PDHonline Course C391 (4 PDH)

Environmental Investigation and Remediation of a Hazardous Waste Site
 Part 6 - Risk Assessment, Feasibility Study and Engineered

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Course Content

Introduction

A research institute ("Institute") operated a small (0.65 acre) hazardous chemical and radioactive waste burial facility on its campus for about 20 years, starting in the mid 1960s. All waste buried at the site resulted from the use of radioactive elements and chemicals in research experiments. Waste brought to the disposal site was in both solid and liquid form, and the liquids were in various types and sizes of containers. The waste was placed into narrow trenches dug into the soil at the burial site. The trenches were about 8 to 12 feet deep. Once waste reached about 4 feet from the surface, dirt was used to fill the trench to grade.

When the site was decommissioned and no longer used, it was fenced, posted and locked. Minimal grounds maintenance was done until the State Radiation Protection Agency (RPA) notified the Institute that they were to keep the fence clear of vegetation and the area within the fence mowed and free of trees. The following photo shows the disposal area after the site was decommissioned and the grounds maintenance started:

Figure 1: Decommissioned waste disposal site at the Institute

Yearly testing of soil, surface water and vegetation by the State RPA following decommissioning of the site showed no evidence of significant radioactive contamination outside the burial area. In the late 1980s the State RPA recommended that the Institute install a series of monitoring wells to allow sampling and testing of the groundwater. In response, and under the guidance of the State Groundwater Protection Agency (GPA), the Institute installed five monitoring wells around the waste disposal site. The location of the five wells is shown on the following figure.

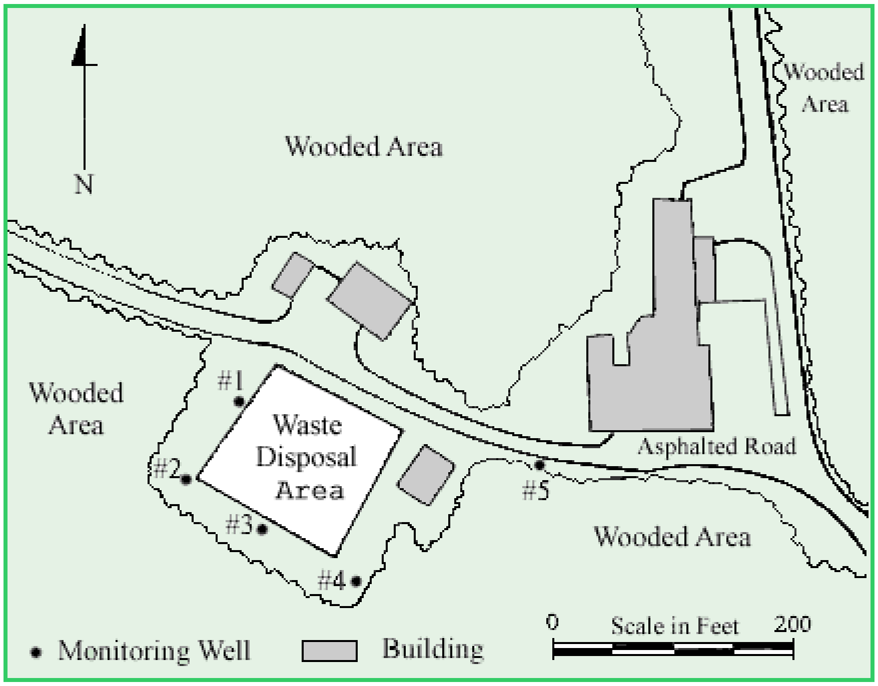

Figure 2: Location of Initial Monitoring Wells Surrounding the Waste Disposal Site

About a month after installation, the State RPA collected groundwater samples from the five monitoring wells for radiological analysis. A year later, an additional groundwater sample was collected from Well No.3 for radiological and organic chemical analysis. The radiological analyses indicated that some of the groundwater samples in the immediate surroundings of the restricted area had elevated Tritium activities. It also appeared that organic chemical contamination might be present in the groundwater in the vicinity of the waste disposal area. Discovery of both chemical and radiological contamination outside the burial area prompted the State RPA to require the Institute to design and implement an extensive investigation program. The Institute issued an RFP to environmental and engineering firms for a technical services consultant (“Consultant”). The winning bidder reviewed existing information within the Institute’s files and developed an estimate of the inventory of the waste disposed of at the site and evaluated existing soil, vegetation, groundwater and surface water test results. The Consultant issued a Preliminary Site Condition Report summarizing the results of these initial studies. The State RPA and other State Regulatory Agencies then requested additional soil, groundwater and surface water sampling, including the installation of additional groundwater monitoring wells, in order to determine the size, extent, and characteristics of the contaminant plume, and characterize the geology and hydrology of the area.

Because the disposal site contained hazardous chemicals and radioactive isotopes, no additional field investigations could be started until a project-specific Health and Safety Plan was developed. A project-specific Quality Assurance Plan was also created, and the technical requirements were developed as part of the Sampling and Testing Plan. A set of Project Procedures was written to guide the field sampling and analysis programs that incorporated the requirements of each of the project plans. The relationship of the various plans, procedures and the field and laboratory activities is shown on the following flowchart.

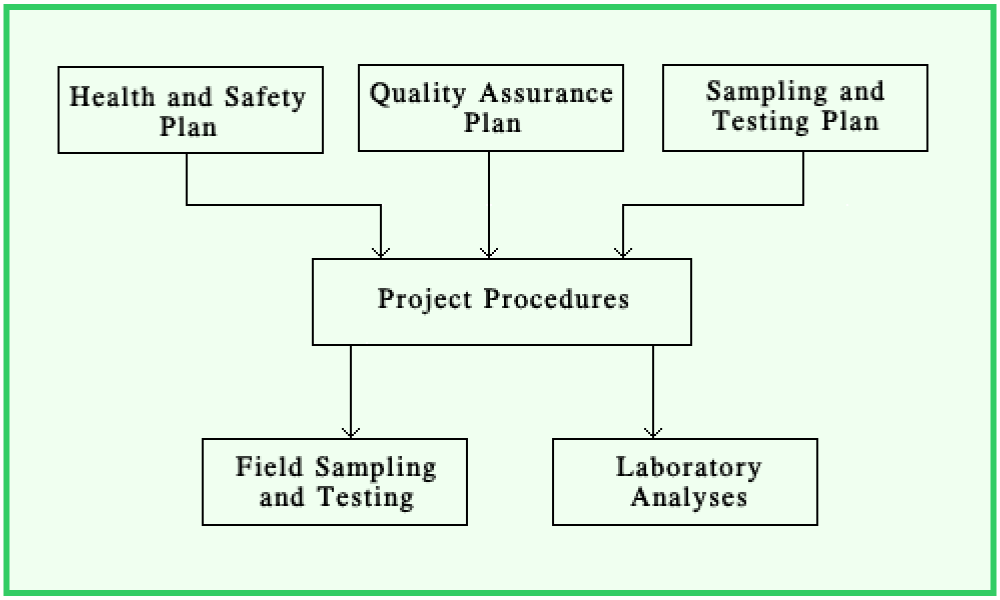

Figure 3: Relationship of the Various Project Plans, Procedures and Activities

Field investigations were divided into two phases. The Phase 1 work provided insights with respect to:

- Geologic setting,
- Grain size of soil samples,
- Surface water conditions,
- Groundwater conditions,
- Groundwater travel times,
- Chemical and radiological analyses of groundwater samples, and
- Chemical and radiological analyses of soil samples

One of the recommendations of the Phase 1 studies was to initiate the Phase 2 field investigation program, including additional work in the up-gradient direction as well as the down-gradient direction. This approach was taken to verify the extent and configuration of the area considered up-gradient and therefore free of contamination, and to determine the extent and nature of contamination down-gradient of the waste disposal area.

The Phase 2 field investigations included the implementation of the following activities at the Site:

- Preparation of an accurate topographic map
- Installation of up-gradient monitoring wells
- Collection of geologic and hydrologic information from these new wells

- Performance of permeability tests in the new wells
- Installation of new down-gradient monitoring wells
- Performance of a Hydropunch™ investigation in the floodplain
- Collection of groundwater and surface water samples for chemical analysis, and
- Interpretation of the laboratory test results

The collected data were evaluated, integrated and interpreted to arrive at the recommendation to perform a public health risk assessment, prepare an engineering feasibility study, recommend a remedial action plan, obtain the necessary regulatory approvals and implement the remedial measures to control the contamination and improve existing conditions.

Course Content

Risk Assessment

The flow chart of the health risk assessment process is presented in Figure 4, below.

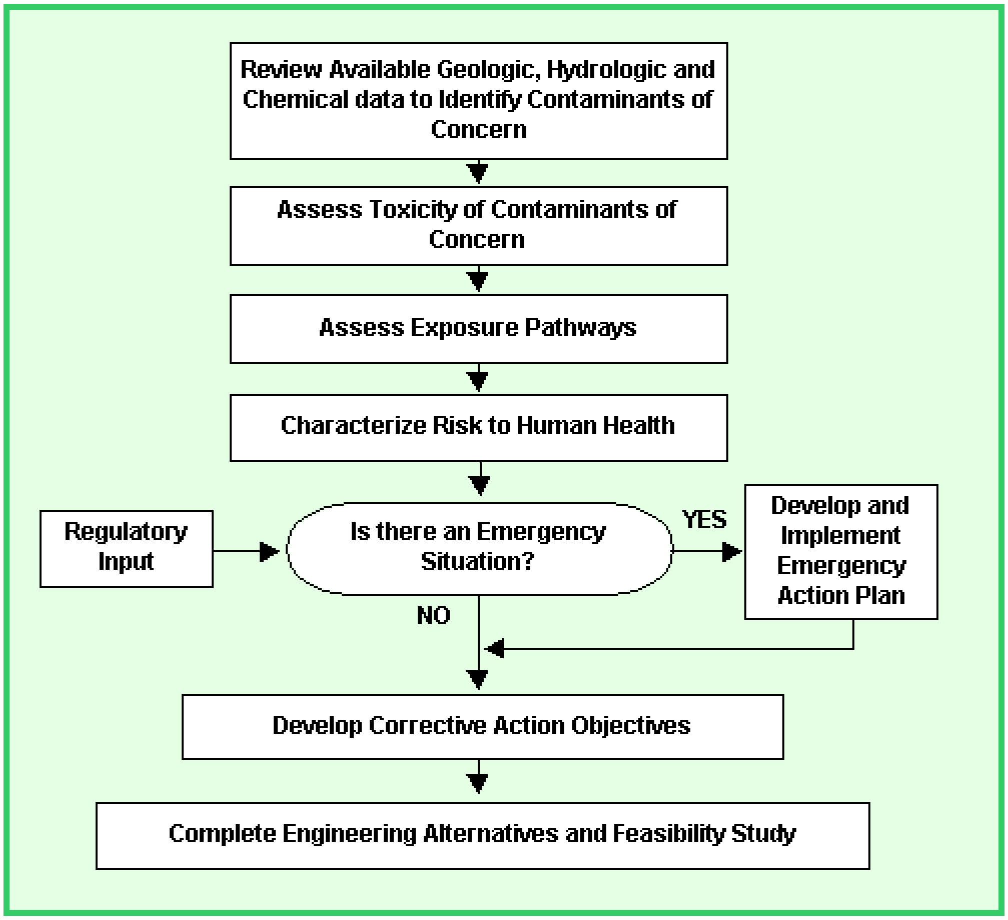

Figure 4 - Flowchart illustrating the Health Risk Assessment Process

As shown on the flowchart, the health risk assessment is completed to address two fundamental issues:

- Determine if an emergency situation exists that requires immediate action, and
- Develop a set of Corrective Action Objectives to guide the Engineering Feasibility study.

Each of the steps shown on the flowchart is discussed in the following sections.

Review of Available Data

Data evaluation involves gathering and analyzing the site data relevant to the health risk assessment and identifying the chemical substances present at the site that are the focus of the evaluation process. The results of the field investigations, described in Parts 4 and 5 of this course series, concluded that three contaminants: Tritium, chloroform and 1,4-dioxane were detected in the groundwater down-gradient of the waste disposal area. Contamination, beyond the boundaries of the waste disposal area, is restricted to the plume extending between the waste disposal area and the Creek, as shown on the following figure.

