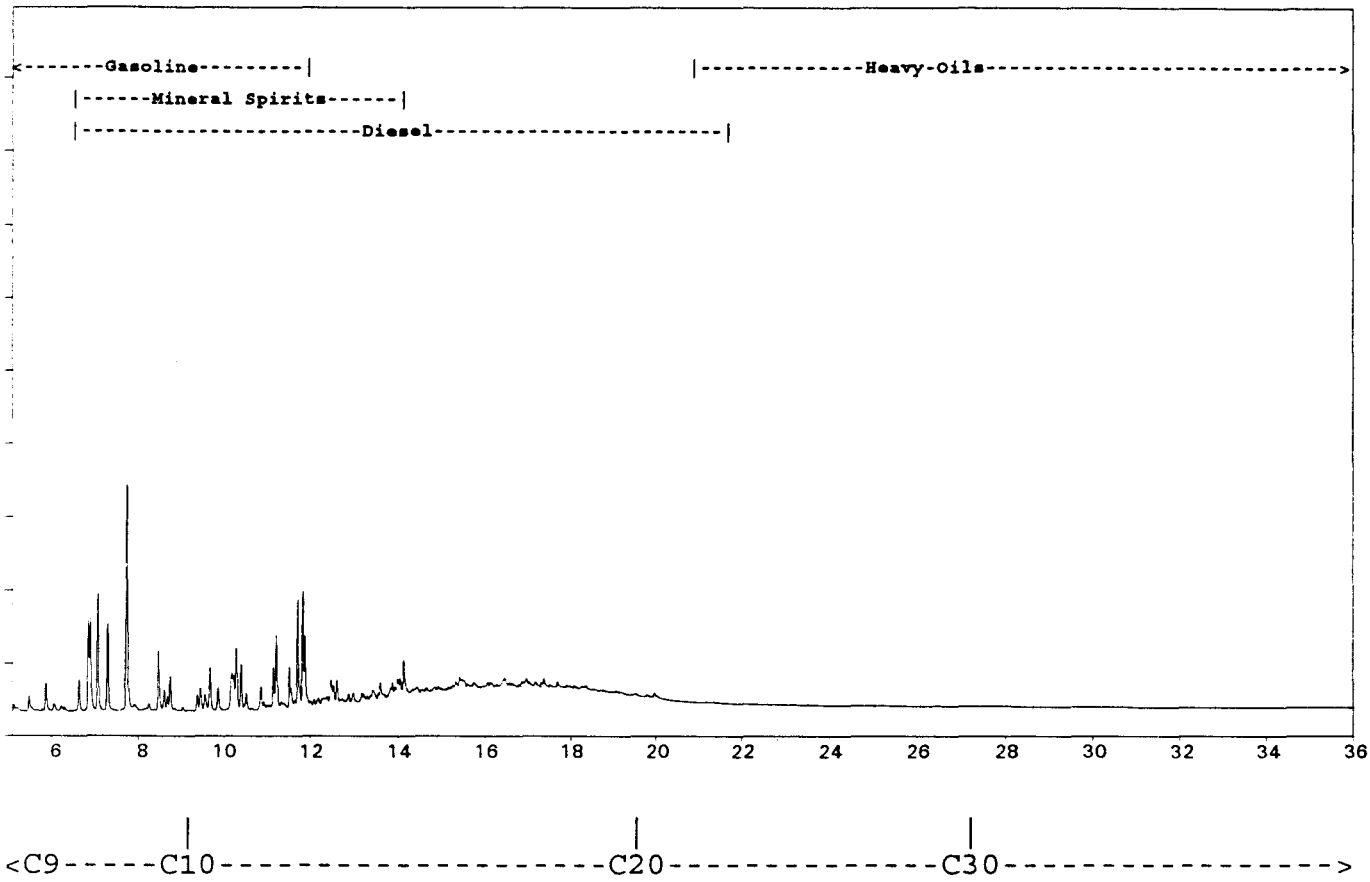
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-17A

Sample acquired: AUG 9, 1996 10:46:35

File Name: c:\TEH\TEHAUG08.57R , Sample Name: G3361 30

Sequence file: TEHAUG08



ASL Sample ID: G3361 30* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	19.3
Carbon 10 to Carbon 20	(C10-C20)	78.7
Carbon 20 to Carbon 30	(C20-C30)	2.0
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

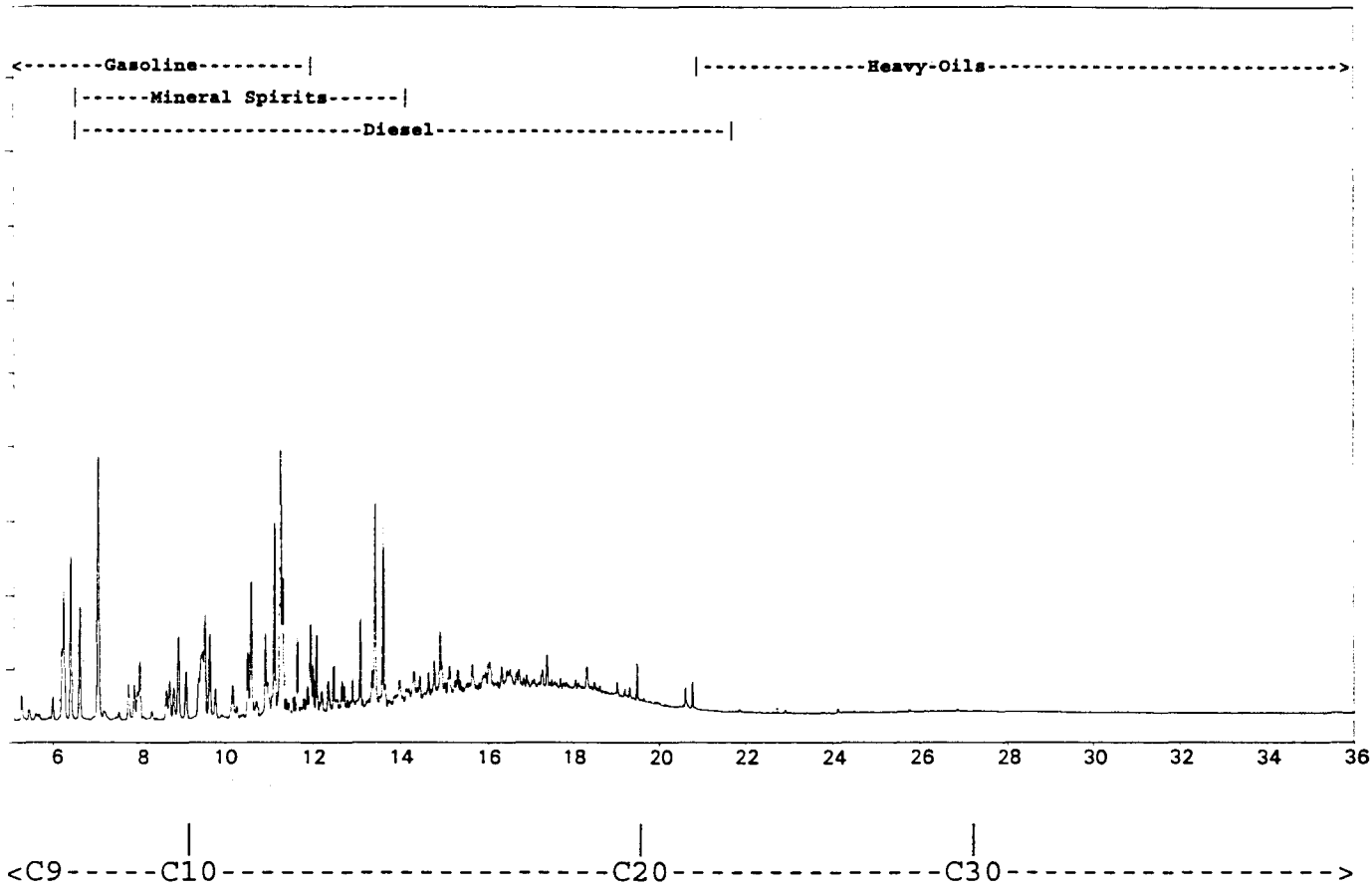
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-17 A**

Sample acquired: SEP 28, 1996 22:20:47

File Name: c:\TEH\TEHSEP27.80R , Sample Name: G5283 4

Sequence file: TEHSEP27



ASL Sample ID: G5283 4* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	14.0
Carbon 10 to Carbon 20	(C10-C20)	83.1
Carbon 20 to Carbon 30	(C20-C30)	2.5
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

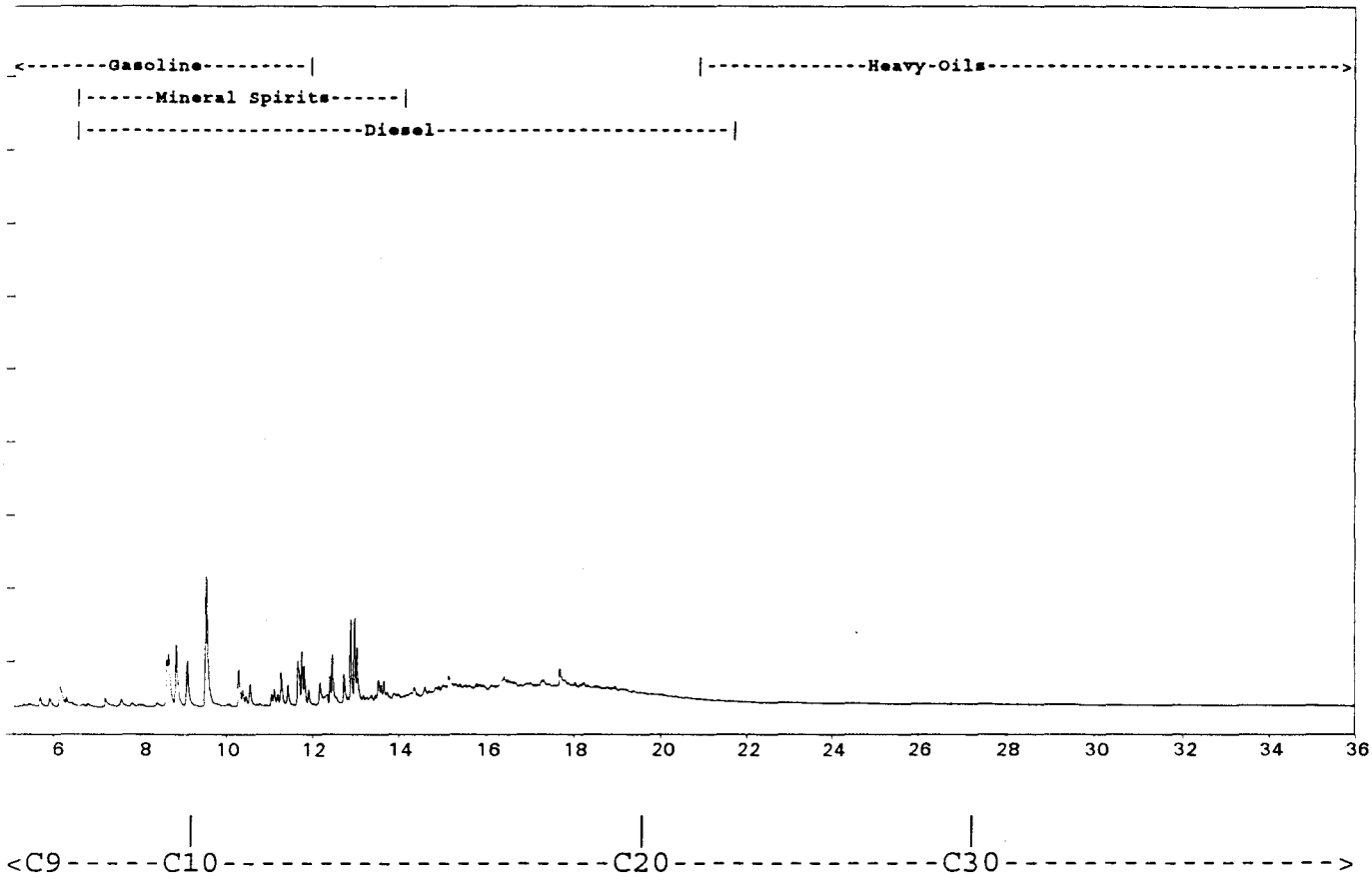
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-17B

Sample acquired: AUG 9, 1996 10:46:35

File Name: c:\TEH\TEHAUG08.58R , Sample Name: G3361 31

Sequence file: TEHAUG08



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	8.0
Carbon 10 to Carbon 20	(C10-C20)	90.8
Carbon 20 to Carbon 30	(C20-C30)	1.3
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

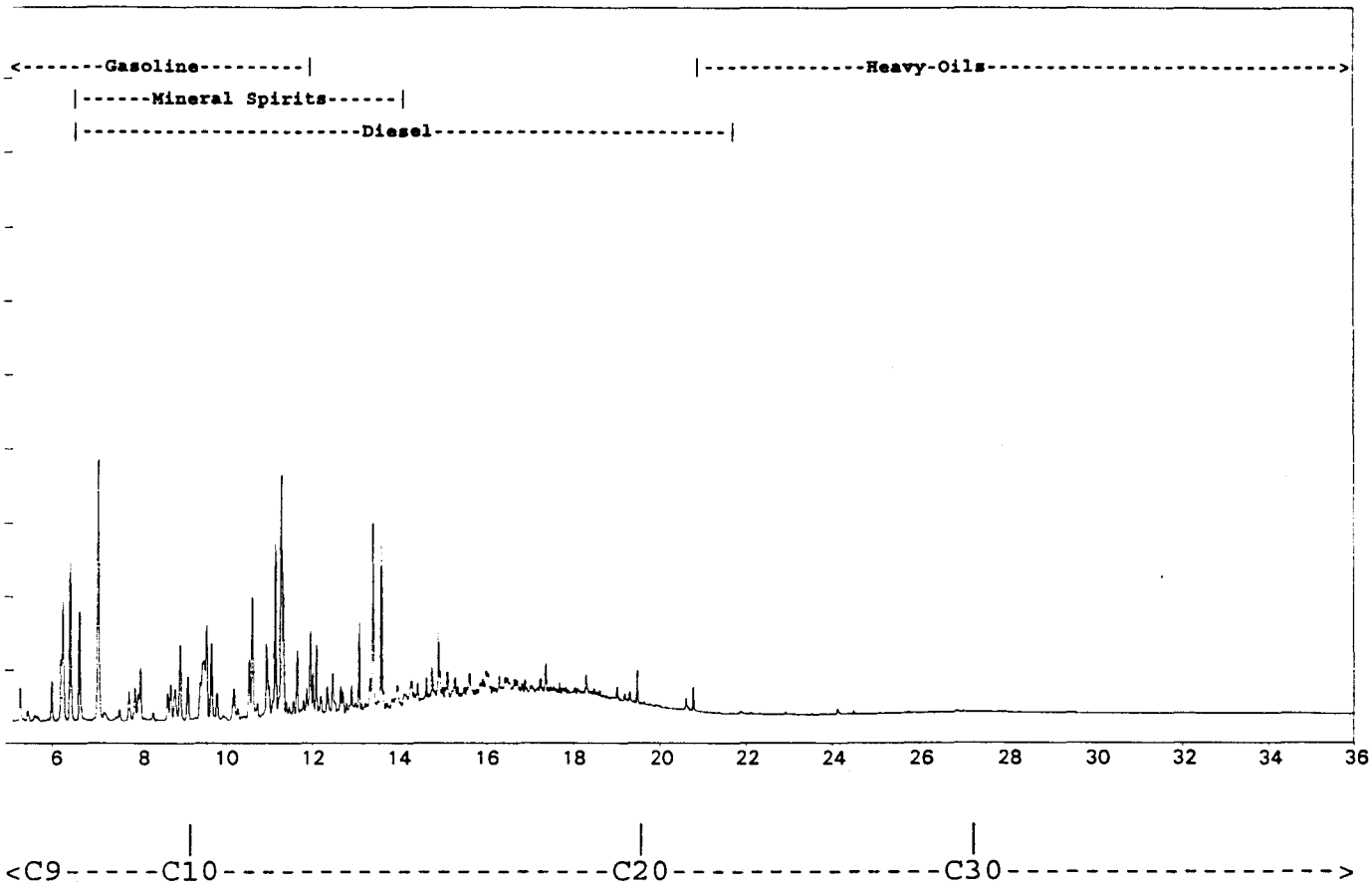
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96B-17 B

Sample acquired: SEP 28, 1996 23:07:23

File Name: c:\TEH\TEHSEP27.82R , Sample Name: G5283 5

Sequence file: TEHSEP27



ASL Sample ID: G5283 5* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	15.2
Carbon 10 to Carbon 20	(C10-C20)	81.4
Carbon 20 to Carbon 30	(C20-C30)	2.7
Greater than Carbon 30	(>C30)	0.6

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

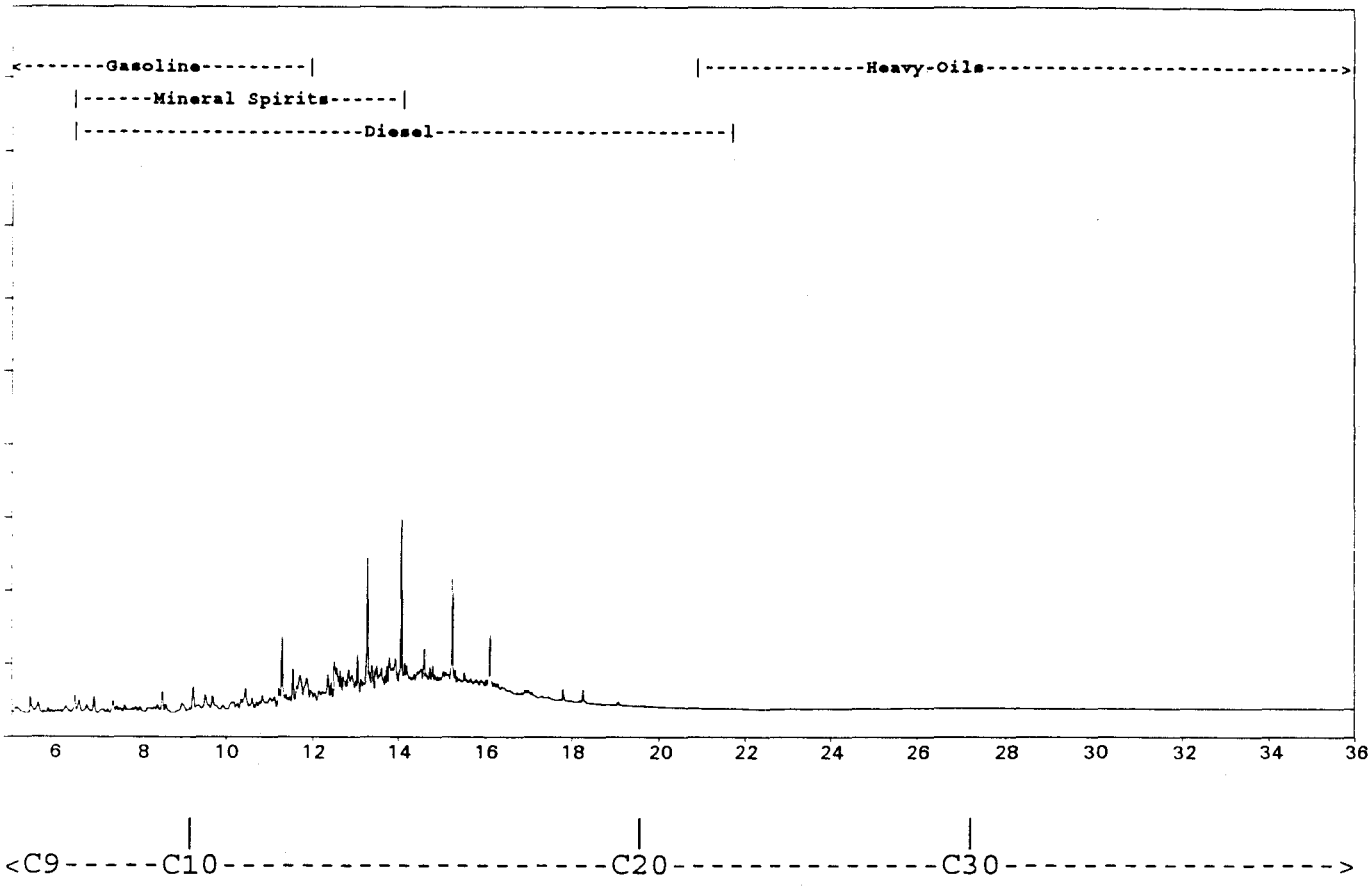
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-19A July 21, 1996

Sample acquired: AUG 5, 1996 06:52:23

File Name: c:\TEH\TEHAUG04.47R , Sample Name: G3361 23

Sequence file: TEHAUG04



ASL Sample ID: G3361 23* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	6.9
Carbon 10 to Carbon 20	(C10-C20)	93.0
Carbon 20 to Carbon 30	(C20-C30)	0.1
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

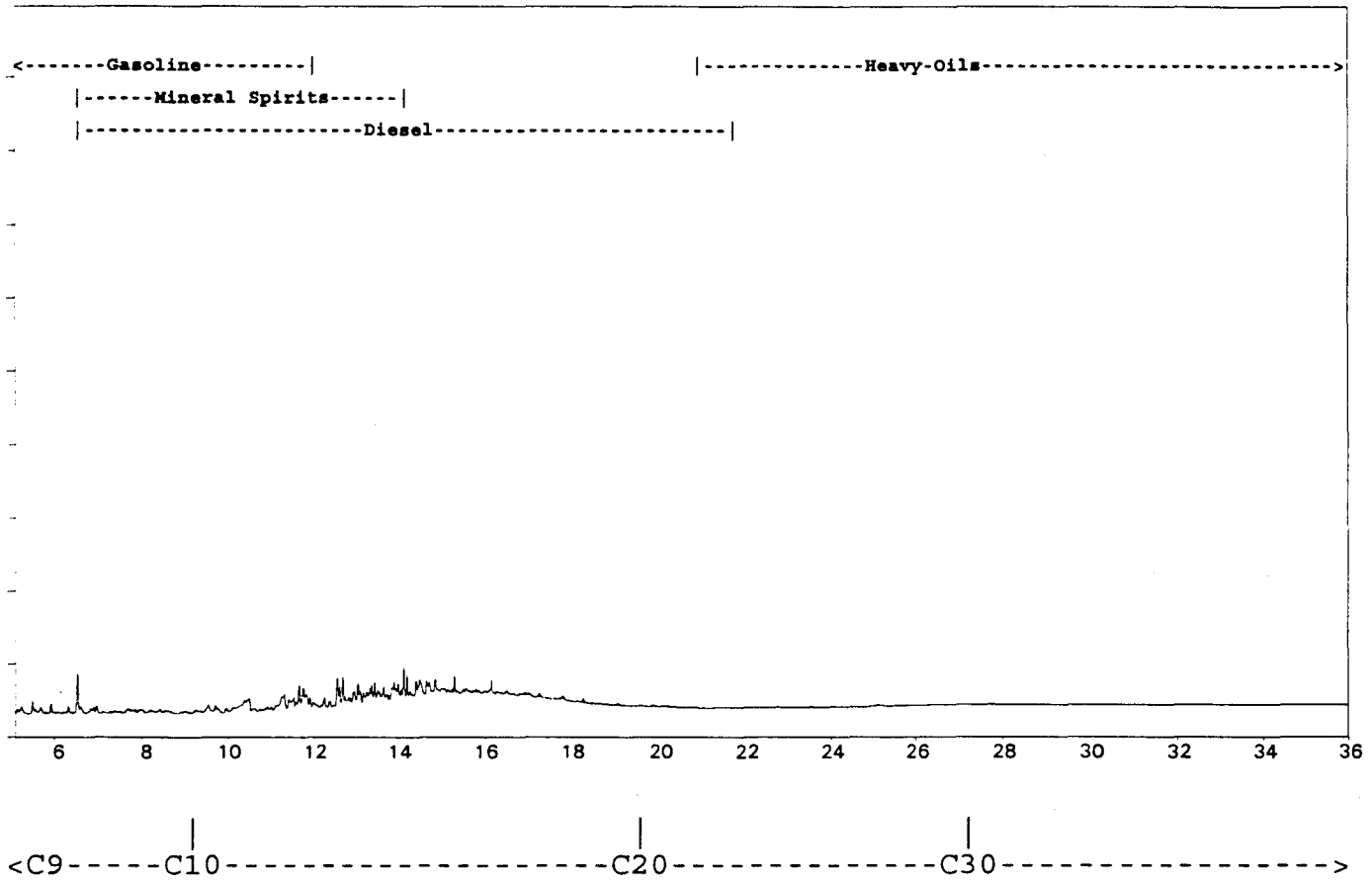
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-19 A**

Sample acquired: SEP 28, 1996 23:54:00

File Name: c:\TEH\TEHSEP27.83R , Sample Name: G5283 6

Sequence file: TEHSEP27



ASL Sample ID: G5283 6* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	10.3
Carbon 10 to Carbon 20	(C10-C20)	88.0
Carbon 20 to Carbon 30	(C20-C30)	1.1
Greater than Carbon 30	(>C30)	0.6

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

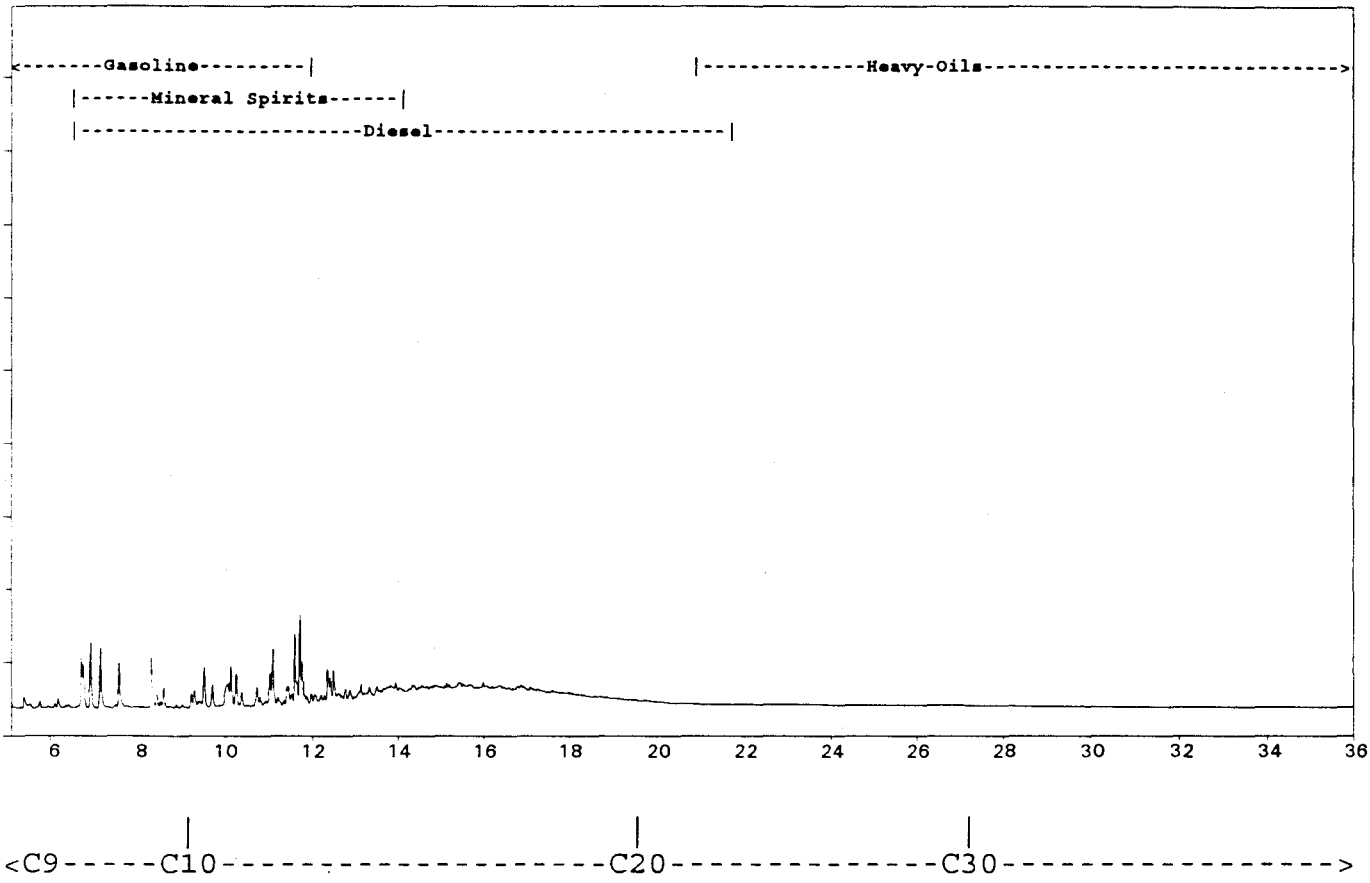
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-20A July 21, 1996

Sample acquired: AUG 5, 1996 06:52:23

File Name: c:\TEH\TEHAUG04.48R , Sample Name: G3361 24

Sequence file: TEHAUG04



ASL Sample ID: G3361 24* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	14.9
Carbon 10 to Carbon 20	(C10-C20)	84.6
Carbon 20 to Carbon 30	(C20-C30)	0.5
Greater than Carbon 30	(>C30)	0.0

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

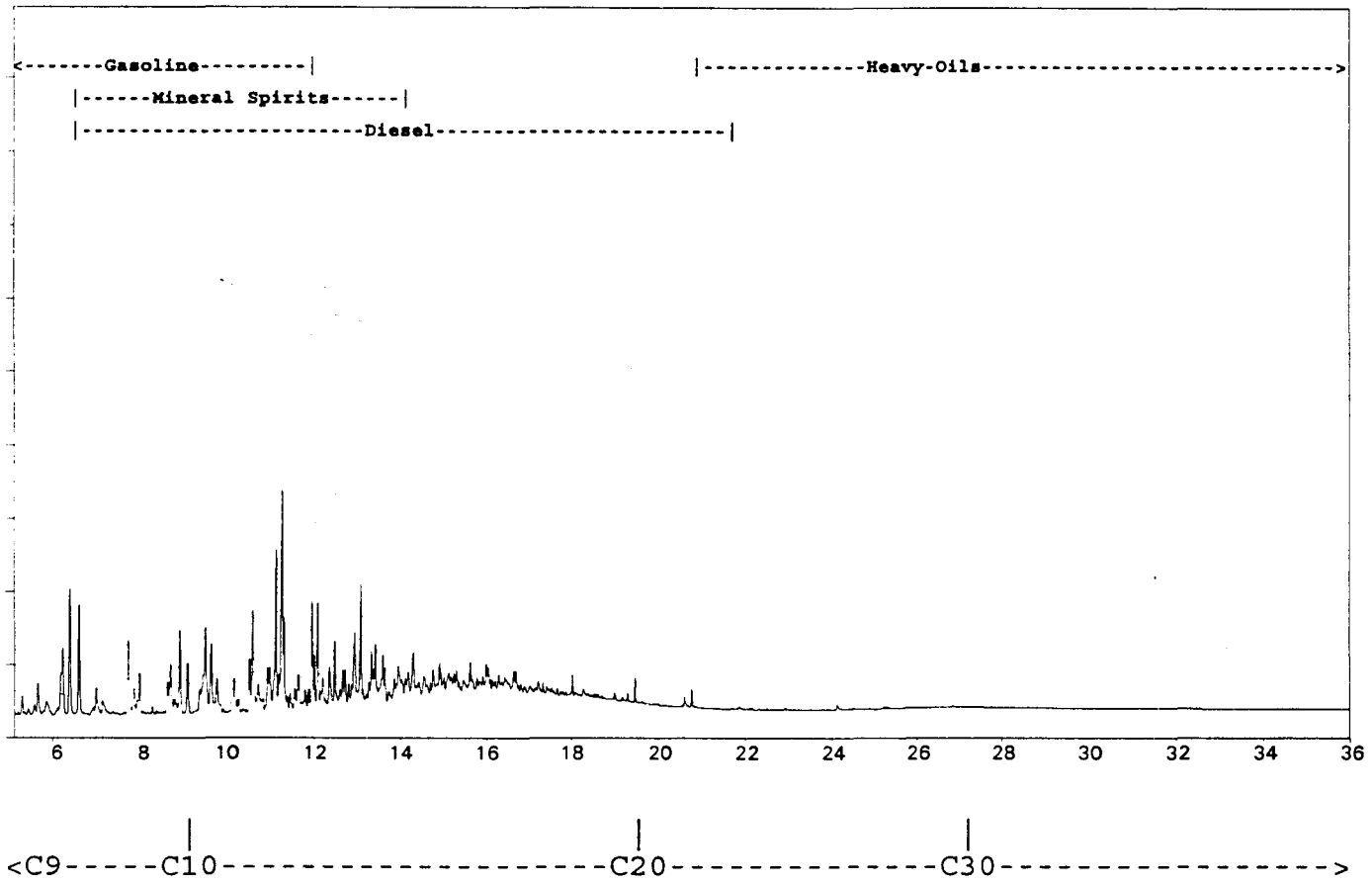
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-20 A**

Sample acquired: SEP 28, 1996 23:54:00

File Name: c:\TEH\TEHSEP27.84R , Sample Name: G5283 7

Sequence file: TEHSEP27



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	13.7
Carbon 10 to Carbon 20	(C10-C20)	84.3
Carbon 20 to Carbon 30	(C20-C30)	1.6
Greater than Carbon 30	(>C30)	0.4

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

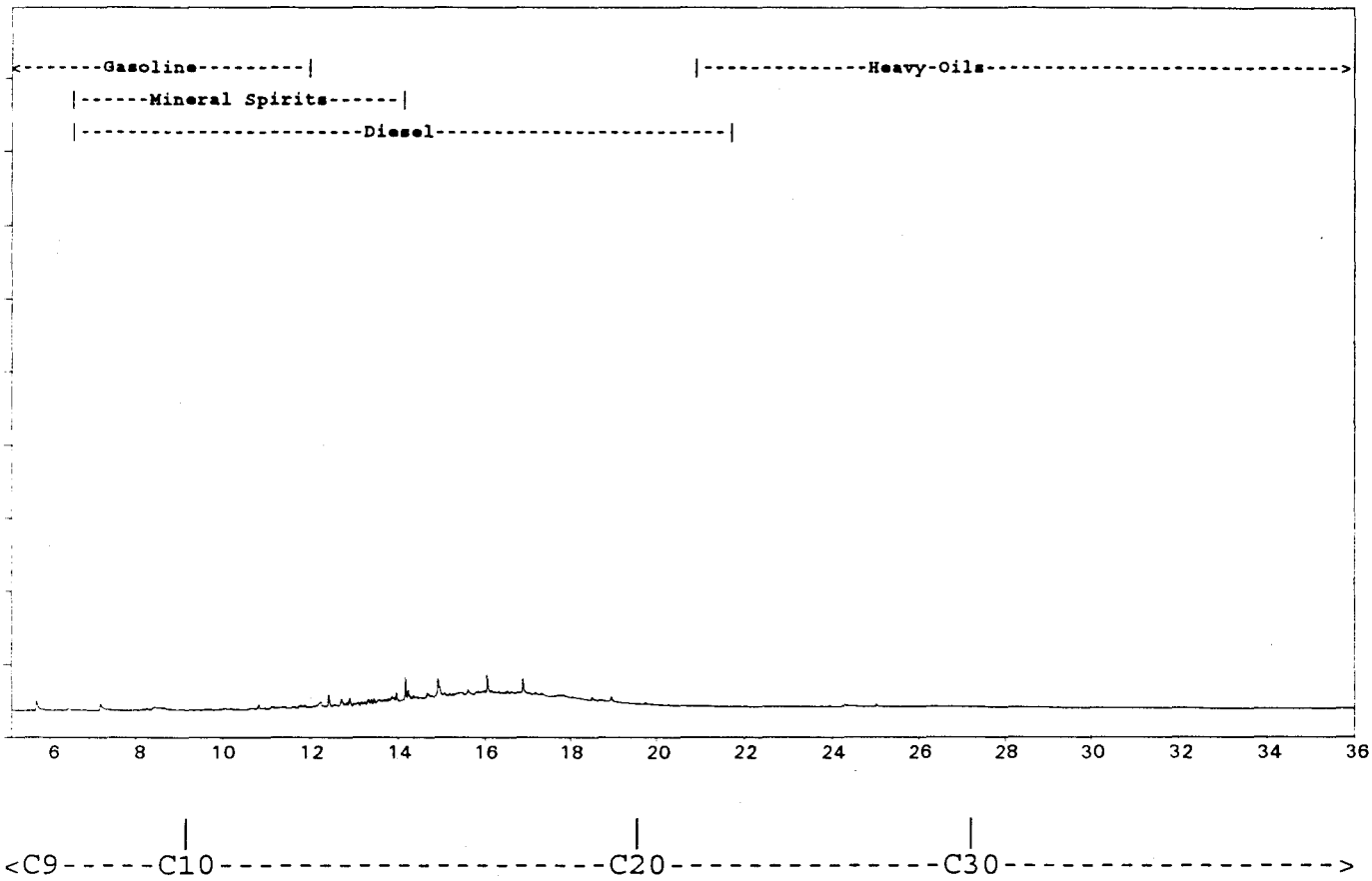
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: BH96-21C July 21, 1996

Sample acquired: AUG 9, 1996 09:12:20

File Name: c:\TEH\TEHAUG08.54R , Sample Name: G3361 27

Sequence file: TEHAUG08



ASL Sample ID: G3361 27* 1.0Dilution

HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	3.1
Carbon 10 to Carbon 20	(C10-C20)	90.4
Carbon 20 to Carbon 30	(C20-C30)	6.3
Greater than Carbon 30	(>C30)	0.2

The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

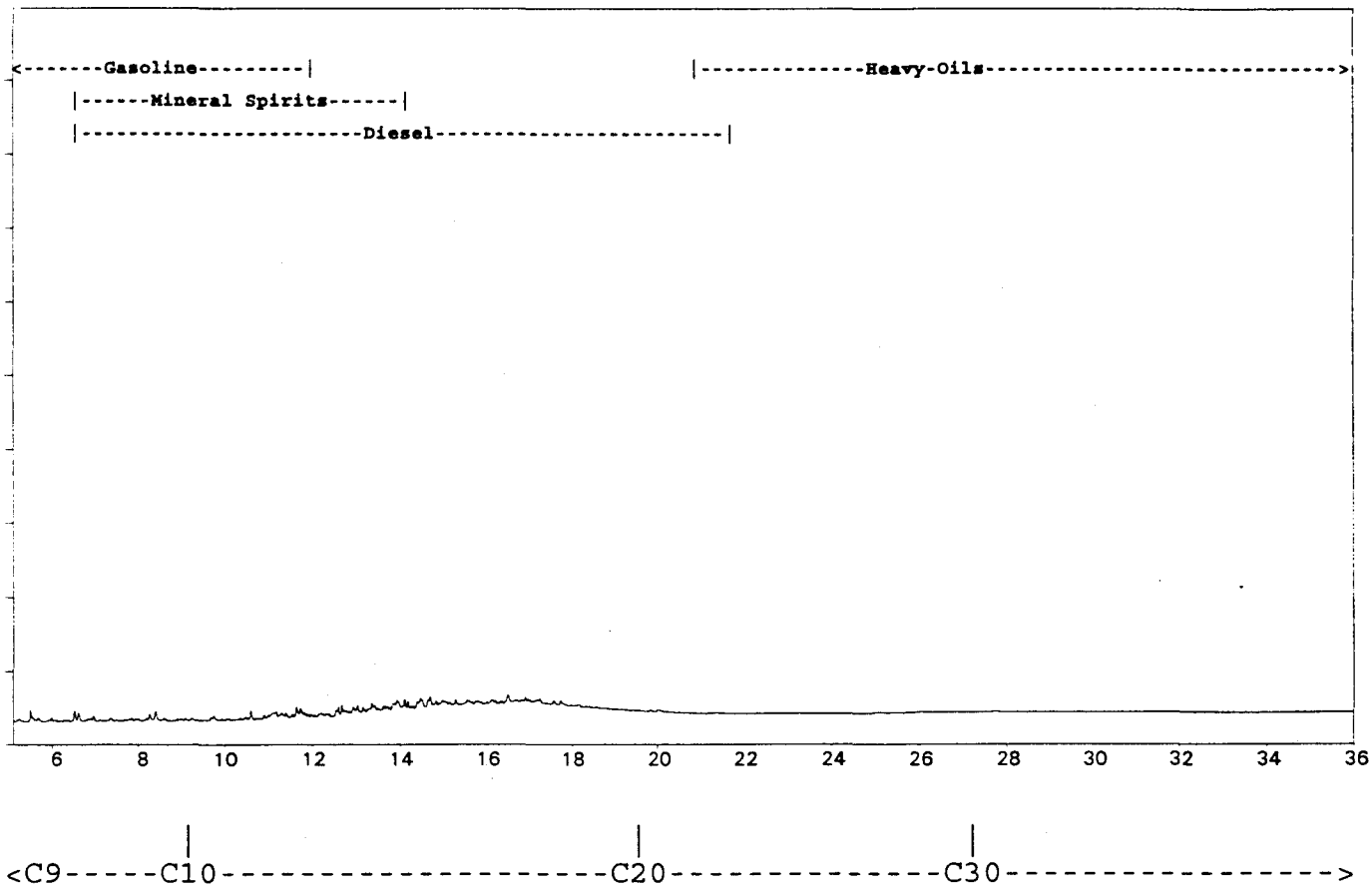
HYDROCARBON DISTRIBUTION REPORT

SAMPLE NAME: **BH96B-21 A**

Sample acquired: SEP 29, 1996 00:40:46

File Name: c:\TEH\TEHSEP27.85R , Sample Name: G5283 8

Sequence file: TEHSEP27



HYDROCARBON RANGE (C#)		RELATIVE AMOUNT (%)
Less than Carbon 10	(<C10)	7.8
Carbon 10 to Carbon 20	(C10-C20)	88.3
Carbon 20 to Carbon 30	(C20-C30)	2.3
Greater than Carbon 30	(>C30)	1.6

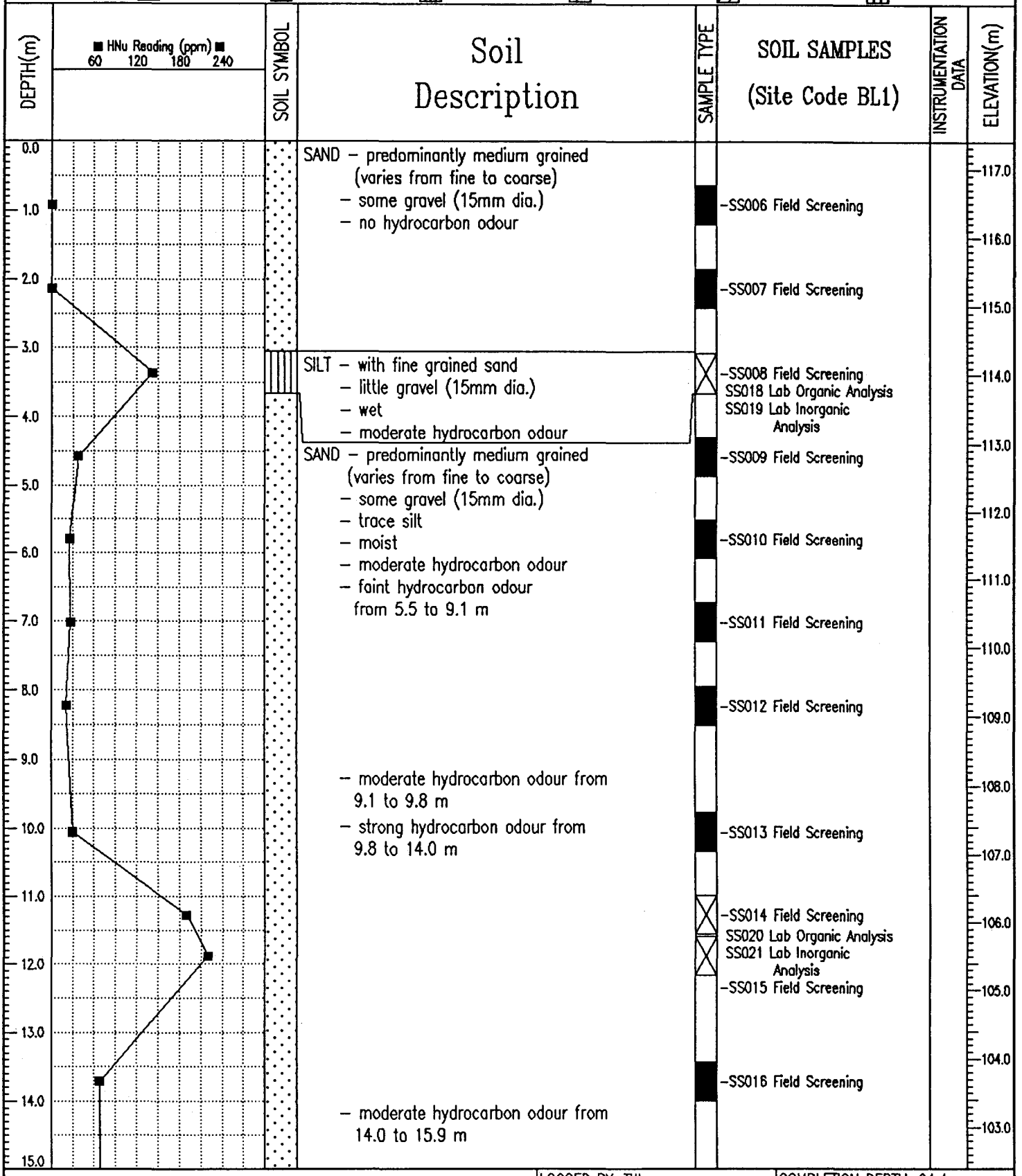
The Hydrocarbon Distribution Report is intended to assist you in characterizing the hydrocarbon product present in a given sample. The scale at the top of the chromatographic trace represents the hydrocarbon range of common petroleum products. Comparison of this report with those of reference standards may also assist you in the identification of the hydrocarbon product detected in your sample. The second part of the report is a table that expresses the relative amount of hydrocarbon product present in the ranges specified.