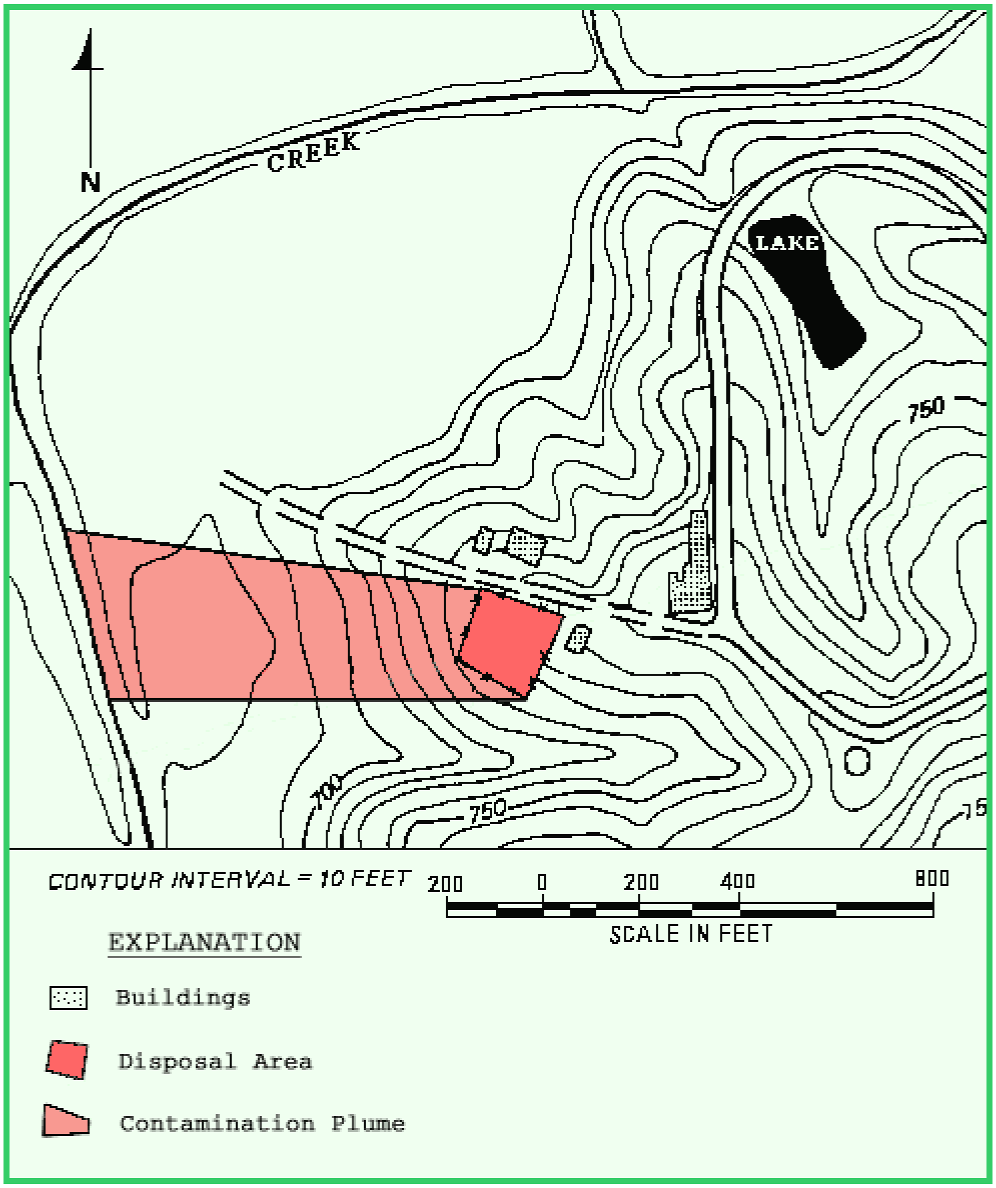

Figure 5: Diagram of the waste disposal area and down-gradient plume of contamination

The plume geometry and contaminant concentrations were determined based on the sampling and testing of a series of ten monitoring wells installed around the perimeter of the waste disposal area and at the eastern edge of the floodplain, as shown on the following figure.

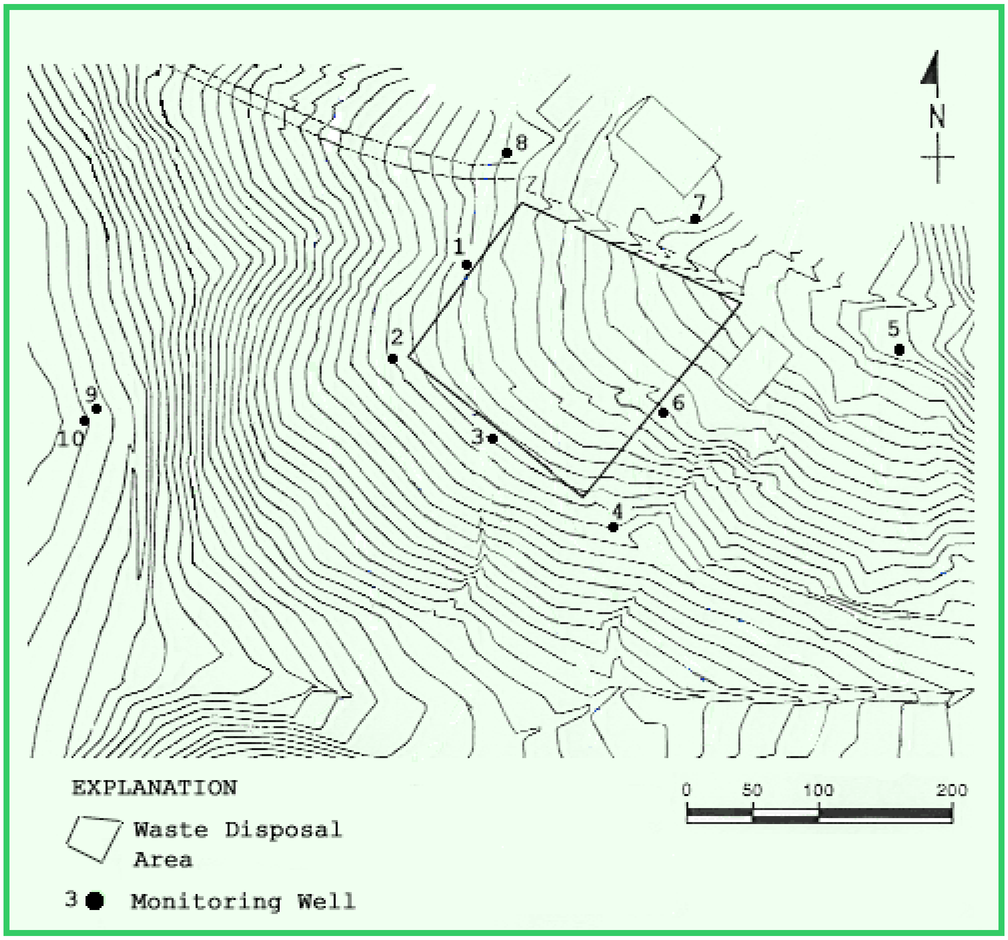

Figure 6: Location of Monitoring Wells surrounding the waste disposal area

Several rounds of water level measurements and geochemical testing of groundwater samples were completed during Phase 1 and Phase 2 field investigations (Parts 4 and 5 of this course series). For most of the samples collected, a total of 150 organic compounds and inorganic elements were tested for, as well as a complete scan for radioactive elements. Tritium, chloroform and 1,4-dioxane were the only contaminants identified in appreciable concentrations. The concentrations of these contaminants in the ten monitoring wells are summarized in the following table.

TABLE 1-Summary of Analytical Results of Groundwater Samples Collected from Monitoring Wells

Well No.	Tritium	Chloroform	1,4-Dioxane
1	3,200	1,500	2,800
2	2,100	1,300	3,000

3	14,000	1,500	2,900
4	nd	nd	nd
5	nd	nd	nd
6	nd	nd	nd
7	nd	nd	nd
8	nd	nd	nd
9	7,500	1,800	2,600
9D	7,200	2,200	3,200
10	nd	nd	nd
Detection Limit:	1000 pCi/L	5 ug/L	50 ug/L
Notes: Tritium activity is in picoCuries/liter (pCi/L). Chemical concentrations are in micro-grams/liter (ug/L). Sample 9D is a duplicate sample from Well#9 for quality assurance. Well Number 10 was installed in fresh bedrock, while 9 was in the overlying weathered rock. ‘nd’ indicates not detected (concentration below detection limit).			

The groundwater level and chemical data indicate that Monitoring Wells #4, 5, 6, 7 and 8 are up-gradient of the waste disposal area (not-contaminated), and Monitoring Wells #1, 2, 3, and 9 are down-gradient of the waste disposal area (contaminated). Well #10, screened in the granite bedrock, is also not contaminated and appears to be part of a different groundwater regime.

The information presented above indicates that the groundwater contaminants chloroform, and 1,4-dioxane are found in the same approximate concentrations at the edge of the waste disposal area (Wells #1, 2 and 3) and at the base of the slope at the eastern edge of the floodplain (Well #9).

The fact that the chemical concentrations are nearly equal but the Tritium activity at the base of the slope is half that at the perimeter of the waste disposal site (well #3) provides some insight into the travel time of the groundwater. The travel time for that distance (between well #3 and well #9) should be on the order of 12 years, or about one half-life of tritium.

A series of Hydropunch^{TM} samples were taken in the floodplain east of the Creek. This technology allows sampling the groundwater for chemical testing without the installation of permanent monitoring wells. The distribution of Hydropunch sampling locations is shown on the following figure.

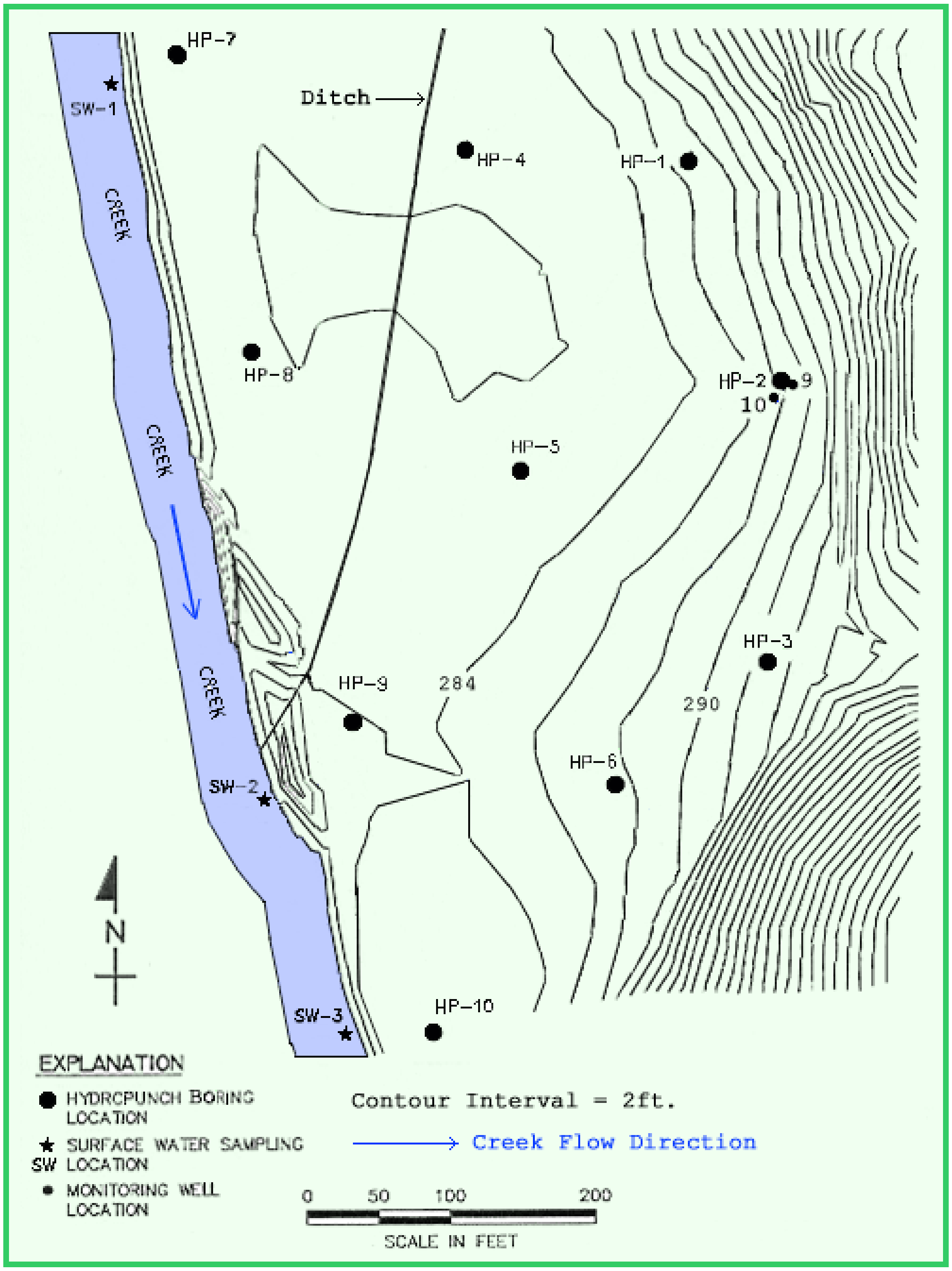

Figure 7: Location of Hydropunch^{TM} samples in the floodplain. Monitoring Wells #9 and #10 correspond to those same monitoring wells shown on figure 6.

Hydropunch samples were taken at various depths in the floodplain soils. The soil types and depth to bedrock were found to be variable in the tested area. The results of the geochemical testing of groundwater samples taken from the Hydropunch^{TM} holes are summarized in the following table.

TABLE 2-Summary of Analytical Results of Groundwater Samples Collected from Floodplain Hydropunch^{TM} Locations

Hydropunch Sample Location	Chloroform (ug/L)	Tritium (pCi/L)
HP-1	nd	nd
HP-2B	400	1,522
HP-3	nd	nd
HP-4	96	nd
HP-5	27	718
HP-6	nd	nd
HP-7	7	308
HP-8	nd	248
HP-9	nd	nd
HP-10	nd	nd
Detection Limit:	1.0 ug/L	200 pCi/L
Notes: Chloroform concentrations are in micro-grams/liter (ug/L). Tritium concentration is in picoCuries/liter (pCi/L). 'nd' indicates not detected (concentration below detection limit).		

Note that no 1,4-dioxane testing was done for the Hydropunch samples. The purpose of the floodplain study was to assess the presence or absence of contamination, not necessarily to measure accurately the actual concentration of all contaminants. Chloroform was selected as the marker contaminant and this approach saved the cost of performing additional chemical analyses while still permitting a reconnaissance tracing of the extent of contamination.

All of the geologic, hydrologic and geochemical information collected thus far was used to develop and overall interpretation of conditions at the site (see Parts 4 and 5 of this course series). This interpretation led to the formulation of the following general conclusions:

- The waste disposal area is still contributing contamination to the groundwater,
- The rate of contaminant leakage from the waste disposal area is probably not diminishing,
- Contamination has moved down-gradient of the waste disposal area and formed a plume
- The contaminant plume is not dispersing longitudinally as it moves downhill,
- Minimal dilution of the plume is taking place down to the eastern edge of the floodplain,
- Well number 9 is close to the centerline of the plume,
- Contamination has already reached the floodplain,
- The contaminant travel time to the eastern edge of the floodplain is about 12 years,
- The highest contamination levels are in the weathered rock portion of the aquifer,
- The underlying fresh bedrock is essentially impervious and uncontaminated,
- The contaminants appear to be layered in the groundwater,
- The organic chemicals are concentrated in the lowermost portions of the plume,

- Tritium, being the most mobile, appears to be uniformly mixed with the groundwater,
- A portion of the contamination may be below the bottom elevation of the creek, and
- The Contaminants of Concern are Tritium, chloroform, and 1,4-dioxane.

Toxicity Assessment

Once the Contaminants of Concern have been identified, a toxicity assessment is completed using available published information. This step in the process considers: 1) the types of adverse health effects associated with chemical exposure, 2) the relationship between magnitude of exposure and adverse effects, and 3) the uncertainties associated with the health effects in humans. This section reviews the known qualitative and quantitative toxicity information about the Contaminants of Concern: Tritium, chloroform and 1,4-dioxane.

Tritium

Tritium is the radioactive isotope of hydrogen that decays by the emission of negative beta particles. Radiation hazard is a function of radionuclide concentration, half-life, emission type or mode of decay and, ultimately, mobility of the isotope through the environment and the body. The rate of decay is expressed in term of half-lives, or the amount of time required for half of the radioactive atoms to decay. After 10 half-lives, this in the case of Tritium amounts to about 123 years, 0.1% of the initial radioactivity will remain.

The amount and type of radiation humans absorb is a function of the duration of exposure and distance from the exposure source. Radiation exposure decreases with distance according to the inverse square law. Thus, decreasing the time and increasing the distance near a radiation source will greatly lower risk. Shielding is also very effective as a means of providing protection from radiation.

Although it can be considered inconsequential by comparison to other sources of radioactivity, tritium is considered toxic because of its radiochemical decay and mobility especially if ingested or inhaled. Mobility refers to the high solubility and volatility of the isotope and its chemically bound forms.

Tritium was detected within the plume of contamination in activities above those recorded in the up-gradient monitoring wells. However, measured Tritium concentrations in all the down-gradient-monitoring wells did not exceed the National Primary Drinking Water Standard of 20,000 pCi/L. Tritium activities in the down-gradient wells ranged from a low of 2,100 (well #2) to a high of 14,000 pCi/L (well #3).

At this point, tritium was no longer considered a contaminant of concern within the plume because all detected concentrations were below 20,000 pCi/L. The State RPA felt that any source remediation that will eventually be implemented would also lower the tritium activity within the plume. For these reasons, the State RPA ceded its regulatory enforcement lead to the State GPA and the State WMA, Superfund Section.

Chloroform

Chloroform, also known as trichloromethane, methyl trichloride, formyl trichloride, methane trichloride, trichloroform, methenyl trichloride, and trichlormethan, is a clear colorless liquid with a sweet odor. Chloroform is stable, but may decompose on exposure to light. It is incompatible with a wide variety of materials and especially with strong oxidizing agents.

Chloroform causes cancer in laboratory animals, and is listed by the International Agency for Research on Cancer as a probable human carcinogen. It is an irritant and inhalation and ingestion are harmful. It may cause reproductive damage, and may be fatal. Prolonged or repeated skin contact may cause dermatitis. The typical Threshold Limit Value (TLV) is 50 ppm. The threshold value is the dose at which it is possible to begin measuring a toxic response. The lowest published oral lethal dose for man is given as 2,514 mg/kg (or 2,514 ppm). The water quality criteria published by EPA reflect pollutant concentrations which when not exceeded reasonably protect human health, aquatic life and the environment. For chloroform, these criteria list a concentration of 0.1 mg/L for the Maximum Contaminant Limit (MCL) and as 0.00019 mg/L at a risk of 10-6 (1 in a million). The 10% Effective Dose (ED10) for ingestion and for inhalation is listed by EPA as 0.508 mg/kg/day. The ED10 is the dose in mg/kg/day at which 10% incidence above control is observed for a tumor type showing a statistically significant incidence.

At this point, it should be emphasized that the concentration of chloroform in the down-gradient monitoring wells ranged from a low of 1,300 to a high of 2,200 ug/L (parts per billion), which is well below the TLV of 50 ppm (parts per million). Chloroform is also produced by the process of chlorinating drinking water. For example, tested drinking water wells in New York and New Jersey detected chloroform concentration in the range 67 to 490 ug/L. Other US cities report chloroform concentrations values in the drinking water in the range 0 to 190 ug/L. The reported values tend to be highest in summer and lowest in winter. No adverse health effects appear to result from these concentrations in the drinking water supply.

1,4-Dioxane

1,4-dioxane, also known as dioxane, diethelene dioxide, 1,4-diethylene dioxide, diethylene ether, glycol ethylene ether, dioxane-1,4, and tetrahydro-p-dioxin is a clear colorless liquid. 1,4-dioxane is commonly used as a solvent, cleaning agent, chemical stabilizer, surface coatings, adhesive agent and an ingredient in chemical manufacture. 1,4-dioxane is stable, and is incompatible with oxidizing agents, oxygen, halogens, and reducing agents. It is highly flammable and has a wide explosive range. May form explosive peroxides in storage, with the rate of formation increased by heating, evaporation or exposure to light.

1,4-dioxane is a toxic substance and a probable carcinogen – based on sufficient evidence of carcinogenicity in animals. It is harmful when inhaled or ingested by drinking and is a skin irritant and can be absorbed into the body through the skin. The typical Threshold Limit Value (TLV) is 25 ppm in air. The threshold value is the dose at which it is possible to begin measuring a toxic response. The Occupational Safety and Health Administration (OSHA) standard is set at 100 ppm in air. According to the International Agency for Research on Cancer, the human lowest published lethal concentration by inhalation is 470 ppm over a period of 3 days. The water quality criteria published by EPA reflect pollutant concentrations which when not exceeded reasonably protect human health, aquatic life and the environment. For 1,4-dioxane, these criteria specify that the concentration that should not be exceeded is 0.007 mg/L at a risk of 10^{-6} (1 in a million). The 10% Effective Dose (ED10) for ingestion and for inhalation is listed by EPA as 29.40 mg/kg/day. The ED10 is the dose in mg/kg/day at which 10% incidence above control is observed for a tumor type showing a statistically significant incidence.

At this point, it should be emphasized that the concentration of 1,4-dioxane in the down-gradient monitoring wells ranged from a low of 2,600 to a high of 3,200 ug/L (or parts per billion). These values are well below the lowest published lethal concentration of 470 ppm (parts per million) and the OSHA standard of 100 ppm by inhalation (or ingestion).

Exposure Pathway Assessment

The pathway assessment is conducted to estimate the potential for human exposure to the Contaminants of Concern. During this step, the probable frequency and duration of the exposure, and the pathways by which humans are potentially exposed to the contaminants are identified. Reasonable maximum estimates of exposure are also developed for both current and future land-use assumptions. Current exposure estimates are used to determine whether a health threat exists based on existing conditions at the site in the absence of implementing an engineered remedial measure.

At this point in the process, the waste disposal area itself was fenced, posted and locked. These measures effectively served to control access to the area where the trenches are located and prevent inadvertent public exposure to the contaminants at the source. In addition, the entire research campus is also surrounded by a high cyclone fence, and the only access is through a double fenced entrance gate monitored around the clock by a security guard.

The floodplain, west of the waste disposal area, was mapped by the Federal Emergency Management Agency (FEMA) and classified as a high hazard area prone to a "100-year flood". This classification implies that the flood plain is susceptible to a base flood level of 5 feet with a one percent or greater chance of being equaled or exceeded in any given year. As such, this area is subject to zoning restrictions and special flood ordinances that would limit construction, placement of fill or similar alteration of topography that would reduce the area available to convey flood waters. Also, vehicular access to the floodplain from the campus is restricted by a locked high gate. The land of the floodplain is and will remain undeveloped in the foreseeable future.

At the recommendation of the Consultant, the cultivation of a corn crop on the southern part of the floodplain, reported in Part 4 of this course series, has been discontinued. As explained above, and in compliance with existing regulations, the land of the floodplain will remain undeveloped.

Risk Characterization

This step in the process summarizes and combines the results of the exposure and toxicity assessments to characterize baseline risk. The characterization can be expressed in quantitative expressions and/or qualitative statements. Two questions need to be addressed: 1) is there an emergency situation that must be remediated immediately? and 2) what are the objectives of a corrective remedial action program?

Because of the effective institutional controls that are enforced around the clock, the waste buried in the trenches within the waste disposal area is inaccessible to inadvertent human intrusion. In addition, the concentration of the contaminants within the down-gradient plume is measured in parts per billion, presenting only a low hazard that is also not readily accessible to humans by direct contact or ingestion. Therefore, the contamination that exists at the source and within the down-gradient plume is effectively isolated from the accessible human environment.

Because no credible contamination pathway for human exposure appears to exist and chemical concentrations outside the waste disposal area are well below the credible toxic levels established by the EPA and OSHA, no emergency action plan or special interim measures were called for immediate implementation in this case.

Corrective Action Objectives

In terms of Corrective Action Objectives, two issues are addressed: the down gradient plume that has reached the floodplain, and the waste disposal area, which is the source of the contamination. Each of these issues is discussed in the following sections.

Contaminant Plume

Although the contaminant levels in the plume were low and the chance of significant human exposure was remote, it was still desirable to investigate the implementation of active intervention methods that would bring down the concentration of the contaminants to levels that are at or below the published regulatory drinking water standards. This was also done to familiarize the student with approaches that can be used to lower the concentration of chemicals within a contaminant plume. Because two contaminants (chloroform and 1,4-Dioxane) co-exist within the plume in this case, the combined toxic effects of these substances should be considered additive and any reduction in the concentration of either one that could be achieved would be advantageous.

The Corrective Action options that were considered for the plume included bio-remediation and pumping and treating the contaminated groundwater.

Waste Disposal Area

A corrective action objective for the waste disposal area is to significantly reduce the infiltration of surface water into the trenches. An optimal corrective action should be capable of substantially reducing the leaching of contaminants from within the trenches in order to prevent their migration downward to the groundwater table. Effective implementation of source control measures would also result in gradually reducing the concentration of the groundwater contamination within the plume, since the source of the contamination would be greatly reduced or stopped at its source.

The corrective action objective could also be achieved by the total removal and the proper re-disposal of the hazardous wastes buried onsite. Another approach could be to stabilize the hazardous waste in the trenches by transforming it into a form that cannot be readily leached.

Periodic analysis of groundwater samples from the down-gradient monitoring wells should be continued. This monitoring is needed to evaluate the effectiveness of the proposed remedial measures to control and stop the continued spread of the contamination.

Feasibility Study

At this point, the Corrective Action Objectives have been identified. The next step is to address these objectives by completing an evaluation and screening of a universe of appropriate and proven engineering remediation alternatives. The following figure presents a flowchart of the process leading to the selection and implementation of a Corrective Action Plan.

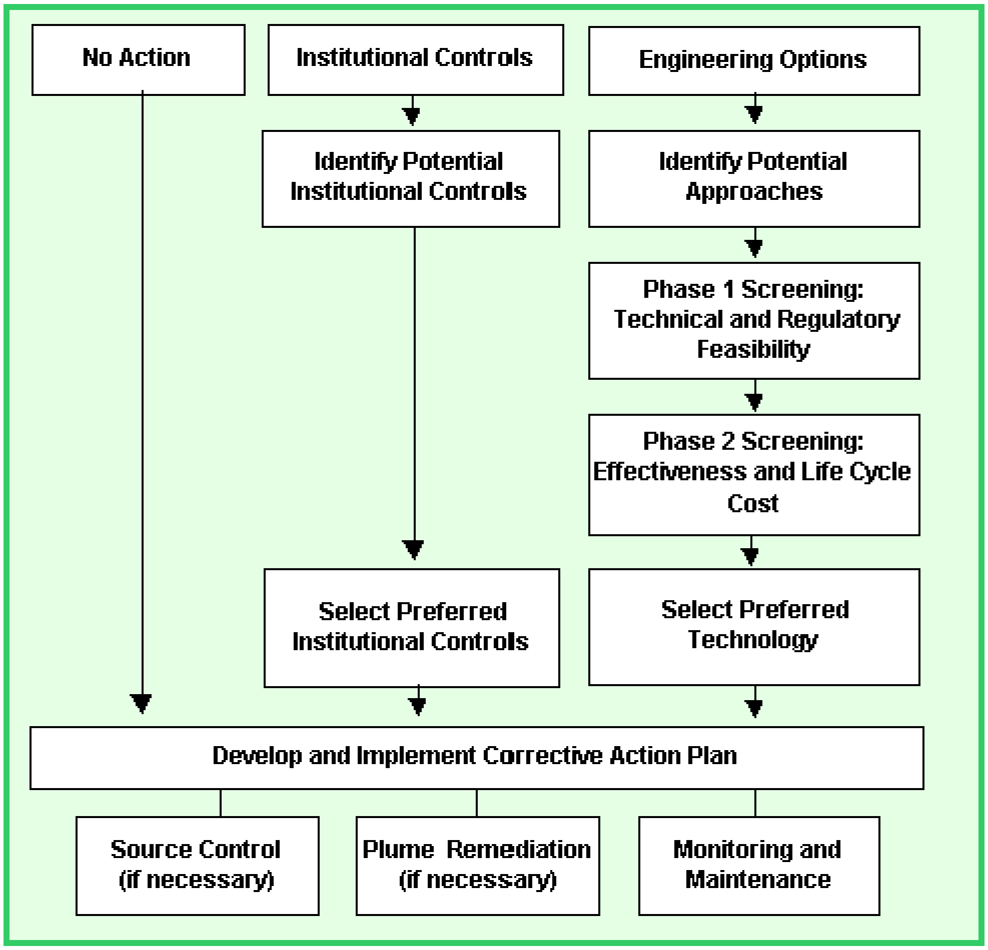

Figure 8: Flowchart illustrating the steps involved in developing a Corrective Action Plan

As shown on the flowchart, three independent assessment paths are initiated at the start of the process. The first assessment path considers the "No Action" option. This assessment is required by the EPA and includes addressing what may happen if nothing at all is done at the site. The "No Action" option becomes the baseline against which all other options are compared.