Appendix C: Borehole Logs and Soil Gradational Analysis

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–7
Testhole Co-ordinates: 13N , 142E	Location: SOUTH OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 117.39 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



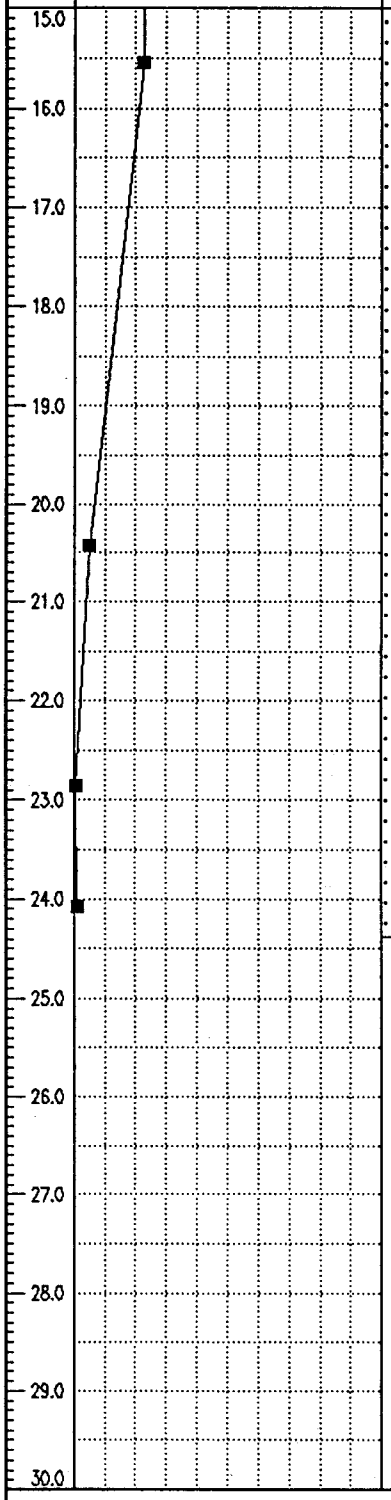
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
	REVIEWED BY: TW	COMPLETE: 95/07/13
	Fig. No:	Page 1 of 2

96/11/14 02:50PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–7
Testhole Co–ordinates: 13N , 142E	Location: SOUTH OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 117.39 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



DEPTH(m)	Soil Description	SAMPLE TYPE	SOIL SAMPLES (Site Code BL1)	INSTRUMENTATION DATA	ELEVATION(m)
15.0					102.0
16.0	– faint hydrocarbon odour from 15.9 to 22.0 m		–SS017 Field Screening		101.0
17.0					100.0
18.0					99.0
19.0					98.0
20.0					97.0
21.0			–SS022 Field Screening		96.0
22.0	– some silt – little gravel – dense – moist to dry with depth – no odour				95.0
23.0			–SS023 Field Screening		94.0
24.0			–SS024 Field Screening SS025 Lab Organic Analysis –SS026 Lab Inorganic Analysis		93.0
25.0	END OF TESTHOLE IN SAND @ 24.38m				92.0
26.0					91.0
27.0					90.0
28.0					89.0
29.0					88.0
30.0					

UMA Environmental
Winnipeg, Manitoba

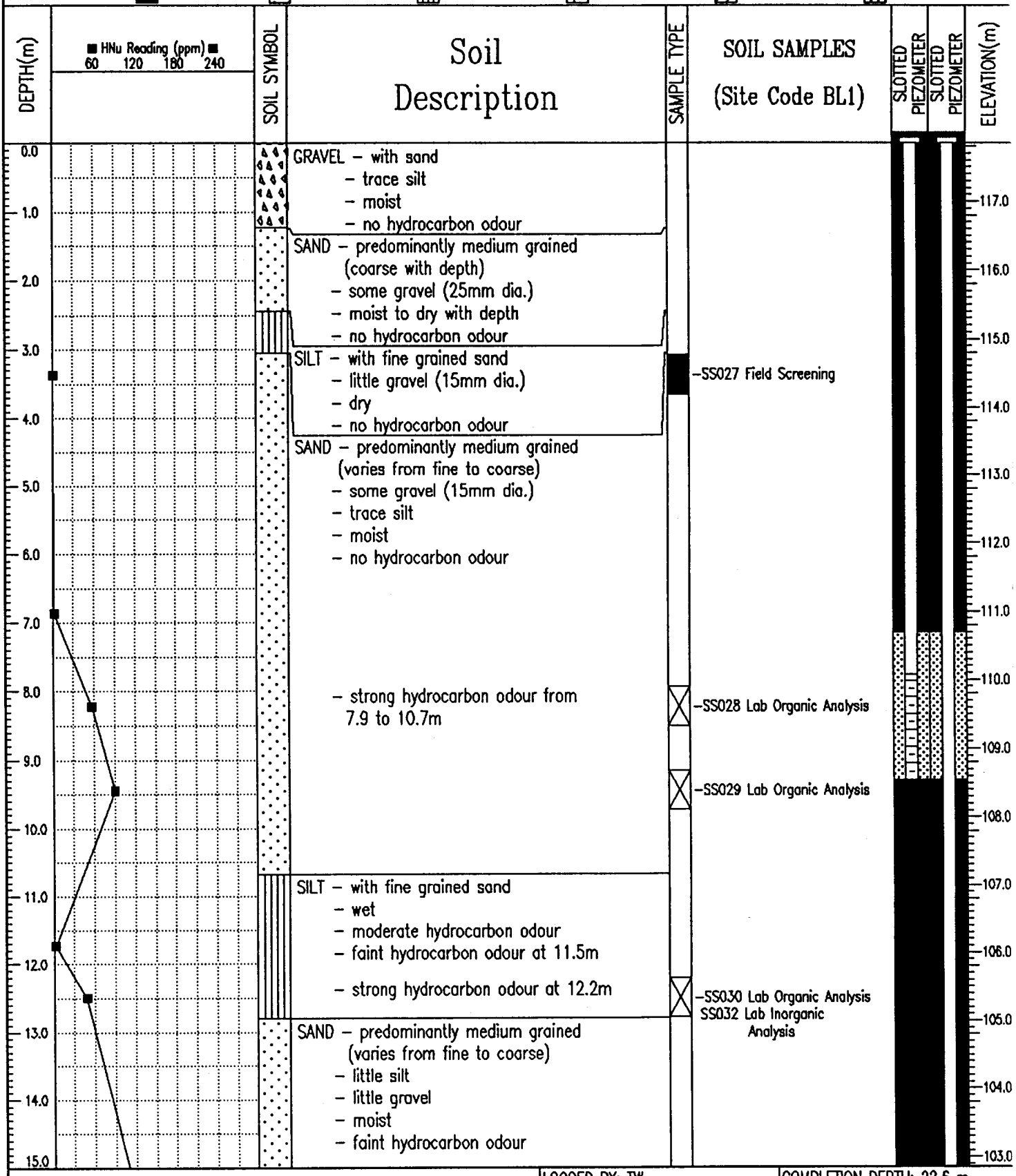
LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
REVIEWED BY: TW	COMPLETE: 95/07/13
Fig. No:	Page 2 of 2

96/11/14 02:50PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–8
Testhole Co-ordinates: 15N, 73E	Location: SOUTHWEST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 117.85 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



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Winnipeg, Manitoba

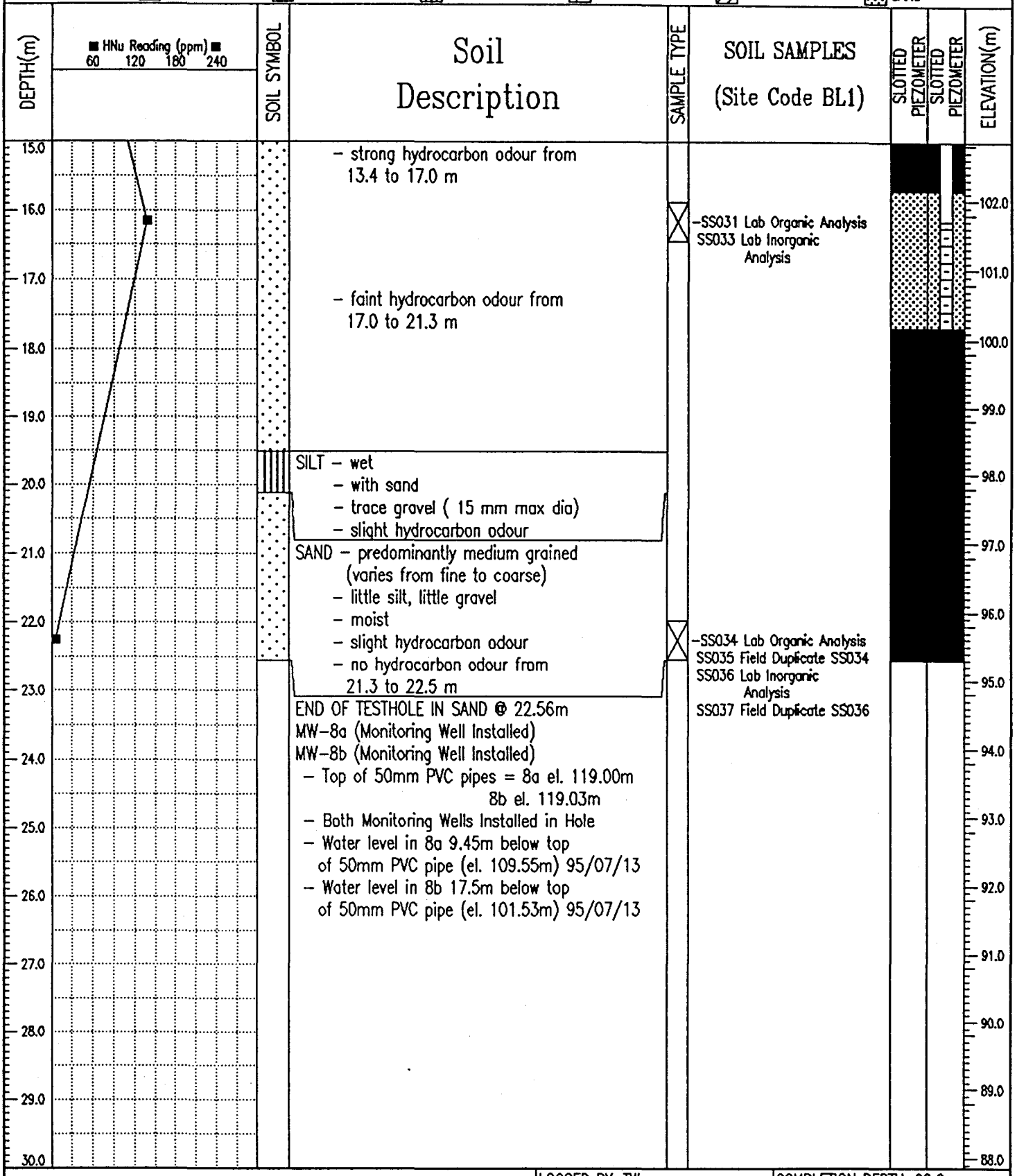
LOGGED BY: TW	COMPLETION DEPTH: 22.6 m
REVIEWED BY: TW	COMPLETE: 95/07/13
Fig. No:	Page 1 of 2

96/12/02 10:02PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–8
Testhole Co–ordinates: 15N, 73E	Location: SOUTHWEST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 117.85 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



– strong hydrocarbon odour from 13.4 to 17.0 m

–SS031 Lab Organic Analysis
SS033 Lab Inorganic Analysis

– faint hydrocarbon odour from 17.0 to 21.3 m

SILT – wet
– with sand
– trace gravel (15 mm max dia)
– slight hydrocarbon odour

SAND – predominantly medium grained (varies from fine to coarse)
– little silt, little gravel
– moist
– slight hydrocarbon odour
– no hydrocarbon odour from 21.3 to 22.5 m

–SS034 Lab Organic Analysis
SS035 Field Duplicate SS034
SS036 Lab Inorganic Analysis
SS037 Field Duplicate SS036

END OF TESTHOLE IN SAND @ 22.56m
MW–8a (Monitoring Well Installed)
MW–8b (Monitoring Well Installed)
– Top of 50mm PVC pipes = 8a el. 119.00m
8b el. 119.03m
– Both Monitoring Wells Installed in Hole
– Water level in 8a 9.45m below top of 50mm PVC pipe (el. 109.55m) 95/07/13
– Water level in 8b 17.5m below top of 50mm PVC pipe (el. 101.53m) 95/07/13

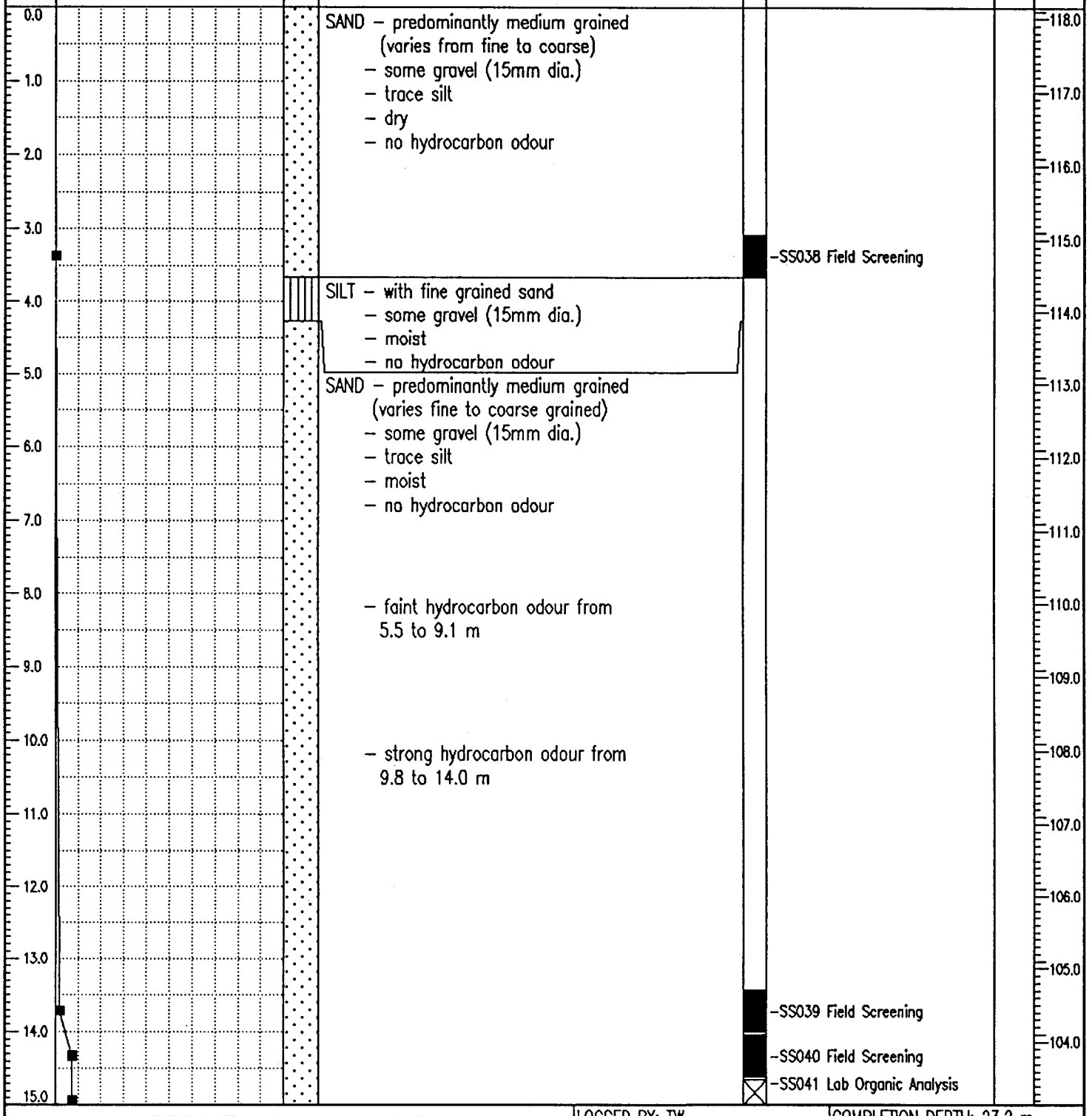
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 22.6 m
	REVIEWED BY: TW	COMPLETE: 95/07/13
	Fig. No:	Page 2 of 2

96/12/02 10:03PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–9
Testhole Co–ordinates: 16N , 10E	Location: SOUTHWEST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 118.14 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



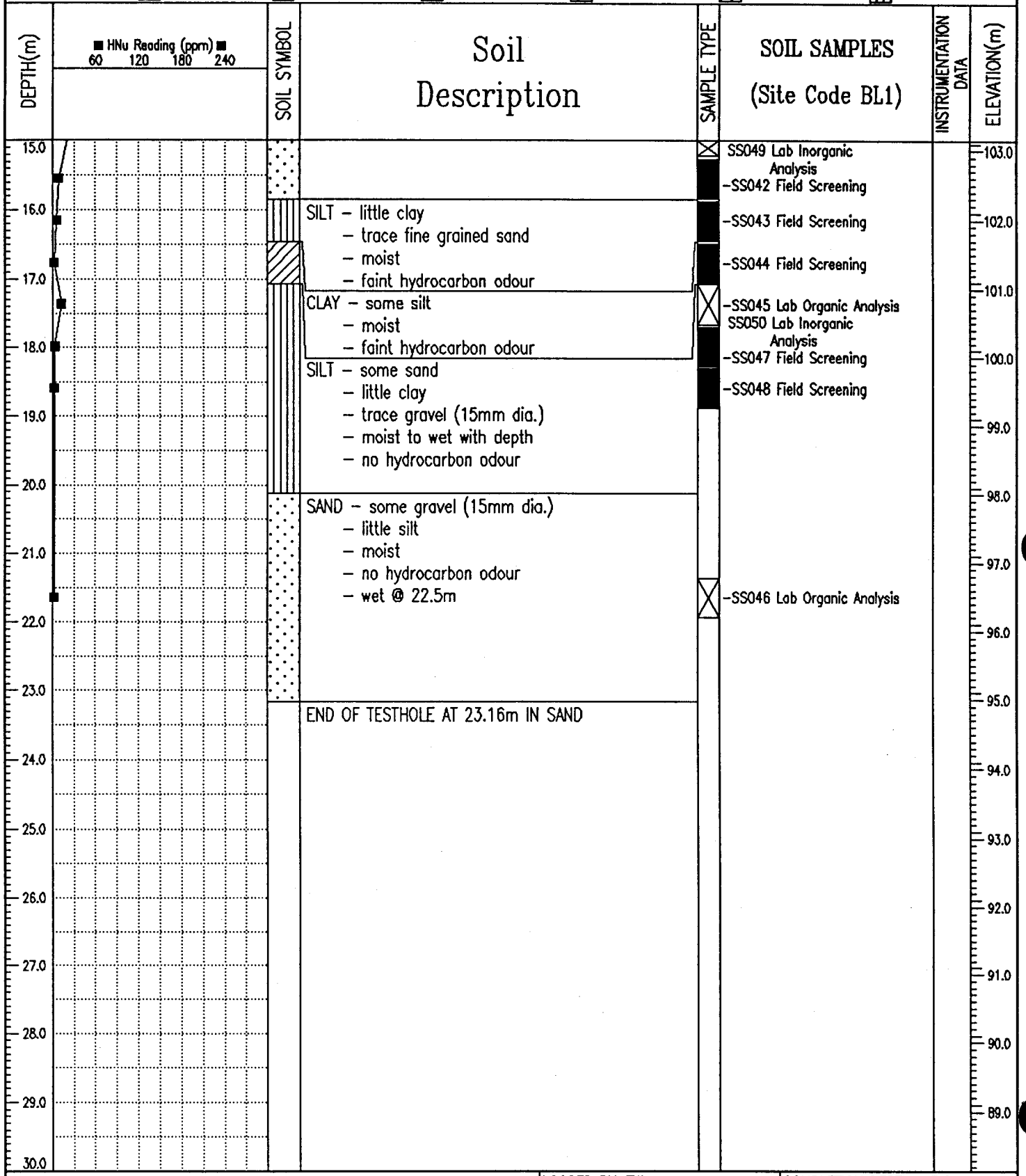
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 23.2 m
	REVIEWED BY: TW	COMPLETE: 95/07/13
	Fig. No:	Page 1 of 2

96/11/14 02:54PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–9
Testhole Co-ordinates: 16N , 10E	Location: SOUTHWEST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 118.14 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



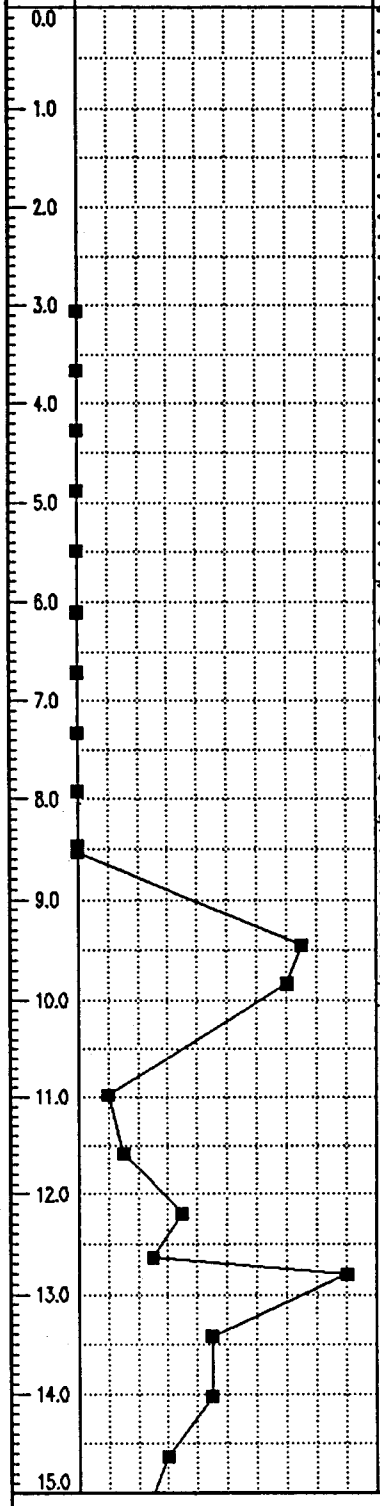
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 23.2 m
	REVIEWED BY: TW	COMPLETE: 95/07/13
	Fig. No:	Page 2 of 2

96/11/14 12:54PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-10
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.88 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS
	SAND – dry – varies from fine to very coarse – some gravel (25 mm dia)			
	– moist – with gravel at 4.57 m (50 mm dia)			
	GRAVEL – moist to wet – maximum diameter 25 mm – with sand (varies from medium to very coarse)			
	SAND – moist to wet – medium to very coarse grained – some gravel (50 mm dia) – slight hydrocarbon odour 9.15 to 9.83 m		10-01	EPH, Chlor
	– some silt from 9.15 to 9.83 m		10-02	EPH
	SILT – wet – some stones, trace clay – slight hydrocarbon odour			
	SAND – wet – medium to very coarse grained – trace to some gravel (20 mm dia) – trace sand – moderate hydrocarbon odour to 15.0m		10-03	EPH
	– fine to medium grained from 13.7 to 15.2 m			

SLOTTED PIEZOMETER

ELEVATION(m): 117.(116.(115.(114.(113.(112.(111.(110.(109.(108.(107.(106.(105.(104.(103.(

UMA Environmental
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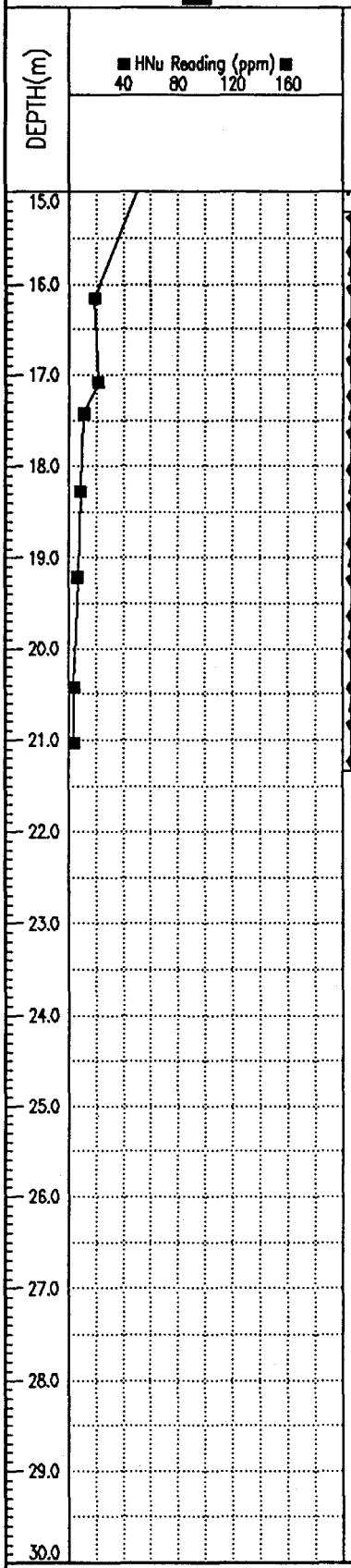
LOGGED BY: TW	COMPLETION DEPTH: 21.3 m
REVIEWED BY: TW	COMPLETE: 96/07/12
Fig. No:	Page 1 of 2

96/12/03 11:14AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-10
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.88 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
	GRAVEL (Till) – wet – with fine sand – some silt, trace clay		10-04	EPH Particle Size		102.0 101.0 100.0 99.0 98.0
			10-05	EPH		97.0
	END OF TEST HOLE AT 21.34 m IN GRAVEL (Till)					96.0 95.0 94.0 93.0 92.0 91.0 90.0 89.0 88.0

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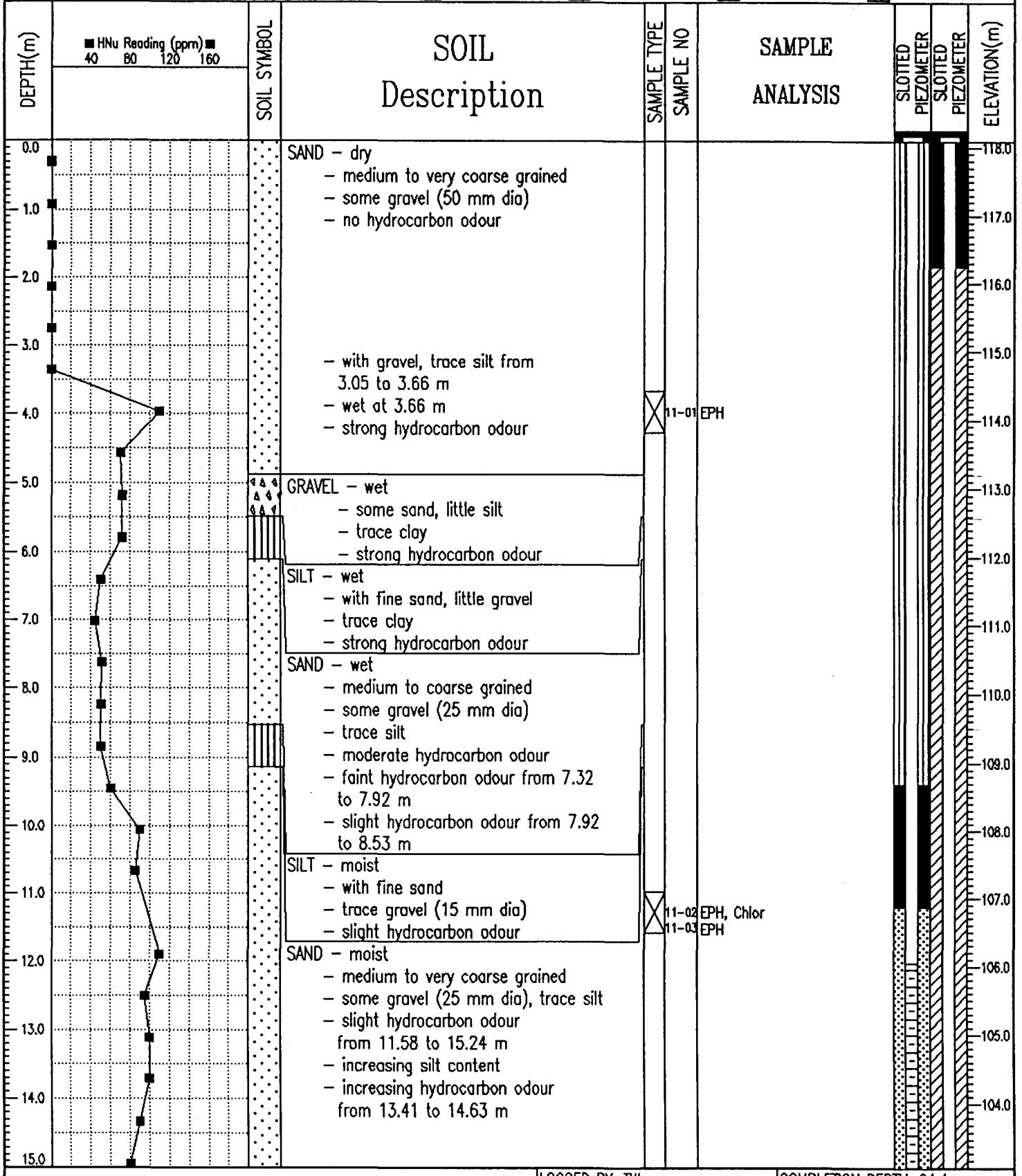
LOGGED BY: TW	COMPLETION DEPTH: 21.3 m
REVIEWED BY: TW	COMPLETE: 96/07/12
Fig. No:	Page 2 of 2

96/12/03 11:15AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-11
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 118.08 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



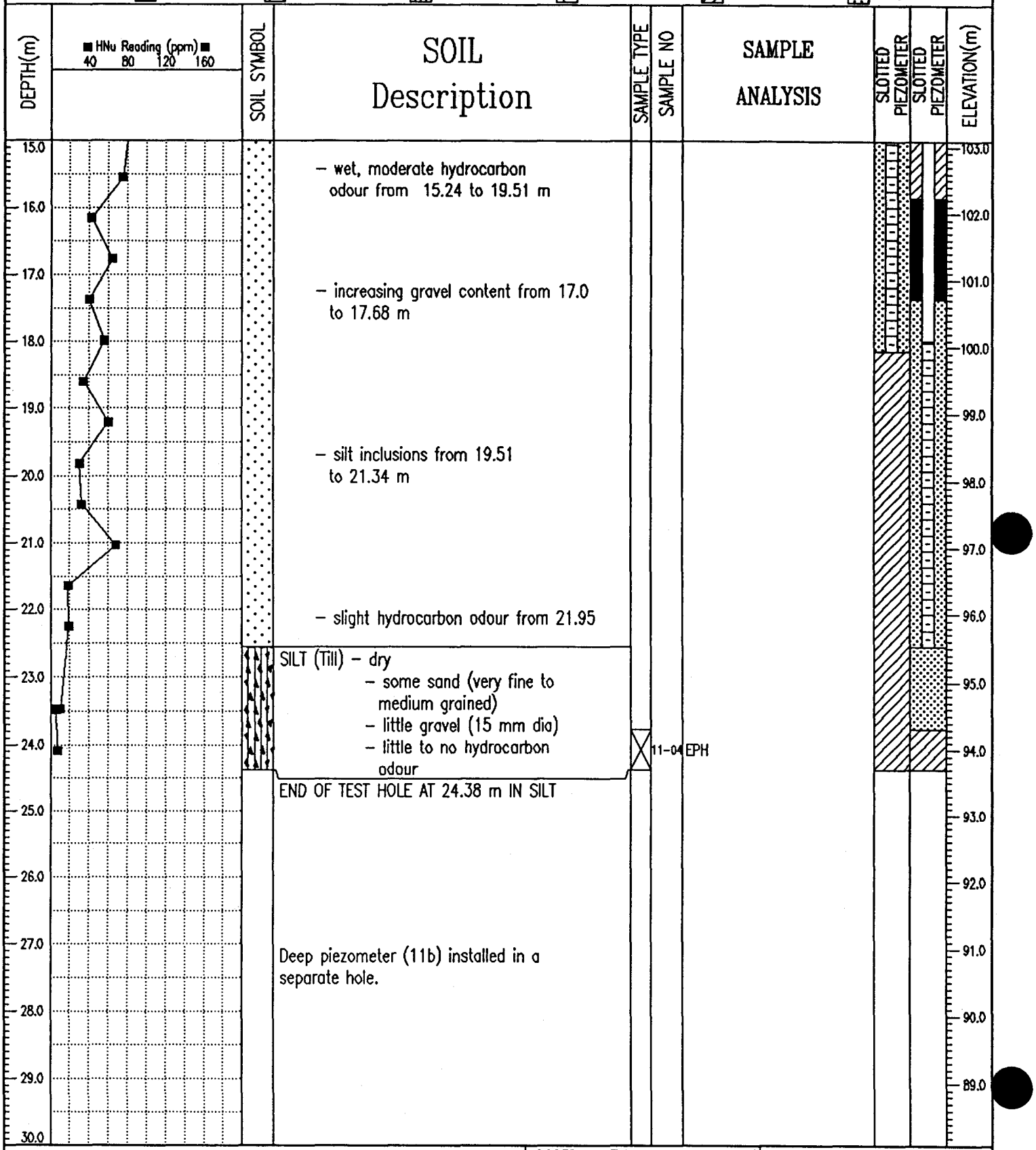
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/13
	Fig. No:	Page 1 of 2

96/11/05 03:15PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-11
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 118.08 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



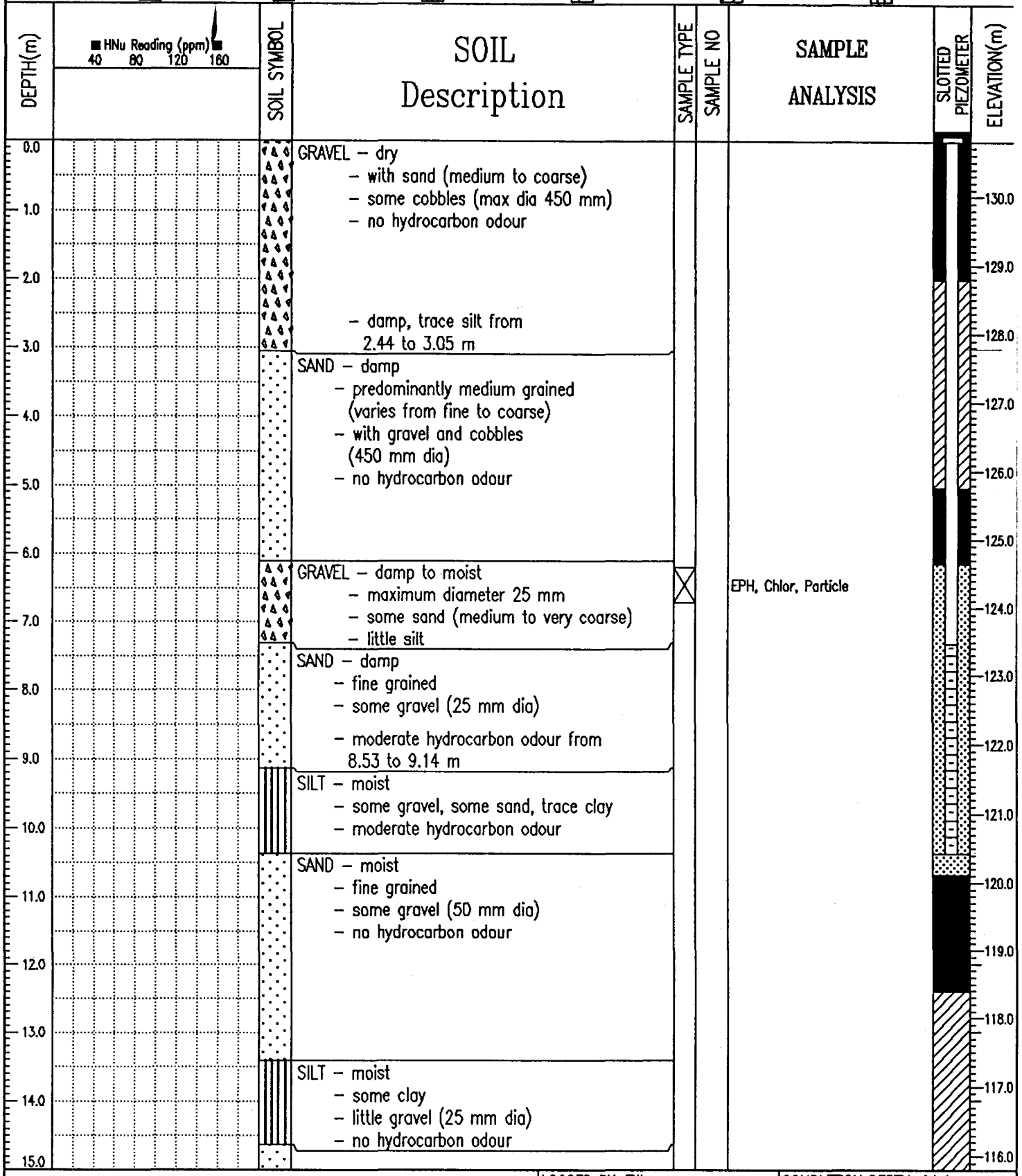
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/13
	Fig. No:	Page 2 of 2