The second assessment path is based solely on setting effective institutional controls. Institutional controls are those activities that address the protection of humans from inadvertently contacting the waste in the absence of implementing any remedial measures. Such controls include fencing the area and installing a locked gate, posting signs warning of the danger, placing security guards at the site, and more permanent monuments with metal plaques explaining the contents of the site and dangers to human health. Institutional controls also include ensuring that records of the site contents, the layout of the trenches and boundaries of the contaminated area exist and are filed with the appropriate regulatory agencies. These steps are taken to ensure that no one "forgets" that there is hazardous and radioactive waste buried in this area.

The site is currently protected by effective institutional controls. The waste disposal area itself is surrounded by a fence with a locked gate and warning signs are posted on the fence. Also, the campus itself is fenced and the main gate is manned 24/7 by security personnel. Although these controls have been effective to date, the selected corrective action plan needs to address the viability of such measures as a long-term solution, both alone and in combination with the preferred site remediation measures for a period of at least 30 years.

The third assessment path calls for the evaluation of engineering options for the remediation of the existing contamination. At this site, both the source of the contamination (the waste disposal area) and the downgradient plume of contaminated groundwater are addressed. As shown on the flowchart, the first step is the identification of potential engineered approaches to remediation. Once this is accomplished, a Phase 1 screening is performed to establish technical and regulatory feasibility. Those technologies that pass Phase 1 screening are then evaluated for effectiveness and life cycle costs in a Phase 2 screening step. Approaches that pass Phase 2 screening are then compared and a preferred alternative selected for inclusion in the Corrective Action Plan. This process is made somewhat more complex by the consideration of engineering alternatives both individually and in combination.

The following sections present the engineering alternatives that were evaluated and discuss the various steps in the evaluation process.

The No Action Alternative

This approach provides a basis for evaluating potential human health impacts in the absence of remediation. The No Action scenario assumes that the waste disposal area is abandoned and no institutional controls are implemented. It is customary, however, to include periodic site status re-evaluation. This alternative provides no protection against present or future hazardous material releases to the environment. The No Action scenario may be used to evaluate the severity or emergency status of the Site. This evaluation is expressed in terms of excursion rates and potential receptors, as discussed below.

Excursion Rates

Excursion rate is the quantification of plume advancement. Fate and transport modeling is one means by which to quantify excursion. This approach, however, requires the availability of a great deal of site specific information such as: dispersion coefficients, retardation factors, effective porosity and hydraulic conductivity. Very little of that information was available for this Site. Other alternatives include assuming that all of the contaminants are advancing at the rate of the groundwater movement, ignoring dispersion and retardation effects. In Part 5 of this series of courses it was estimated that the contaminants would take about 9 to 12 years to reach the eastern edge of the flood plain, and an additional 9 to 17 years to reach the Creek.

At the time this study was conducted the waste disposal site had been decommissioned for about 10 years. Since during this investigation the plume of contaminants was found to have already reached the Creek, it can be inferred that contaminants started their migration into the groundwater during the period of active waste disposal at the site. Therefore, it can be inferred that the existing ground conditions within the trenches were not conducive to waste isolation at the time when active waste disposal was taking place. Finally, testing the water of the Creek did not detect the presence of contaminants, possibly because of the high degree of dilution or because the bulk of the contamination plume may be moving below the bottom of the Creek.

Potential Receptors

For the purpose of this evaluation, a receptor is defined as a person at a point of potential contact with the contamination. This was assumed to occur through direct ingestion of contaminated soil or groundwater, or indirectly by ingestion of plant or animal material that uptake the contaminants. Because there are no residents, water wells or springs down-gradient from the waste disposal site, the possibility of direct ingestion appears remote. Although the taproots of some trees may have penetrated the plume of contaminants within the slope, west of the waste disposal area, this vegetation is not available for human consumption. In addition, the area on the western side of the Creek is wooded, undeveloped and uninhabited. Consequently, based on the absence of potential points of human contact with the plume of contaminants, it became apparent that an emergency cleanup scenario was not warranted.

Although the choice to adopt a “No Action” course of action is financially attractive, it is not acceptable to the regulatory agencies. As long as hazardous waste is within the waste disposal area and the potential for the leaching of contaminants into the groundwater exists, the applicable federal and state regulations will require some form of active intervention. Therefore, this approach is carried forward only to provide a baseline for comparison with other potential engineered remedial alternatives.

Institutional Controls

This approach entails the continued use of existing institutional controls at the Site for a period of 30 years into the future. Examples include site access restrictions and prohibitions against site disturbance. A restriction on groundwater use down-gradient from the waste disposal area should also be added as a control measure. During this period the existing soil cover over the waste disposal area should be maintained to minimize erosion. Following the 30-year period, conditions would be re-evaluated. When implemented effectively, institutional controls can protect against inadvertent human exposure. These measures alone would not, however, protect the environment from further degradation resulting from future releases associated with leachate production. Institutional controls by themselves are not as reliable as more proactive engineered measures for long term remediation.

Engineered Options

The engineered options analysis was divided into two parts: remediation of the contaminant plume and the isolation of the waste disposal area, the source of contamination. Each part is addressed below.

Options for Plume Remediation

Two remedial alternatives were examined for the plume: bio-remediation and pumping and treating the groundwater. At the time of the study, some success with bio-remediation (using bacteria introduced into the soil to digest contaminants) had been demonstrated for certain types of oils and other organic contaminants. However, no specific examples of chloroform and/or 1,4-dioxane remediation using bacteria had been reported in the literature. This alternative, therefore, was dropped from further consideration.

The pump and treat option, on the other hand, consists of pumping contaminated groundwater from specifically designed pumping wells, treating the water to remove contamination, then re-injecting the clean water at some other uncontaminated down-gradient place on site. This option was considered feasible, although due to the generally low hydraulic conductivity of the soils, pumping rates would necessarily have to be low in order to keep the pumping wells from drying out. Also, pumping down-gradient of the waste disposal area would accelerate the movement of contamination downslope. Therefore, source control measures should already be in place so that the pump and treat operation could eventually recover uncontaminated water in some reasonable period of time.

In this case a mobile packed column air stripper would be well suited for the removal of the volatile organic compounds, chloroform and 1,4-Dioxane, from the groundwater. Air stripping involves the mass transfer of the volatile contaminants from water to air and is accomplished as described below.

A typical mobile packed column air stripper includes a spray nozzle at the top of a tower to distribute contaminated water over the packing in the column. A fan at the bottom of the column forces air countercurrent to the water flow. The packed bed which consists of molded plastic, metal or ceramic shapes is specifically designed to maximize the contact with the air stream described above. After passing through the bed, the decontaminated water is collected in a pan or holding chamber at the base of the column before being discharged. After receiving the contaminants from the water stream, the air is passed through a device to eliminate water droplets from the air stream and is discharged from the top of the column. The following figure shows a diagrammatic representation of this process.

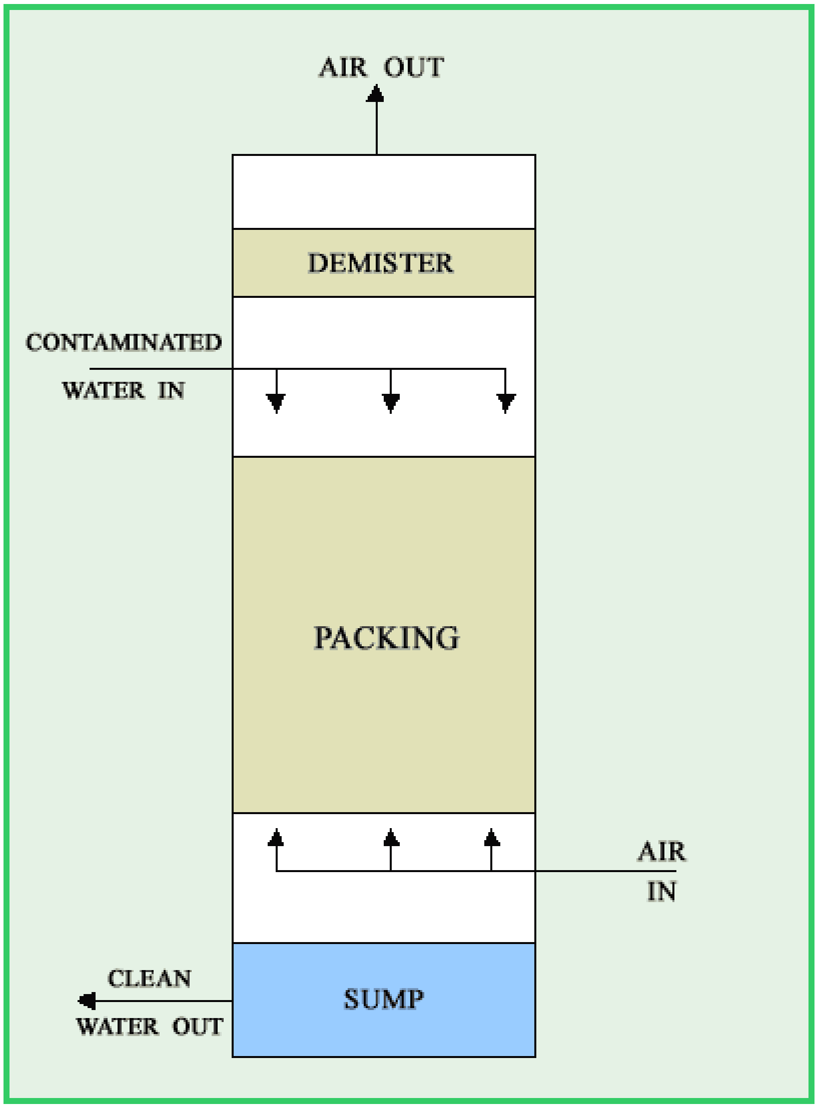

Figure 9: Simplified diagram of the packed column air stripping process

The following figure is a photograph of a mobile column air stripper.

Figure 10 Photograph of a typical operating mobile packed column air stripper

Auxiliary equipment that can be added to the basic air stripper to increase functionality and safety includes an air heater to improve removal efficiencies; automated control systems with sump level switches and safety features, such as differential pressure monitors, high sump level switches, and explosion-proof components.

Because the concentration of contaminants in the plume is low, it is not anticipated at this time that there will be a need to apply for a permit to discharge chloroform and 1,4-Dioxane into the atmosphere. Nonetheless, the Bureau of Air Quality Control will be notified and asked to monitor the contaminant levels and decide when and if it will be necessary to issue a permit and/or request that steps be taken to reduce levels if they become too high. If deemed necessary by the Bureau of Air Quality Control, the tower can be equipped with air emission control and treatment systems, such as activated carbon units, catalytic oxidizers, or thermal oxidizers which prevent the contaminants from dissipating into the atmosphere.

Air stripping in theory is a simple process, but to operate at maximum efficiency all components of the system must be carefully engineered. Changes in operating parameters (process flow rates, contaminant concentrations, etc.) will affect the operating balance of the system and must be examined on a case-by-case basis to determine their influence on process efficiency.

Mobile stripping-systems with capacity of up to 100-gpm are available with variable blower capacities to achieve required efficiencies. The rental cost of the unit shown on Figure 10 would be on the order of a few hundred dollars per day. However, mobilization/demobilization, transportation and set-up charges could run up to $10,000 or more.

The major operating cost of air strippers is the electricity required for the ground water pump, the sump discharge pump, and the air blower. The Horse Power (HP) rating of the ground water pump depends on the pressure head and pressure drop across the column and should be obtained from pump curves. As a general rule, pumps in the 4 to 80 liters per minute (1 to 20-gpm) range, the anticipated capacity of the pumping well at the site, require from 0.33 to 2 HP. Another approximate method of estimating blower motor power assumes that each foot of air stripper diameter requires 1.5 HP. As a cautionary note: algae, fungi, bacteria, and fine particles may foul the equipment, requiring pretreatment of the groundwater or periodic column cleaning.