96/11/05 03:15PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-12
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 130.79 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/13
	Fig. No:	Page 1 of 2

96/11/22 09:15AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-12
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 130.79 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 40 80 120 160	SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
15.0			SAND – dry to moist – fine grained – little gravel (15 mm dia) – no hydrocarbon odour					115.0
16.0			SILT – moist – some fine grained sand – little gravel (25 mm dia) – no hydrocarbon odour					114.0
17.0								113.0
18.0			SAND – dry – fine grained – some silt – little gravel (25 mm dia) – no hydrocarbon odour		12-02	EPH		112.0
19.0								111.0
20.0								110.0
21.0								109.0
22.0			SILT – wet – some gravel, trace clay – no hydrocarbon odour					108.0
23.0			– dry at 22.5 m – with fine grained sand		12-03	EPH, BTEX/VPH		107.0
24.0								106.0
25.0			END OF TEST HOLE AT 24.38 m ON BEDROCK (green, fine grained volcanic tuff)					105.0
26.0								104.0
27.0			NOTE: No vapour readings due to equipment malfunction.					103.0
28.0								102.0
29.0								101.0
30.0								

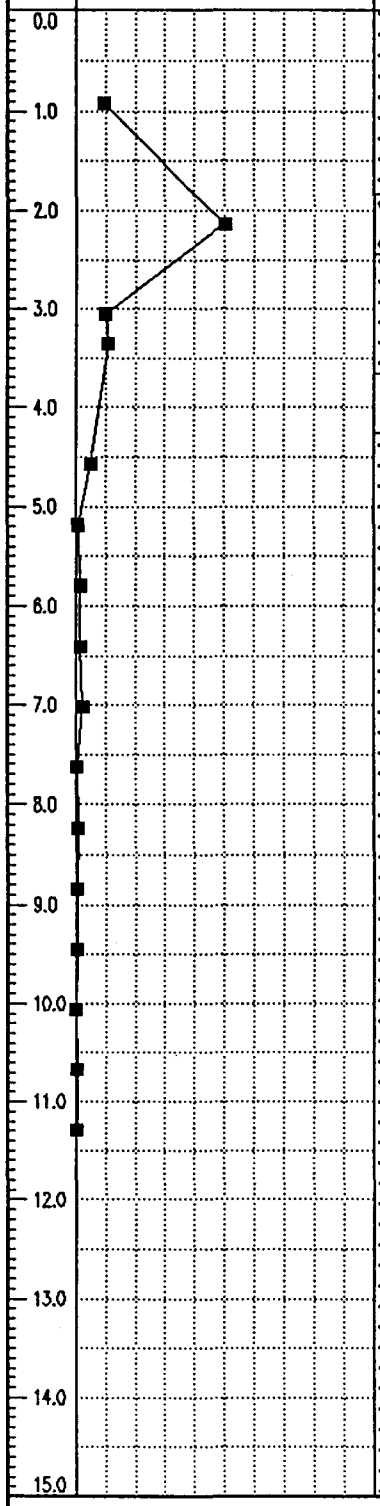
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 24.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/13
	Fig. No:	Page 2 of 2

96/11/22 09:35AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-13
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 130.12 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
	SAND – dry – predominantly medium grained (varies from fine to very coarse) – some gravel (40 mm dia) – trace silt – strong hydrocarbon odour		13-01	EPH, BTEX/VPH		130.0 129.0
	GRAVEL – wet – maximum diameter 25 mm – with sand (medium to coarse) – some cobbles and boulders – strong hydrocarbon odour			Particle Size		128.0 127.0
	SAND – wet – predominantly medium grained (varies from fine to very coarse) – some gravel (40 mm dia) – trace silt – strong hydrocarbon odour		13-02 13-03	EPH EPH		126.0 125.0
	SILT – moist – some clay, little sand – moderate hydrocarbon odour					124.0
	SAND – dry – fine grained – some gravel (25 mm dia) – little silt – slight hydrocarbon odour from 4.26 to 5.49 m					123.0 122.0 121.0 120.0 119.0 118.0 117.0 116.0

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LOGGED BY: TW	COMPLETION DEPTH: 17.1 m
REVIEWED BY: TW	COMPLETE: 96/07/14
Fig. No:	Page 1 of 2

96/11/22 09:22AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-13
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 130.12 (m)

SAMPLE TYPE ■ GRAB SAMPLE ▨ SHELBY TUBE ▩ LAB SUBMITTED ▤ NO RECOVERY ▥ SPLIT SPOON ▮ WIRE LINE-TYPE

BACKFILL TYPE ■ BENTONITE ⁘ PEA GRAVEL ▦ SLOUGH ⁘ GROUT ▨ DRILL CUTTINGS ▩ SAND

DEPTH(m)	■ HNu Reading (ppm) ■ 40 80 120 160	SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
15.0		⁘						115.0
16.0		▤	BEDROCK – green – fine grained volcanic tuff					114.0
17.0			END OF TEST HOLE AT 17.07 m IN BEDROCK					113.0
18.0								112.0
19.0			NOTE: Vapor reading completed in the evening due to equipment problems.					111.0
20.0								110.0
21.0								109.0
22.0								108.0
23.0								107.0
24.0								106.0
25.0								105.0
26.0								104.0
27.0								103.0
28.0								102.0
29.0								101.0
30.0								

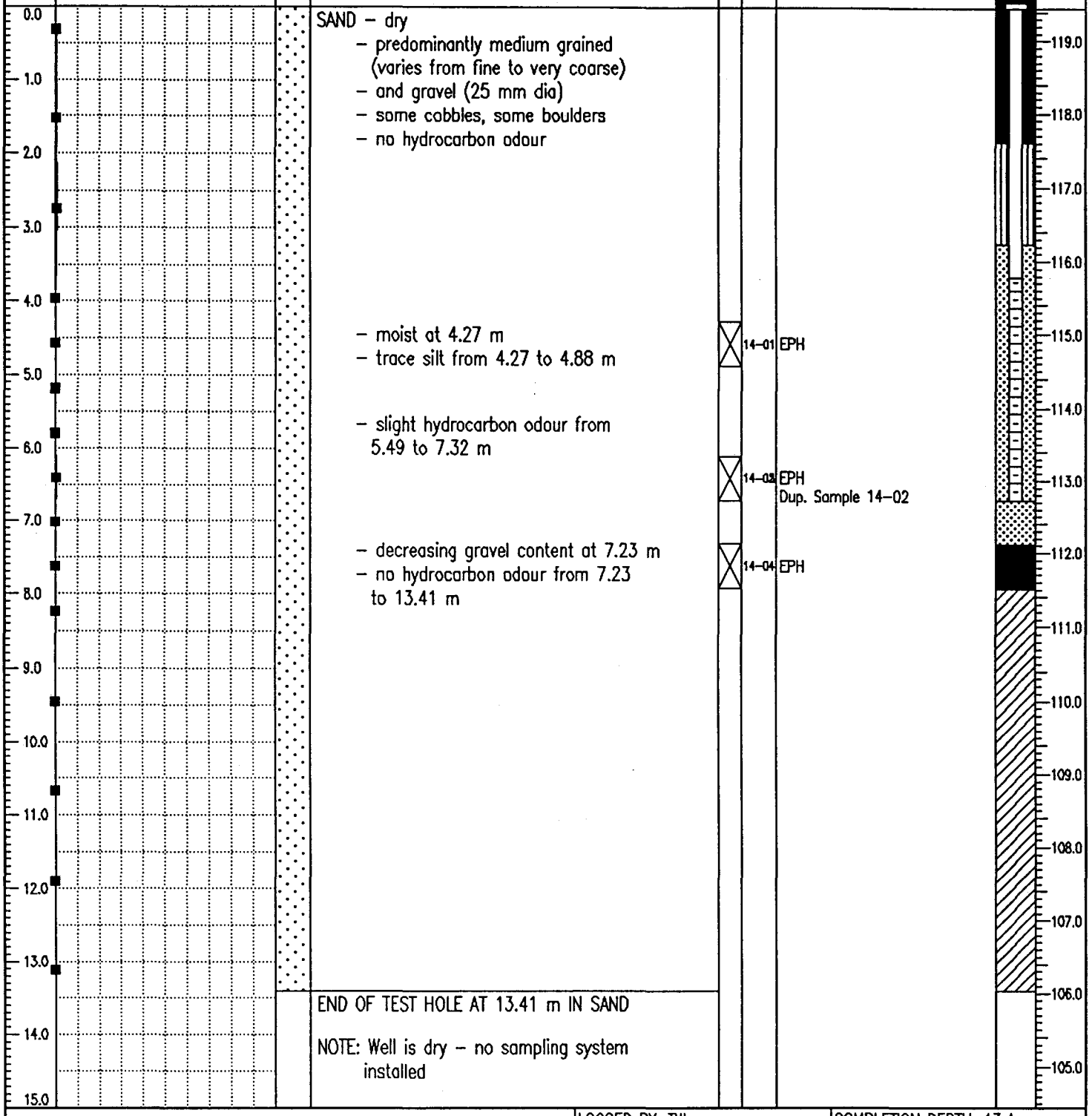
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 17.1 m
	REVIEWED BY: TW	COMPLETE: 96/07/14
	Fig. No:	Page 2 of 2

96/11/22 09:23AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-14
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 119.44 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



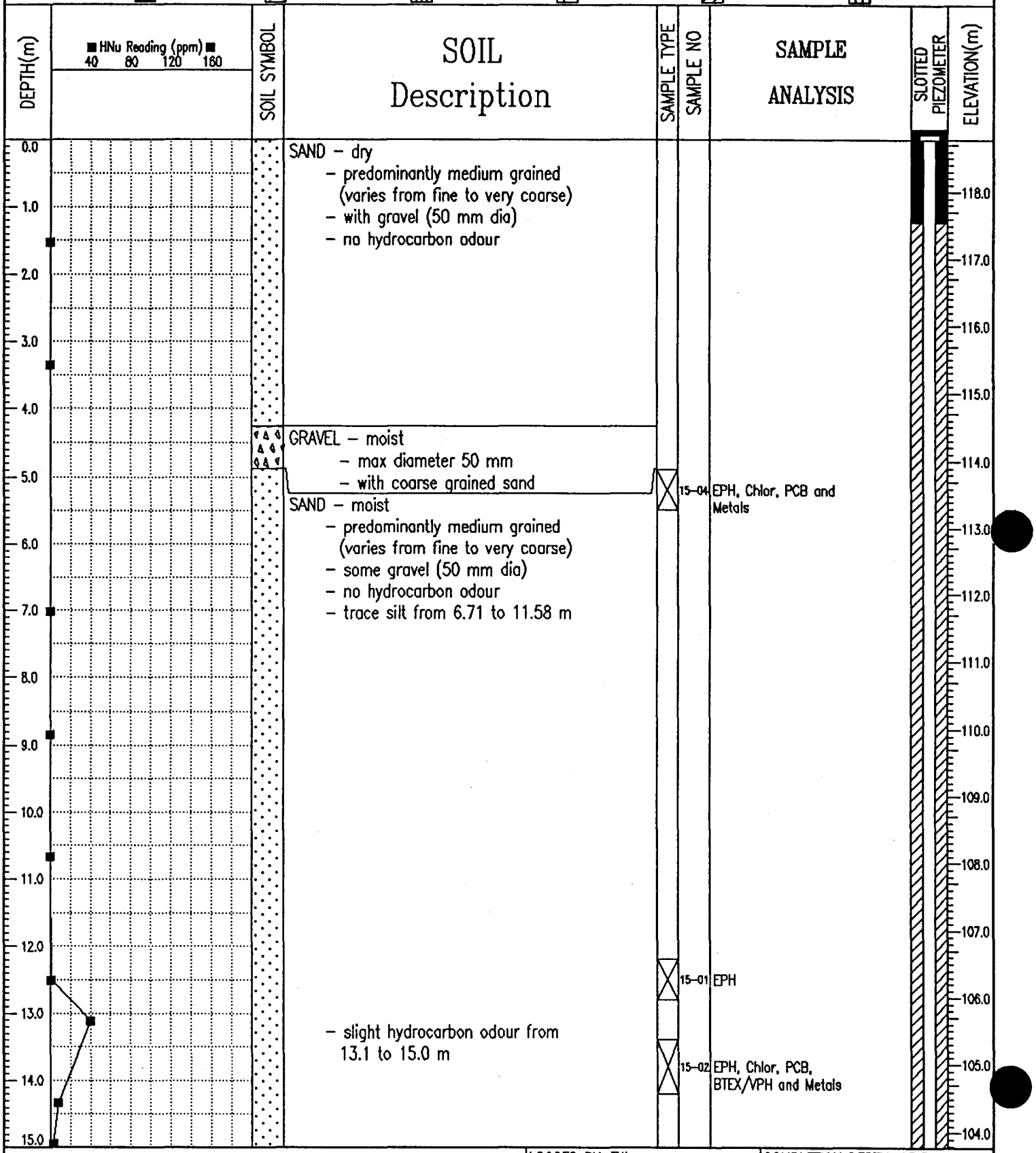
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 13.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/15
	Fig. No:	Page 1 of 1

96/11/14 03:18PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-15
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 118.77 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



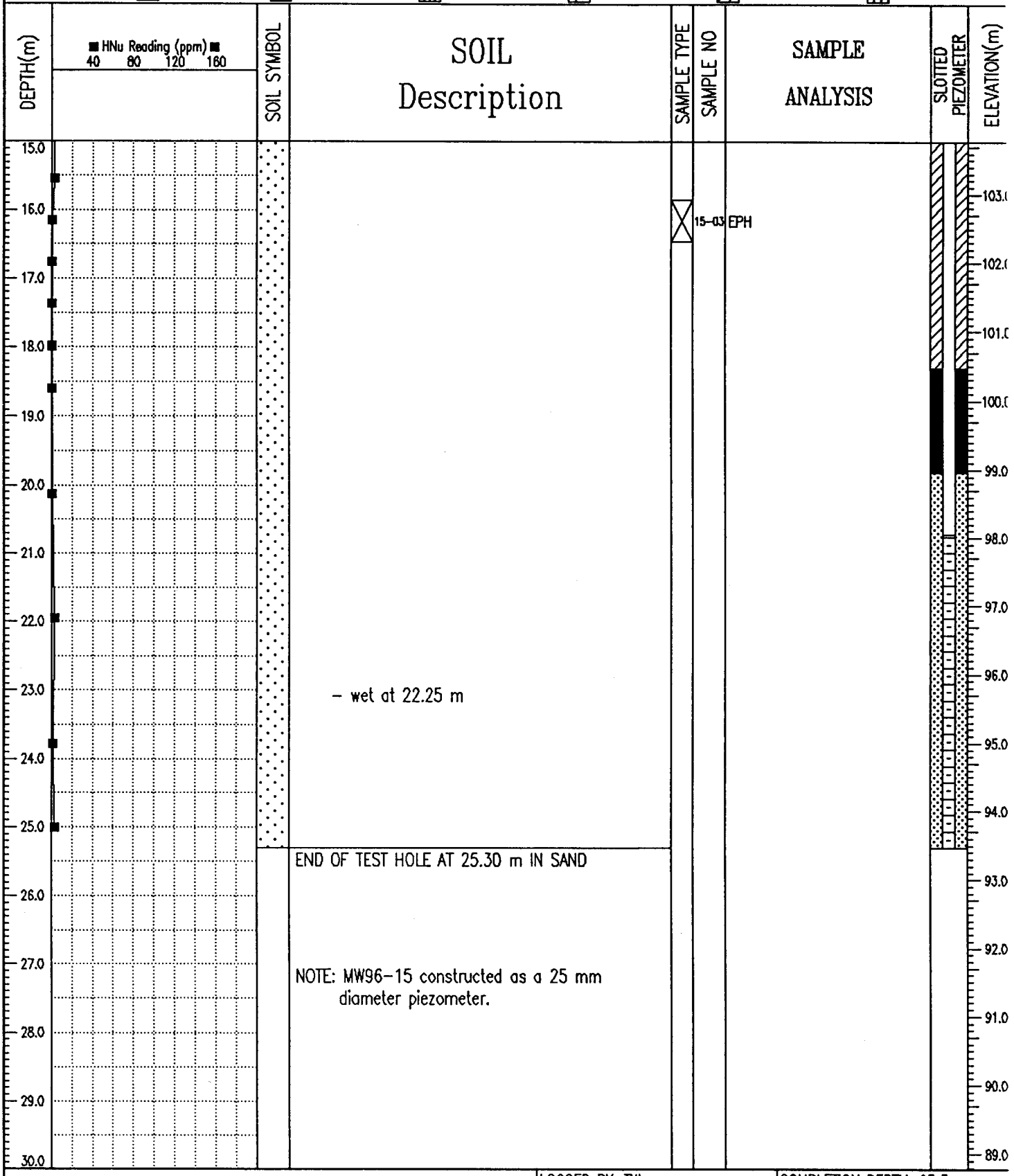
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 25.3 m
	REVIEWED BY: TW	COMPLETE: 96/07/15
	Fig. No:	Page 1 of 2

96/11/07 10:55AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-15
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 118.77 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



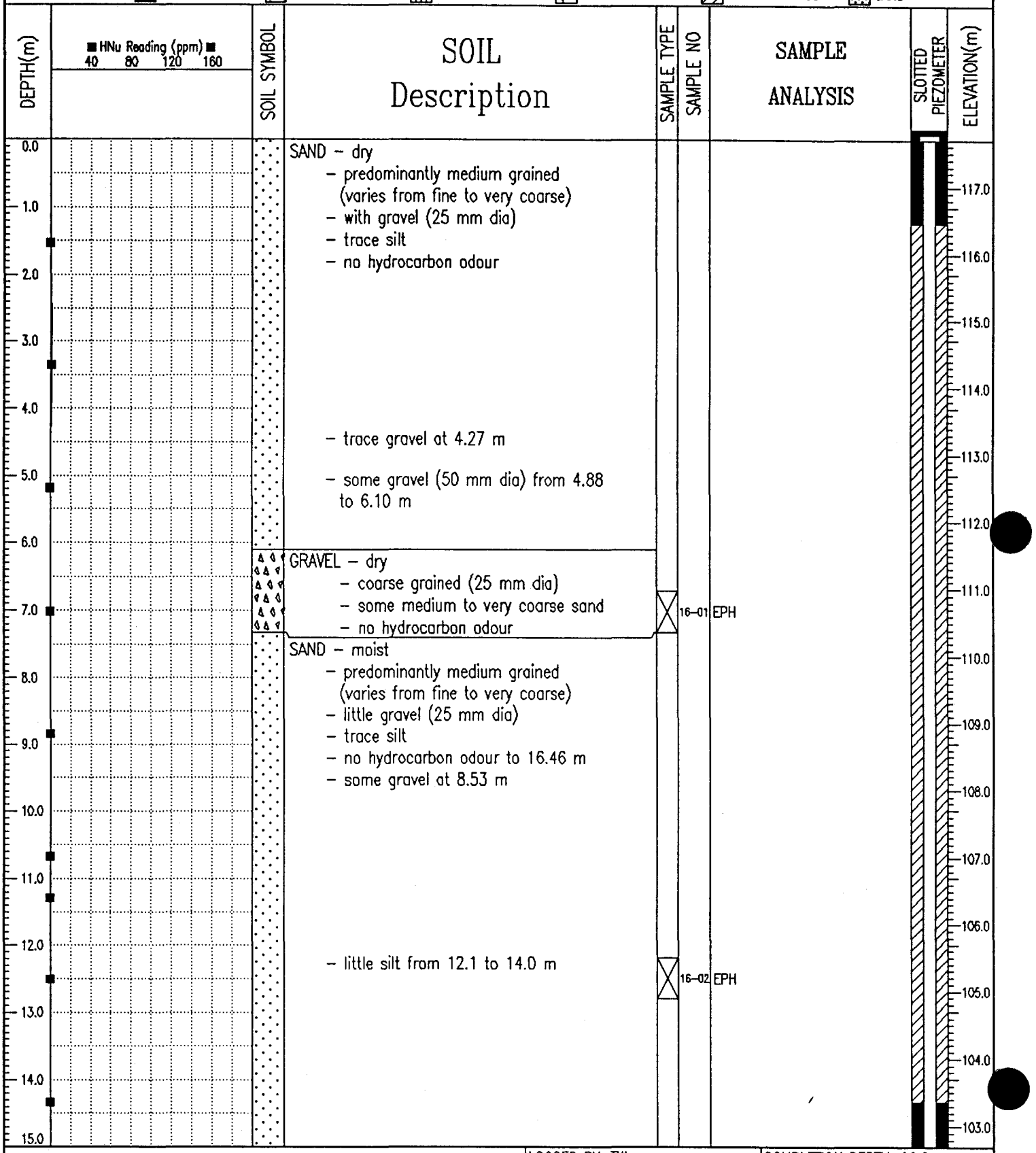
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 25.3 m
	REVIEWED BY: TW	COMPLETE: 96/07/15
	Fig. No:	Page 2 of 2

96/11/07 10:56AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-16
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.69 (m)

SAMPLE TYPE: ■ GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: ■ BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



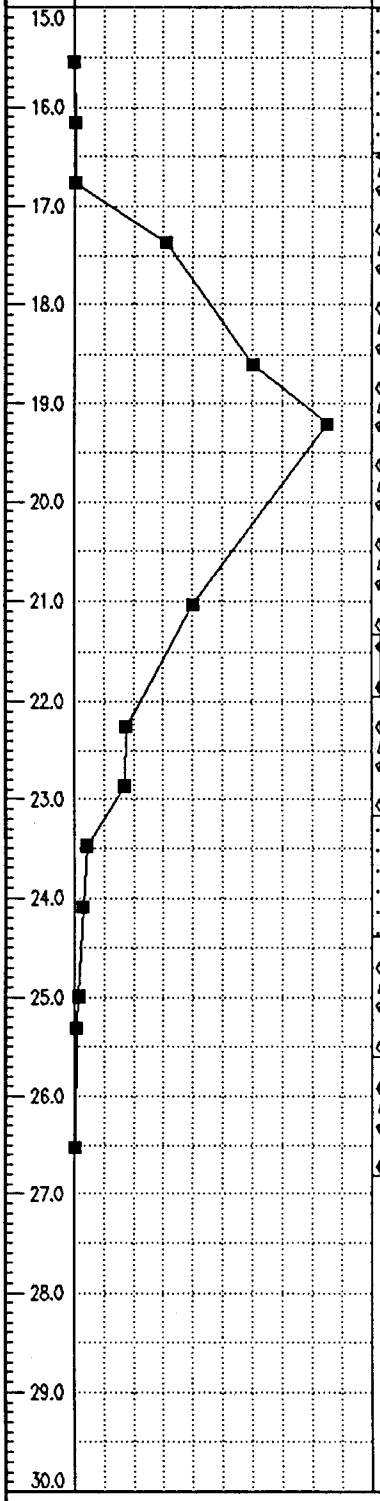
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 26.8 m
	REVIEWED BY: TW	COMPLETE: 96/07/16
	Fig. No:	Page 1 of 2

97/01/10 09:29AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-16
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.69 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS
	– slight hydrocarbon odour at 16.46 m			
	GRAVEL – wet – 25 mm diameter – with sand (medium to coarse) – slight hydrocarbon odour from 16.46 to 17.07 m – strong hydrocarbon odour from 17.07 to 21.33 m			Particle Size
			16-03	EPH, Chlor, BTEX/VPH
				Particle Size
	SILT (Till) – very wet – with gravel, with sand – little clay – moderate hydrocarbon odour from 21.33 to 25.00 m			Particle Size
			16-05	EPH, BTEX/VPH, Chlor
	GRAVEL – wet – little coarse sand, trace silt – moderate hydrocarbon odour		16-06	EPH, BTEX/VPH, Chlor
	SAND – wet – medium to very coarse grained – with gravel, little silt – trace clay – moderate hydrocarbon odour			
	GRAVEL – very wet – some silt, little sand (coarse grained) – no hydrocarbon odour from 25.0 to 26.82 m			Particle Size
			16-07	EPH, BTEX/VPH, Chlor
	SILT (Till) – wet – some gravel (25 mm dia), some clay – trace sand			
	END OF TEST HOLE AT 26.82 m IN SILT (Till)			

SLOTTED PIEZOMETER

ELEVATION(m): 102.0, 101.0, 100.0, 99.0, 98.0, 97.0, 96.0, 95.0, 94.0, 93.0, 92.0, 91.0, 90.0, 89.0, 88.0

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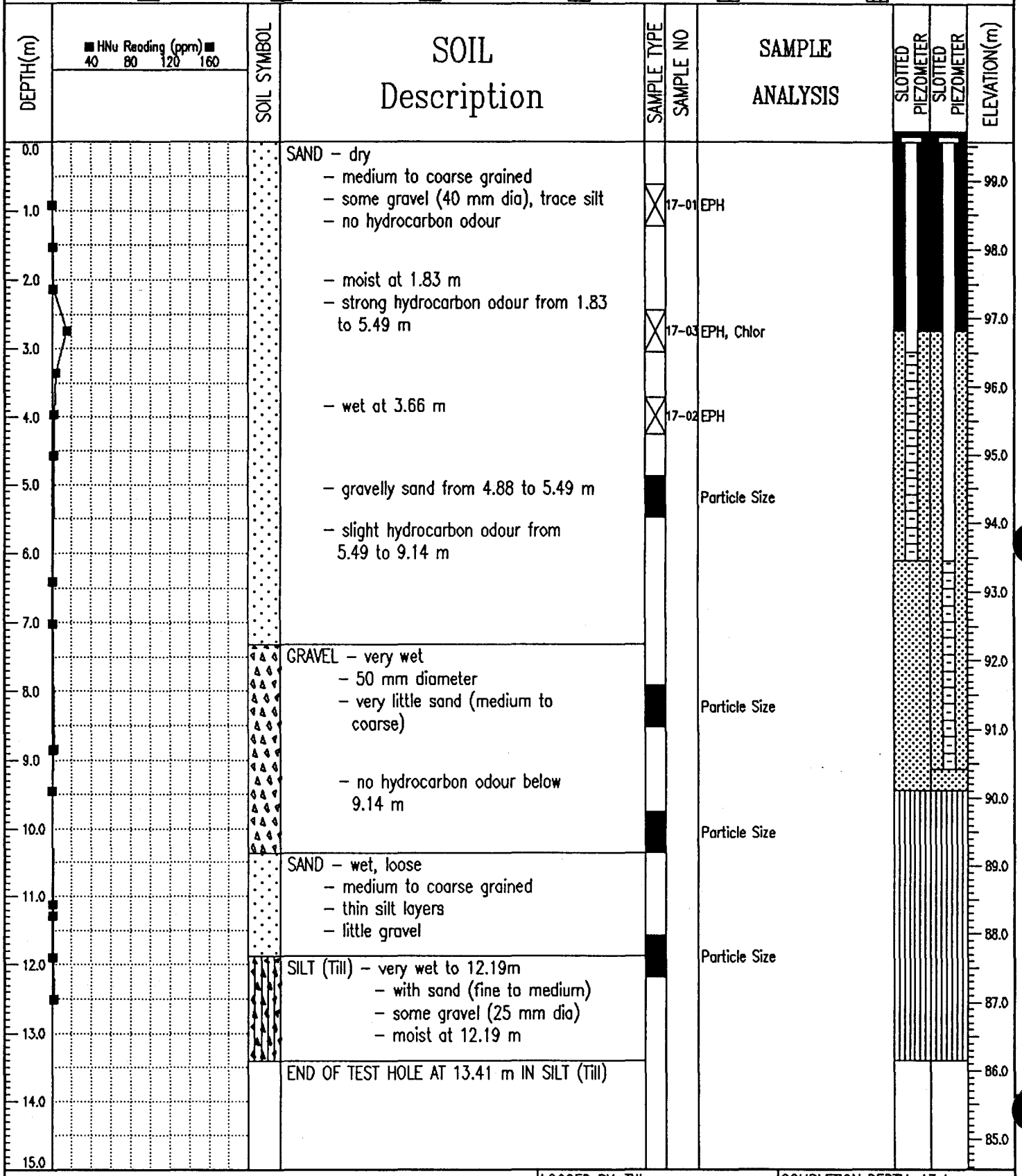
LOGGED BY: TW	COMPLETION DEPTH: 26.8 m
REVIEWED BY: TW	COMPLETE: 96/07/16
Fig. No:	Page 2 of 2

97/01/10 09:29AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-17
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 99.56 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 13.4 m
	REVIEWED BY: TW	COMPLETE: 96/07/17
	Fig. No:	Page 1 of 1

96/12/03 11:17AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-18
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 99.04 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 40 80 120 160	SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
0.0			SAND – dry – predominantly medium grained (varies from fine to coarse) – with gravel (25 mm dia), trace silt – no hydrocarbon odour		18-01	EPH, Chlor		99.0
1.0								98.0
2.0								97.0
3.0					18-02	EPH, Chlor and Particle Size		96.0
4.0			– moist at 3.66 m					95.0
5.0			GRAVEL – wet – 25 mm diameter – some sand (medium to very coarse)		18-03	EPH, Particle Size		94.0
6.0					18-04	Field Dup. 18-03 EPH, Particle Size		93.0
7.0						Particle Size		92.0
8.0			SAND – wet – medium to very coarse – some gravel (15 mm dia) – little to some silt			Particle Size		91.0
9.0								90.0
10.0			END OF TEST HOLE AT 9.75 m IN SAND					89.0
11.0								88.0
12.0								87.0
13.0								86.0
14.0								85.0
15.0								

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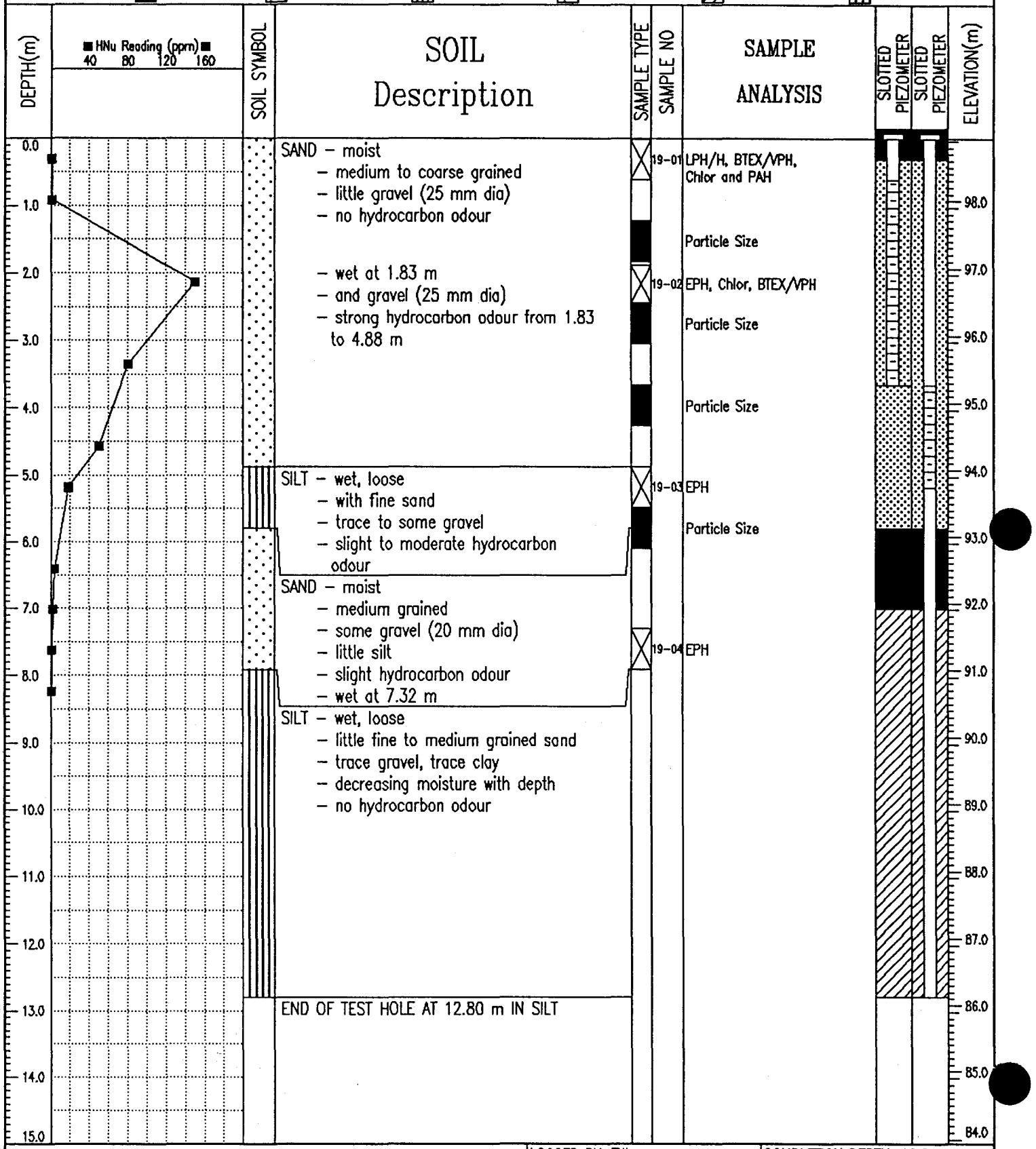
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REVIEWED BY: TW	COMPLETE: 96/07/18
Fig. No:	Page 1 of 1

96/11/14 03:19PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-19
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 98.93 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



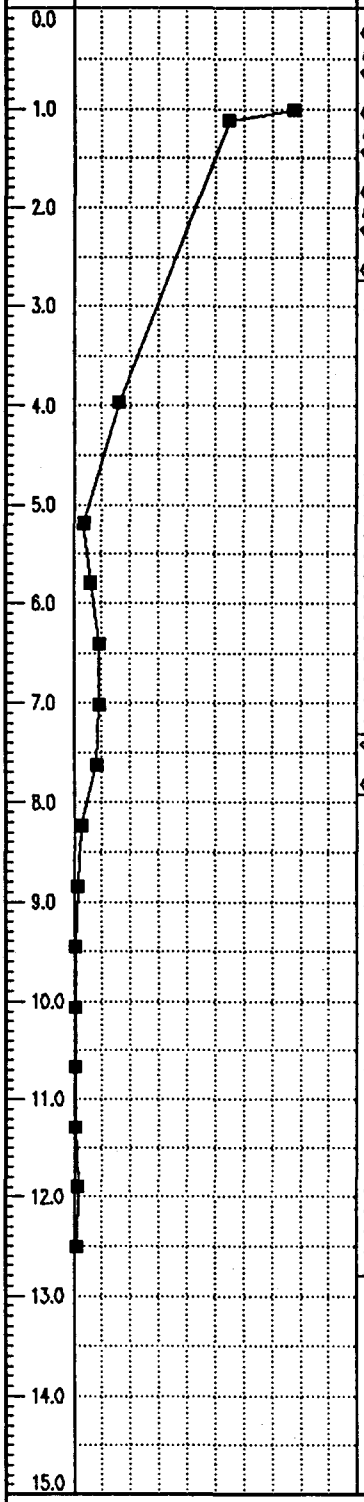
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 12.8 m
	REVIEWED BY: TW	COMPLETE: 96/07/19
	Fig. No:	Page 1 of 1

96/11/20 12:50PM

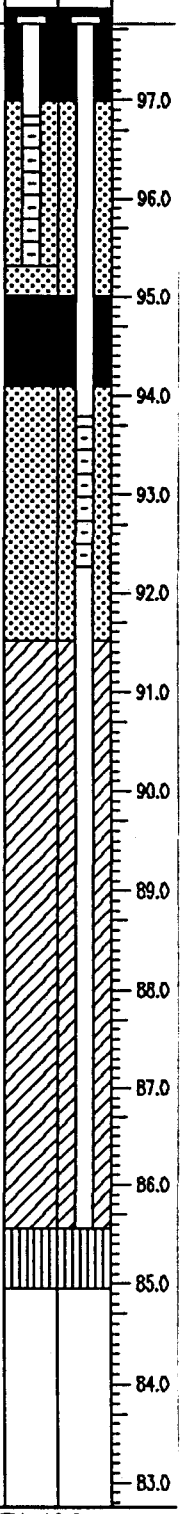
PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-20
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 97.75 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS
	GRAVEL – wet – little coarse to very coarse sand – trace silt – strong hydrocarbon odour		20-01	LEPH/H, Chlor, BTEX/VPH, PAH and Particle Size
				Particle Size
	SAND – moist, medium grained – with gravel (40 mm dia) – little silt – moderate hydrocarbon odour to 6.0 m			Particle Size
				Particle Size
	– slight hydrocarbon odour from 6.10 to 7.31 m		20-02	EPH
	GRAVEL – wet – maximum diameter 25 mm – with coarse to very coarse sand – little silt – slight hydrocarbon odour			
	SAND – wet – medium to coarse grained – little gravel (25 mm dia) – trace silt – slight hydrocarbon odour to 9.0 m – increasing hydrocarbon odour from 9.75 to 10.36 m – no hydrocarbon odour from 10.36 to 12.80 m			
	END OF TEST HOLE AT 12.80 m IN SAND			



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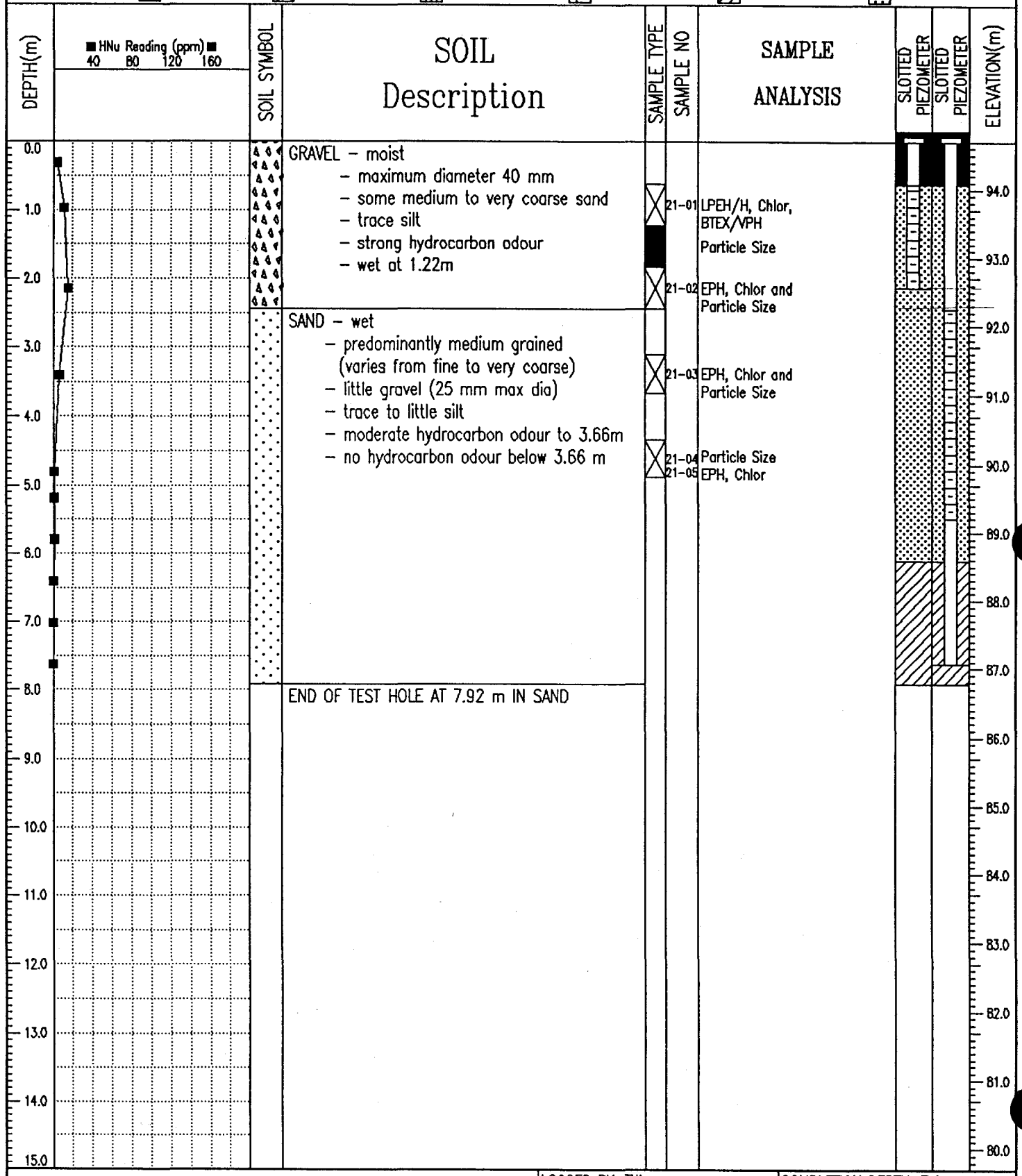
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REVIEWED BY: TW	COMPLETE: 96/07/19
Fig. No:	Page 1 of 1

96/12/02 11:32AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-21
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 94.69 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



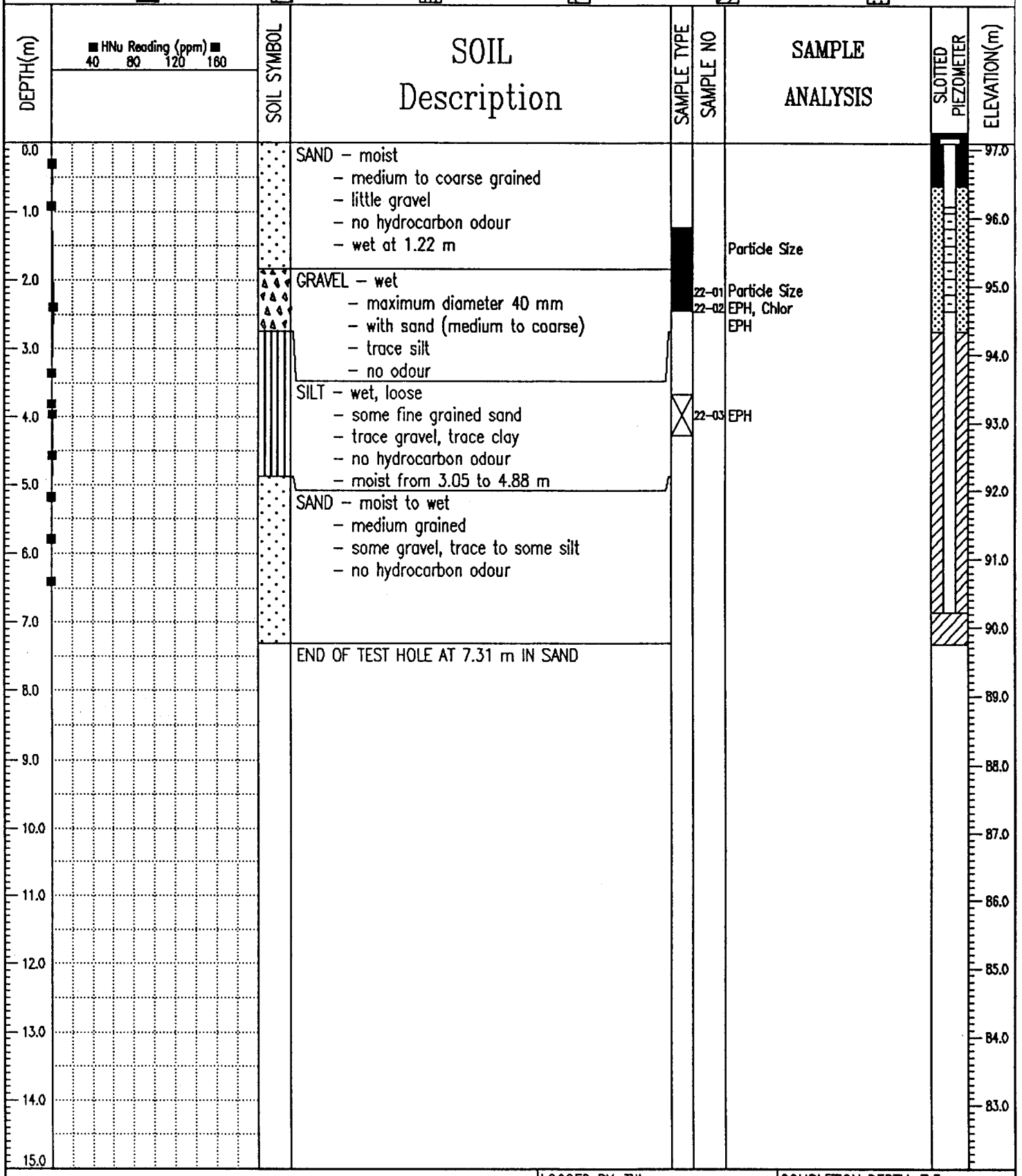
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 7.9 m
	REVIEWED BY: TW	COMPLETE: 96/07/20
	Fig. No:	Page 1 of 1

96/11/20 01:24PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-22
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 97.08 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 7.3 m
	REVIEWED BY: TW	COMPLETE: 96/07/20
	Fig. No:	Page 1 of 1

96/11/20 03:40PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-23
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 116.97 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 40 80 120 160	SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	SLOTTED PIEZOMETER	ELEVATION(m)
0.0			SILT – damp – little gravel (25 mm dia) – little sand, trace clay – no hydrocarbon odour					116.0
1.0			SAND – damp – medium to coarse grained – little gravel (20 mm dia) – little silt – no hydrocarbon odour					115.0
2.0			SILT – moist – little gravel, little sand – little clay – no hydrocarbon odour					114.0
3.0			SAND – damp – predominantly medium grained (varies from fine to very coarse) – little gravel (25 mm dia) – trace silt – no hydrocarbon odour					113.0
4.0								112.0
5.0								111.0
6.0								110.0
7.0					23-01	EPH		109.0
8.0								108.0
9.0								107.0
10.0								106.0
11.0								105.0
12.0								104.0
13.0								103.0
14.0								102.0
15.0								

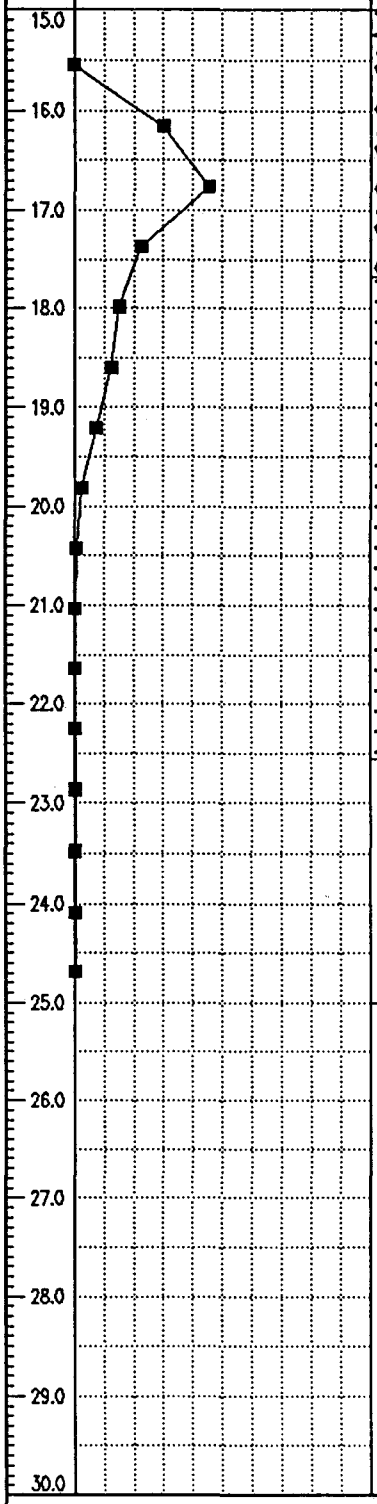
UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 25.0 m
	REVIEWED BY: TW	COMPLETE: 96/07/21
	Fig. No:	Page 1 of 2

96/11/14 03:20PM

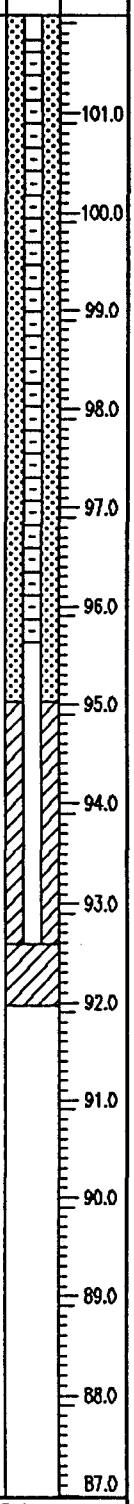
PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-23
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 116.97 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS
	– moist at 15.0 m			
	GRAVEL – moist – 20 mm diameter – some sand (medium to coarse) – trace silt – strong hydrocarbon odour from 15.84 to 17.68 m		23-02 23-03	EPH EPH, Particle Size EPH
	SAND – wet – fine to coarse grained – with gravel (25 mm) – little silt – moderate hydrocarbon odour from 17.68 to 19.51 m – sand size decreasing from fine to medium from 18.3 to 18.9 m – very wet at 19.51 m – no hydrocarbon odour from 19.51 to 21.34 m – some silt, little gravel – sand is fine grained		23-04 23-05	EPH Particle Size EPH EPH Particle Size
	SILT – moist – some gravel (25 mm dia) – trace sand – no hydrocarbon odour		23-06 23-07	EPH EPH
	END OF TEST HOLE AT 25.00 m IN SILT			



UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 25.0 m
	REVIEWED BY: TW	COMPLETE: 96/07/21
	Fig. No:	Page 2 of 2

96/11/14 03:20PM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-24
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.24 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 40 80 120 160	SOIL SYMBOL	SOIL Description	SAMPLE TYPE	SAMPLE NO	SAMPLE ANALYSIS	INSTRUMENTATION DATA	ELEVATION(m)
0.0			SAND – moist – predominantly medium grained (varies from fine to very coarse) – trace to some gravel (25 mm dia) – trace silt – no hydrocarbon odour		24-01	EPH		117.0
1.0								116.0
2.0								115.0
3.0								114.0
4.0								113.0
5.0								112.0
6.0								111.0
7.0					24-02	EPH		110.0
8.0								109.0
9.0								108.0
10.0			– slight hydrocarbon odour from 10.36 to 14.02 m					107.0
11.0								106.0
12.0								105.0
13.0								104.0
14.0			– no hydrocarbon odour from 14.02 to 15.85 m					103.0
15.0								

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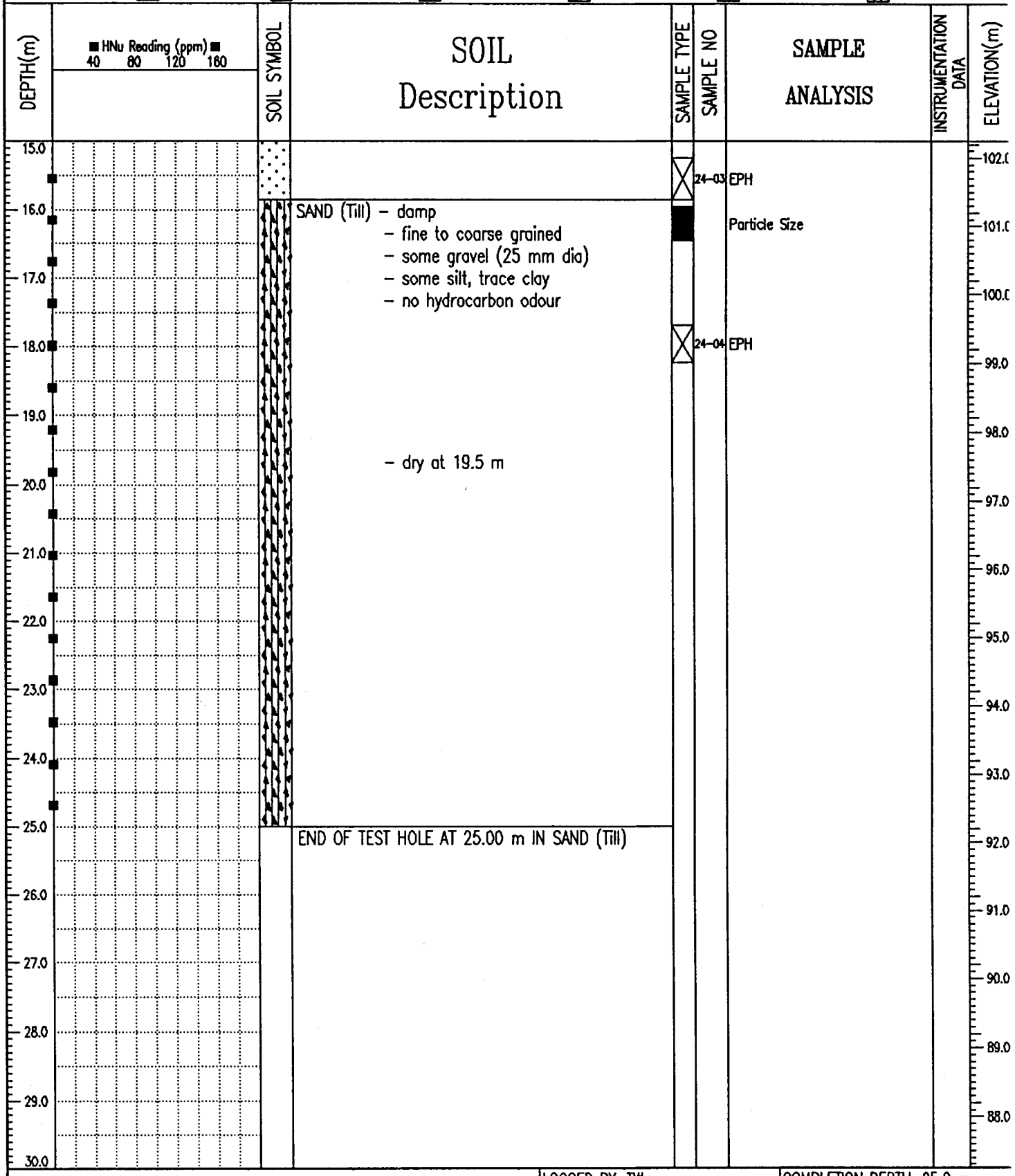
LOGGED BY: TW	COMPLETION DEPTH: 25.0 m
REVIEWED BY: TW	COMPLETE: 96/07/22
Fig. No:	Page 1 of 2

96/12/02 11:35AM

PROJECT: Rainy Hollow	DRILLED BY: Midnight Sun Drilling	TEST HOLE NO: MW96-24
CLIENT: DIAND	DRILLED USED: Schramm Odex System	PROJECT NO: C799-001-01-02
PROJECT ENGINEER: TW		ELEVATION: 117.24 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | SPLIT SPOON | WIRE LINE-TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND



UMA Environmental Winnipeg, Manitoba	LOGGED BY: TW	COMPLETION DEPTH: 25.0 m
	REVIEWED BY: TW	COMPLETE: 96/07/22
	Fig. No:	Page 2 of 2

96/12/02 11:35AM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–6
Testhole Co-ordinates: 12N , 233E	Location: SOUTHEAST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 115.95 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 60 120 180 240	SOIL SYMBOL	Soil Description	SAMPLE TYPE	SOIL SAMPLES (Site Code BL1)	INSTRUMENTATION DATA	ELEVATION(m)
0.0			SAND – predominantly medium grained (varies from fine to coarse) – some gravel (25mm dia) – trace silt – brown – no odour				115.95
1.0					–SS001 Field Screening SS004 Lab Inorganic Analysis SS005 Lab Organic Analysis		115.0
2.0			– grey at 2.4m		–SS002 Field Screening		114.0
3.0					–SS003 Field Screening		113.0
4.0							112.0
5.0							111.0
6.0							110.0
7.0							109.0
8.0							108.0
9.0							107.0
10.0							106.0
11.0							105.0
12.0							104.0
13.0							103.0
14.0							102.0
15.0							101.0

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LOGGED BY: TW	COMPLETION DEPTH: 23.2 m
REVIEWED BY: TW	COMPLETE: 95/07/12
Fig. No:	Page 1 of 2

96/11/14 02:49PM

Project: HAINES–FAIRBANKS PIPELINE ESA	Client: DIAND	TEST HOLE NO: TH–6
Testhole Co–ordinates: 12N , 233E	Location: SOUTHEAST OF DDT STORAGE	PROJECT NO: 4440–034–00–02
Location: BORDER STATION	Drill Type: ROTARY CASING HAMMER	ELEVATION: 115.95 (m)

SAMPLE TYPE: GRAB SAMPLE | SHELBY TUBE | LAB SUBMITTED | NO RECOVERY | CORE BARREL | WIRE LINE–TYPE

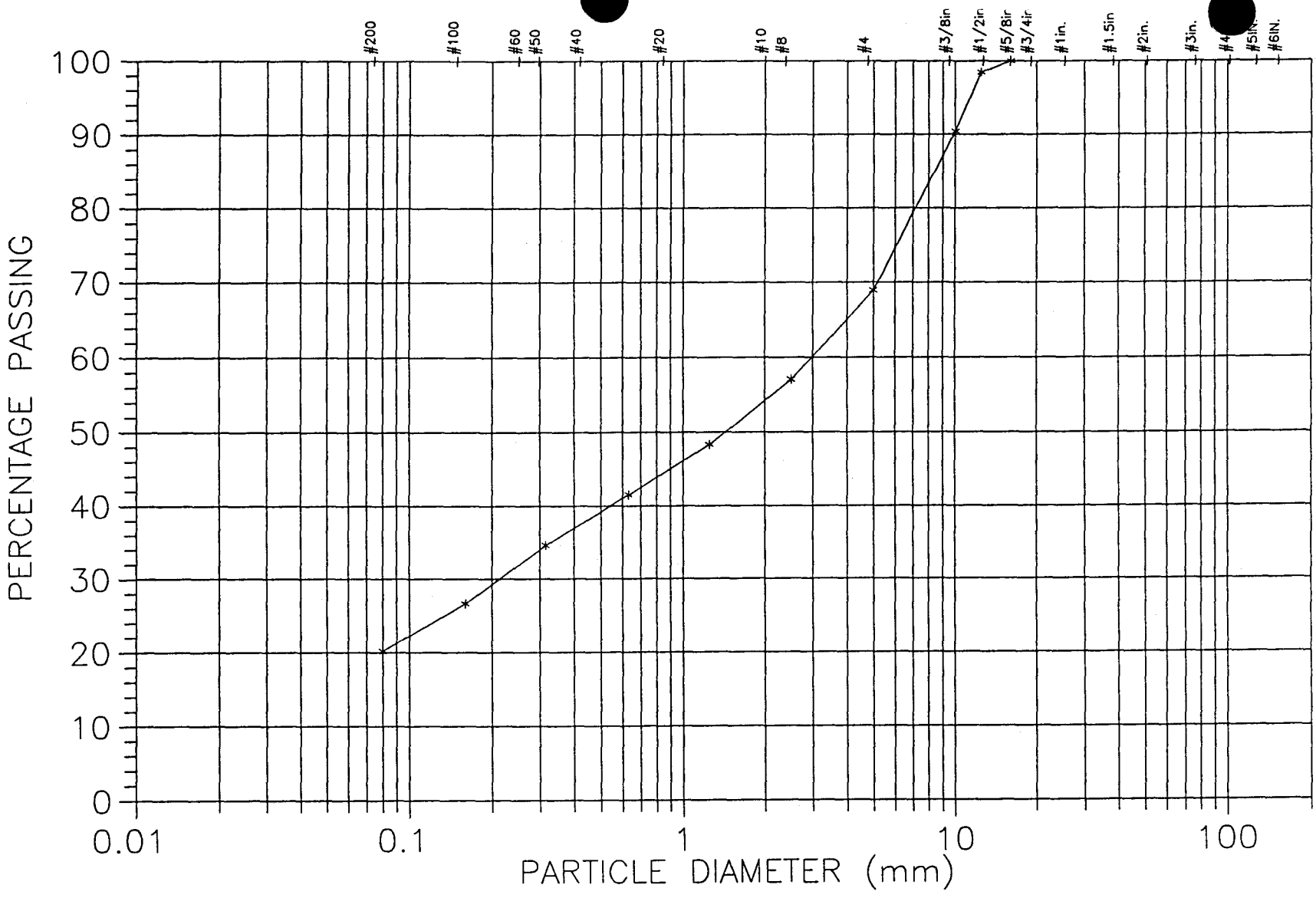
BACKFILL TYPE: BENTONITE | PEA GRAVEL | SLOUGH | GROUT | DRILL CUTTINGS | SAND

DEPTH(m)	HNu Reading (ppm) 60 120 180 240	SOIL SYMBOL	Soil Description	SAMPLE TYPE	SOIL SAMPLES (Site Code BL1)	INSTRUMENTATION DATA	ELEVATION(m)
15.0							
16.0			SILT (Till) – with fine sand – trace clay – grey – dry to damp with depth – occasional stones				100.0
17.0							99.0
18.0			SAND – fine to medium grained – some silt – little gravel – grey – dry				98.0
19.0							97.0
20.0			SILT (Till) – with fine sand – dense – occasional stones – dry				96.0
21.0							95.0
22.0							94.0
23.0							93.0
24.0			END OF TESTHOLE AT 23.14 m IN SILT (Till)				92.0
25.0							91.0
26.0							90.0
27.0							89.0
28.0							88.0
29.0							87.0
30.0							86.0

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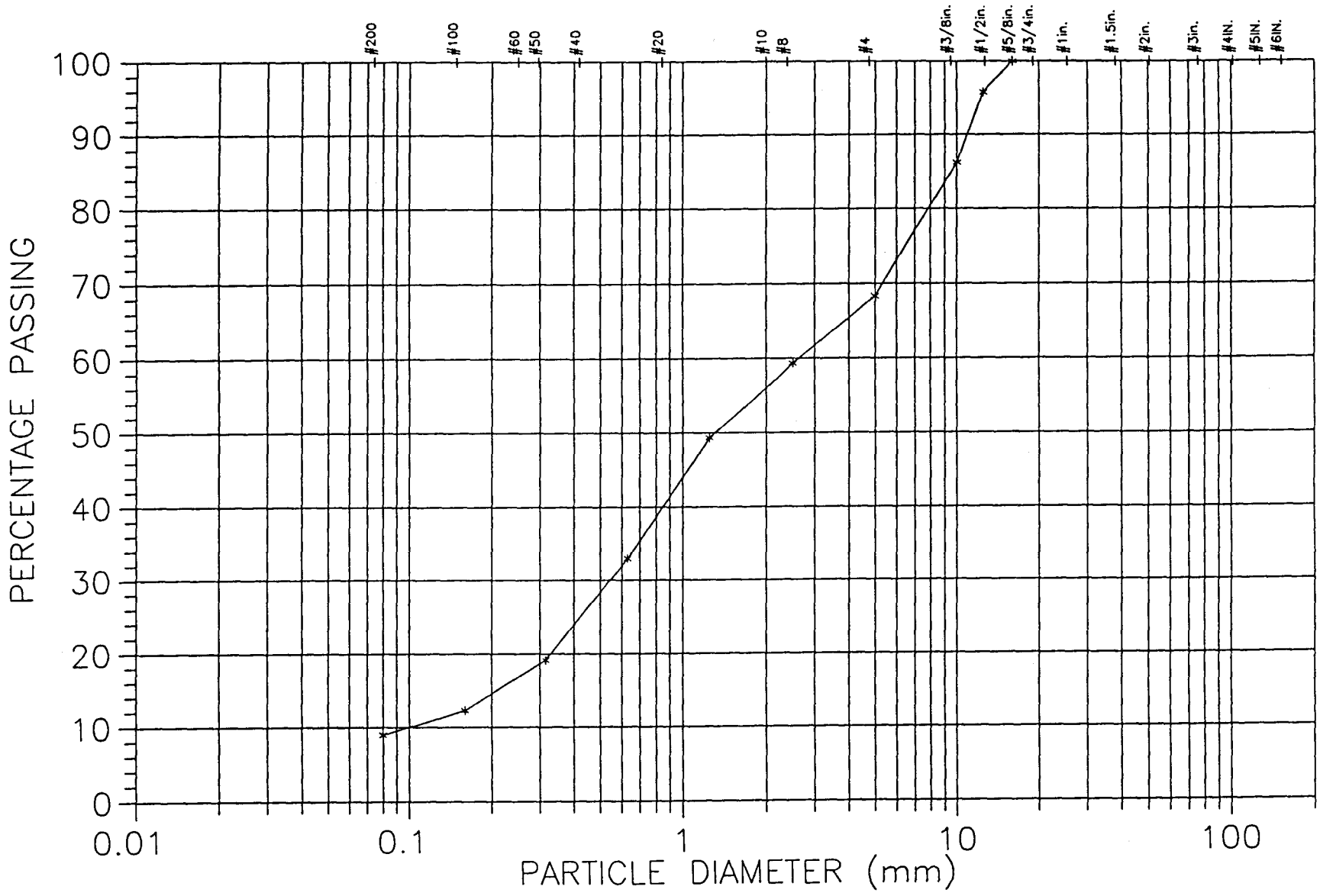
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REVIEWED BY: TW	COMPLETE: 95/07/12
Fig. No:	Page 2 of 2

96/11/14 02:50PM



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 47.3 % SAND 32.5 % SILT & CLAY 20.2 %	TEST HOLE: MW 96-10 DEPTH (m): 17.07 - 17.68	



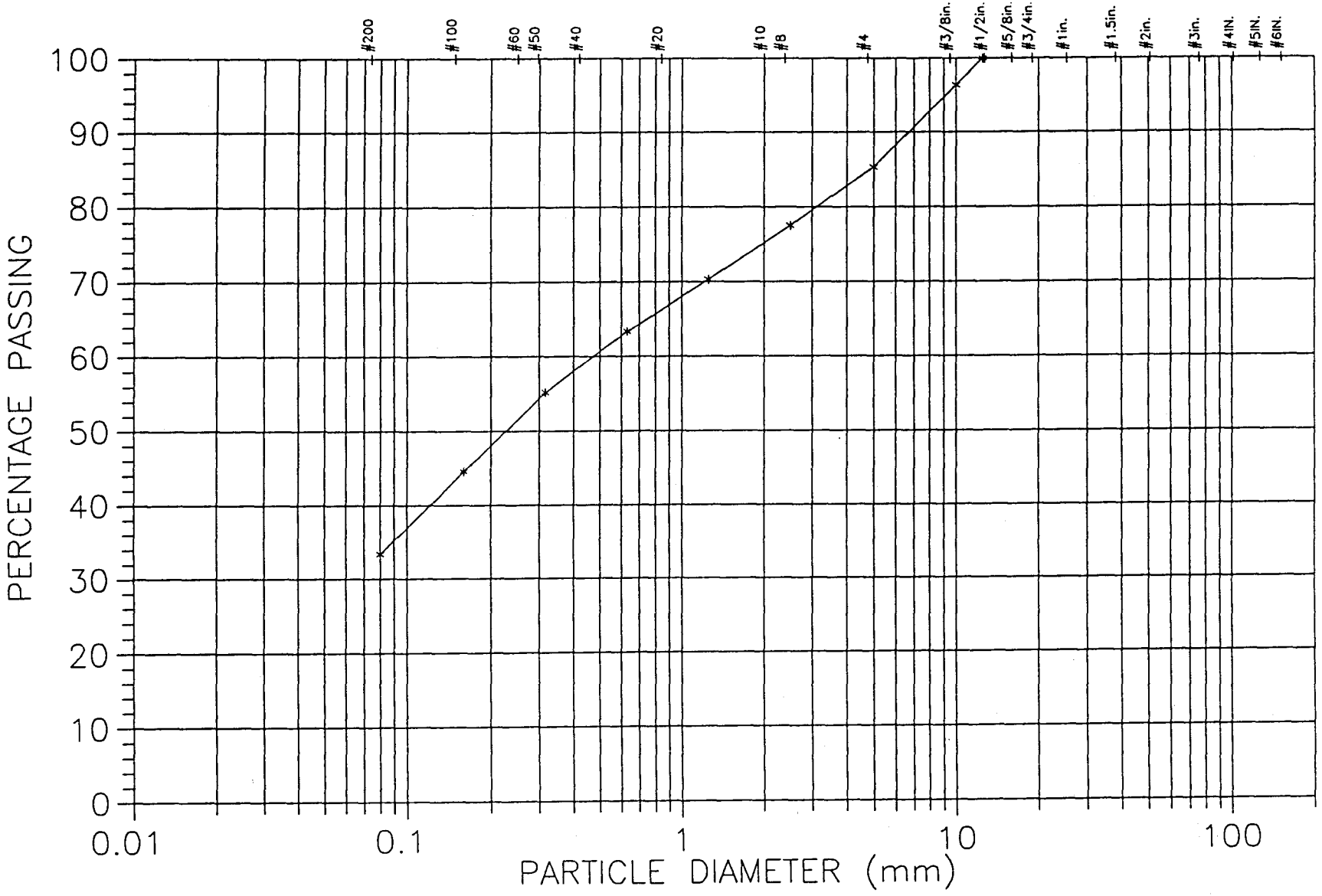
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	45.7 %	
SAND	45.3 %	
SILT & CLAY	9.0 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

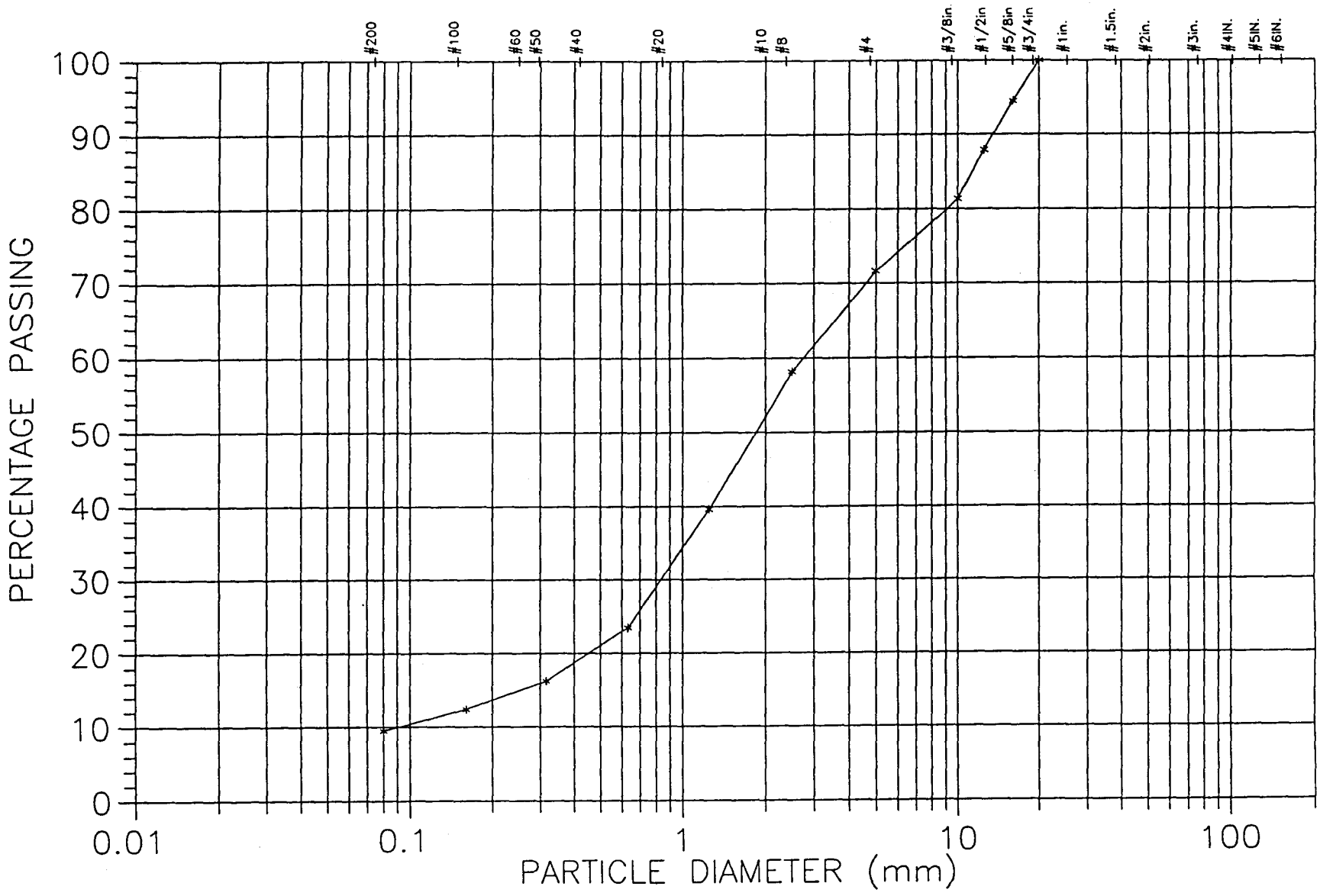
TEST HOLE: MW 96-11B
DEPTH (m): 18.90 - 19.51

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



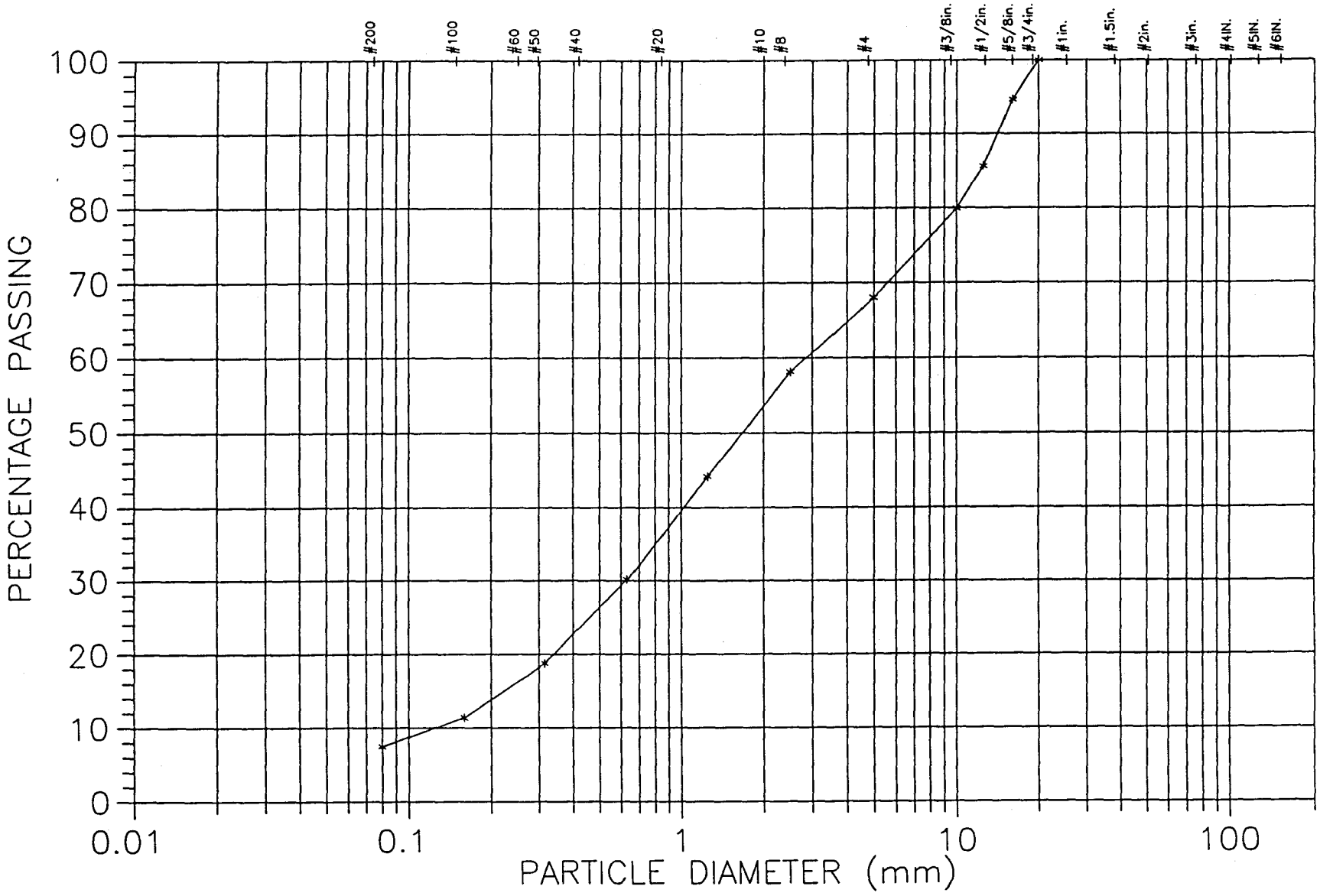
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 26.1 % SAND 40.5 % SILT & CLAY 33.4 %	***** SIEVE ANALYSIS ***** TEST HOLE: MW 96-11B DEPTH (m): 23.16 - 23.77	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



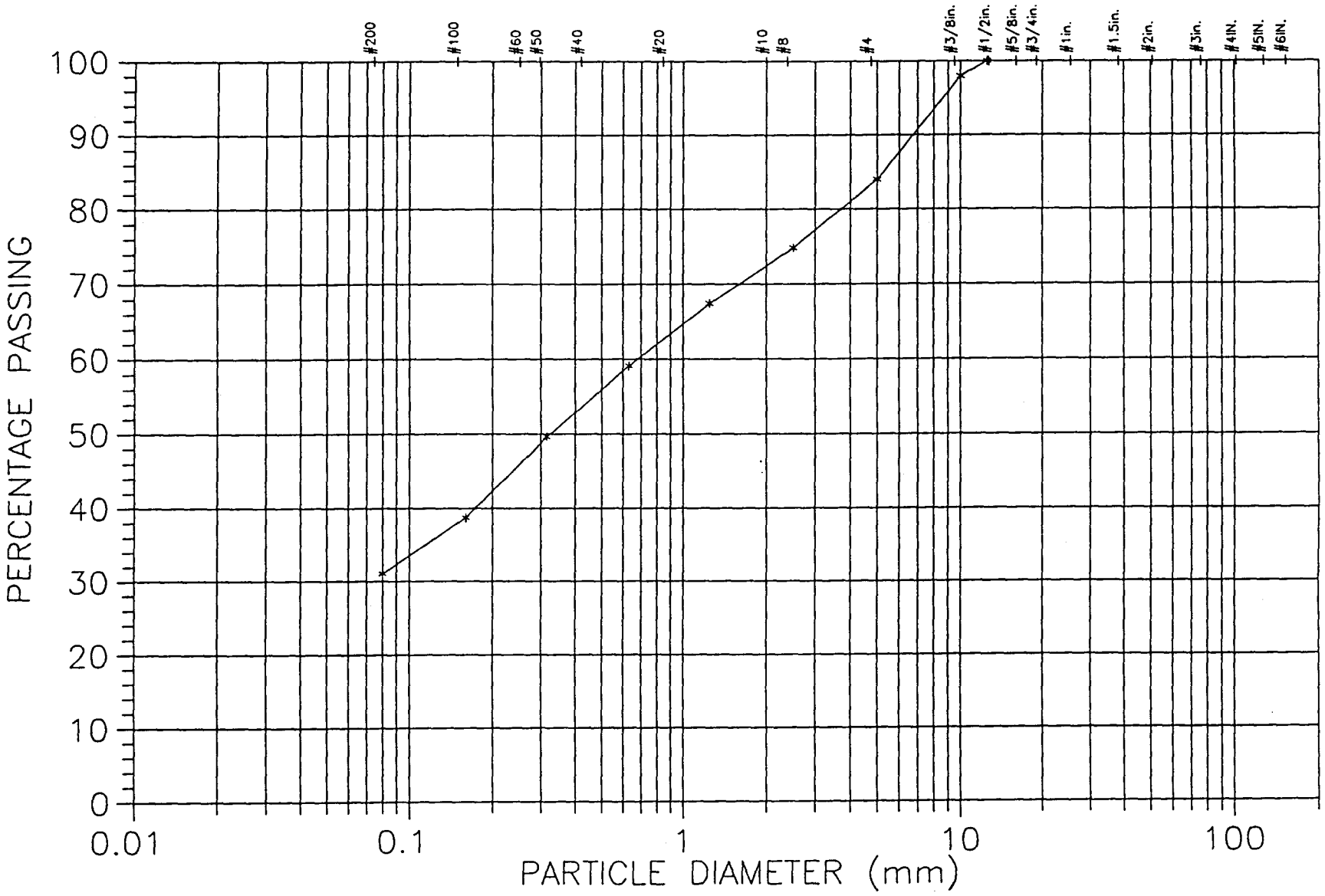
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 51.1 % SAND 39.4 % SILT & CLAY 9.5 %	TEST HOLE: MW 96-12 DEPTH (m): 6.10 - 6.71	



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 48.9 % SAND 43.6 % SILT & CLAY 7.5 %	***** SIEVE ANALYSIS ***** TEST HOLE: MW 96-13 DEPTH (m): 2.44 - 3.05	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



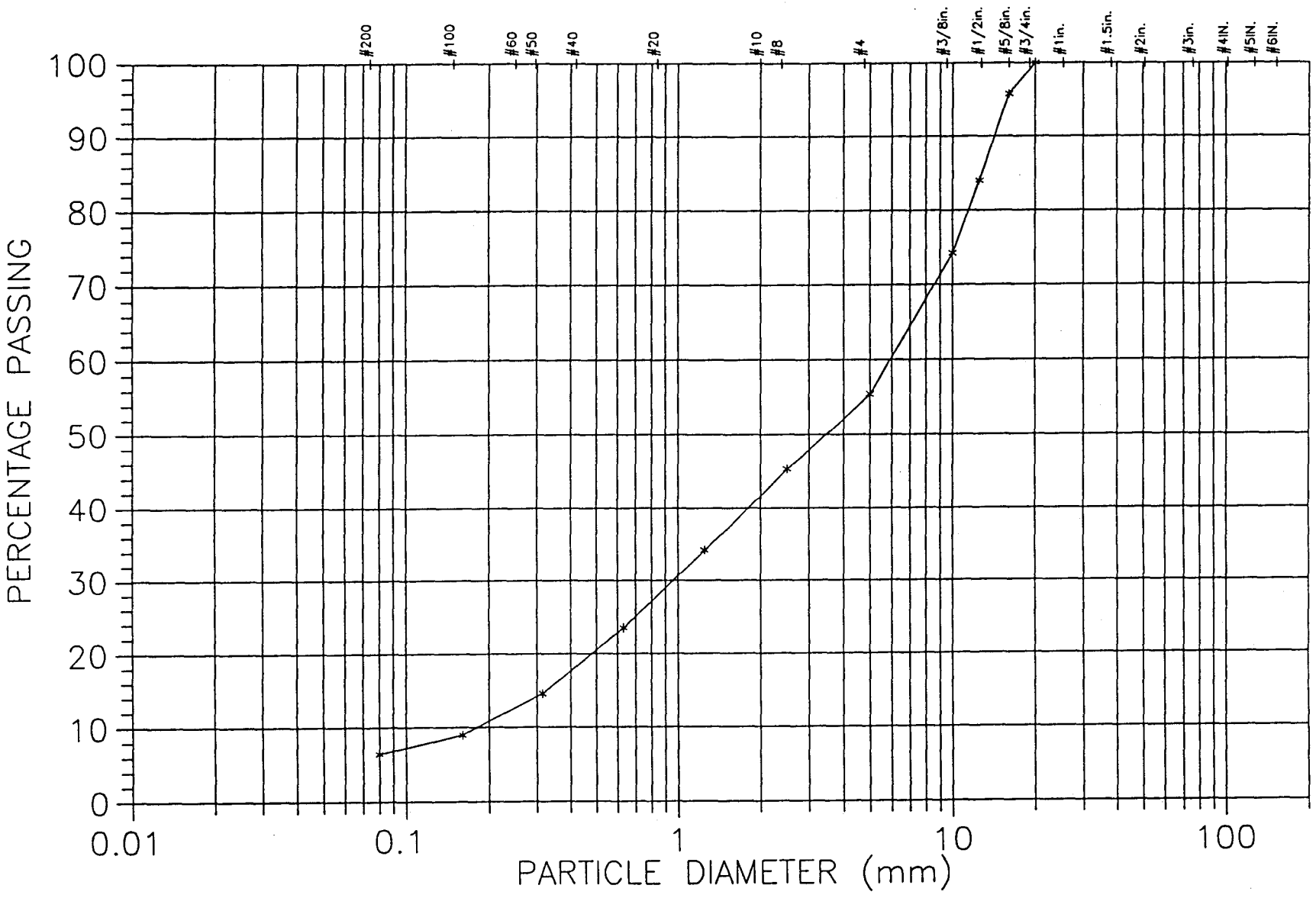
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	28.9 %	
SAND	40.0 %	
SILT & CLAY	31.1 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