The Consultant felt that placing pumping wells immediately down gradient of the waste disposal site was not advisable because of proximity to the source of contamination and because the permeability of the weathered rock zone is too low. In addition, the low level of contamination in the plume within the flood plain and the absence of credible human exposure scenarios did not warrant the implementation of a plume remediation program at this time. However, in case such a program became advisable to run, the Consultant proposed implementing a pilot study to test the feasibility of the pump and treat option. Well #9 is ideally located close to the centerline of the plume, at the eastern edge of the flood plain and it penetrated the highest contamination levels within the weathered rock portion of the aquifer. Therefore, the existing Well #9 could be used to pump the groundwater for testing the extraction of chloroform and 1,4-dioxane from the groundwater. If proven successful and deemed necessary, the pilot study could then be expanded to a full-scale treatment operation by installing additional pumping wells in the flood plain, if needed, to stop the contaminated groundwater from reaching the creek.

At this point, however, plume remediation was not carried forward in the Engineered Options study. The Consultant believed that implementing an effective source control measure will by itself attenuate the concentration of the contaminants within the plume to below regulatory limit levels.

Options for Source Control

In order to identify the preferred technology for source control, a conceptual Feasibility Study was conducted. The primary objective of this study was to screen a universe of acceptable technologies in order to provide the Institute with a technical, regulatory and economic basis to determine which corrective action would be most appropriate to isolate the source of contamination.

Identification of Potential Alternatives and Phase 1 Screening

As shown on Figure 8, the first step in the evaluation of available options is to identify potential engineered approaches for source control. This process focused on the proven technologies that were chosen for similar situations at other hazardous waste disposal sites. Several sources of information were consulted during this phase of the study including for example EPA guidance documents, vendor materials and experience gained from work on similar projects.

The second step involved the implementation of a Phase 1 screening of the identified options in which each potentially applicable technology was evaluated with respect to technical feasibility and the possibility that some regulatory issues may render the option impractical to implement. The options that did not pass the Phase 1 screening step were eliminated from further consideration.

The technologies that were evaluated at the onset fell into several categories, as follows:

- Capping Technologies, including single and multiple barrier caps
- Excavation, Treatment and Disposal Technologies
- In-Situ Treatment technologies
- Auxiliary Control measures

The final item, Auxiliary Controls, is not a stand-alone remedial alternative, but it addresses additional approaches meant to augment the capping or in-situ and off-site treatment and disposal technologies. Each of these categories is presented below.

Capping Technologies

Capping is used to minimize infiltration of surface water into the trenches and prevent inadvertent human contacts with the buried hazardous wastes. Capping technologies fall into two major categories: single barrier caps and multiple barrier caps. The various cap designs which were considered are summarized below.

Single Barrier Caps

Four types of single barrier caps were evaluated: clay, asphalt, concrete, and synthetic membranes. Each type is discussed below together with the results of the Phase 1 screening.

Clay Cap

Description: Clay is frequently used to line and cover both hazardous and non-hazardous wastes. Naturally occurring local deposits are quarried to obtain the clay that is transported to the site and placed in thin layers over the waste disposal area. The thin layers of clay are compacted at optimum moisture content to assure low permeability. This produces a barrier to infiltration and leachate formation. Foundation preparation, including some fill placement and grading, will be needed to ensure the optimal performance of the cap.

Phase 1 Screening: A clay cap is a single layer barrier, which is susceptible to leaks resulting from storm runoff erosion and to cracking from freeze-thaw and wet-dry climatic cycles. Clay caps may also be susceptible to differential settlement cracking, rodent burrowing, and natural invasion by deep-rooted vegetation. Careful design and continuous maintenance is typically required. Clay layers are frequently used as a component in multi-layer infiltration barrier systems. Based on its stand-alone performance, the clay cap is not considered sufficiently adequate and was eliminated from further consideration.

Asphalt Cap

Description: This type of cap consists of an asphalt layer placed on top of a crushed stone or gravel layer placed on top of the waste disposal area. Before the cap is constructed, the foundation surface requires some fill placement and grading in order to ensure the performance of the cap and minimize cracking.

Phase 1 Screening: The asphalt cap is a single layer barrier which is effective in preventing the infiltration of surface water and the ensuing leaching of the waste. Asphalt is unstable on steep or excessively sloping surfaces, susceptible to cracking from differential settlement and freeze-thaw stresses, but has the advantage of resistance to erosion or penetration by roots and burrowing animals. Although it is not retained for further evaluation as a single barrier option, it will be further evaluated as a component of a multiple layer cap that can provide a usable level or gently sloping planar surface, for parking for example.

Concrete Cap

Description: This type of cap consists of placing concrete directly on top of the prepared and graded surface of the waste disposal area. Concrete would be poured in jointed segments and would be reinforced by steel bars or steel wire mesh. Flexible expansion joint material would be used to tie in the various segments into a cohesive unit.

Phase 1 Screening: The concrete cap would be effective at preventing infiltration of surface runoff and would inhibit the leaching of the waste by the percolating water. However, the structural integrity of the concrete cap can be affected by soil and water chemistry. Another disadvantage is its susceptibility to cracking to a much greater degree relative to other capping technologies. Because of these disadvantages and the requirement to use flexible jointing to join adjacent blocks, the concrete cap is not retained for further consideration.

Synthetic Membranes

Description: Synthetic membranes have been used as both liners and caps in landfills and other types of waste storage and disposal facilities, such as those containing low-level radioactive wastes. The membrane is installed in sections by unrolling the material and covering the area to be isolated. Adjacent sections are joined together by field welding during installation. When used as a single barrier, the synthetic membrane must be left uncovered to permit periodic visual examination of the protective surface to identify tears and defects that may develop over time.

Phase 1 Screening: Most synthetic membranes will provide an effective and protective impermeable layer if they are installed properly. Vigilance during installation should be exercised to avoid incompatibility problems between solvents and types of membrane materials. Synthetic materials are susceptible to weathering and deterioration over time and may eventually have to be replaced, but they are expected to last for up to 25 years and possibly longer. Recent advances in the formulation of polymers have resulted in the production of membranes that have superior durability, flexibility and elongation characteristics without the use of plasticizers. In-place repair of these membranes is relatively simple. The synthetic membrane cap can accomplish the corrective action objectives and is retained for further consideration.

Multiple Barrier Caps

Description: This technology combines two or more of the single capping options described above along with appropriate protective layers and drainage features. A multiple barrier cap would be designed to cover the waste disposal area and provide protection from direct exposure to the buried waste and prevent infiltration from precipitation and surface runoff.

Phase 1 Screening: Properly designed multiple barrier caps are capable of meeting the corrective action objectives for closure. When a synthetic membrane is used with compacted clay as a dual barrier system, the membrane is protected by an overlying layer of soil. This overlying layer of soil is stabilized at its base by a drainage layer and at its top by an erosion control mat and vegetation. The clay layer itself is protected by the overlying synthetic membrane and the soil layers. When properly installed in accordance with accepted quality assurance procedures, this type of cap requires minimal active maintenance. Because of these advantages, this technology is retained for further evaluation.

Excavation and Re-Disposal Technologies

This category of technologies involves the physical removal of the trench contents and surrounding contaminated soil with the intention of re-disposal in a more secure setting either off-site or on-site.

Excavation and Off-Site Disposal

Description: This type of removal technology refers to the use of conventional construction equipment such as backhoes, bulldozers, front-end loaders, drag-lines, and dump trucks to excavate and handle the waste and contaminated soil. Once removed, the materials have to be separated, treated for stabilization and hauled to a permitted facility for disposal.

Phase 1 Screening: The concentration of the contaminants at the source (within the trenches) is assumed to be at least one order of magnitude higher than the concentration measured within the down-gradient plume in the immediate vicinity of the waste disposal area. Since excavation would be required as the initial material-handling step in any alternative involving removal of the contaminated trench contents, it should be performed with great care. To minimize the potential hazards associated with the release of volatile organic compounds and radioactive sources, excavation can be shrouded and health and safety measures, such as the use of personal protective equipment, air monitoring and dust suppression, can be implemented. Provided that these concerns are adequately addressed, excavation could effectively remove the trench contents, down to a depth of about 12 feet. Once removed, the materials can be segregated, treated for stabilization and hauled for off-site disposal.

Unfortunately, it should also be assumed that the soil and the weathered granite that occur between the bottom of the trenches and the top of the slightly weathered to fresh granite are also contaminated. This large volume of material will need to be excavated, treated and stabilized in preparation for off-site disposal as well. Based on the information developed in Parts 4 and 5 of this course series, the contaminated soils are estimated to extend about 40 feet below the bottom of the trenches. Excavating the waste disposal area down to a depth of about 40 to 50 feet would require the use of specialized digging equipment. Additional process options, such as de-watering to reduce moisture content of the soil, are expected to be required for the portion of the excavation that extends below the groundwater table. Also, once the contaminated soil and weathered granite have been excavated and hauled for off-site disposal, the deep excavation left behind will have to be refilled up to grade with clean soil imported to the Site.

At the time this study was conducted, there were no commercial facilities that were permitted to dispose of mixed waste (defined as both radioactive and hazardous). It is quite likely that some of the material in the trenches consists of intimately mixed radioactive and chemical compounds and therefore could not be disposed off-site. This approach, however, is retained for further evaluation because a licensed facility may become available and could in the future accept the trench contents for permanent off-site disposal.

Excavation and On-Site Disposal

Description: On-site re-disposal of the waste by land-filling involves removal of the trench contents and surrounding contaminated soil, segregation, stabilization and its on-site re-disposal in a new properly constructed engineered and permitted landfill.

Phase 1 Screening: Although this option can be designed to meet the corrective action objectives, it is subject to the same land disposal restrictions as the off-site disposal option. This approach entails the on-site construction of a new landfill with double liners, providing a leachate collection and monitoring system, complying with various siting criteria, and obtaining all the necessary permits for a full-scale disposal facility. In addition, this approach is also impractical because of space limitations on the Institute's campus. Because of these reasons, this technology option is not evaluated any further.

Excavation and Treatment Technologies

This category of technologies involves the physical removal of the trench contents and surrounding contaminated soil and the treatment to solidify and fix or incinerate to destroy and/or significantly reduce the volume of contaminants. These options are discussed below.

Excavation and Solidification-Fixation

Description: Solidification-fixation is a physical treatment process whereby the trench contents and contaminated soils are immobilized in a stable, cement-type matrix. Cement, lime, fly ash, sodium silicate, organic polymers, pozzolan and asphalt are among the compounds that are used to immobilize contaminants. Cementatious solidification uses alkaline reagents (similar to Portland cement) to form bonds between the solid particles in the medium. Pozzolanic fixation mixes fine silicate reagents (similar to fly ash) with or without alkaline additives (e.g. lime) to achieve the same objective. Vendors offer a variety of proprietary additives that function as chelating agents or chemical precipitants to assist in the chemical binding process. Soils treated with one or more of these agents develop properties that range from clay-like to monolithic consistency. The stable end product is expected to immobilize the contaminants so that they will not leach. The method of disposal of the end product would depend on an acceptable test procedure, such as the Toxicity Characteristic Leaching Procedure (TCLP). Some of the State Regulatory Agencies may require the performance of tests with more restrictive criteria than the TCLP to test the extent of effective solidification-fixation.

Phase 1 Screening: Chemical solidification-fixation is an effective and commercially available process for stabilizing and reducing the leachability of the contaminants in the soils. This technology can substantially increase the volume of the trench contents and treated soils resulting in higher transportation and disposal costs. Volatile organic compounds may not be adequately fixed by this technology, resulting in potential leaching or release as air emissions both during and after the process is implemented. Also, since permitted on-site disposal is difficult or impossible to obtain and the off-site disposal option is not yet available to receive the mixed waste end product, this option is not retained for further evaluation.

Excavation and Off-Site Incineration

Description: Incineration is the most common thermal process option that can be used to destroy a wide variety of organic contaminants present in soils, sludge or liquids. Typical types of incinerators include rotary kiln, multiple hearths, infrared and fluidized bed. Each is suited for a particular type of waste. The organic contaminants in the soil would be destroyed at temperatures ranging from 1,500º to 2,200º F. Any inorganic contaminants present in the soil would pass through the process and remain essentially unchanged, concentrating in one of the residual streams such as ash, scrubber effluent or off-gas.

Phase 1 Screening: Incineration is an effective and proven means of treating the organic-contaminated soil, but it does not affect or reduce the radioactive component. Incineration could be performed off-site provided that all regulatory requirements are met. Since separation of debris and soil is required before incineration, this could involve potential exposure to the waste by the personnel involved in this operation. Because incinerators are not usually permitted to process mixed waste (radioactive and chemical) this option is not evaluated any further.

Bio-Remediation

Description: Bio-remediation involves excavating and mixing the waste with water, bio-sludge and nutrients to allow for the destruction of the organic contaminants. Typical applications involve relatively homogeneous wastes that do not contain biocides in the waste spectrum. The results of bio-remediation are not always predictable and the sludge needs to be tested periodically.

Screening: Bio-remediation in this particular case is expected to be difficult to accomplish. Representative samples of the waste would be required for culture development, but would be difficult to obtain. Additionally, the considerable amount of sludge generated would be considered mixed waste, since Tritium would not be affected by this form of treatment. Consequently, this approach is not retained for further evaluation.

In-Situ Treatment Technologies

This category consists of technologies to treat and fix the waste in-place without excavation. The primary purpose is to solidify the waste so that contaminants cannot be leached from it by the infiltrating surface water on its way to joining the groundwater. Several options were considered, as discussed below.