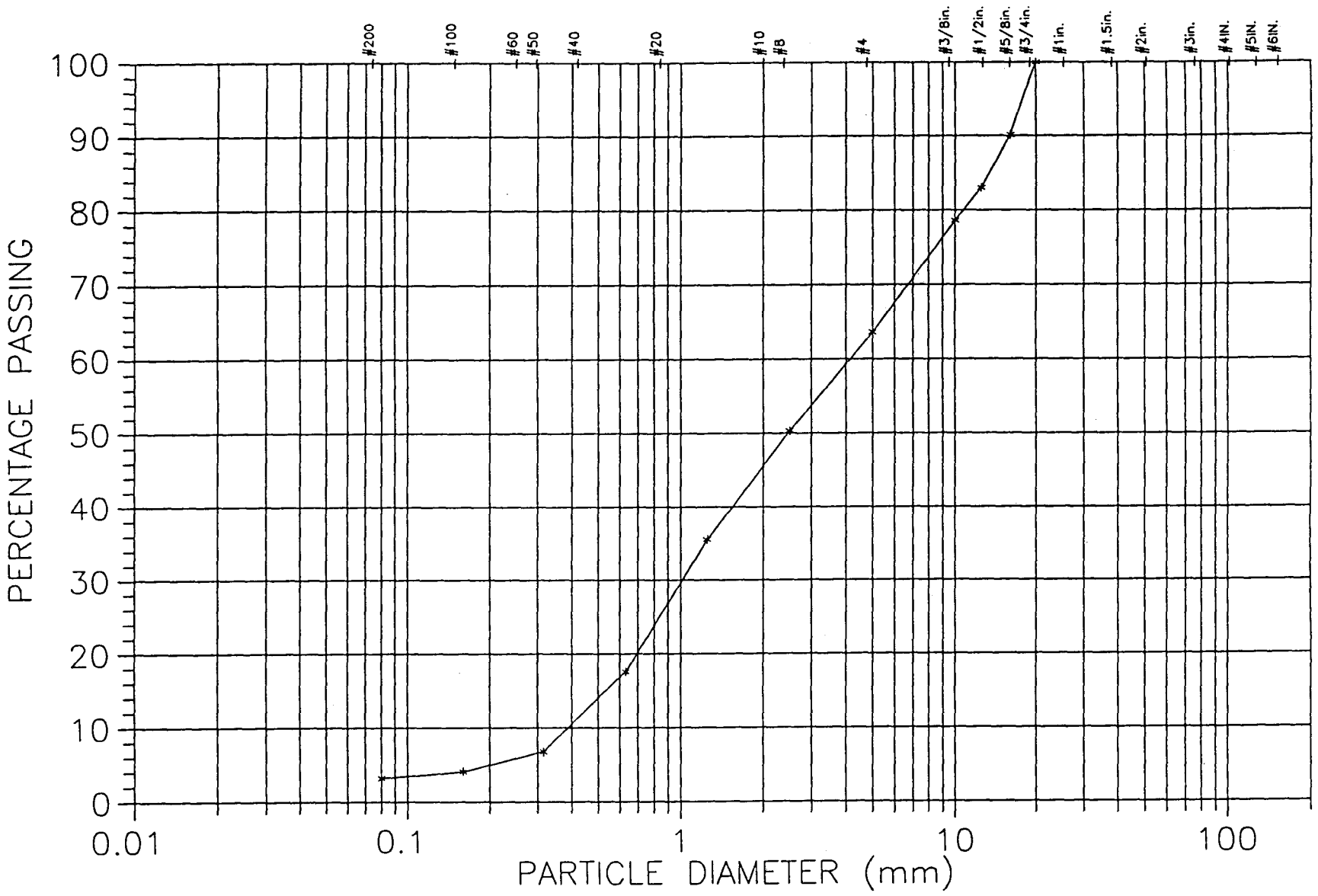
TEST HOLE: MW 96-16
DEPTH (m): 25.60 - 26.21

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



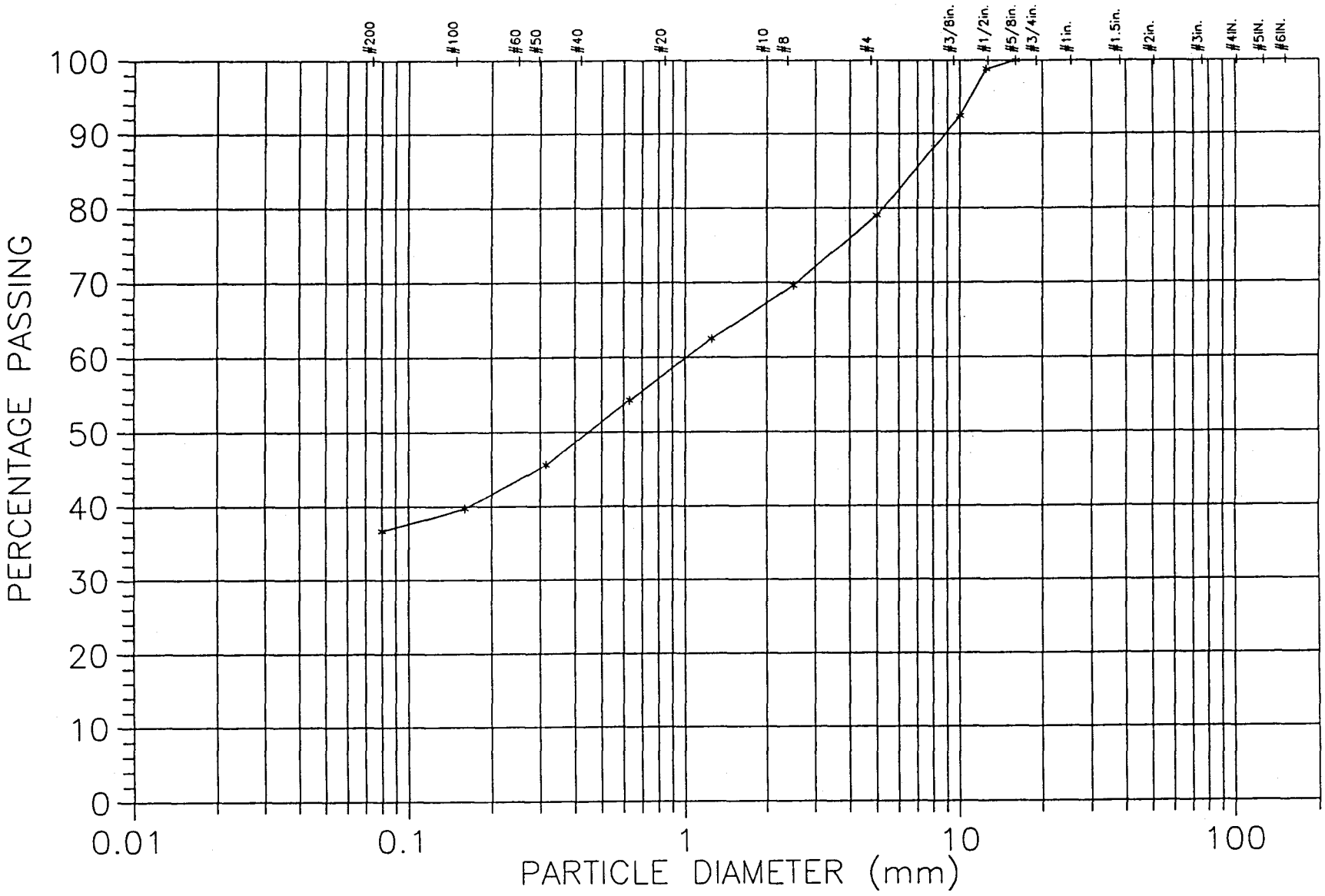
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 58.5 % SAND 35.0 % SILT & CLAY 6.5 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-16 DEPTH (m): 17.68 - 18.29	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



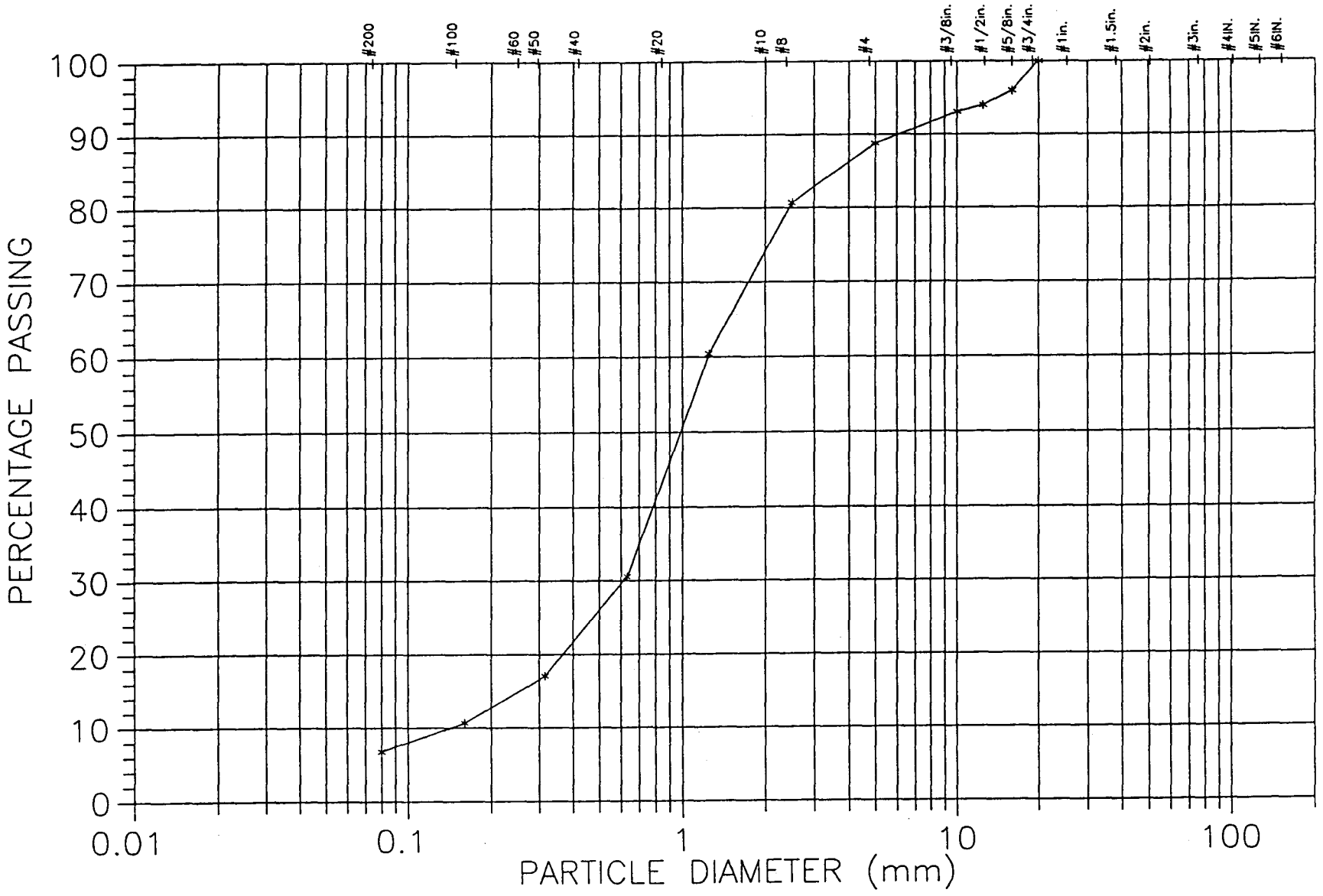
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 54.1 % SAND 42.7 % SILT & CLAY 3.2 %	TEST HOLE: 96-16 DEPTH (m): 19.51 - 20.73	



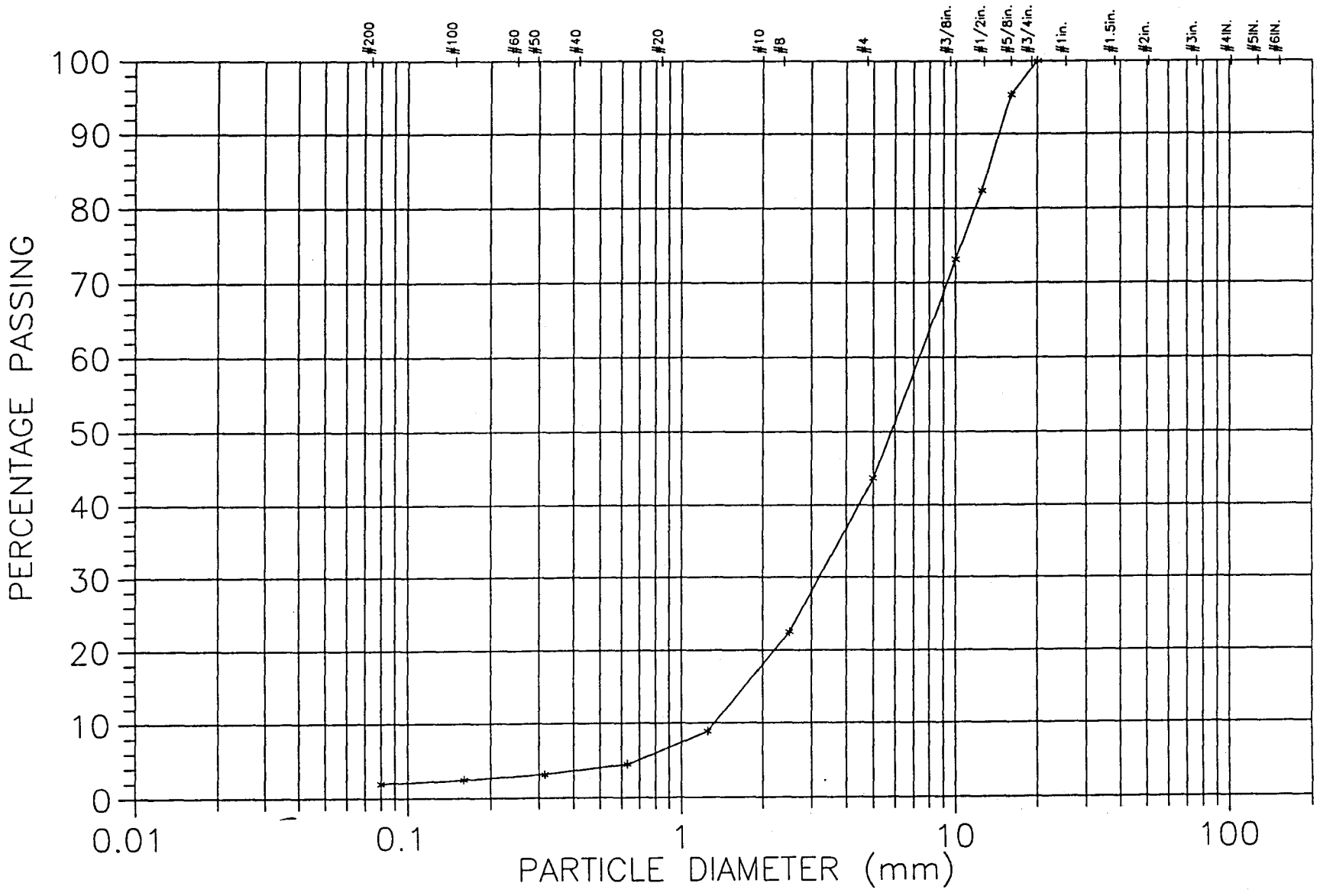
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 32.6 % SAND 30.7 % SILT & CLAY 36.7 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-16 DEPTH (m): 21.34 - 21.95	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



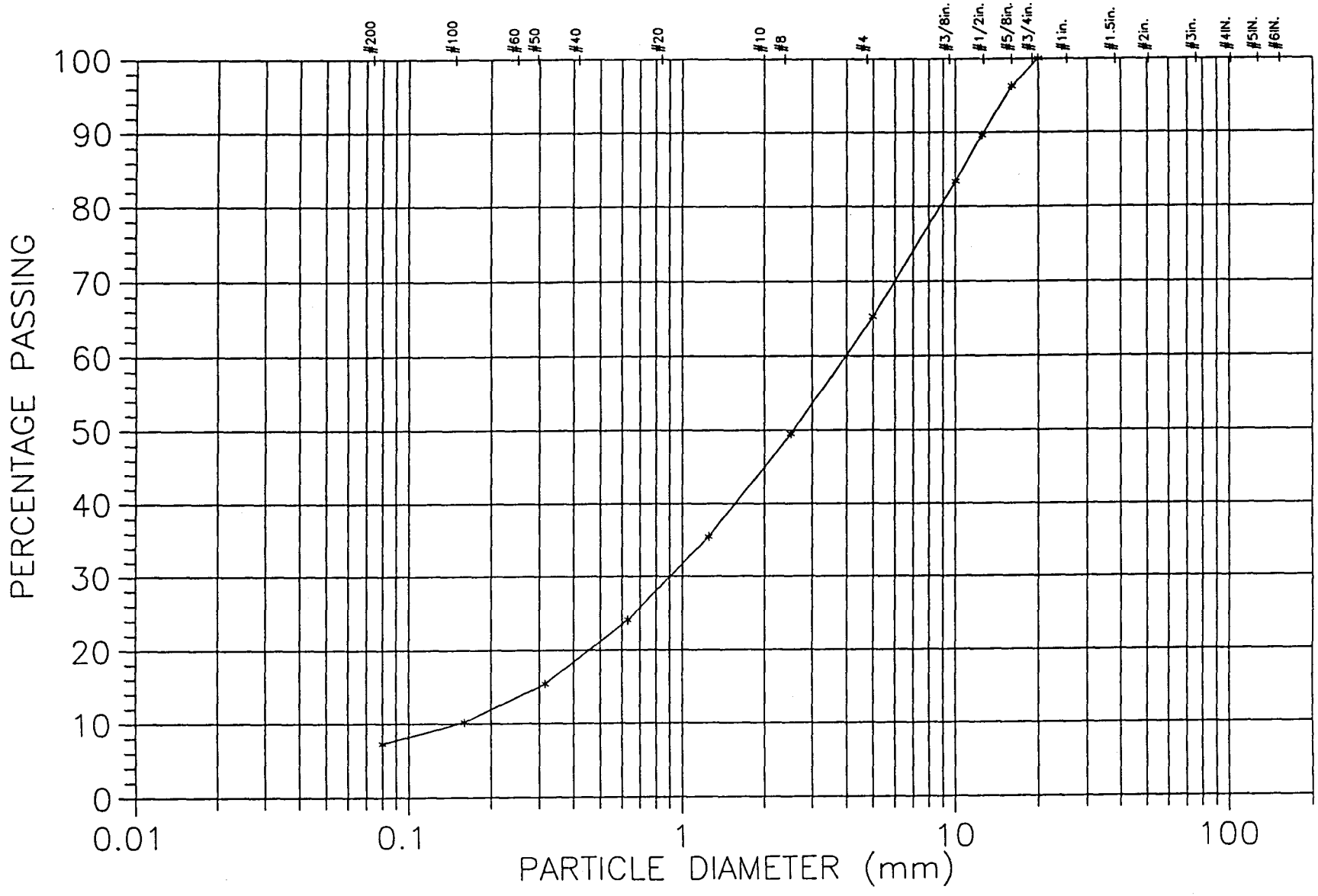
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 25.8 % SAND 67.4 % SILT & CLAY 6.8 %	TEST HOLE: 96-17 DEPTH (m): 4.88 - 5.49	



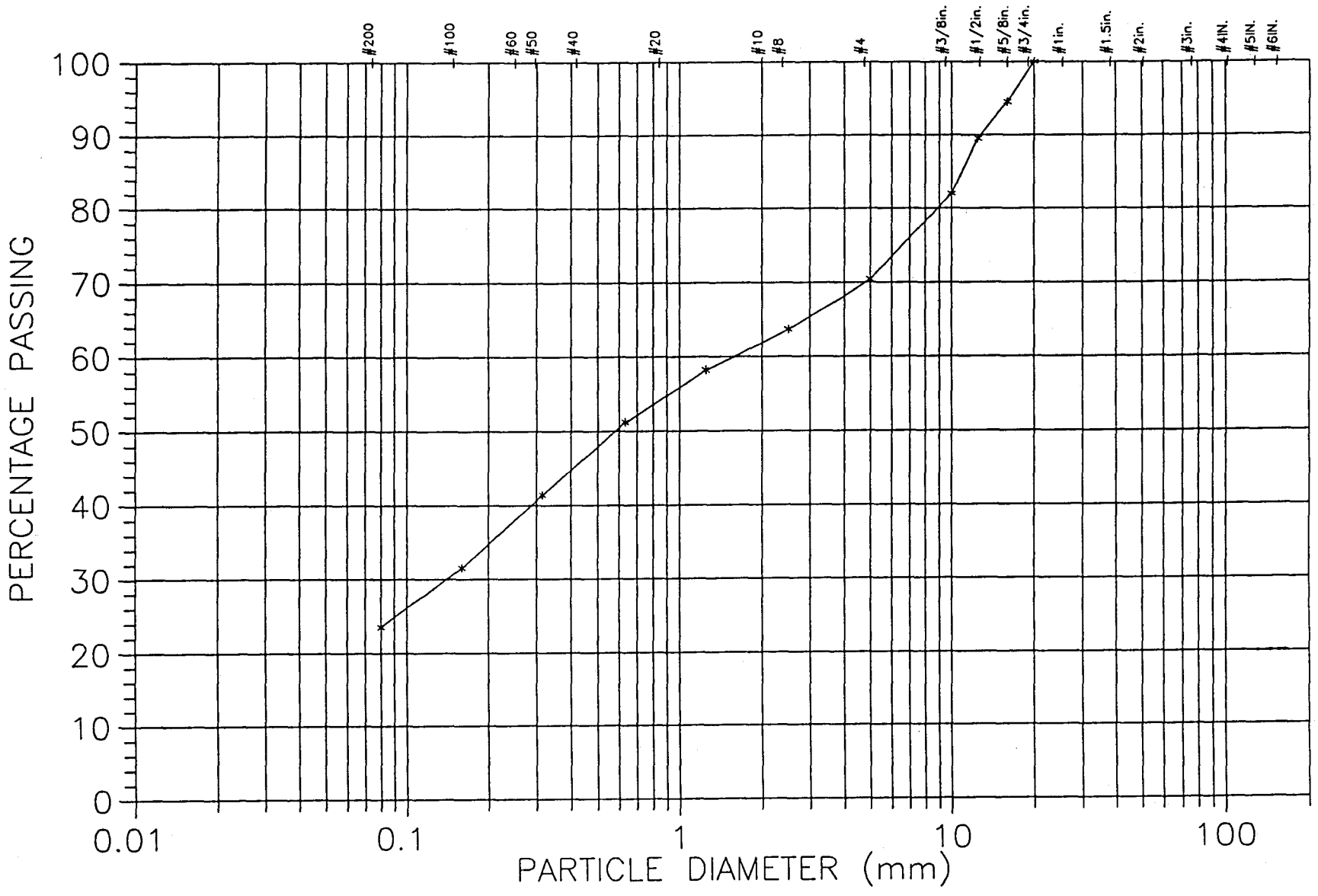
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 82.2 % SAND 15.8 % SILT & CLAY 2.0 %	TEST HOLE: 96-17 DEPTH (m): 7.92 - 8.53	



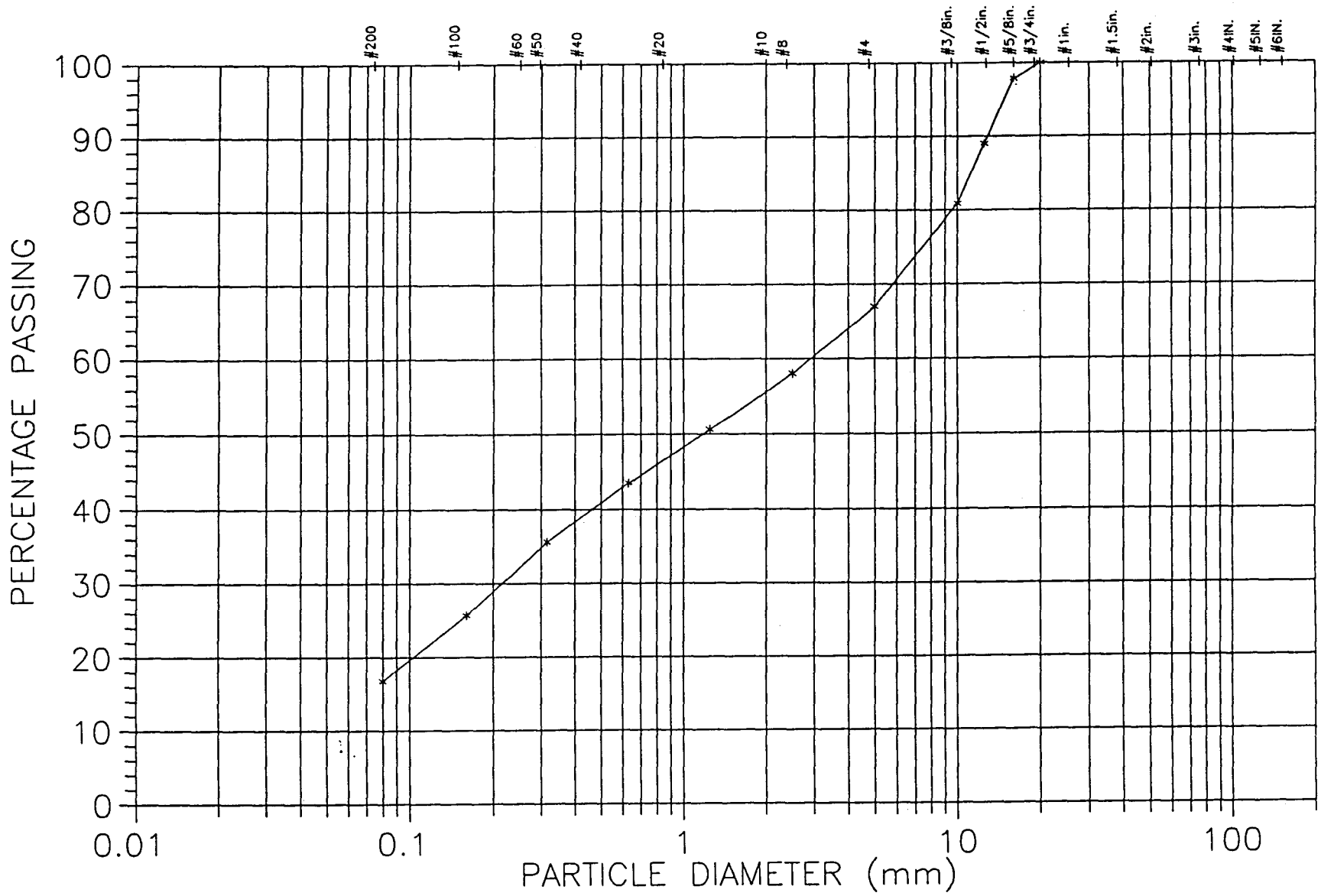
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 55.0 % SAND 37.7 % SILT & CLAY 7.3 %	TEST HOLE: 96-17 DEPTH (m): 9.75 - 10.36	



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 38.2 % SAND 38.2 % SILT & CLAY 23.6 %	TEST HOLE: 96-17 DEPTH (m): 11.58 - 12.19	



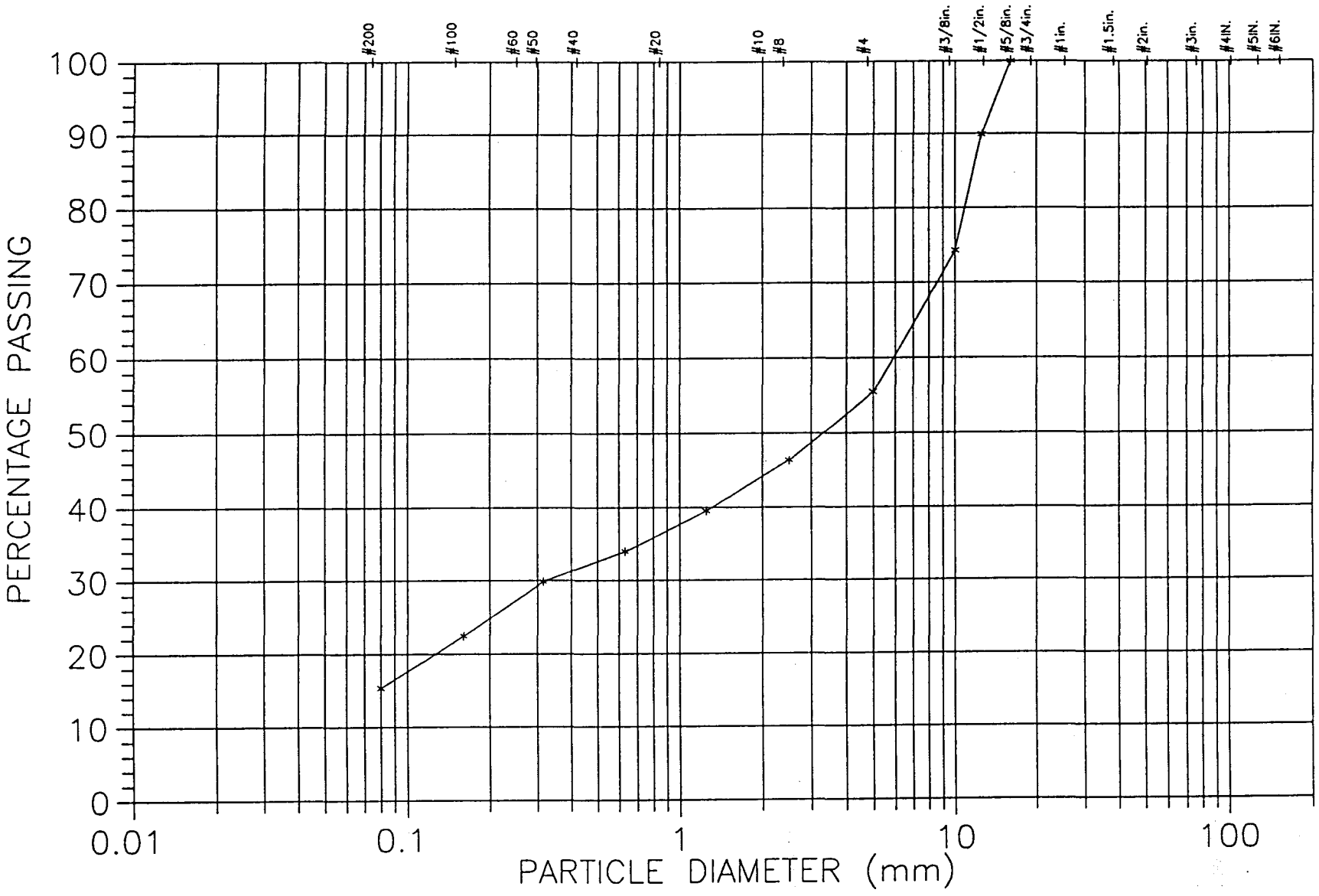
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	44.5 %	
SAND	38.6 %	
SILT & CLAY	16.8 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

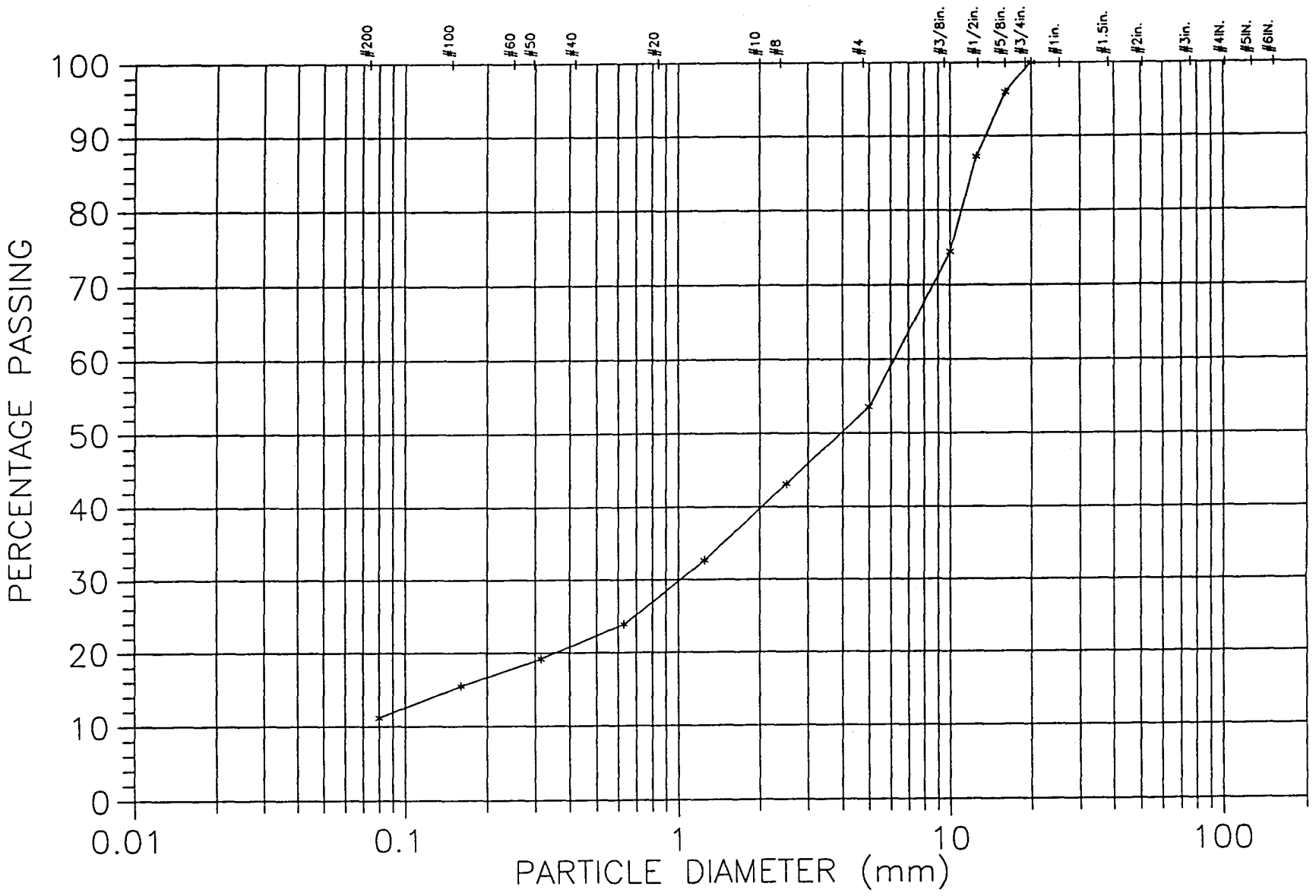
TEST HOLE: 96-18
DEPTH (m): 2.44 - 3.05

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 57.8 % SAND 26.8 % SILT & CLAY 15.4 %	TEST HOLE: 96-18 DEPTH (m): 4.88 - 5.49	



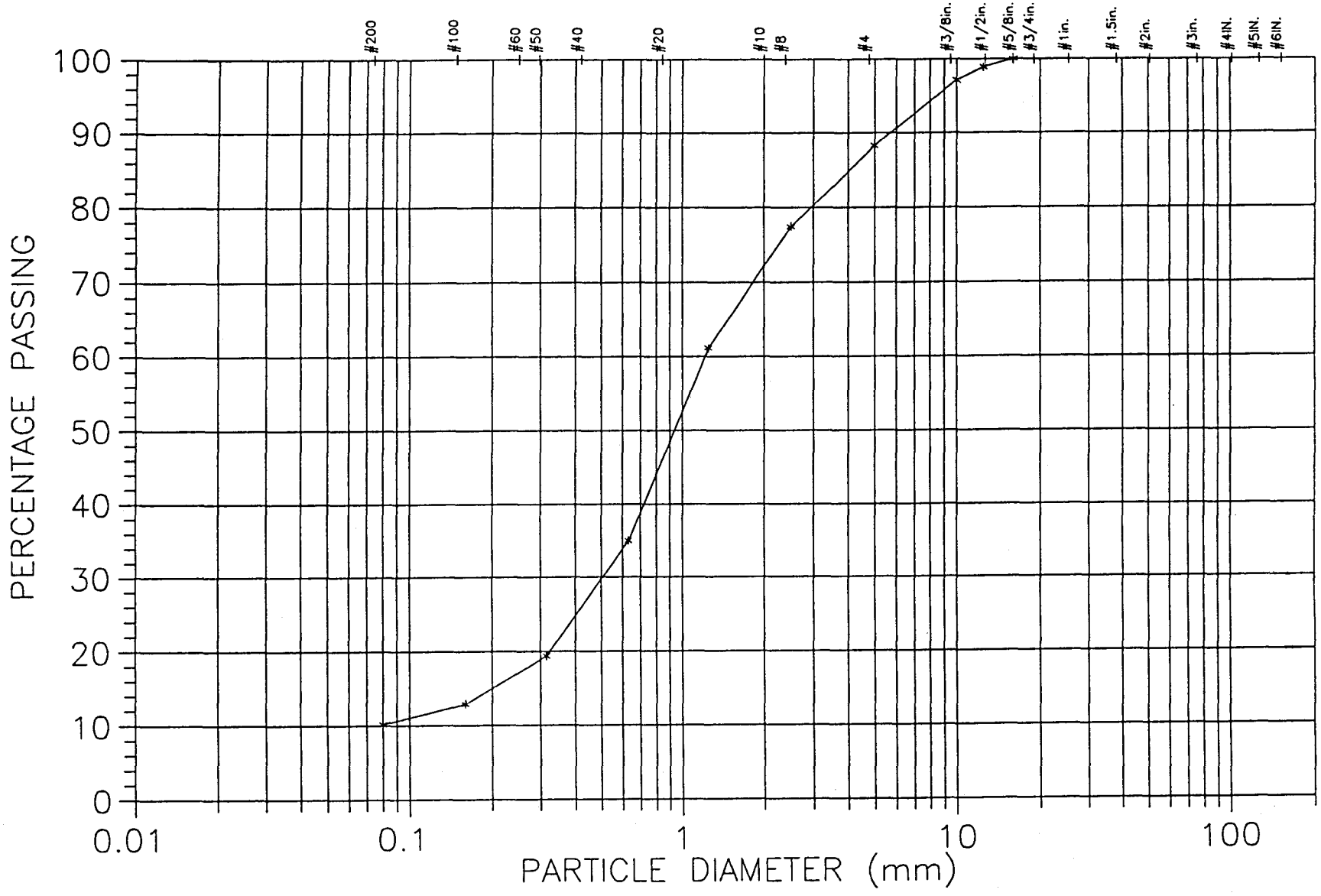
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	60.0 %	
SAND	28.8 %	
SILT & CLAY	11.2 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

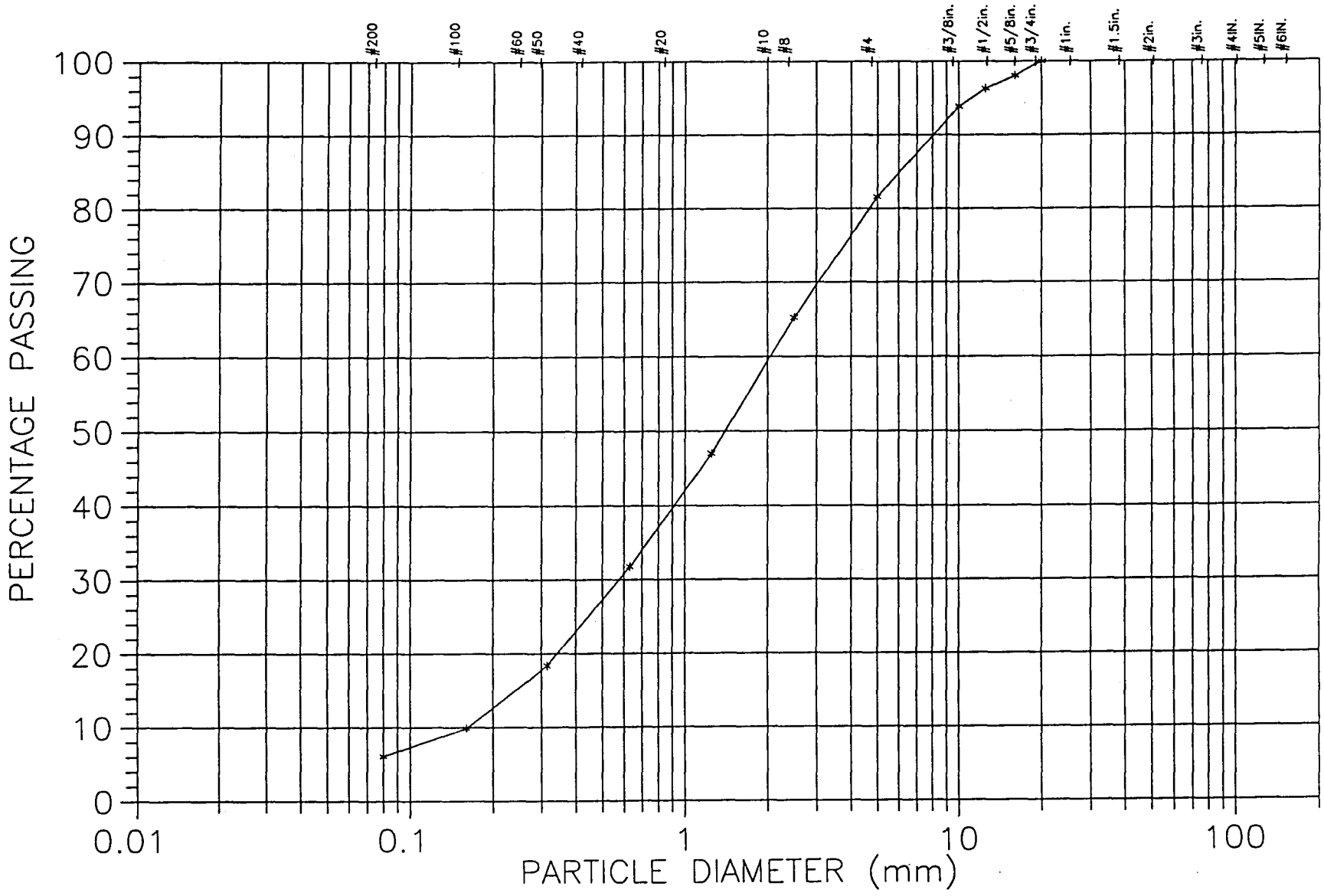
TEST HOLE: 96-18
DEPTH (m): 6.10 - 6.71

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



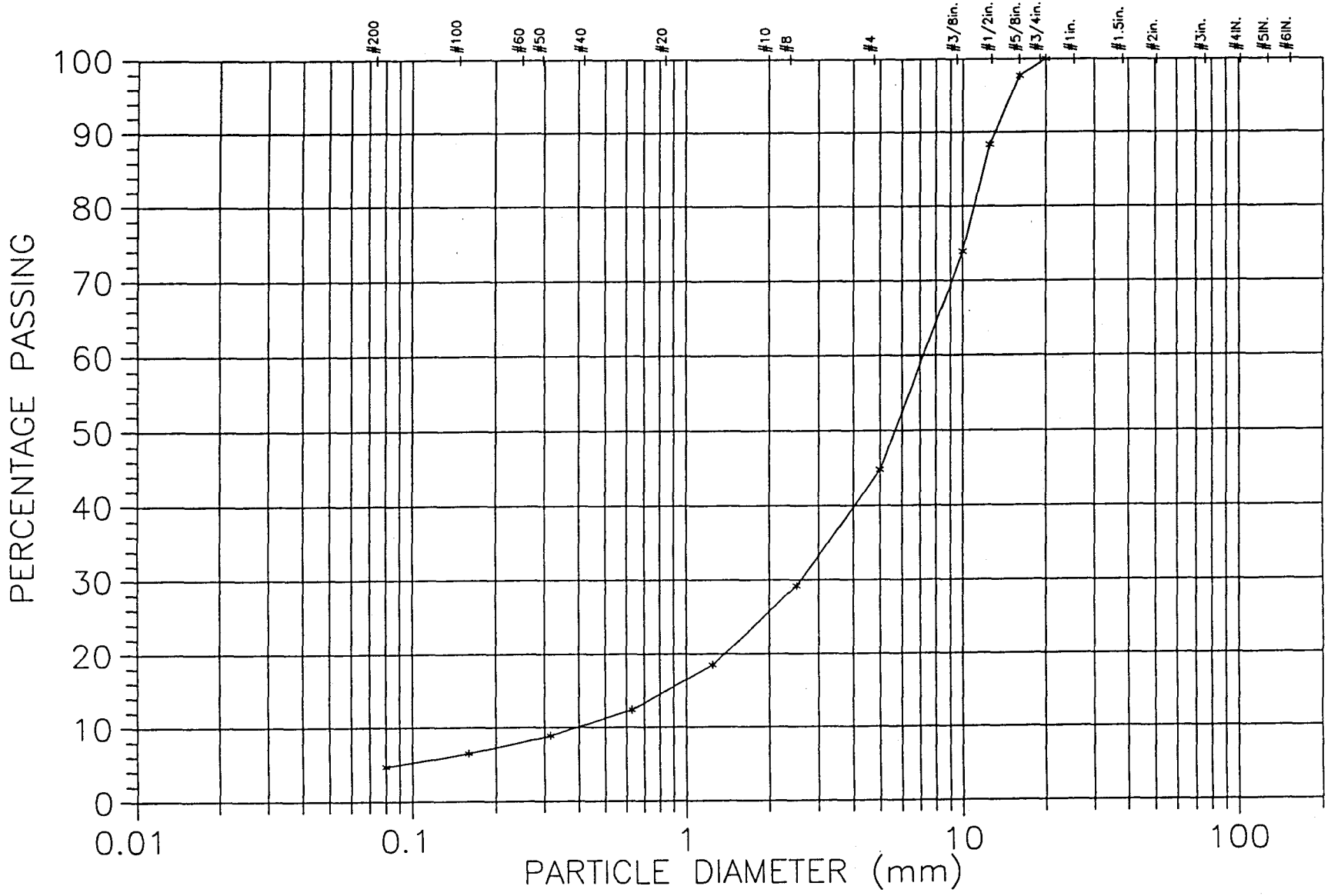
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 28.0 % SAND 61.8 % SILT & CLAY 10.2 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-18 DEPTH (m): 7.92 - 8.53	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



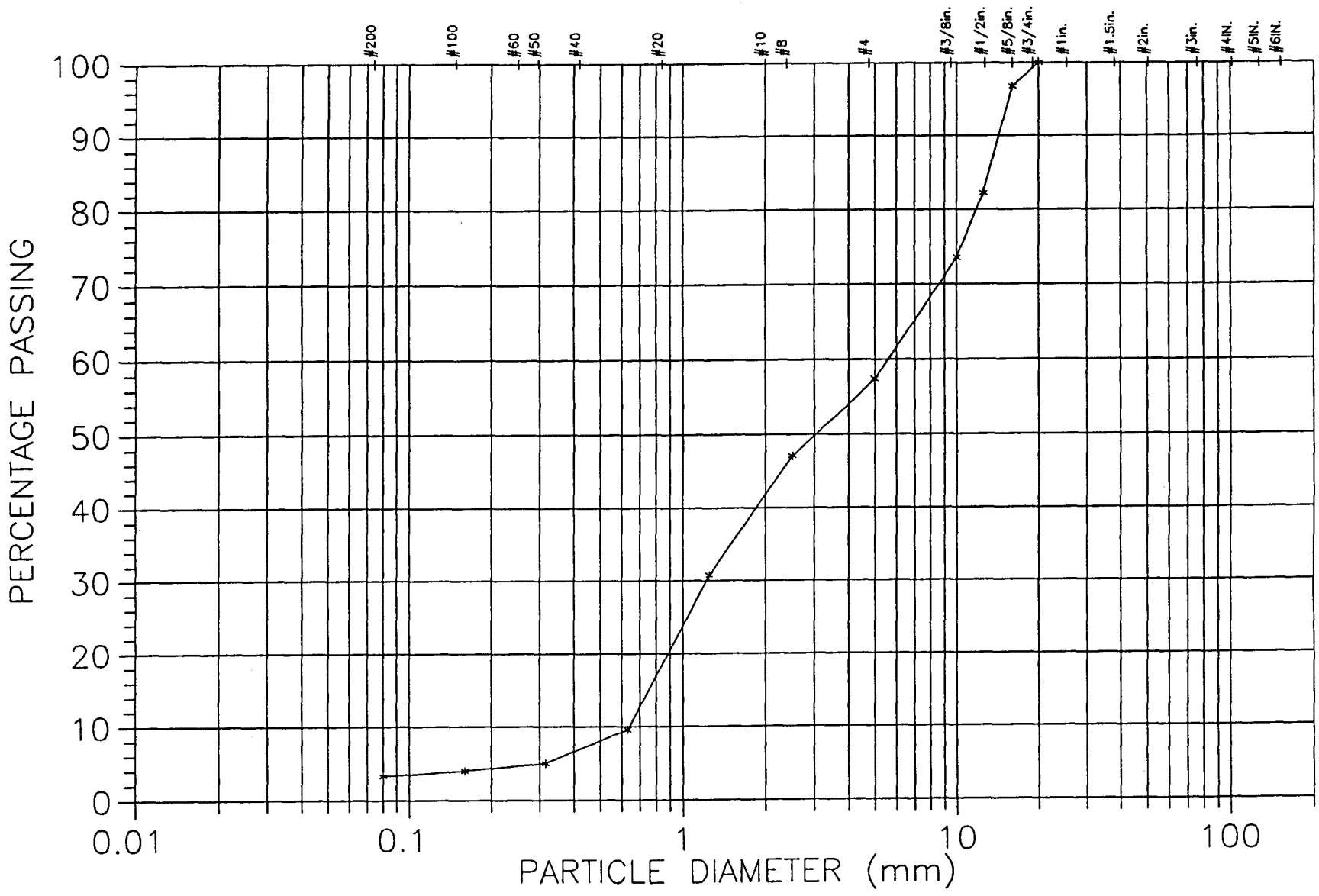
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 40.2 % SAND 53.7 % SILT & CLAY 6.1 %	TEST HOLE: 96-19 DEPTH (m): 1.22 - 1.83	



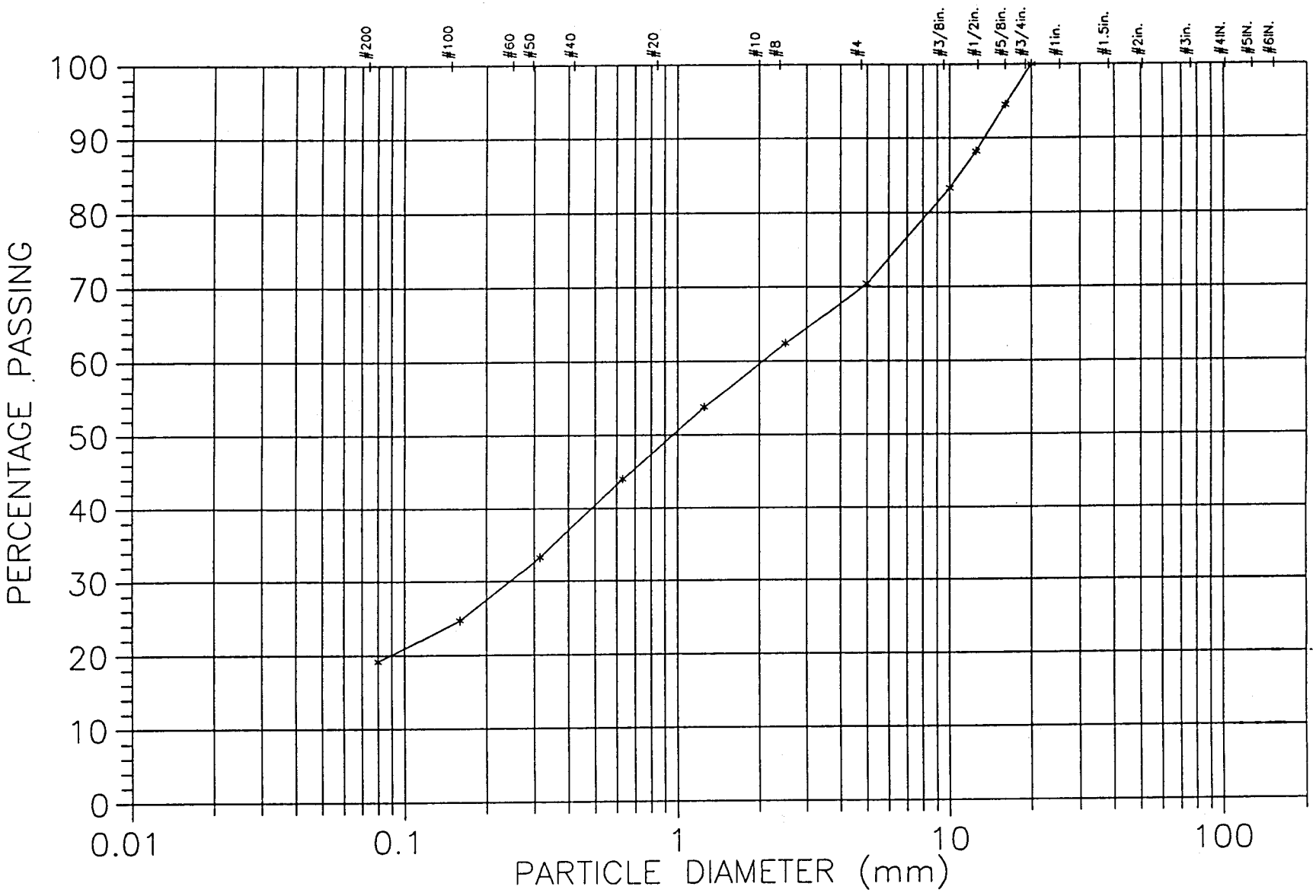
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 74.3 % SAND 21.0 % SILT & CLAY 4.7 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-19 DEPTH (m): 2.44 - 3.05	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



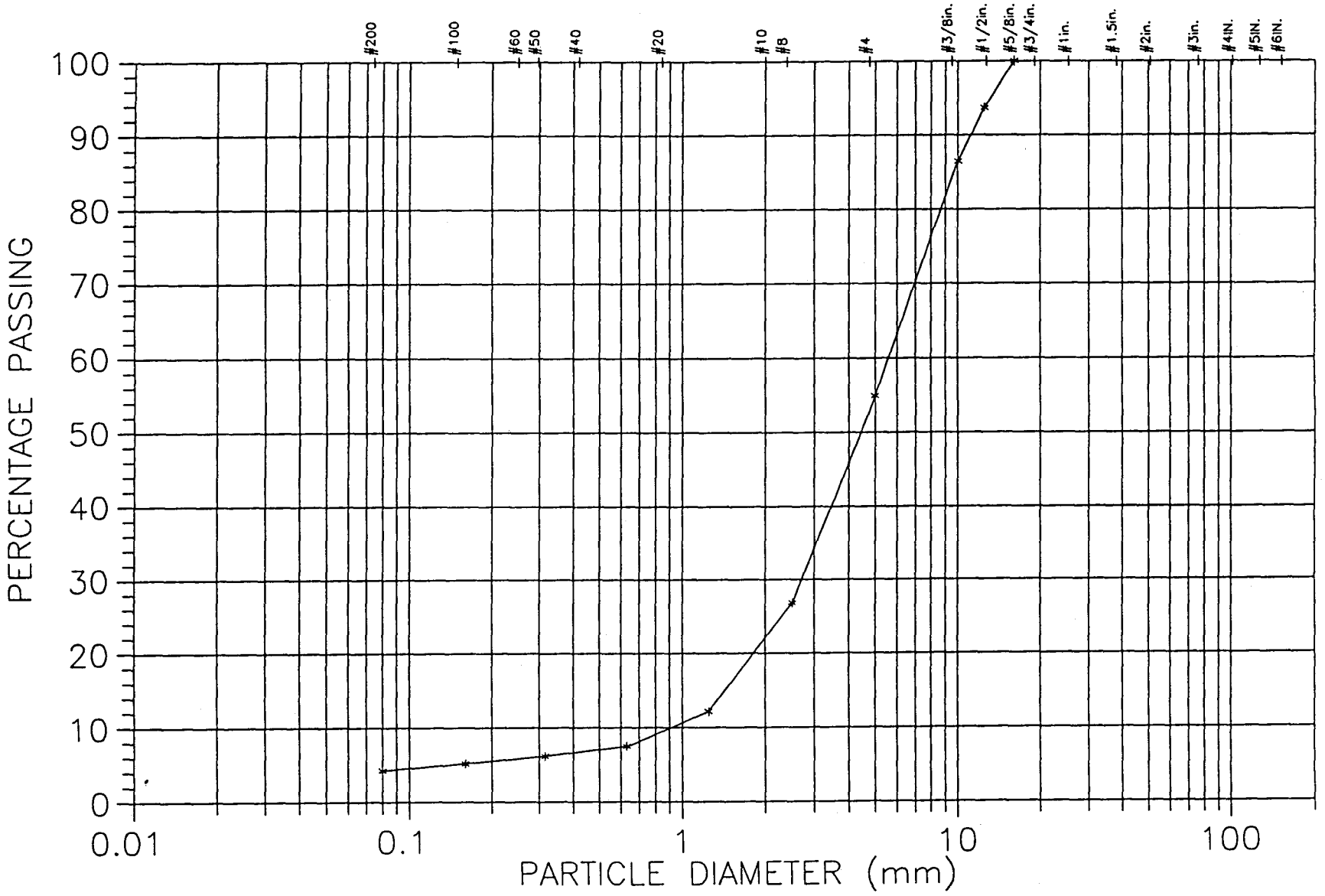
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 58.1 % SAND 38.6 % SILT & CLAY 3.3 %	TEST HOLE: 96-19 DEPTH (m): 3.66 - 4.27	



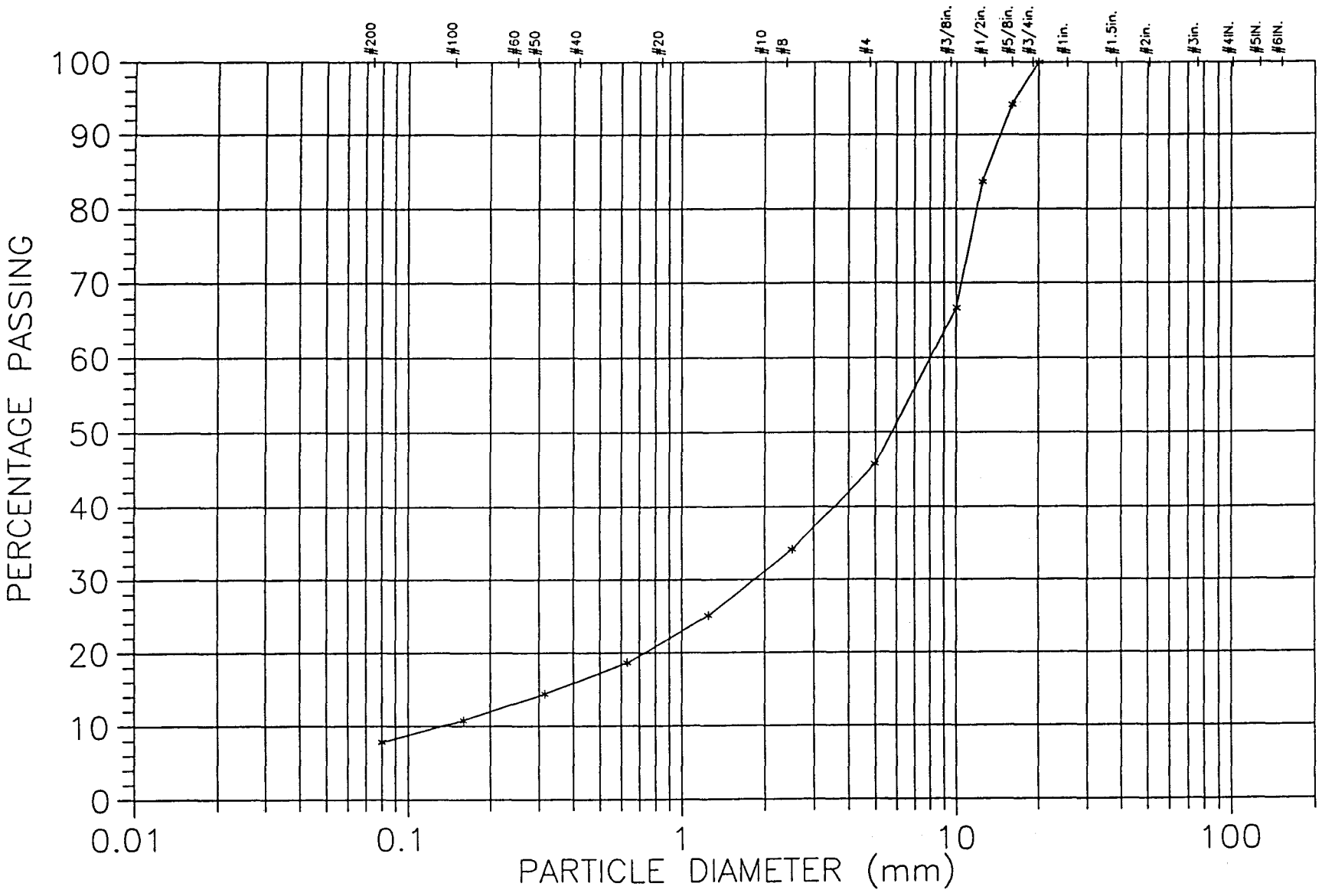
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 40.1 % SAND 40.7 % SILT & CLAY 19.2 %	TEST HOLE: 96-19 DEPTH (m): 5.49 - 6.10	



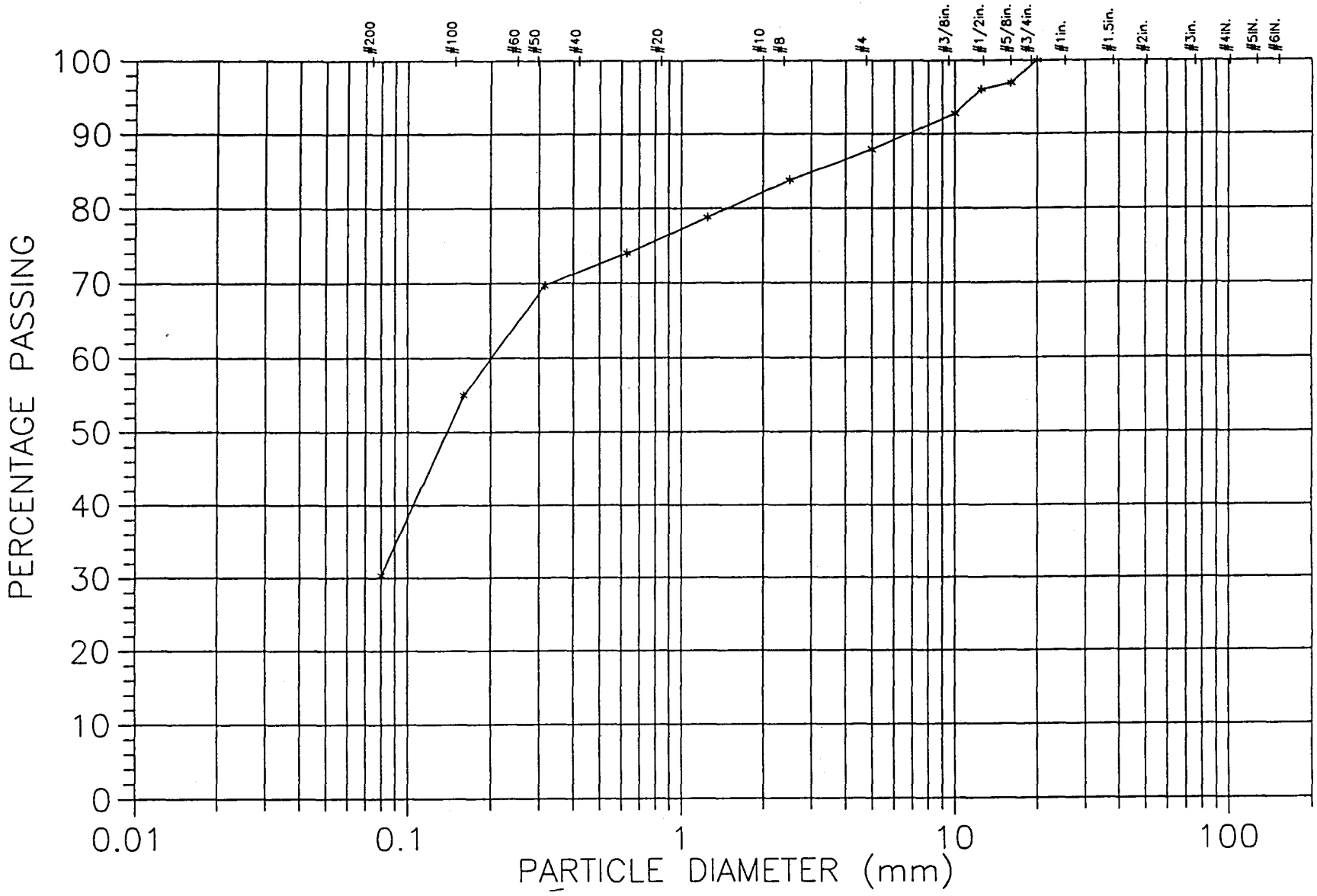
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 78.0 % SAND 17.7 % SILT & CLAY 4.3 %	TEST HOLE: 96-20 DEPTH (m): 0.61 - 1.22	



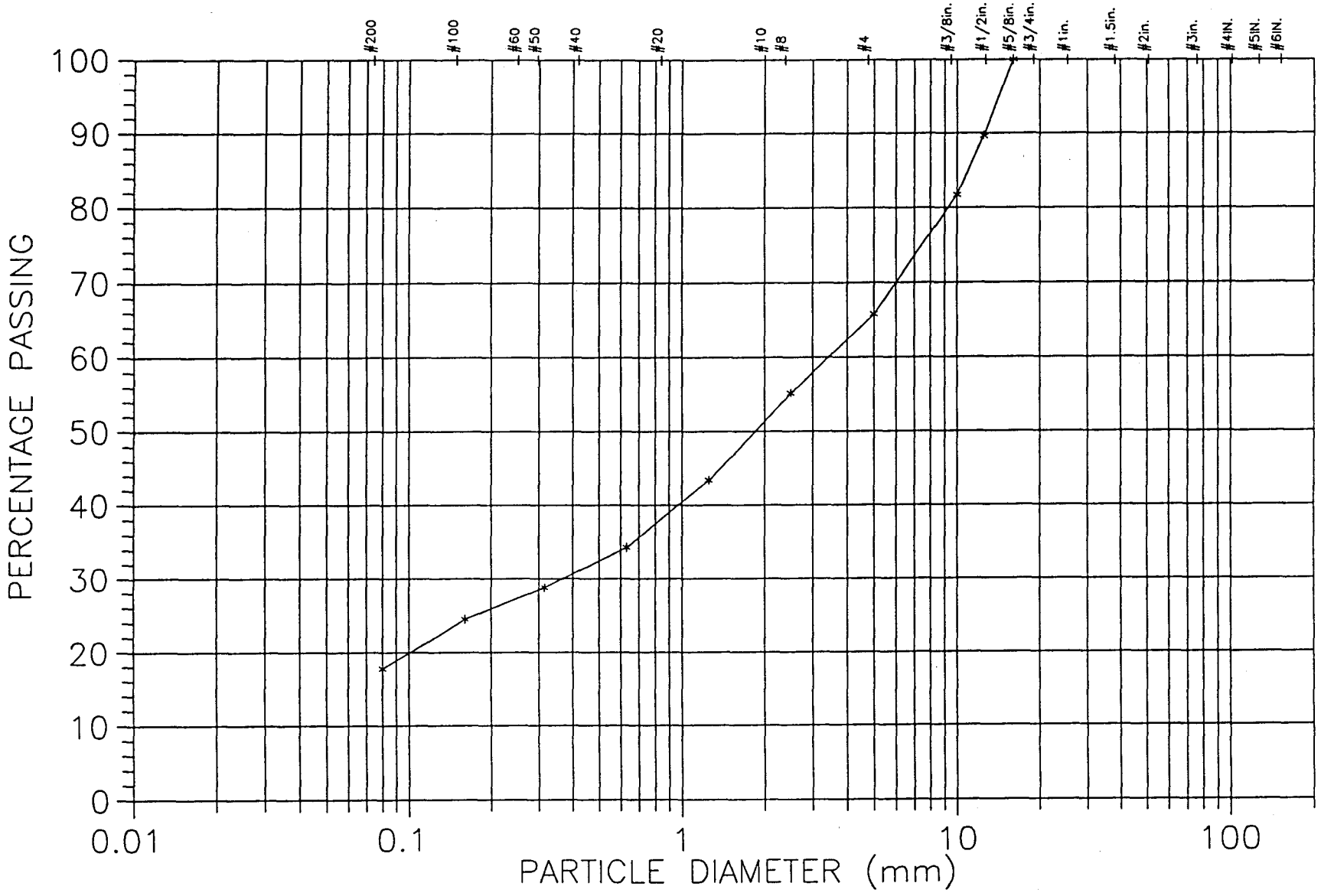
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 69.0 % SAND 23.1 % SILT & CLAY 7.9 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-20 DEPTH (m): 1.83 - 2.44	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 17.7 % SAND 51.9 % SILT & CLAY 30.4 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-20 DEPTH (m): 3.05 - 3.66	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



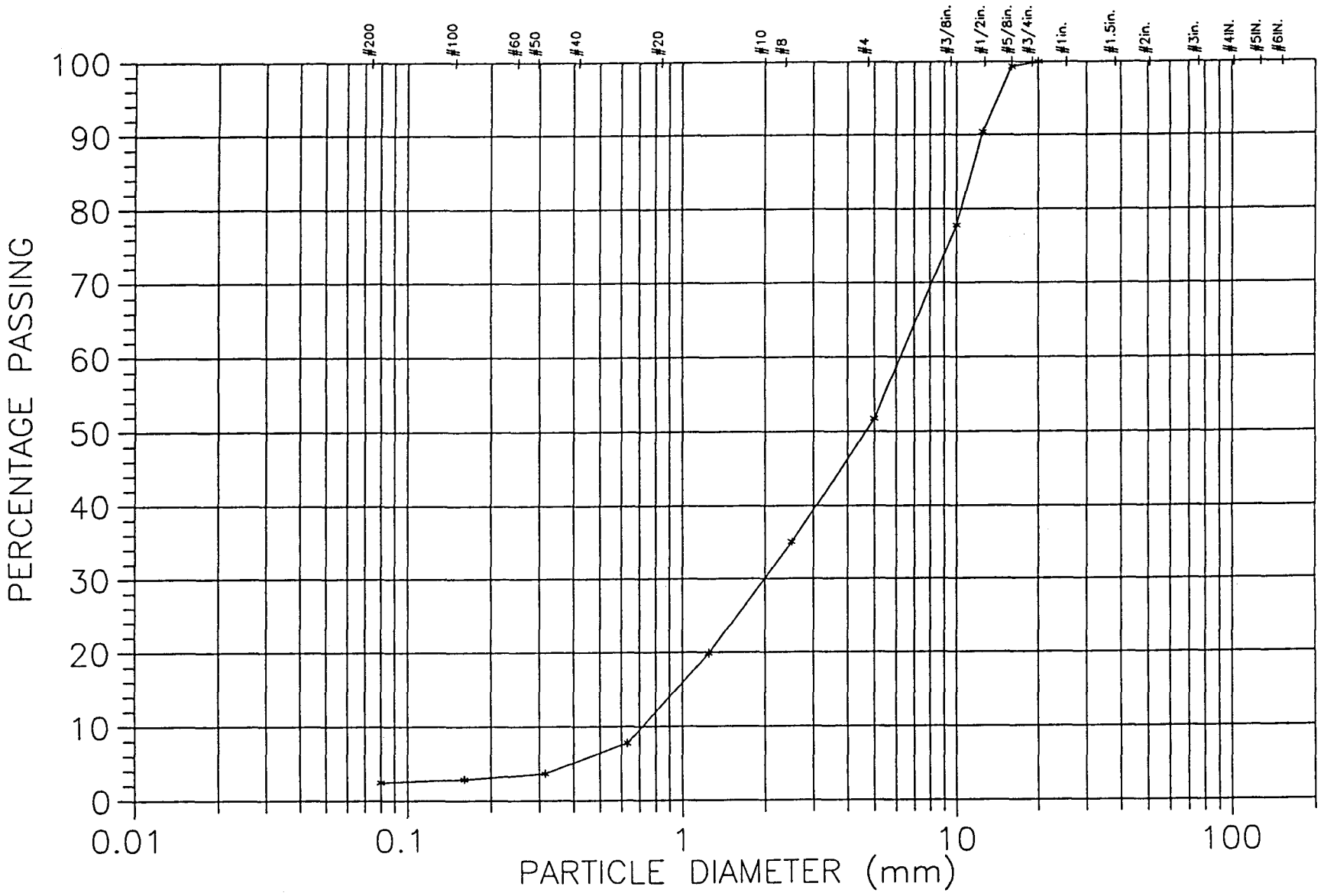
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	49.0 %	
SAND	33.2 %	
SILT & CLAY	17.8 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

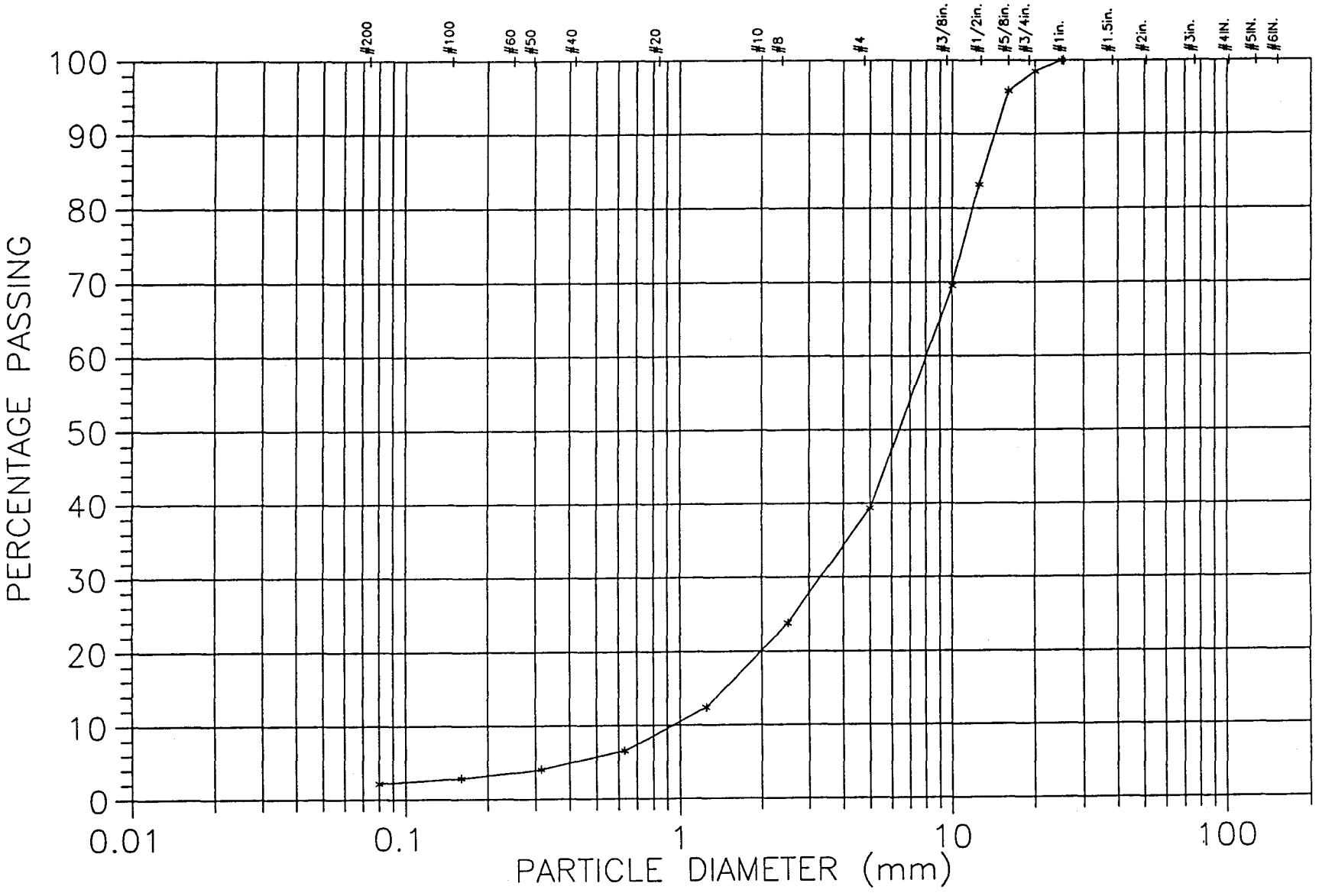
TEST HOLE: 96-20
DEPTH (m): 4.27 - 4.88

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



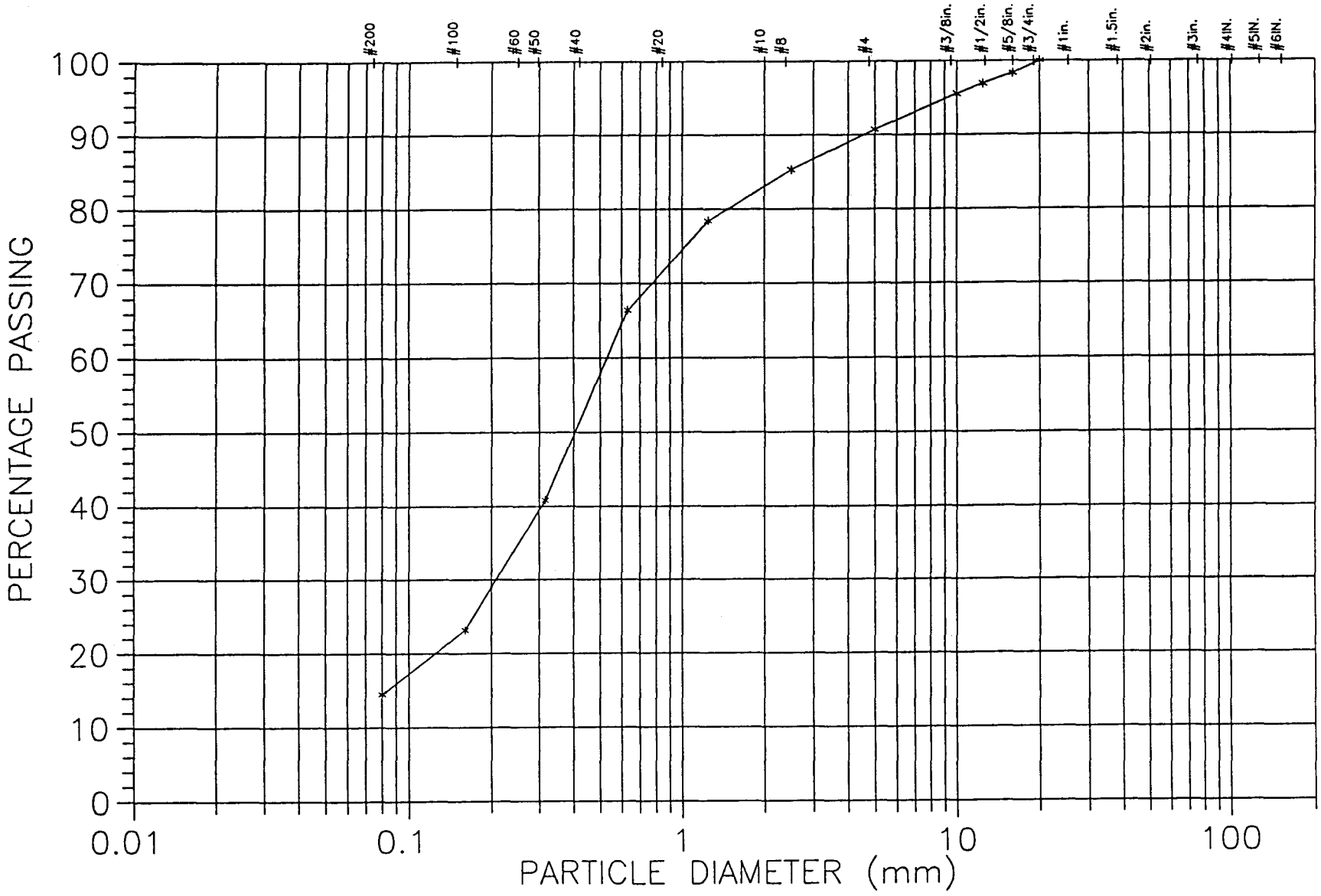
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 70.0 % SAND 27.5 % SILT & CLAY 2.5 %	TEST HOLE: 96-21 DEPTH (m): 1.22 - 1.83	