In-Situ Solidification-Fixation

Description: In-situ solidification-fixation is a stabilization technology that may be performed without excavating the waste. The method can utilize proprietary equipment or common construction machinery equipped with an additive or chemical feed system to accomplish the mixing process. In-situ fixation immobilizes the contaminants in the trenches and soil by creating a stable matrix resistant to leaching and without the need for any soil removal.

Phase 1 Screening: In-situ solidification-fixation can be effective in reducing the mobility of the contaminants and preventing inadvertent human exposure. An obvious advantage is that this method does not require the removal of the contaminated trench contents. Traditionally this technology is successful in treating lagoon sludges and viscous wastes that are at or near the ground surface. However, bulky and hard items in the trenches (such as metal containers and discarded equipment), as well as the presence of granite boulders in the sub-surface, could cause auger mixing problems resulting in the uneven distribution of the additives and chemicals thus reducing the effectiveness of the treatment. It may also be difficult to obtain representative samples of waste to conduct treatability testing. Because of these implementation difficulties, in-situ solidification-fixation is not retained for further evaluation.

In-Situ Vitrification (ISV)

Description: In-Situ vitrification is a thermal treatment process intended to provide in-place stabilization of trench wastes and chemically contaminated soils. ISV destroys organic compounds by pyrolysis and immobilizes inorganic contaminants into a glass-like material. The ISV equipment consists of an electrical power supply system, electrode support hood, off-gas containment and treatment system, and a process control station. Successful implementation of this technology would render the contaminated waste and soil non-leachable.

Phase 1 Screening: Due to its complexity, high energy demand and high cost, ISV has been mostly restricted to the treatment of highly radioactive and highly toxic chemical wastes. The major factors that determine the effectiveness of the ISV process are burial depth, solubility, and vapor pressure of the contaminants. Due to the presence of volatile organic compounds in the trenches which may move both horizontally and vertically away from the treatment zone, it would be difficult to collect them effectively for vapor phase treatment. These concerns, coupled with the high-energy requirements, the need to use specialized equipment and trained personnel limit the applicability of this technology in this case. For these reasons ISV is not retained for further evaluation.

In-Situ Vapor Extraction (ISVE)

Description: In-situ Vapor Extraction involves the installation of multiple vapor extraction points equipped with vacuum pumps and associated piping to extract gases from the waste. High vapor-pressure organic contaminants are volatilized from the waste and soil, collected in a recovery system and treated. In-situ Vapor Extraction has often been used in the remediation of gasoline spills in soil.

Phase 1 Screening: Although ISVE could potentially be effective in the removal of free solvents from the waste, it is anticipated that much of the waste itself is encapsulated in the original disposal containers and cannot be volatilized using this process. Therefore ISVE is not considered an efficient approach in this case and is not evaluated any further.

Auxiliary Controls

Auxiliary control measures are intended to augment other technologies. They are not stand-alone remediation methods, but further increase the reliability and performance of other measures. This type of technology generally includes the diversion of the flow of groundwater and/or surface water.

Slurry Walls

Description: The construction of an effective slurry wall requires excavating a continuous trench around the perimeter of the waste disposal area. This trench should extend into the slightly weathered to fresh granite. It is important to anchor the trench into the bedrock because it is relatively impermeable. The trench would then be filled with a bentonite, cement or similar slurry. This low permeability barrier will divert the groundwater and prevent it from flowing beneath the waste disposal area. A conceptual diagram of this technology in plan view and cross section is presented in the following figures.

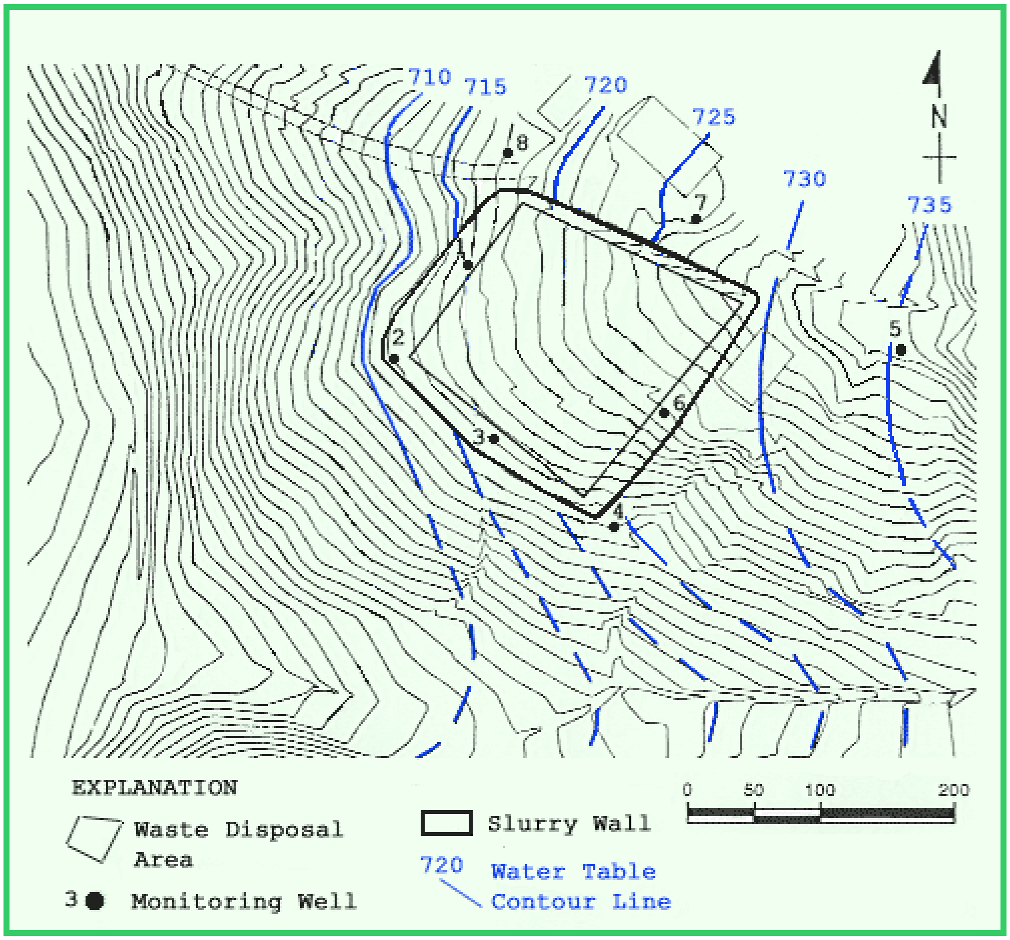

Figure 11: Plan view of a Slurry Wall surrounding the waste disposal area

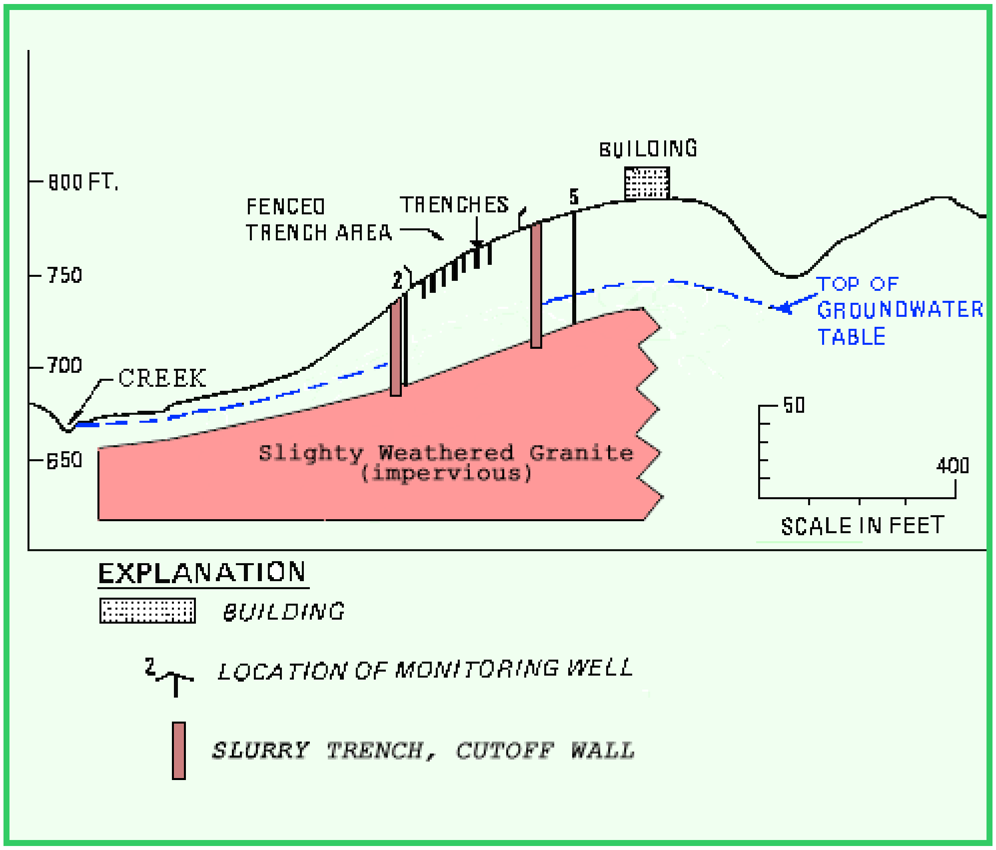

Figure 12: Cross-section showing the Slurry Trench Cutoff Wall anchored in the granite bedrock

<u>Phase 1 Screening</u>: The construction of a slurry wall, coupled with the installation of a low permeability cap on top of the waste disposal area, would effectively contain the waste and the contaminated groundwater immediately beneath it within a well defined and confined space. The depth to which the slurry wall would need to be constructed is dependent on the depth to the slightly weathered to fresh granite. On the northern and western sides of the waste disposal area that depth is expected to be on the order of 40 to 50 feet. On the eastern and southern sides of the waste disposal area that depth is expected to be on the order of 50 to 60 feet. The excavation of a continuous trench a few feet wide, several hundred feet long and 60 feet deep would be an intricate undertaking that would require the use of specialized construction equipment to dig a continuous trench through soil, weathered rock and hard rock (granite).

There are mechanized continuous trenchers that can perform from the surface the in-situ mixing and homogenization of the native soils with bentonite slurry down to a depth of 35 to 40 feet. This specialized equipment is designed to excavate in relatively soft soils and sediments at a rate of 300 to 500 linear feet of slurry wall installation per day. In the case at hand, however, the equipment would have difficulty reaching down to 60 feet or more if needed in order to anchor the slurry wall into the hard rock, the slightly weathered granite beneath the waste disposal area.

It is worth noting at this point that the existing separation between the bottom of the trenches and the top of the ground water table is already on the order of 15 to 20 feet. In addition, the up-gradient recharge area is relatively small and does not cause a large volume of groundwater to flow beneath the trenches. Because of possible construction difficulties and because the groundwater table can be protected and lowered by other methods, this technology is not evaluated any further.

Surface Water Controls

Description: Surface water controls are measures taken to minimize or eliminate the sources that produce up-gradient storm-water runoff that may reach the waste disposal area and add to the infiltration problem into the trenches and the raising the ground water table. These measures may be interim or permanent, depending on when and how they are implemented. Examples include installation of gutters on the buildings north and east of the waste disposal area, using drainage grates or berms in the paved road to reroute the surface water into lined waterways that by-pass the waste disposal area. These corrective measures would intercept the storm water runoff originating uphill from the waste disposal area and carry that runoff water safely down gradient around and to the west side of the waste disposal area.

Phase 1 Screening: Installation of surface water control measures is easy to implement and expected to provide immediate benefits. The amount of surface water flowing over the waste disposal area would be reduced, and less water would percolate through the trenches. These measures are retained for further consideration.

Pumping and Monitoring

Description: This controlled pumping and monitoring technique is sometimes used to control the elevation of the groundwater table beneath buried wastes. Extraction wells would be placed in an up-gradient direction, east and north of the waste disposal area. These extraction wells would then be pumped and the clean water conveyed down gradient through a discharge pipe to a down-gradient stone filled trench for recharge into the groundwater. Periodic monitoring should be performed to document the effective lowering of the groundwater table beneath the waste disposal area and ensure that no contaminated water is pulled by the pumping cone of depression. A conceptual diagram of this technique is presented in map view below.

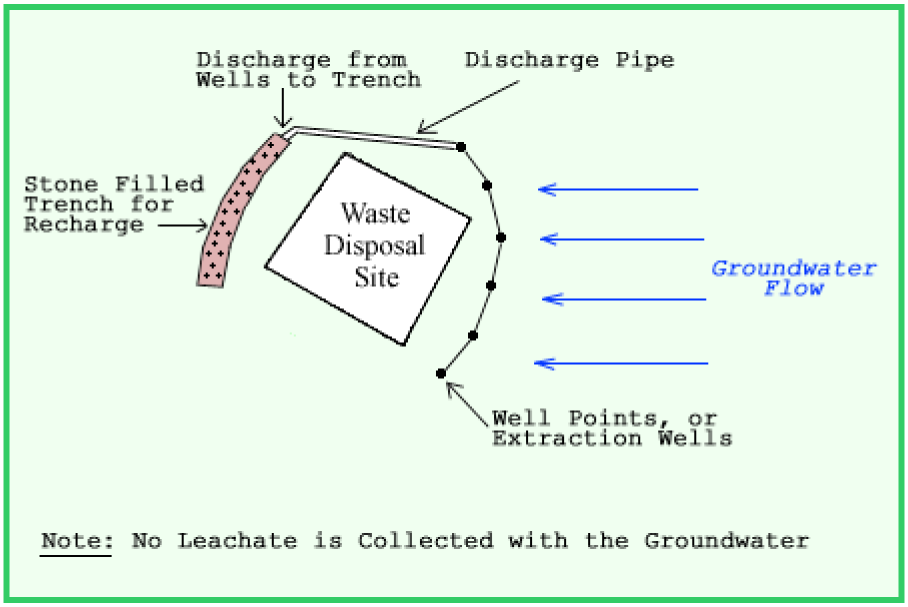

Figure 13: Plan view of up-gradient extraction wells used to lower the groundwater elevation

Phase 1 Screening: There is already a large separation between the bottom of the waste disposal trenches and the top of the groundwater table. With the installation of a low permeability cap on top of the waste disposal area to eliminate the infiltration problem, the groundwater could flow beneath the waste disposal area without being significantly affected by the contents of the trenches. Also, continuous pumping with monitoring is less desirable than more passive technologies that do not require careful maintenance and frequent inspection. In addition, the position of the building east of the waste disposal area would hinder the installation of some of the extraction wells. Consequently, pumping and monitoring is not a desirable approach for source control in this case and will not be considered any further.