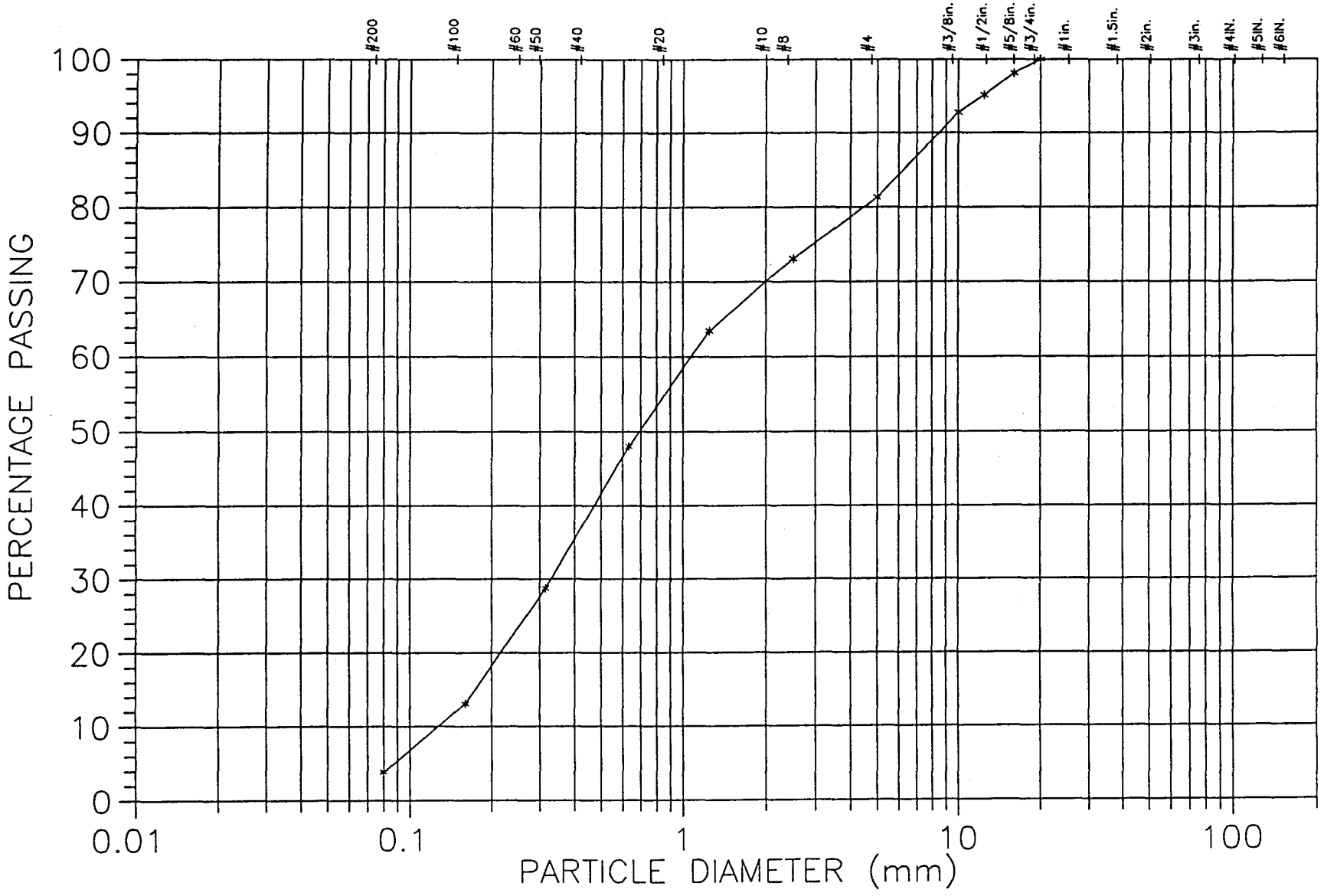
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 80.0 % SAND 17.8 % SILT & CLAY 2.2 %	TEST HOLE: 96-21 DEPTH (m): 1.83 - 2.44	



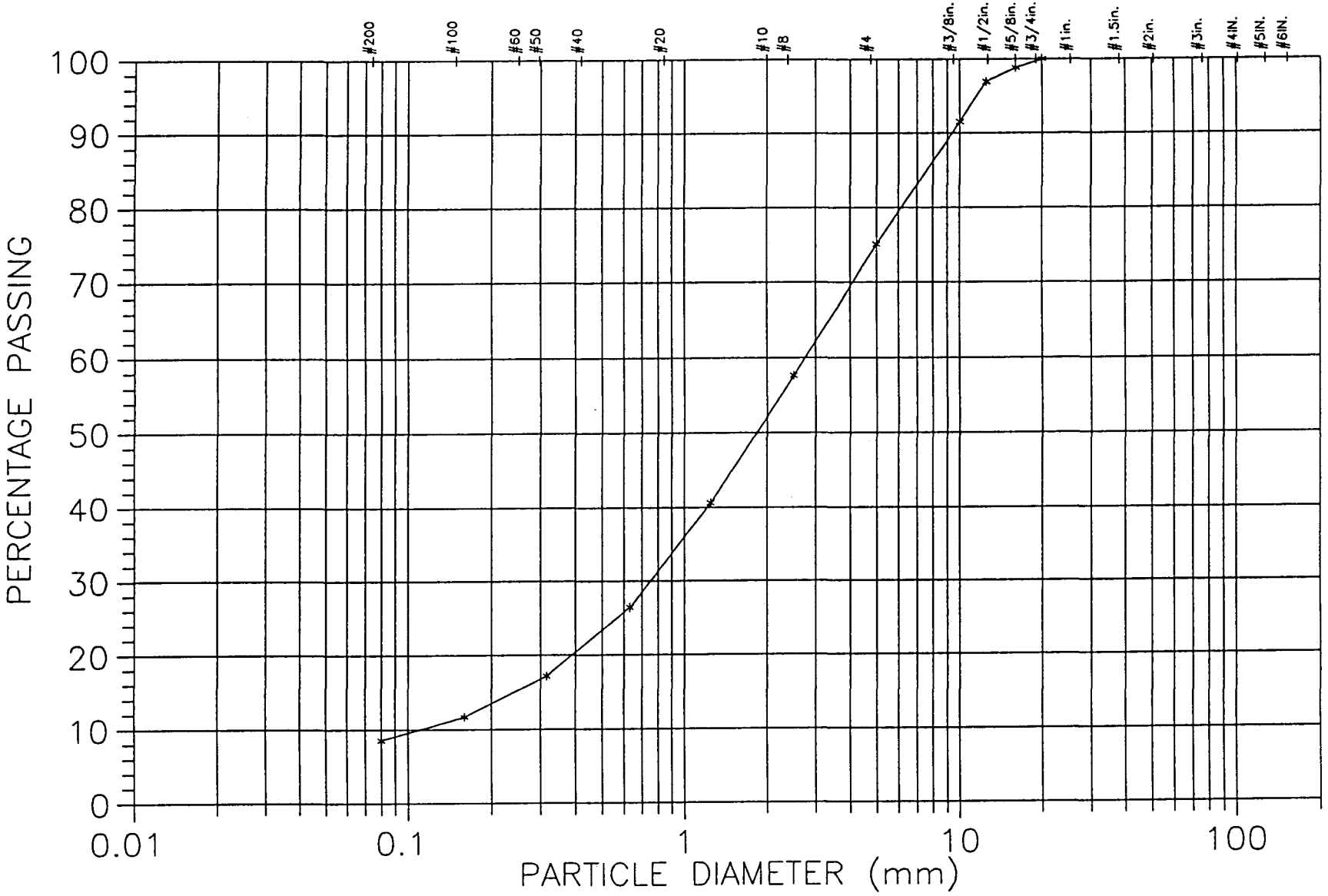
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 17.0 % SAND 68.5 % SILT & CLAY 14.5 %	TEST HOLE: 96-21 DEPTH (m): 3.05 - 3.66	



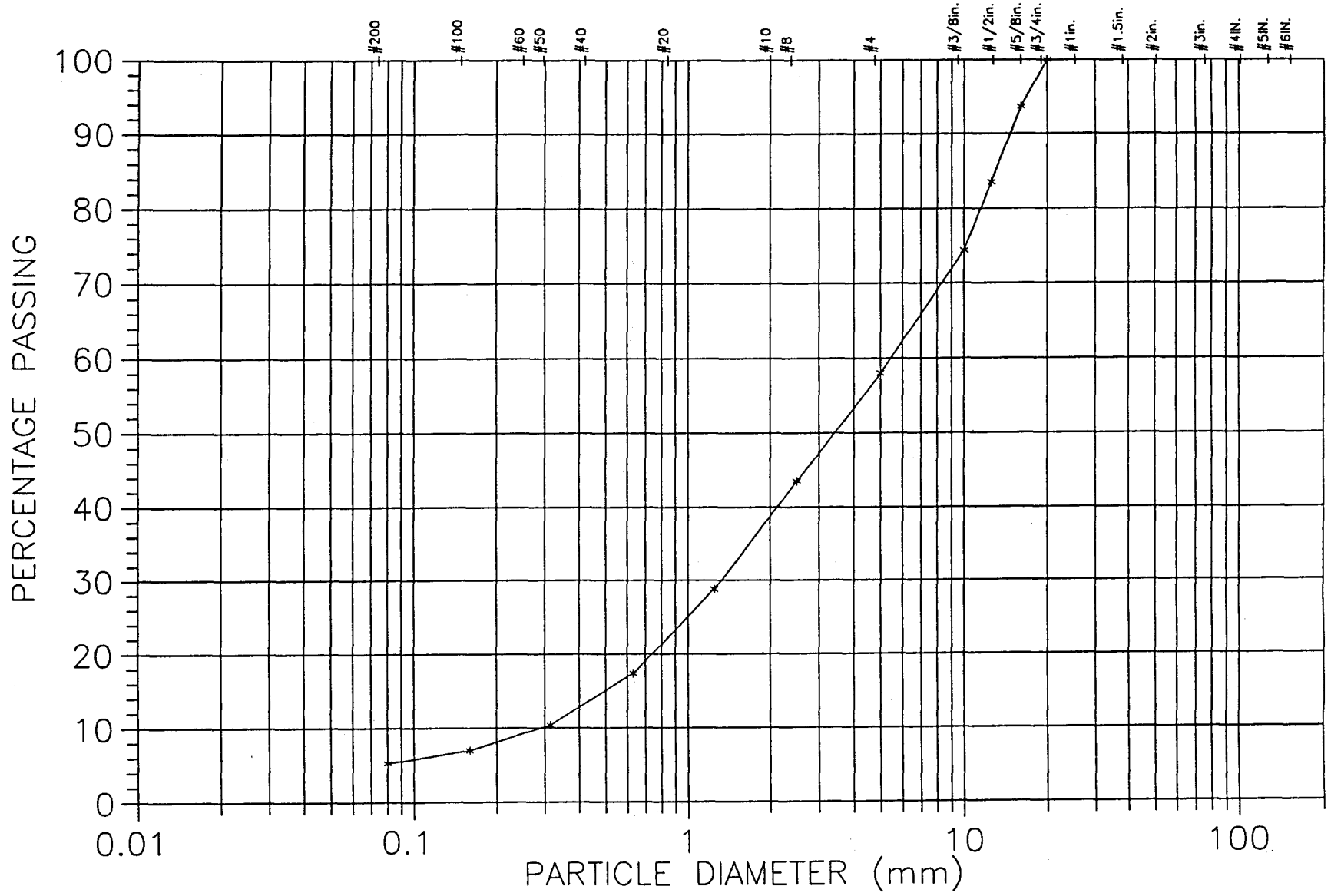
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 30.0 % SAND 66.1 % SILT & CLAY 3.9 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-21 DEPTH (m): 4.27 - 4.88	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



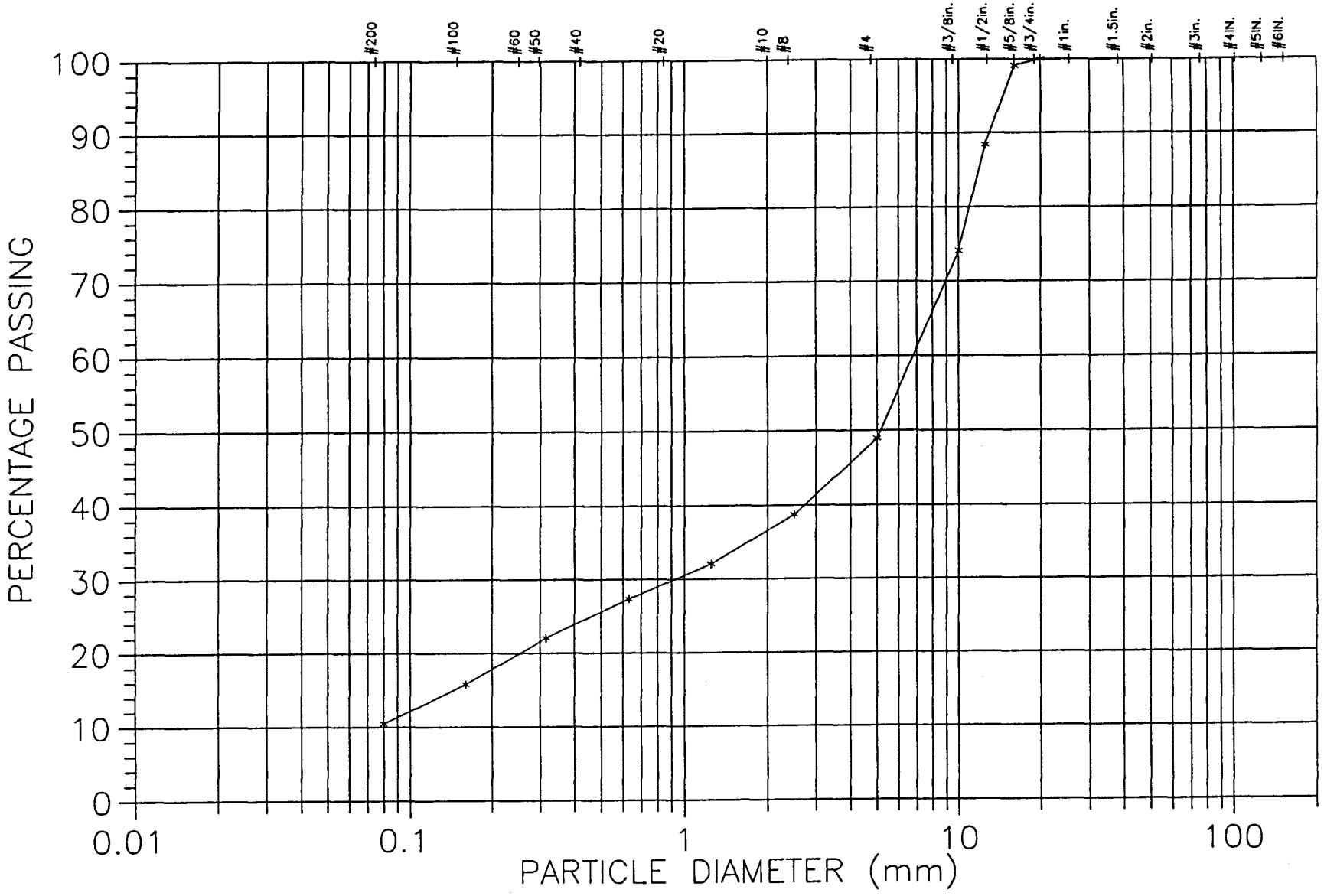
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD.	JOB NO.: C799-001-01-02
GRAVEL 47.8 % SAND 43.6 % SILT & CLAY 8.6 %	***** SIEVE ANALYSIS ***** TEST HOLE: 96-22 DEPTH (m): 1.22 - 1.83	CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 61.5 % SAND 33.2 % SILT & CLAY 5.3 %	TEST HOLE: 96-22 DEPTH (m): 1.83 - 2.44	



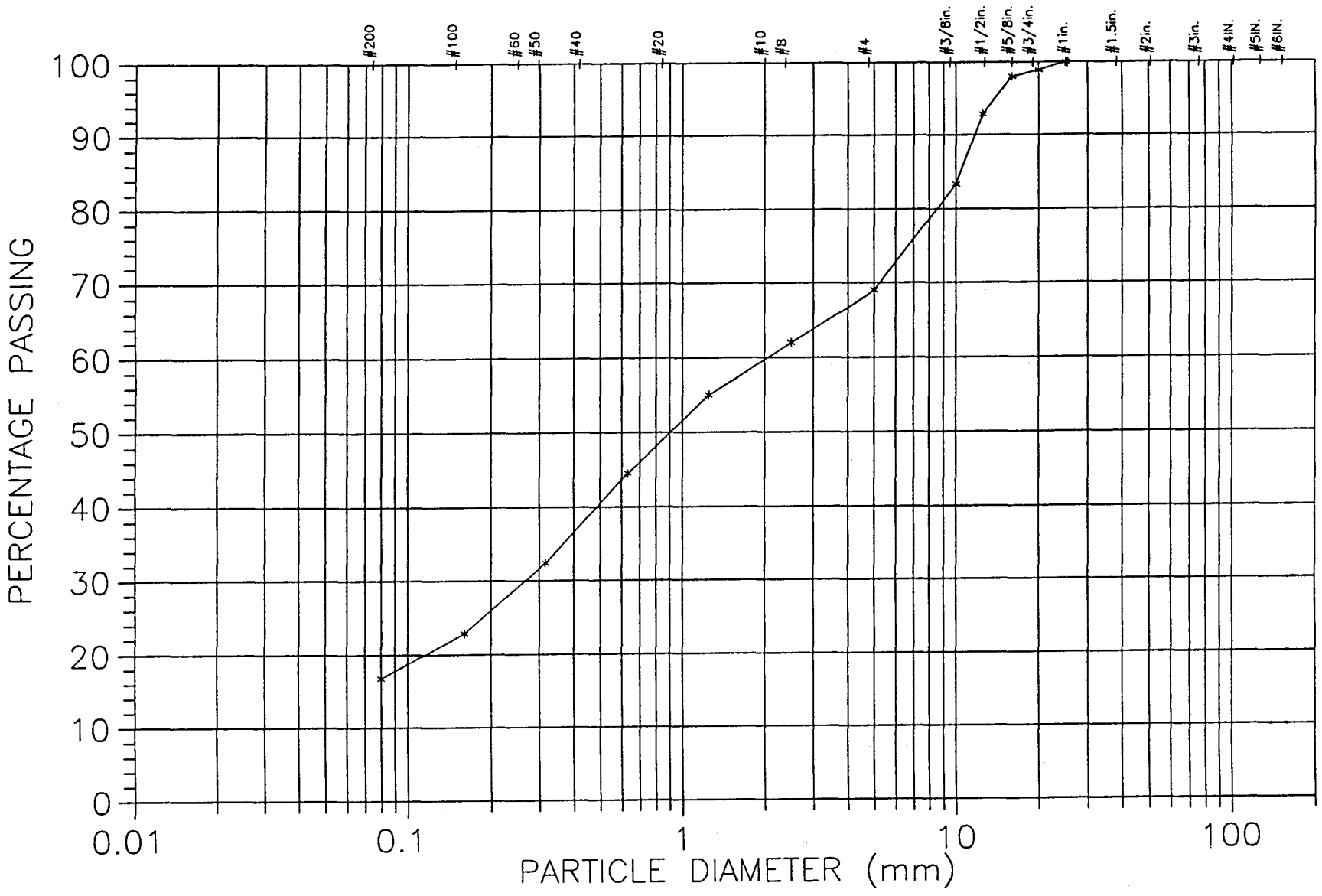
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION		
GRAVEL	63.7 %	
SAND	25.8 %	
SILT & CLAY	10.5 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

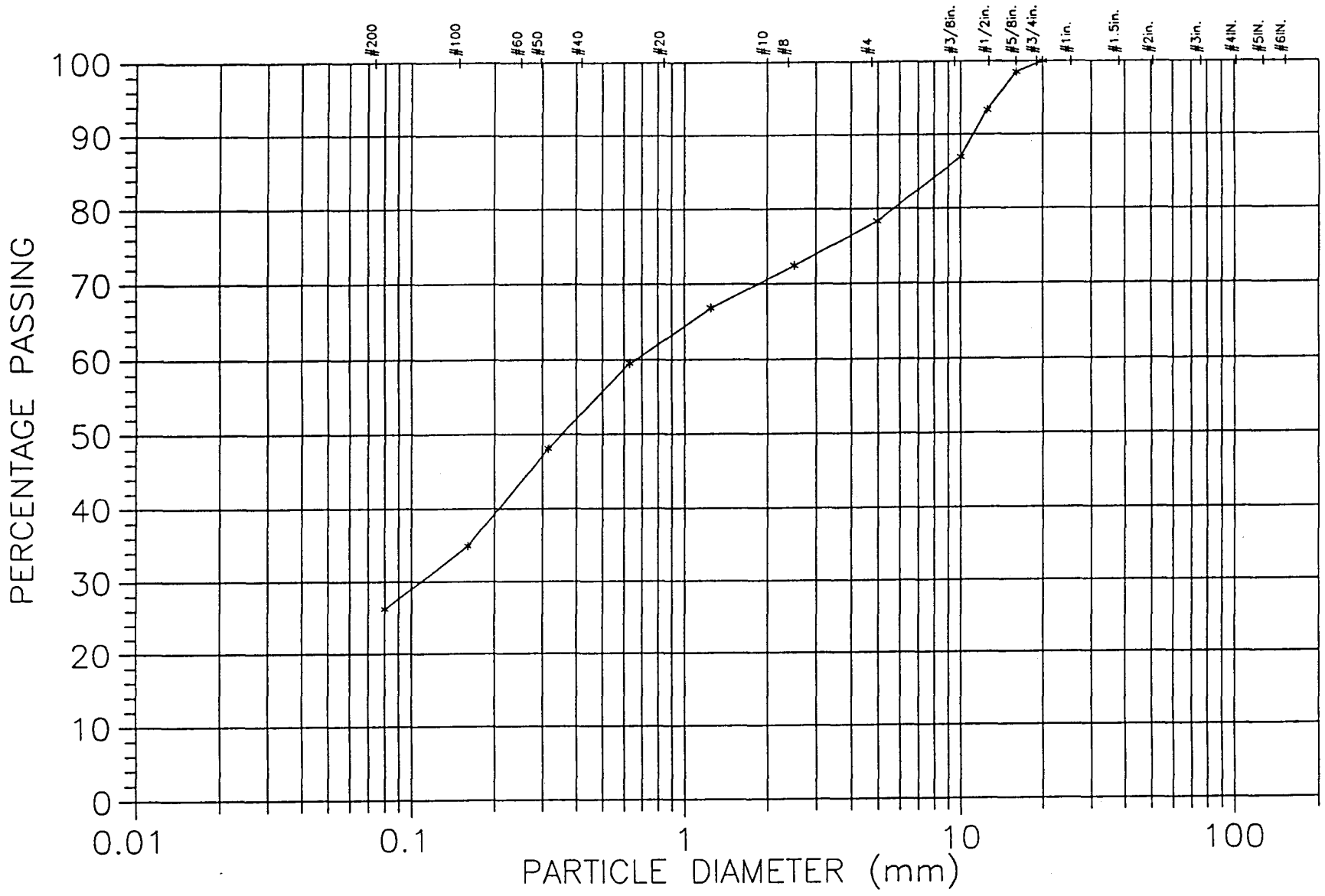
TEST HOLE: 96-23
DEPTH (m): 15.85 - 16.46

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996



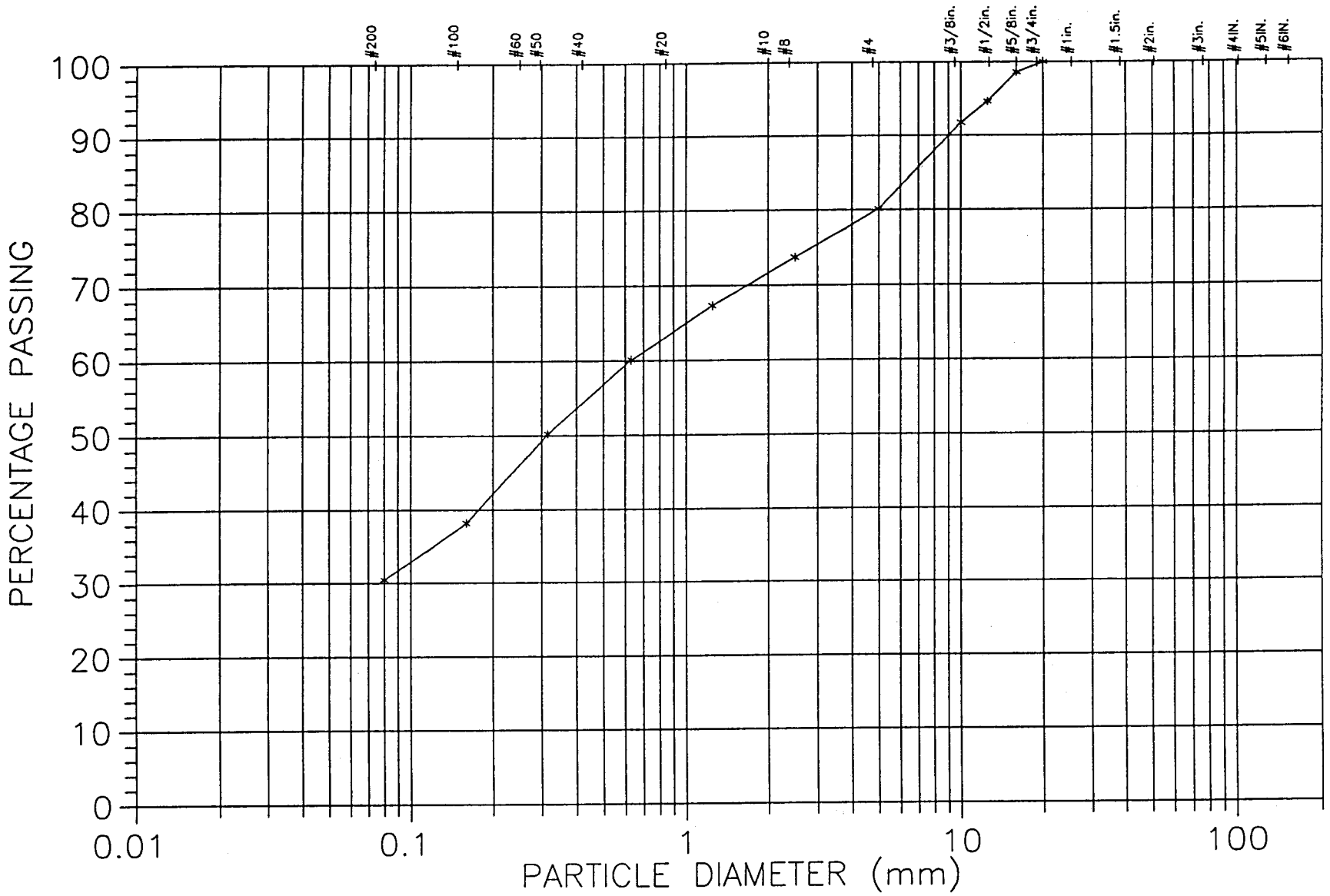
CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 40.2 % SAND 43.0 % SILT & CLAY 16.8 %	TEST HOLE: 96-23 DEPTH (m): 18.29 - 18.90	



CLAY & SILT	SAND	GRAVEL	COBBLES

SAMPLE DESCRIPTION	UMA ENGINEERING LTD. ***** SIEVE ANALYSIS *****	JOB NO.: C799-001-01-02 CLIENT: Royal Roads University PROJECT: Rainy Hollow DATE: November 19, 1996
GRAVEL 29.7 % SAND 44.0 % SILT & CLAY 26.3 %	TEST HOLE: 96-23 DEPTH (m): 21.95 - 22.56	



CLAY & SILT	SAND	GRAVEL	COBBLES

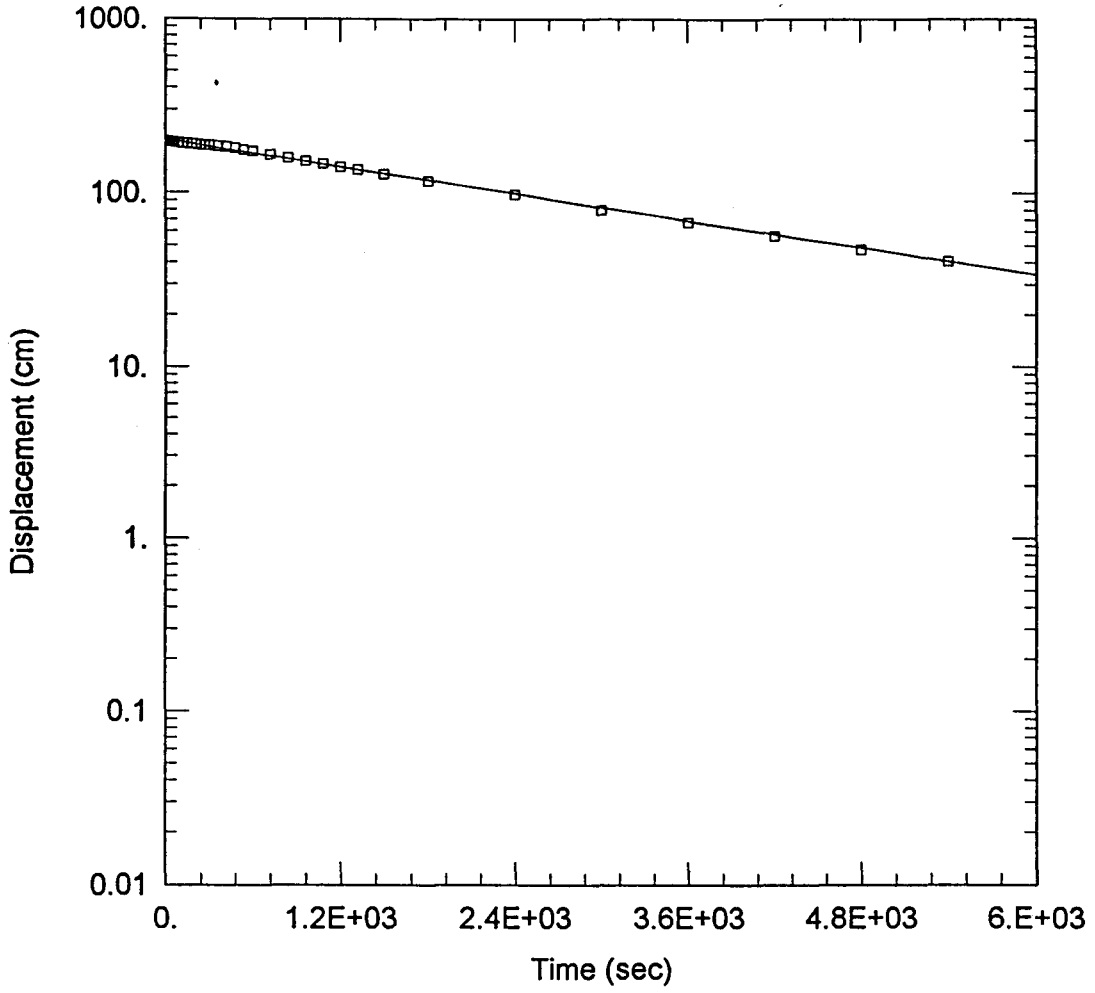
SAMPLE DESCRIPTION		
GRAVEL	28.6 %	
SAND	40.9 %	
SILT & CLAY	30.5 %	

UMA ENGINEERING LTD.
***** SIEVE ANALYSIS *****

TEST HOLE: 96-24
DEPTH (m): 15.85 - 16.46

JOB NO.: C799-001-01-02
CLIENT: Royal Roads University
PROJECT: Rainy Hollow
DATE: November 19, 1996

Appendix D: Estimation of Groundwater Permeability, Including Response Tests



RAINY HOLLOW MW-10

Data Set: C:\96PROJ~1\RAINYH~1\MW-10.AQT
Date: 01/09/97 Time: 16:47:34

AQUIFER DATA

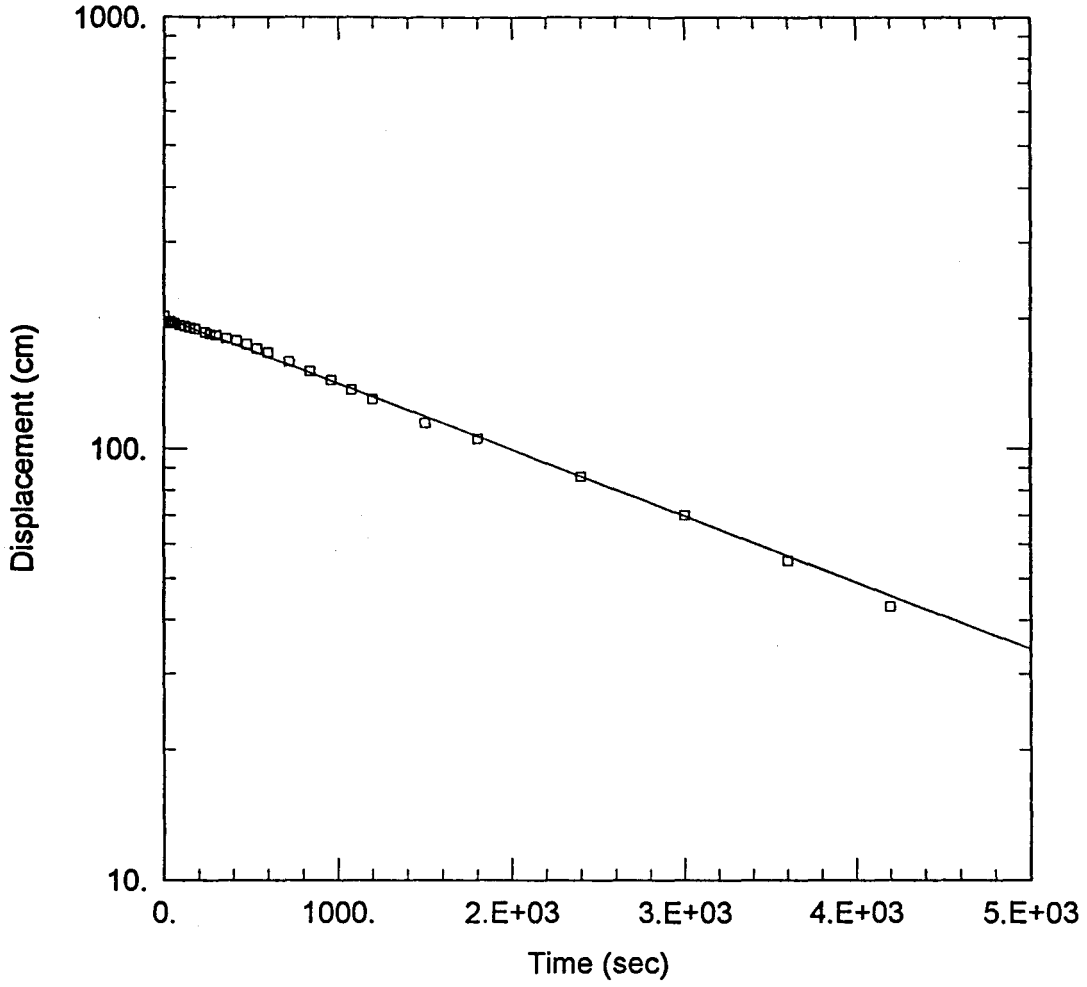
Saturated Thickness: 472. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 197. cm
Water Column Height: 472. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 305. cm

SOLUTION

Aquifer Model: Unconfined
K = 9.358E-06 cm/sec
Solution Method: Bouwer-Rice
y0 = 199.9 cm



RAINY HOLLOW MW-11B

Data Set: C:\96PROJ~1\RAINYH~1\MW11B.AQT
Date: 01/09/97 Time: 16:49:44

AQUIFER DATA

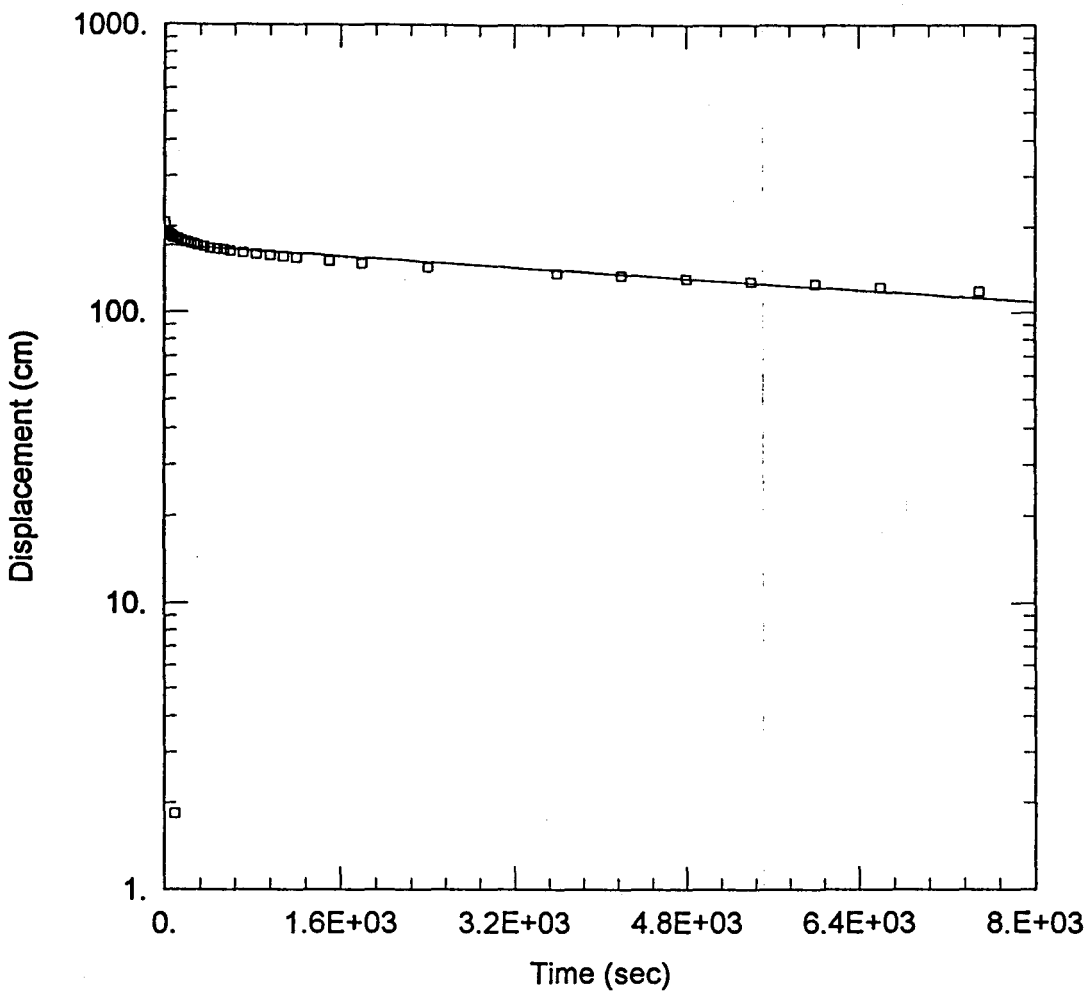
Saturated Thickness: 376. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 202. cm
Water Column Height: 376. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 376. cm

SOLUTION

Aquifer Model: Unconfined
K = 8.802E-06 cm/sec
Solution Method: Bouwer-Rice
y0 = 201.1 cm



RAINY HOLLOW MW-12

Data Set: C:\96PROJ~1\RAINYH~1\MW-12.AQT
Date: 01/09/97 Time: 16:51:30

AQUIFER DATA

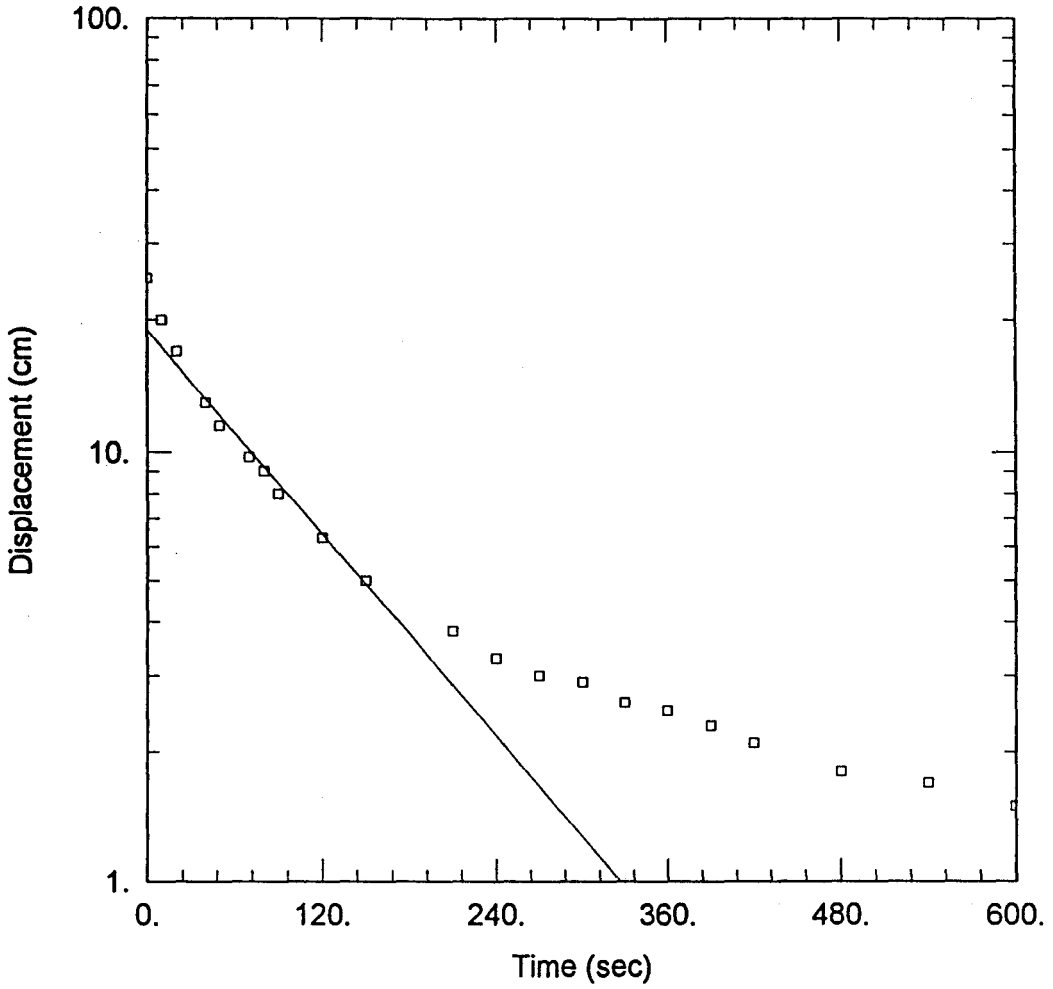
Saturated Thickness: 335. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 207. cm Water Column Height: 335. cm
Casing Radius: 2.54 cm Wellbore Radius: 8.4 cm
Screen Length: 305. cm

SOLUTION

Aquifer Model: Unconfined K = 1.699E-06 cm/sec
Solution Method: Bouwer-Rice y0 = 172.7 cm



RAINY HOLLOW MW-16

Data Set: C:\96PROJ~1\RAINYH~1\MW16(1).AQT
Date: 01/09/97 Time: 16:55:03

AQUIFER DATA

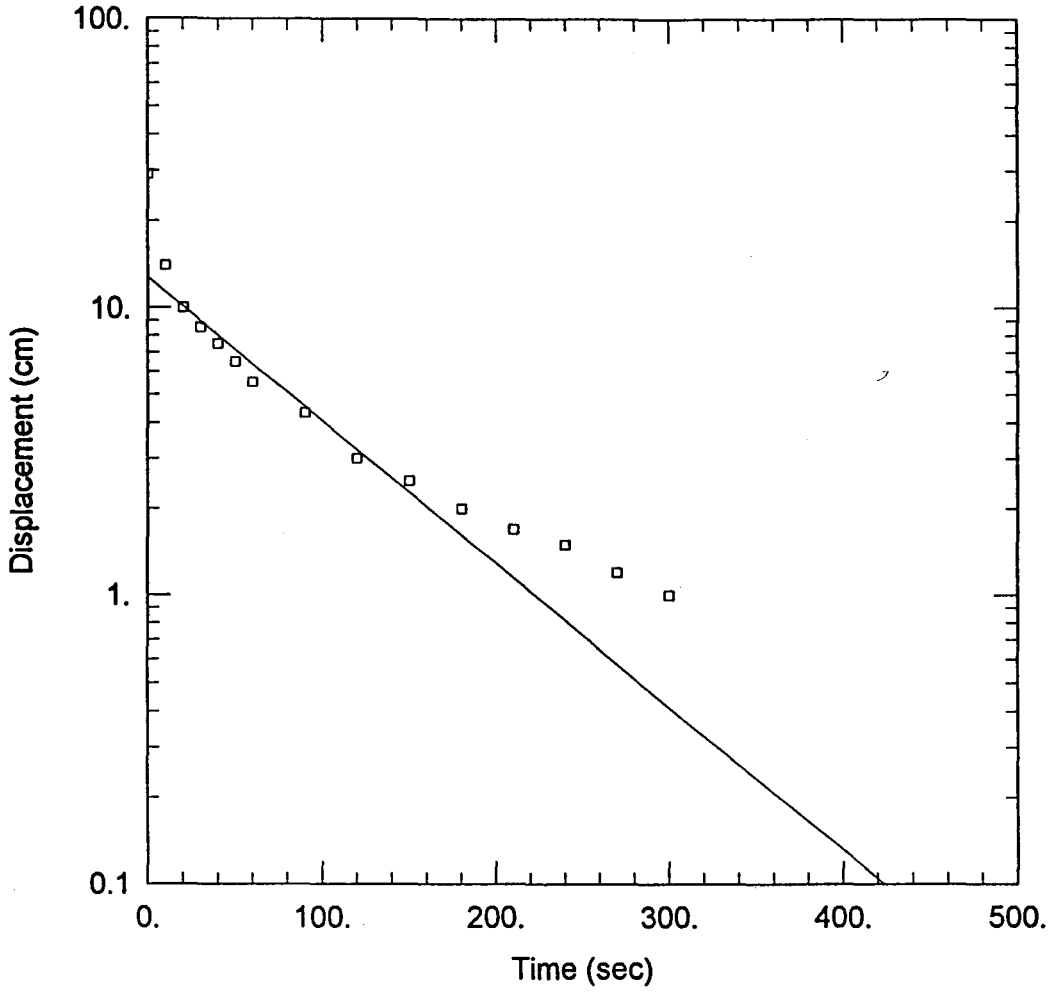
Saturated Thickness: 185. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 25. cm
Water Column Height: 185. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 185. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.0003626 cm/sec
Solution Method: Bouwer-Rice
y0 = 19.01 cm



RAINY HOLLOW MW-17A

Data Set: C:\96PROJ~1\RAINYH~1\MW17A1.AQT
Date: 01/09/97 Time: 16:59:00

AQUIFER DATA

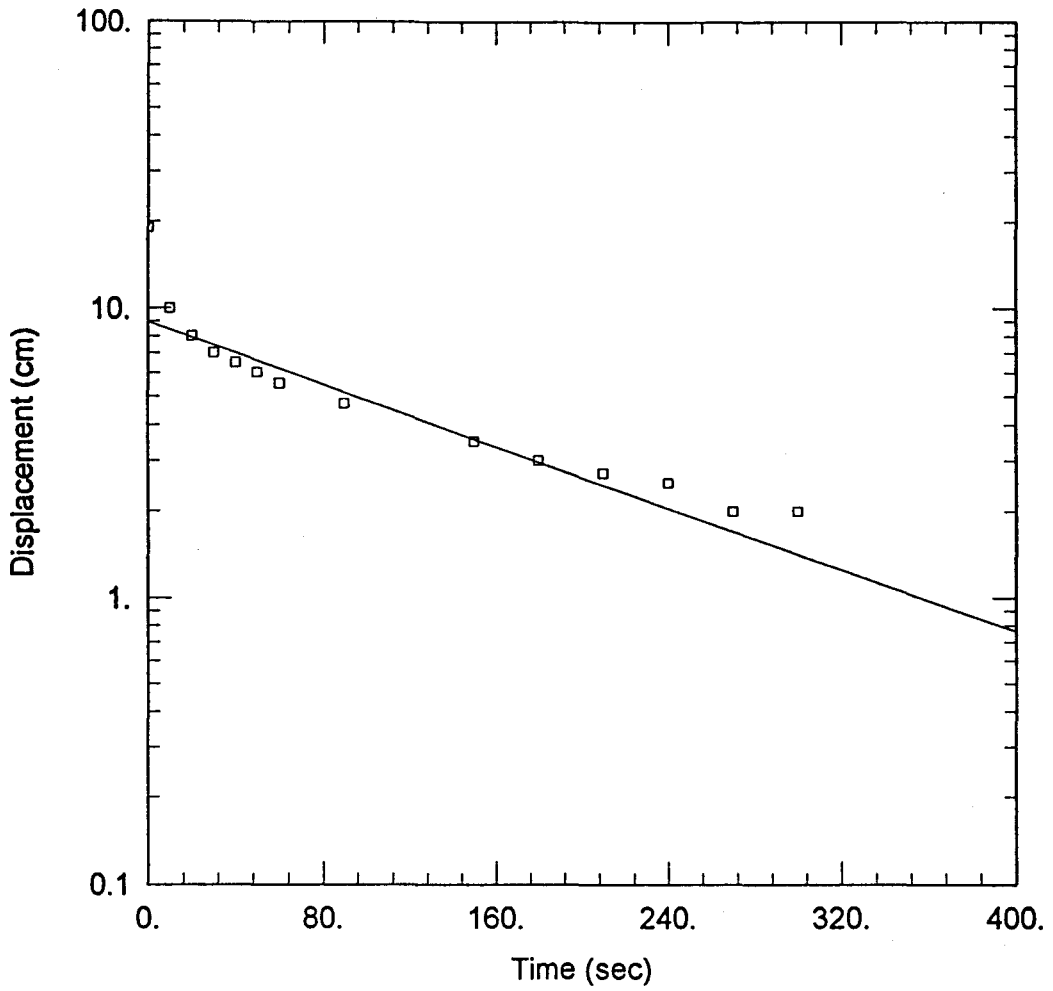
Saturated Thickness: 699. cm
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 29. cm
Water Column Height: 699. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 305. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.0003914 cm/sec
Solution Method: Bouwer-Rice
y0 = 12.69 cm



RAINY HOLLOW MW-17B

Data Set: C:\96PROJ~1\RAINYH~1\MW17B1.AQT
Date: 01/09/97 Time: 17:07:17

AQUIFER DATA

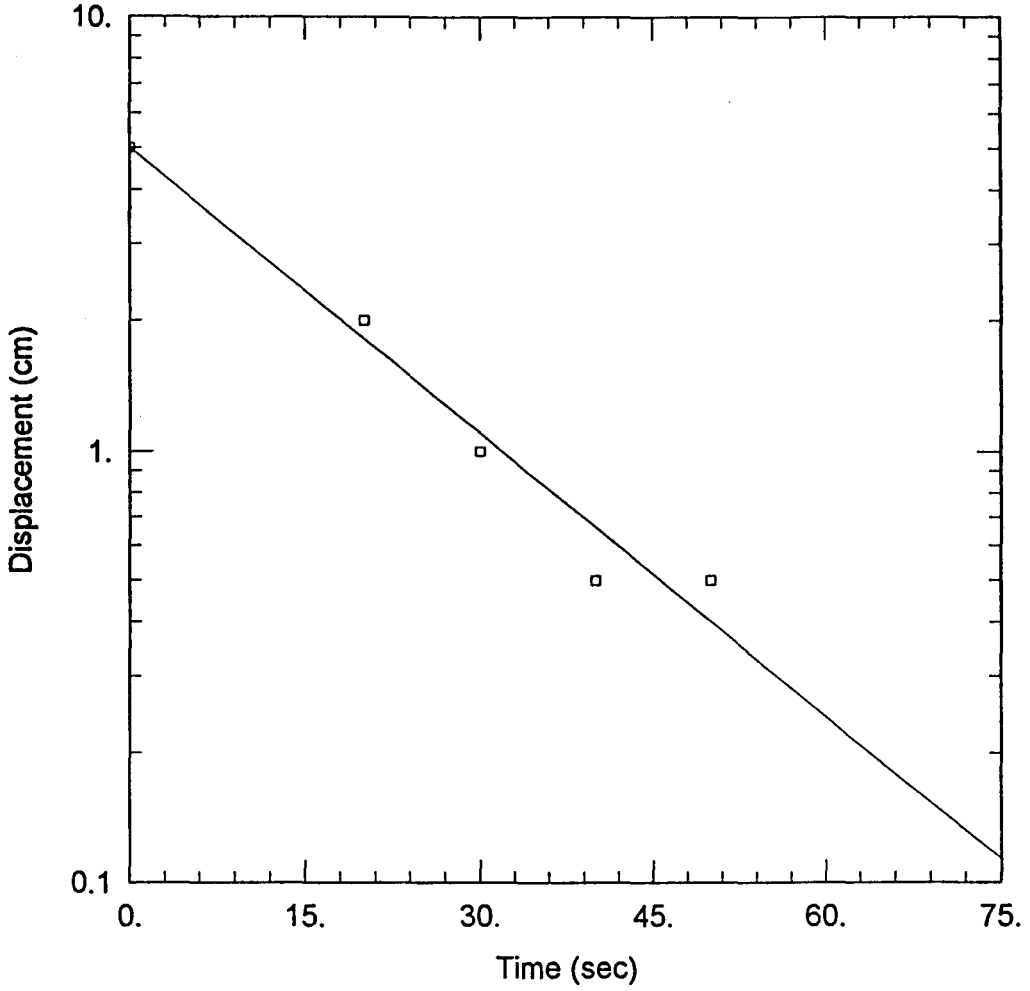
Saturated Thickness: 689. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 19. cm Water Column Height: 689. cm
Casing Radius: 2.54 cm Wellbore Radius: 8.4 cm
Screen Length: 305. cm

SOLUTION

Aquifer Model: Unconfined K = 0.0002103 cm/sec
Solution Method: Bouwer-Rice y0 = 8.943 cm



RAINY HOLLOW MW19A

Data Set: C:\96PROJ~1\RAINYH~1\MW19A.AQT
Date: 01/09/97 Time: 17:12:36

AQUIFER DATA

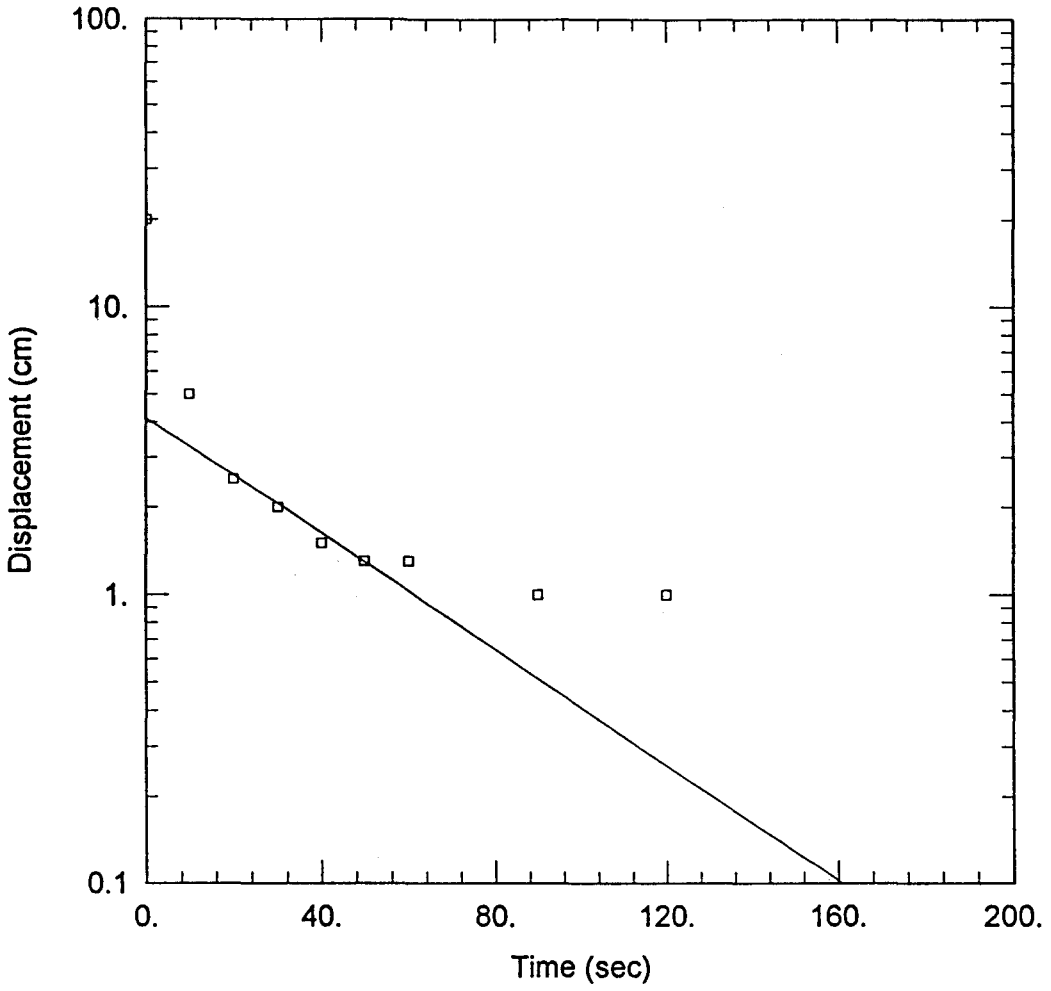
Saturated Thickness: 212. cm
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 5. cm
Water Column Height: 92. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 92. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.002524 cm/sec
Solution Method: Bouwer-Rice
y0 = 5. cm



RAINY HOLLOW MW-19B

Data Set: C:\96PROJ~1\RAINYH~1\MW19B(1).AQT
Date: 01/09/97 Time: 17:15:24

AQUIFER DATA

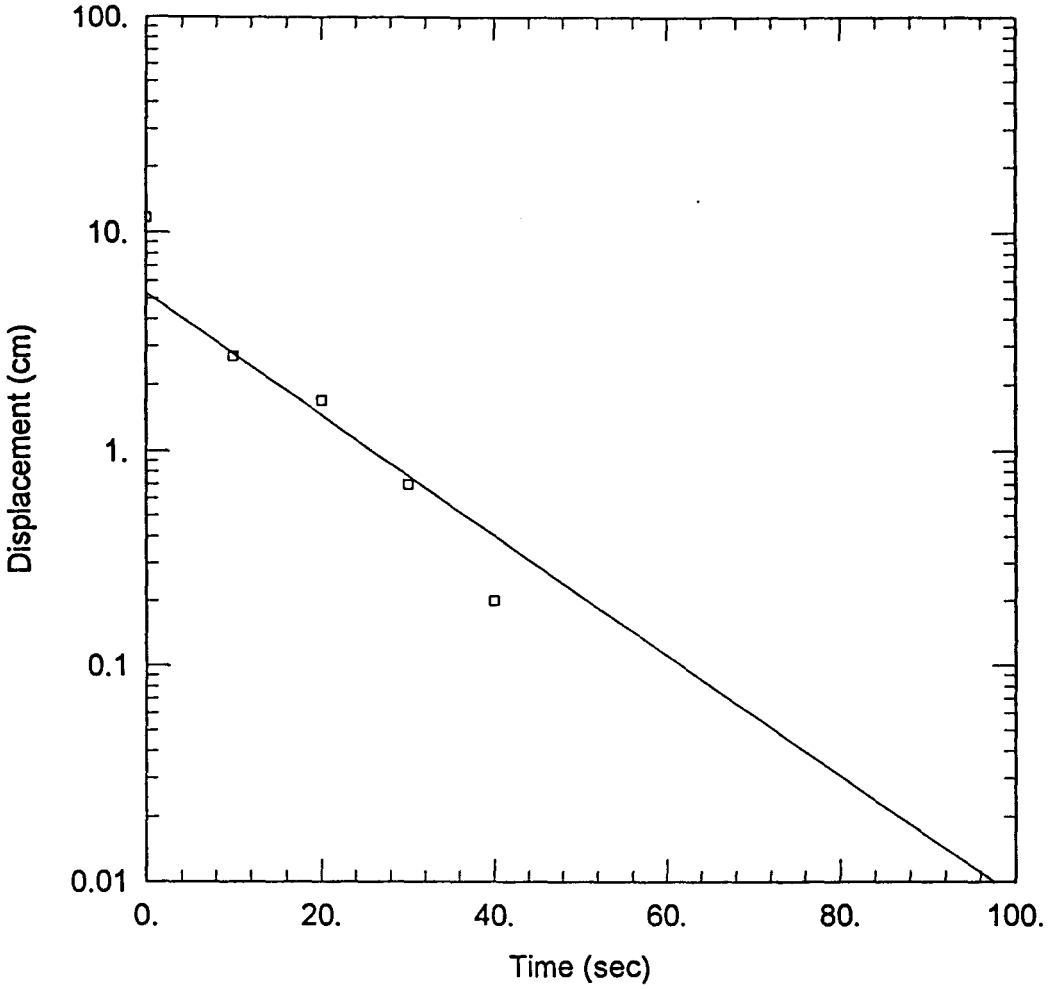
Saturated Thickness: 223. cm
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 20. cm
Water Column Height: 223. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 115. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.001469 cm/sec
Solution Method: Bouwer-Rice
y0 = 4.118 cm



RAINY HOLLOW MW-20A

Data Set: C:\96PROJ~1\RAINYH~1\MW-20A.AQT
Date: 01/09/97 Time: 17:18:41

AQUIFER DATA

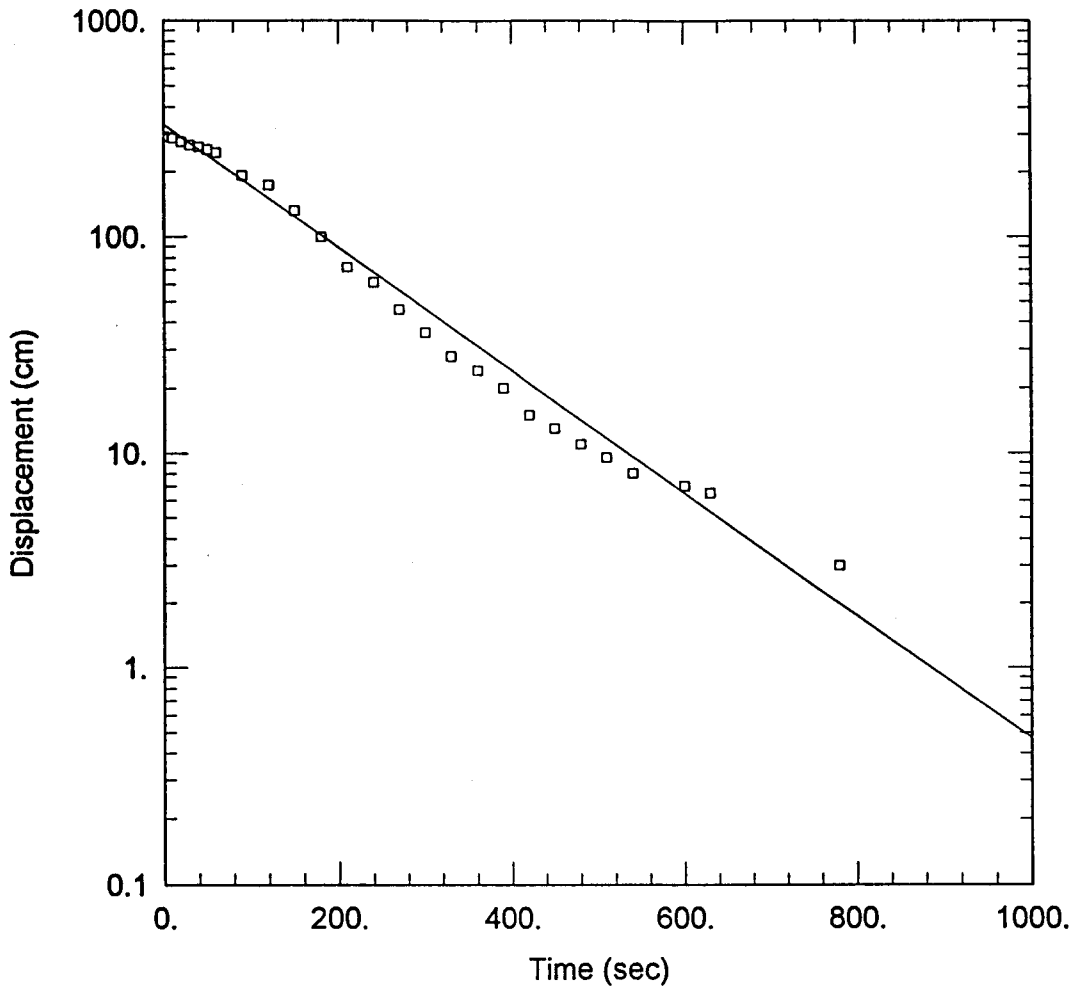
Saturated Thickness: 82. cm
Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 11.7 cm
Water Column Height: 82. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 82. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.004127 cm/sec
Solution Method: Bouwer-Rice
y0 = 5.283 cm



RAINY HOLLOW MW-20B

Data Set: C:\96PROJ~1\RAINYH~1\MW20B.AQT
Date: 01/09/97 Time: 17:20:06

AQUIFER DATA

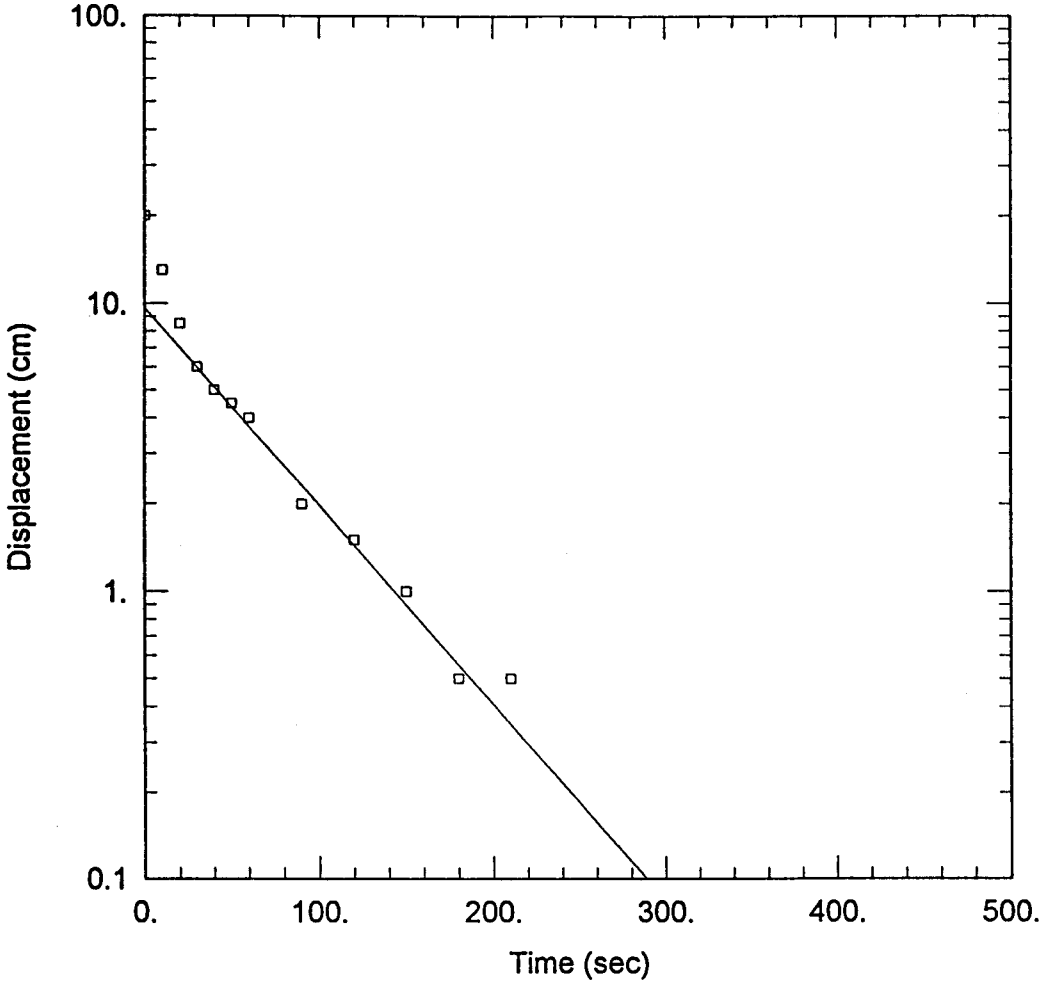
Saturated Thickness: 374. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 292. cm
Water Column Height: 374. cm
Casing Radius: 2.54 cm
Wellbore Radius: 8.4 cm
Screen Length: 152. cm

SOLUTION

Aquifer Model: Unconfined
K = 0.0003677 cm/sec
Solution Method: Bouwer-Rice
y0 = 331.4 cm



RAINY HOLLOW MW-21B

Data Set: C:\96PROJ~1\RAINYH~1\MW21B(2).AQT
Date: 01/09/97 Time: 17:21:42

AQUIFER DATA

Saturated Thickness: 707. cm Anisotropy Ratio (Kz/Kr): 1.

WELL DATA

Initial Displacement: 20. cm Water Column Height: 707. cm
Casing Radius: 2.54 cm Wellbore Radius: 8.4 cm
Screen Length: 305. cm

SOLUTION

Aquifer Model: Unconfined K = 0.0005434 cm/sec
Solution Method: Bouwer-Rice y0 = 9.633 cm

Appendix E: Modeling of Human Exposure to DDT via Inhalation of Dust

APPENDIX E

ESTIMATION OF ATMOSPHERIC FUGITIVE DUST CONCENTRATIONS AND INTAKE RATES FOR ON-SITE HUMAN RECEPTORS

1.0 INTRODUCTION

Fugitive dust emissions in outdoor air from soils at the site due to long term wind erosion were estimated for the Rainy Hollow site. Using the estimated dust emissions, dust and corresponding contaminant concentrations in the breathing zone were estimated using a simple box dispersion model. In this assessment, concentrations of fugitive dust measured at the site were evaluated, and a risk-based concentration was calculated for DDT in surficial soils.

Details regarding the model used to estimate fugitive dust emissions from wind erosion are presented below, along with pertinent input parameters. The input parameters are further summarized in TableI-1.

Sample calculations used in these models for estimation of particulate emission factors are also provided for clarity. Finally concentrations of fugitive dust from wind erosion were used to estimate potential exposure of on-site receptors to contaminant in fugitive dust. A sample calculation for estimation of dose rates to the receptors is also provided.

2.0 WIND/SOIL EROSION FUGITIVE DUST MODEL

The fugitive dust model used in this study to estimate wind generated emissions uses principles described by Cowherd (1985), which have been adopted by U.S. EPA (1991), for a rapid assessment procedure applicable to a Superfund site where the surface contamination provides a relatively continuous and constant potential for emission over a period of years. For this site, emissions were evaluated assuming exposure of receptors for 60 years at the site (assuming hunting/camping exposure).

The particulate emission factor (PEF) relates the contaminant concentration in soil with the concentration of respirable particles in the air due to wind-driven fugitive dust emissions from surface contamination sites. Dust generated from open sources is termed "fugitive" because it is not discharged to the atmosphere in a confined flow stream but rather as uncontrolled dispersion. The modelling assumes that the entire area under

consideration is contaminated with a uniform contaminant concentration. Cowherd's emission assessment methodology addresses only respirable particulate matter, defined as particles equal to or smaller than 10 micrometers aerodynamic diameter (denoted as PM_{10}). PM_{10} particulate matter is most relevant for human exposure assessment because particles (and adsorbed contaminants) larger than 10 micrometers generally do not deposit in the lungs due to the natural filtering abilities of the human respiratory system. The concentration of contaminant in the respirable particulate emissions is assumed to be the same as that measured in surface soils.

The emission rate of particulate matter less than 10 micrometers aerodynamic diameter (E_{10}) is a function of the erodibility of the surface material. The model employed is representative of a surface with "unlimited erosion potential", which is characterized by bare surfaces of finely divided material with an unlimited reservoir of erodible particles. In general, these surfaces erode at low wind speeds, and particulate emission rates are relatively time-independent at a given wind speed. The Cowherd model was selected because it provides conservative estimates for the emission rates of respirable particulates (US EPA, 1991).

Other assumptions used in this model are listed below:

- fugitive dust emissions generated from wind erosion are "continuous and steady";
- surface contamination provides a relatively continuous and constant potential for emission over a period of years;
- meteorology is the same at the source and the receptor;
- concentrations of particulates in the breathing zone (i.e., ground level concentrations) are conservative because deposition of particulates are not considered;
- only respirable-size particles (< 10 micrometers) are considered (i.e., PM_{10}); and
- emissions are uniform over the source area.

3.0 INPUT PARAMETERS FOR WIND EROSION FUGITIVE DUST MODEL

The input parameters used for the wind erosion model are summarized in Table I-1. The derivation and/or sources of key parameters are detailed below.

3.1 Area of Concern

The particulate emission factor (PEF) calculation requires a cross-wind dimension of the area of concern (AEC) to be approximated by a rectangle, and provides greater conservatism when the area is maximized using the smallest dimensions. The area of concern is the portion of the site which is not covered with buildings. For this reason, 100 m was chosen to approximate the width of the areas at the site with an area on the order of 10,000 m^2. The approximate area of the AEC is used to calculate the total emissions and the exact shape of the area is not relevant at the screening level assessment stage.

3.2 Box Model Mixing Height

The box model mixing height (DH), is conservatively assumed to be 2 m. This height corresponds well with the breathing zone of the receptor (i.e., on-site receptors), and is based on the well mixed region as a result of near-surface turbulence. The box model mixing height is independent of receptor height and is considered conservative for a child and adult receptors.

3.3 Particle Size Distribution

The soils on-site were determined to be largely silty sand. The mode of the particle size distribution (d_m) for the soil was approximated to be 0.1 mm (100 μm), based on the observations for surficial soils. Actual grain size analyses were available for soils at depths below 0.6 m, which indicate sand and gravel soils. Therefore, the more conservative observations for surface soils were used to estimate the mode of the particle size distribution.

3.4 Surface Roughness (z_o)

The local surface roughness height (z_o) was approximated to be 1 m based on information provided in Figure I-1, taken from Cowherd (1985). The roughness height for a site

depends on the land-use and vegetation for an area several kilometers around the site, and is required for the determination of local windspeed. The site is in a mountainous area, with heavy forest surrounding the open area of the site.

3.5 Threshold Friction Factor

The threshold friction factor, $u_{*_t}[\mathrm{m/s}]$ is determined by the mode of the particle size distribution, d_m [mm], following the empirical relationship of Cowherd, (1985).

$$u_{*_t} = 0.65\, d_m^{0.421} \tag{1}$$

3.6 Windspeed

The meteorological information most influential to the emission of dust is the windspeed, and functions of the windspeed. These parameters are site specific and are ideally derived from an on-site meteorological tower or local monitoring station. The local windspeed was estimated using a model which utilizes data from the closest meteorological station with adequate windspeed data obtained from the Whitehorse airport. The model estimates the local windspeed at 7 m height based on the surface roughness height at the airport, the site surface roughness height and the height of the meteorological tower.

Annual mean windspeed (U_{air}) at the airport is 3.9 m/s measured at a meteorological tower height (Z_{met}) of 10 m. The surface roughness height ($z_{o\ air}$) at the airport is taken to be 0.01 m, while the surface roughness height (z_o) at the site is taken to be 1 m (see Figure I-1). The average local windspeed (U) is estimated at a height of 7 m, which is a basis of the Cowherd (1985) model. The average local windspeed at 7 m height at the site is estimated to be 2.3 m/s.

3.6.1 Threshold Windspeed

The threshold windspeed, u_t [m/s], is the windspeed above which appreciable erosion will take place. The threshold windspeed is a function of the local surface roughness height, z_o [cm], and the threshold friction velocity, u_{*t} [m/s]. The following relationship may be used for determining the threshold windspeed (Cowherd, 1985).

$$\frac{u_t}{u_{*t}} = 16.5 - 2.5\ln(z_o) \quad (2)$$

3.6.2 Windspeed in Mixing Zone

The windspeed in the mixing zone, V [m/s] (windspeed within the box model), is the windspeed in a well mixed region of air near the ground surface. This region is at least 2 m due to turbulence near the ground surface. A conservative assumption in the box model assumes 2 m as the top of the mixing zone for particulates entering the atmosphere. The local windspeed at 2 m can be estimated based on the windspeed at the meteorological station by using a power law expression for the variation of windspeed with height and by assuming the velocities are the same at the two locations at the top of the atmospheric boundary layer. The windspeed, U_{air} (3.9 m/s), taken at height z_{met} (10 m) at the meteorological station, is adjusted to the mixing height at the local site, z_{local} (2 m), using power law wind profiles:

$$V = U_{air}\left(\frac{\delta}{z_{met}}\right)^{P_{air}} \times \left(\frac{z_{local}}{\delta}\right)^{P_{local}} \quad (3)$$

The exponents P_{air} and P_{local} depend on terrain roughness and atmospheric stability. The values derived by Irwin (1979) and listed in Table I-3 are used here. For simplicity, the model uses a constant surface boundary layer thickness of δ equal to 500 m, and assumes that P_{air} is in a terrain roughness of z_o=0.01 m and P_{local} is in a terrain roughness of 1 m in Table I-3. The stability class used for this assessment is the average of Classes "C", "D" and "E". This is not a worst case scenario and is meant to approximate the average stability.

TABLE I-3
Windspeed Power Law Exponents for Varying Atmospheric Stability Class and Terrain Roughness z_o from Irwin (1979)

	Wind Speed Exponent p		
Pasquill-Gifford Stability Class	z_o=0.01m flat, rural	z_o=0.1m wooded, suburban	z_o=1.0m forested, urban
A Very unstable	0.05	0.08	0.17
B Unstable	0.06	0.09	0.17
C Slightly unstable	0.06	0.11	0.20
D Neutral	0.12	0.16	0.27
E Stable	0.34	0.32	0.38
F Very stable	0.53	0.54	0.61
Average of C,D,E	0.173	0.1967	0.283

Based on equation (3) and the information provided above, the windspeed in the mixing zone (V) was estimated to be 1.6 m/s. The sample calculation for this is provided in Section 4.2, equation 4.

4.0 ESTIMATION OF DOSE RATE AND SAMPLE CALCULATIONS

4.1 Dose Rate Estimation

The dose rate for the receptors was estimated for the fugitive dust inhalation pathway for emissions generation from wind erosion. A sample calculation for estimation of dose rate from wind erosion is provided in Section 4.3.

4.2 Average Emissions from Wind - Sample Calculation

For a particle mode of 0.1 mm, the threshold friction velocity, $u_{*_t}[\mathrm{m/s}]$, is estimated to be 0.25 m/s using equation 1 below:

$$u_{*_t} = 0.65\, d_m^{0.421} \qquad (1)$$

where:

d_m = mode of aggregate size distribution [0.1 mm]

The threshold windspeed, u_t [m/s], is estimated to be 1.24 m/s using equation 2 shown below:

$$\frac{u_t}{u_{*t}} = 16.5 - 2.5\ln(z_o) \tag{2}$$

where

z_o = surface roughness height [100 cm]
u_{*t} = the threshold friction velocity [0.25 m/s]

Assuming a continuously erodible surface, the particulate emission rate from the area of concern is given by Cowherd (1985).

$$E_{10} = 0.036(1 - V_f)\left(\frac{U}{u_t}\right)^3 F(x) \tag{3}$$

where E_{10} = PM_{10} emissions, [g/m^2-hr]

0.036 = empirical constant, [g/m^2-hr]

V_f = fraction of soil covered by vegetation [0]

U = local mean annual wind speed, [2.3 m/s]

u_t = threshold velocity, [1.24 m/s]

x = $\pi^{0.5} / 2\ (u_t/U)$

$F(x)$ = is a function of the probability distribution for wind speed [$F(x)$=1.9]

where

$$F(x) = \frac{8}{\pi^{1.5}}\left(\frac{3}{2}x + x^3\right)e^{-x^2} + \frac{6}{\pi}\text{erf}_c(x) \tag{3b}$$

and $erf_c(x)$ is the complementary error function or Normal probability function.

From equation (3), the E_{10} emission rate was calculated to be 0.44 g/m^2-hour.

The windspeed in the mixing zone is estimated to be 1.6m/s using the following equation:

$$V = U_{air}\left(\frac{\delta}{z_{met}}\right)^{P_{air}} \times \left(\frac{z_{local}}{\delta}\right)^{P_{local}} \quad (4)$$

where

U_{air} = mean annual windspeed at meteorological station [3.9m/s]
z_{met} = height of meteorological tower [10 m]
P_{air} = windspeed exponent at meteorological station [0.1733]
z_{local} = height at site [2 m]
P_{local} = windspeed exponent at site [0.283]
δ = constant surface boundary layer thickness [500m]

Using assumptions for the area of concern and a simple box dilution model, the PEF for wind erosion of soil was calculated to be 2.6E+5 m^3/kg as follows (US EPA 1991):

$$PEF = \frac{\frac{Ls \times V \times DH}{A} \text{x3600 sec / hr} \times UCF}{E_{10}} \quad (5)$$

where:

- PEF = particulate emission factor [m^3/kg]
- Ls = length of the side of the contaminated area [100 m]
- V = wind speed in the mixing zone [1.6 m/sec]
- DH = diffusion height [2m]
- A = area of contamination [10,000 m^2]
- UCF = conversion from g to kg [1000 g/kg]
- E_{10} = PM_{10} emissions [0.44 g/m^2-hr]

4.3 Dose Rate - Sample Calculation

The following is a sample calculation of dose achieved from inhalation of fugitive dust emissions from wind erosion. Using the equation listed below, and assuming 173 mg

DDT/kg soil, the dose rate for DDT via inhalation of fugitive dust from wind erosion is 2E-5 mg/kg body weight-day:

$$\text{Dose Rate} = \frac{Cs \times (1/PEF) \times IR_{inh} \times EF \times ED \times ET \times BF}{BW \times AT \times UCF_2} \quad (6)$$

where:

Dose Rate	= intake of chemical [mg/kg body weight-day]
Cs	= concentration of chemical in fugitive dust [173 mg DDT/kg soil]
PEF	= particulate emission factor [2.6E+5 m^3/kg]
IR_{inh}	= inhalation rate [0.958 m^3/hr]
EF	= exposure frequency [48 days/year]
ED	= exposure duration [60 year]
ET	= exposure time at site [16 hr/day]
BF	= bioavailability factor [1, assuming 100% bioavailability]
BW	= adult body weight [70 kg]
AT	= averaging time [60 years]
UCF_2	= unit conversion factor [365 days/year]

The hazard quotient for this exposure scenario is calculated to be 3E-2 (i.e., dose rate / RfD of 5E-4 mg/kg BW-day).

5.0 REFERENCES

Cowherd, C., Muleski, G.E., Englehart, P.J. and Gillette, D.A. 1985. *Rapid Assessment of Exposure to Particulate Emissions from Surface Contamination Sites.* Midwest Research Institute, Kansas City, Missouri. Office of Health and Environmental Assessment. Office of Research and Development. U.S. Environmental Protection Agency. Washington, D.C. EPA/600/8-85/002. February.

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Table I-1
Input Parameters for Fugitive Dust Model
Wind Erosion

Input Parameter	Value
Area of Concern	
length of side of contaminated area (Ls)	100 m
area of contamination (A)	1000 m^2
vegetated area (V_f)	0
Meteorological Parameters	
local windspeed (U)	2.3 m/s
mean annual windspeed at airport (U_{air})	3.9 m/s
threshold windspeed at 10 m (U_t)	1.24 m/s
threshold friction factor (u_{*_t})	0.25 m/s
windspeed in mixing zone (V)	1.6 m/sec
height of meteorological tower (z_{met})	10 m
height at site (z_{local})	7 m
box model mixing height (DH)	2 m
mode of particle size (d_m)	0.1 mm (100 μm)
local surface roughness (z_o)	1 m
surface roughness at meteorological station ($z_{o_{air}}$)	0.01 m
windspeed exponent at meteorological station (P_{air})	0.1733
windspeed exponent at site (P_{local})	0.283
constant surface boundary layer thickness (δ)	500