Recharge Management

Description: Recharge management consists of identifying source areas of infiltration up-gradient from the waste disposal area. Again, the purpose is to lower the groundwater table beneath the trenches by reducing recharge from precipitation up-gradient of the waste disposal area. This approach can be effective, because the waste disposal area is located near the head of a small local drainage basin described in an earlier course of this series (Part 2 – Analysis of Existing Information and Regulatory Concerns).

Phase 1 Screening: To be effective, significant sources of water infiltration must be identified and diverted to areas that do not recharge the groundwater beneath the trenches. Once these measures are implemented, monitoring data will be needed to evaluate the effectiveness of these measures. As discussed under the pumping and monitoring approach, there is already a relatively large separation between the bottom of the waste disposal trenches and the top of the groundwater table. Therefore, benefits are anticipated to be small to marginal. Recharge management is not considered sufficiently effective and is not considered any further.

Relocation of Utilities

Description: This approach will consist of identifying the buried water conveyance lines in the vicinity of the waste disposal area. Once identified, the lines will be relocated to prevent inadvertent leaks from seeping and infiltrating into the groundwater. The relocation of buried utilities can be implemented with light earth moving equipment.

Phase 1 Screening: Field observations indicate that utility lines supply water to up-gradient buildings located north and east of the waste disposal area. There may be other lines passing through this area as well. This condition can be remedied by identifying and relocating all such lines. This measure can be effective in controlling inadvertent seepage from these lines and is retained for further evaluation.

Summary of Phase 1 Screening

The following Table summarizes the technologies evaluated and the results of the Phase 1 screening for source control. Those technologies that made it through the Phase 1 screening are carried forward to the effectiveness and life cycle cost assessment, performed as part of Phase 2 screening.

TABLE 3 - Summary of Phase 1 Screening

Category and Technology	Phase 1 Screening Results	
Single Barrier Caps		
Clay Cap	Failed	
Asphalt Cap	Failed	
Concrete Cap	Failed	
Synthetic Membrane		**Passed**
Multiple Barrier Caps		
Multiple Barrier Cap		**Passed**
Excavation and Re-Disposal Technologies		
Excavation and Off-Site Disposal	Failed, pre-1995	**Passed, post-1995**
Excavation and On-Site Disposal	Failed	
Excavation and Treatment Technologies		
Excavation and Solidification-Fixation	Failed	
Excavation and Off-Site Incineration	Failed	
Bio-Remediation	Failed	
In-Situ Treatment Technologies		
In-Situ Solidification-Fixation	Failed	
In-Situ Vitrification	Failed	
In-Situ Vapor Extraction		
Auxiliary Controls		
Slurry Walls	Failed	

Surface Water Controls		**Passed**
Pumping and Monitoring	Failed	
Recharge Management	Failed	
Relocation of Utilities		**Passed**

Effectiveness Evaluation and Phase 2 Screening

The technologies that passed the Phase 1 screening were then examined in greater detail. It should be noted that each acceptable alternative has relative advantages and disadvantages. Each alternative is reviewed based on effectiveness, implementation issues and total life-cycle cost. The purpose of this evaluation is to provide a basis for selecting a corrective action approach that will be developed in greater detail.

Evaluation Criteria

The three criteria: effectiveness, implementation issues and total life-cycle cost are described below.

Effectiveness

Each technology was evaluated with respect to its effectiveness in reducing the potential for human exposure and its effectiveness in containing and reducing the toxicity and mobility and the contaminants. Both the short-term and long-term components of effectiveness are evaluated. Short-term refers to the construction and implementation period, and long-term refers to the period following the completion of the corrective action measure. Containment and reducing toxicity and mobility refer to changes in one or more characteristics of the hazardous constituents and contaminated media.

Implementation

Implementation evaluates the technical and administrative feasibility of constructing, operating and maintaining a corrective action measure. Technical feasibility refers to the ability to procure, construct and operate the selected alternative. Administrative feasibility refers to the ability to obtain all necessary approvals from the regulatory agencies, along with the availability of appropriate treatment technologies, interim storage and long term disposal services.

Life-Cycle Cost

Generalized costs estimates were developed for the purpose of comparing acceptable technologies that passed the Phase 1 Screening. The total cost estimate was derived by summing up the engineering, construction and annual operation and maintenance (O&M) costs associated with the implementation of each technology. The O&M cost for each technology includes a 30-year period of maintenance following initial construction. The costs that are presented in this section of the course were drawn from published EPA documents, vendors' information and the Consultant's experience at the time they were developed. As such, they can be considered order-of-magnitude estimates that can be used to evaluate the relative cost effectiveness of the technologies under consideration.

The student should keep in mind that the development of a cost estimate for the execution of an appropriate technology is a complex process that should take into account the time, place and prevailing economic conditions at the time of implementation. Because of these limitations, the cost estimates that are presented here are used for illustration purposes only. As such, they are sufficiently representative for use in the comparative evaluations presented in this course.

Single Barrier Cap - Synthetic Membrane

A single barrier cap consists of a flow barrier which is laid down on appropriate graded bedding. A synthetic membrane is usually selected for its superior flow barrier characteristics. The barrier layer is held to its substrate by distributed weights (such as sandbags) distributed over the surface of the cover as shown on the following figure.

Figure 14: Example of a synthetic membrane used as a single barrier cap, Oak Ridge, Tennessee

The synthetic membrane is left uncovered to allow for periodic inspections to detect and repair any damage when it occurs. The synthetic membrane is fastened into a key trench, at least two feet deep filled with rock, located around the entire perimeter of the Site. This key trench can also be used as a peripheral drain to carry the rainfall runoff from the synthetic membrane to a collection channel for recharge into the ground. An example of a peripheral drain is shown on Figure 14, bottom left to center right of photo.

The elements of a single layer cap consist of the following:

- Placing and grading select fill to meet the manufacturer's warranty requirements for the installation of a synthetic membrane.
- Installation of a synthetic membrane by an authorized vendor, as the impervious barrier. The membrane should remain exposed to facilitate inspection. The installation of the membrane should contain enough slack in its installation to provide dimensional stability.
- Placing a key trench/peripheral drain around the perimeter of the Site to secure the synthetic membrane to the ground and carry the rainfall runoff from the synthetic membrane into a collection channel.

Effectiveness

The single barrier synthetic membrane cap meets the objectives of eliminating infiltration, reducing the mobility of the contaminants, and preventing human contact. The single barrier cap is considered effective and meets the remedial objectives of protecting human health and the environment.

In the past, due to lack of data on durability, EPA has considered this type of remedial measure to be short-lived compared to compacted natural soils. New developments by the synthetic membrane industry have made major improvements in the performance characteristics of the products. It is now accepted that durable synthetic membranes can be made to last for long periods of time. This alternative has been implemented as an interim measure at several Department of Energy (DOE) low-level radioactive waste disposal sites. It has also been approved as a long term (100 years) interim measure at a decommissioned commercial low-level radioactive waste disposal site, with provision for the replacement of the synthetic membrane every 25 years.

Implementation

This technology is easily implemented from a construction perspective. Care should be taken in the construction to ensure that all design requirements are met, and that physical damage does not occur during installation. Panels of the membrane are laid down with sufficient slack to provide dimensional stability, and adjacent panels are overlapped and sealed tightly together in the field.

Life Cycle Cost

A generalized cost estimate to implement the single barrier cap option is presented below.

TABLE 4
Life Cycle Cost Estimate for Single Barrier Cap-Synthetic Membrane

Element	**Quantity**	**Unit Cost**	**Total Cost**
Select Graded Fill	5,000 cubic yard	$10.00	$ 50,000
Synthetic Liner	45,000 square feet	$ 1.00	$ 45,000
Perimeter Drain	1,000 linear feet	$10.00	$ 10,000
Rip-Rap	500 cubic yard	$25	$ 12,500
Mob/Demobilization	one	Not Applicable	$ 30,000
		Construction Subtotal	**$145,000**

Contingency, estimated at 20%	$ 29,000
Liability Insurance, estimated at 10%	$ 14,500
Site Specific Design Services, estimated at 40%	$ 58,000
Construction Management, estimated at 40%	$ 58,000
Operation and Maintenance, estimated at 3% per year for 30 years	$ 130,500
Total Estimated Cost of Single Barrier Cap - Synthetic Membrane	**$ 437,500**

The generalized cost estimate to install and maintain the single barrier alternative for a period of 30 years is on the order of $450,000, or about $10 per square foot of cap area. Other site specific engineering considerations, such as slope stability of the graded fill, will have to be evaluated before developing more precise cost estimates.

Multiple Barrier Cap

A diagrammatic cross section showing a multiple barrier cap installed over the waste disposal trenches is shown on the following figure.

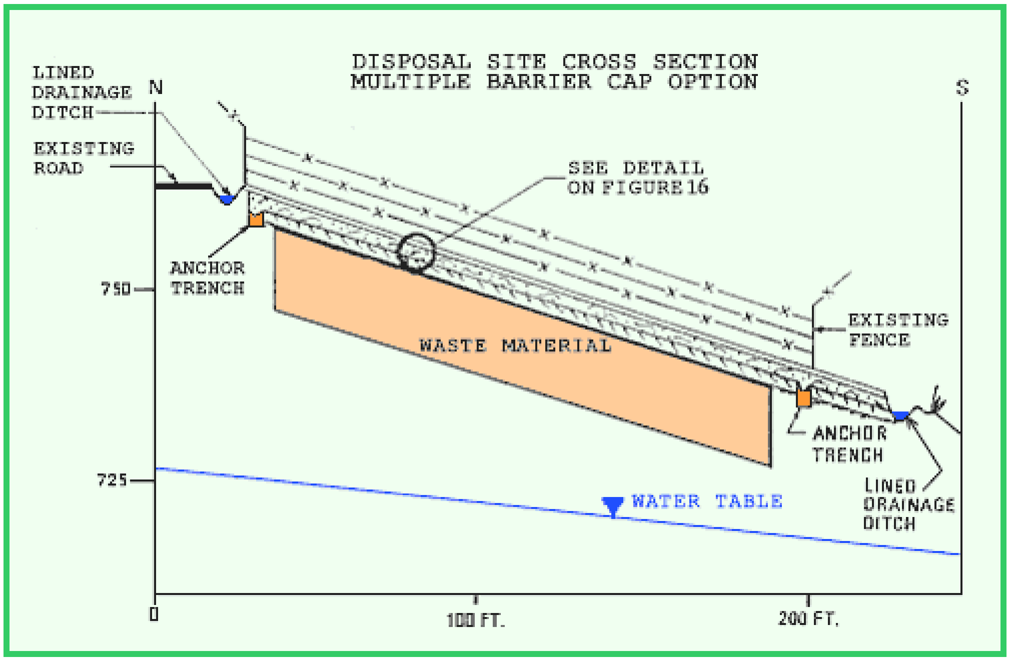

Figure 15: Cross Section of Multiple Barrier Cap installed over the Waste Disposal Trenches

The multi-barrier cap consists of a compacted clay layer and a synthetic geo-membrane layer that function as one system providing a redundant barrier of low permeability. This two component system is overlain by a drainage layer, a cover of fill soil and top soil plus the necessary erosion control measures needed to maintain cap integrity. The multi-layered structure of the cap is shown on the following figure.

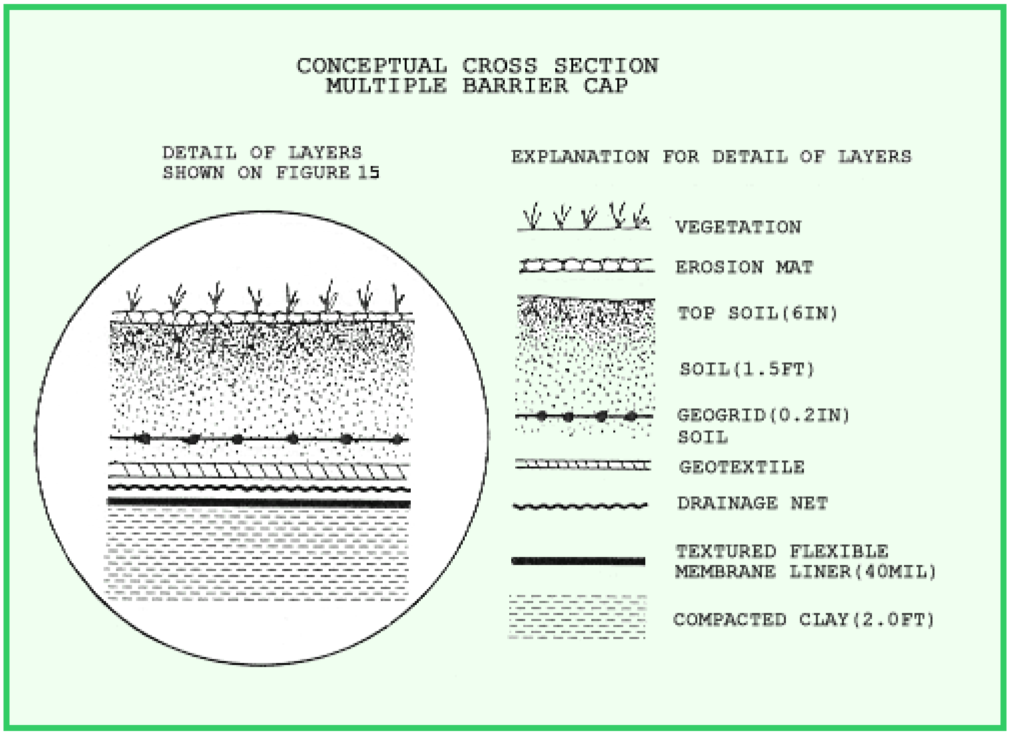

Figure 16: Elements of the Multiple Barrier Cap

From top to bottom, the multi-barrier cap consists of the following components that have the following characteristics:

- The slope of the cap surface would provide for runoff at velocities below the threshold for erosion of the vegetated soil surface. Surface runoff would be collected in lined perimeter drains and routed to a down-gradient collection channel.
- A suitable shallow-rooted vegetative cover through an erosion protective mat in the upper two-foot-thick soil layer to control erosion.
- The creep resistant geo-grid mesh, placed near the bottom of the soil layer, will prevent slippage of the protective soil placed on top of the textured geo-membrane covered slope.
- The geo-textile fabric beneath the upper soil layer will keep soil fines from settling in the drainage layer, thus helping to maintain the efficiency of the drainage layer.
- The drainage net, consisting of a synthetic composite of high permeability, will provide a stable drainage path to the lined peripheral drains that will carry infiltrated water down-gradient of the waste disposal area.
- The 40 mils (1.0 mm) thick synthetic membrane would provide the first infiltration barrier within the cap. It will be protected from the weather by about two feet of overlying soil. The textured

membrane should be in direct contact with the smooth upper surface of the underlying compacted clay.

- The lower compacted two-foot thick clay layer will provide a second infiltration barrier and constitutes the redundant protection against infiltration. The clay layer also provides base support and establishes the desired design grade for the subsequent layers above it.

Effectiveness

The multiple barrier cap option provides long-term safeguards and affords redundancy that is greater than the sum of its parts. For example, the synthetic membrane has the more desirable flow resistance (essentially zero), with the clay layer providing the back-up very low permeability cap (about 1×10^{-7} cm/sec). Placed in this configuration, the synthetic membrane will be protected from direct exposure to the destructive elements of the weather, the sun (especially ultraviolet radiation), snow, frost, wind and rain. The main advantage is that this cap configuration should last for a long period of time with minor custodial maintenance. A disadvantage, of low probability, is that if the covered synthetic membrane is damaged or develops a leak, it cannot be easily repaired. The overall assessment is that the multiple barrier cap option is very effective in preventing the leaching of the waste by water infiltrating into the trenches.

Implementation

As with the case of the single barrier cap, this technology can be easily implemented with conventional construction equipment. This approach also meets the regulatory requirement of protecting human health.

Life Cycle Cost

A generalized cost estimate to implement the multiple barrier cap option is presented below.

TABLE 5
Life Cycle Cost Estimate for Multiple Barrier Cap

Element	Quantity	Unit Cost	Total Cost
Select Clay	10,000 cubic yards	$10.00	$100,000
Textured Liner	44,000 square feet	$ 1.00	$ 44,000
Drainage Net	44,000 square feet	$ 0.35	$ 15,400
Geo-textile	44,000 square feet	$ 0.20	$ 8,800
Geo-Grid	44,000 square feet	$ 0.35	$ 15,400
Quality Soil	7,500 cubic yards	$ 5.00	$ 37,500
Top Soil	2,500 cubic yards	$15.00	$ 37,500
Erosion Mat	44,000 square feet	$ 1.00	$ 44,000
Seeding	44,000 square feet	$ 0.10	$ 4,500
Perimeter Drain	1,000 linear feet	$15.00	$ 15,000

Rip-Rap	500 cubic yards	$25.00	$ 12,500
Mobil/Demobilization	one	Not Applicable	$ 30,000
		Construction Subtotal	**$364,600**
Contingency, estimated at 15%			$ 54,690
Liability Insurance, estimated at 10%			$ 36,460
Site Specific Design Services, estimated at 40%			$145,840
Construction Management, estimated at 40%			$145,840
Operation and Maintenance, estimated at 2% per year for 30 years			$218,760
Total Estimated Cost of Multiple Barrier Cap Option			**$966,190**

The generalized cost estimate to install and maintain the multiple barrier cap option for a period of 30 years is on the order of $950,000 to $1,000,000 or about $20 to $25 per square foot of cap area. This is roughly twice the estimated cost of the single barrier option.

Multiple Barrier Cap with Usable Surface

The client requested evaluation of this option as a dual-use approach to the remedial effort. This option is not strictly a remedial alternative, but rather offers the inclusion of necessary elements to elevate and level the surface of the waste disposal area for parking or storage use. The elevated surface includes construction of steel bins or concrete retaining walls, back-filling and installation of an asphalt surface. The usable surface option consists of all the elements of the multi-barrier cap, with the following additions:

- Construction of vertical retaining walls along the down-slope sections of the waste disposal area.
- Back-filling the lower areas with compacted soil on top of the multiple barrier cap to establish the appropriate finished and level grade.
- Installation of an asphalt surface and providing for the collection and re-routing of any runoff that develops.

Effectiveness

This option is equivalent in effectiveness to the multiple barrier cap option. The asphalt top layer can also be considered as a low permeability cover that would provide another redundant barrier to infiltration. However, because of its continued exposure to the elements, the asphalt surface would need to be maintained on a regular basis in order to repair any cracks that may develop. Nonetheless, the corrective action objectives, of eliminating infiltration and preventing human exposure, will be met.

Implementation

As with the case of the single and multiple barrier caps, this technology can be implemented with conventional construction equipment. This approach also meets the regulatory requirement of protecting human health and the environment.

Life Cycle Cost

The cost for the installation of a usable surface is estimated to be in the range of $300,000 to $400,000. This amount is in addition to the cost of constructing the multiple barrier cap option, and includes elevating the area to a level configuration and the cost of additional construction management oversight. This yields a total estimated cost for this option of about 1.2 to 1.3 million dollars. This cost does not include any regular maintenance of the asphalt surface that will be used for parking or storage, and which will add to the overall total cost.

Excavation and Off-Site Disposal

In the late 1980s and early 1990s, industrial companies and research institutions had very few options for the offsite disposal of their radioactive wastes. At that time a private company located in a remote location in the western U.S. wanted to provide a private disposal option for low-level radioactive wastes and other cleanup byproducts. To that end, the company submitted a license application in 1988 to receive and dispose of Naturally Occurring Radioactive Materials (NORM). Since 1988, the company's Radioactive Material License has been amended several times, expanding the types of radioactive materials approved for disposal to include low-level radioactive waste (LLRW), in addition to NORM.

In 1992, the company was granted a RCRA Part B Permit from the State Division of Solid and Hazardous Waste (DSHW). This permit allowed the company to operate a separate disposal cell at its site to dispose of mixed waste (radioactive and hazardous contaminants). Federal law requires that hazardous waste, including mixed waste, meet minimum treatment standards prior to disposal. In 1995, the company constructed a mixed waste treatment facility to meet the need for treating mixed waste prior to disposal, thus overcoming existing Land Disposal Restrictions. Therefore, since the mid to late 1990s it has become possible to consider the possibility of excavating the waste that has been buried at the site of the research institution for shipment, treatment and ultimate permanent disposal off-site at a fully licensed disposal facility.

Effectiveness

The off-site disposal facility, located in the western U.S., has many characteristics that make the location ideal for the disposal of the LLRW and mixed waste. These characteristics include:

- Low average annual precipitation
- High average annual evapotranspiration
- Low permeability clay soils
- Stagnant, non-potable groundwater
- Stable geology
- Excellent transportation access by both highway and rail

In addition, the disposal facility is isolated within a 100 square mile State/County-established Hazardous Industries Zone with specific deed and title restrictions. The nearest resident is over 45 miles away from the facility. These characteristics offer a high level of confidence that the site provides a safe long-term disposal solution for the waste of the Research Institution with a minimal need for active maintenance.

The remote waste disposal company uses an aboveground-engineered disposal technology. In addition to the standard liner and cover requirements used in the LLRW cell design, the mixed waste cell also has a triple synthetic liner system with a synthetic cover barrier to comply with the hazardous waste land disposal requirements contained in Title 40 of the Code of Federal Regulations (40 CFR 264).

Implementation

For commercial clients, such as the Research Institution, the first step in the process of waste acceptance for treatment and disposal at the remote site is to prepare general information about the anticipated type of waste, waste volume, waste packaging and preferred transportation mode. Provided the proposed waste is acceptable for disposal, this phase of the process ends with the signing of a qualified disposal agreement between the owners of the remote waste disposal site and the management of the Research Institution.

The next step consists of using conventional construction equipment to excavate and segregate the waste buried in the trenches and the contaminated soil within and below the trenches. Conventional controls, such as dust suppression, erosion management and the use of Personal Protective Equipment (PPE) will be incorporated into the excavation procedures, as necessary, to ensure the protection of the workers and the ambient environment at the time the waste is exhumed.

Excavation is usually conducted in continuous lifts of six inches to one foot with frequent sampling and testing to separate clean from contaminated materials. Once removed and brought to the surface, the contaminated materials will be prepared for profiling. Profiling involves collecting samples and obtaining analytical results for the parameters specified on the waste profile form provided by the receiving remote waste disposal site. The results obtained through this profiling process are expected to verify the preliminary characterization that has already been performed and submitted to the owners of the Waste Disposal Company.

In addition, the waste stream will also be evaluated based upon the proposed method of packaging and mode of transportation. These defined characteristics will determine if the waste stream is acceptable to the operators of the remote waste disposal site and will identify any special handling that may be required to properly accept, treat and ultimately dispose of the waste.

Upon receipt, the waste may be placed into storage for a limited time prior to final disposal. In general, the remote waste disposal company has the capability to store packaged LLRW, NORM, and mixed waste that are awaiting treatment. While in storage, both containerized and bulk waste is periodically inspected. Problems identified during these inspections are corrected as needed.

Several permitted treatment technologies are used to reduce the toxicity of the waste materials prior to disposal. Technologies commonly used to achieve the standards established for disposal includes: thermal desorption, stabilization, amalgamation, reduction/oxidation, deactivation, chemical fixation, neutralization, debris spray washing, and encapsulation. Encapsulation consists of stabilizing the waste by mixing it with molten low-density polyethylene (LDPE). Following cooling, the plastic/waste mixture forms a material that does not leach hazardous constituents.

Once treated, the soil and soil-like materials are placed in the disposal cell in 12-inch lifts. After placement, each lift is compacted to 90 percent of its optimum density based on the results of standard proctor compaction tests (ASTM D-698) in a continuous cut and cover process. Placement of all non-soil or solid debris material is done in such a way as to minimize the effects of settlement of the disposal embankment. If necessary all void spaces are filled to ensure that the final waste form is monolithic.

The specific location of each waste shipment in the disposal cell is identified using standard surveying practices. This is done in order to be able to efficiently pinpoint the location of the waste of each owner and keep track of it individually in case an unanticipated problem develops in the future. The waste generator continues to be the long-term owner of the waste and responsible for bearing the cost of any necessary remedial measure that may need to be implemented.

Life-Cycle Cost

No itemized cost breakdown was developed for the excavation and off-site disposal of the waste contained in the trenches of the research institution. However, all steps in the process of ultimate off-site disposal of the waste are likely to be elaborate and expensive to carry out. In 1998 it cost another research institution $1.3 million to excavate and dispose of similar wastes from a site that was 1/3 the size of the waste disposal area under consideration in this study. By analogy, it would therefore cost in 1998 dollars about $3.9 million or more to excavate and dispose of the waste off-site.

A specialized excavation team with the proper equipment and personnel trained in the procedures that will need to be followed to exhume the buried waste will need to be mobilized. This team will work under the close supervision of environmental engineers versed in the precautions that will be implemented for the safe handling and segregation of the exhumed waste. As a first step, it will be necessary to prepare a lay-down area with proper infiltration barriers and a suitable drainage collection system to receive the exhumed waste. During this phase of work, frequent sampling and testing will be performed to categorize and segregate the various kinds of wastes (LLRW, mixed waste, and hazardous waste) from the contaminated and clean soil. The LLRW, mixed waste and contaminated soil will need to be containerized and shipped to the remote site for treatment and ultimate disposal.

At this stage it will be necessary to work closely with the regulatory agencies to agree on a lower threshold of contamination below which the material will be considered clean and will not require special handling for disposal. This is an important step that can drastically affect the total volume, and therefore the ultimate cost, of the waste that needs to be disposed of.

The handling, segregation, packaging, labeling and shipment of the various components of the waste and contaminated soil are also likely to be an expensive undertaking. Cost savings can be realized at this stage by properly planning, characterizing, documenting and sequencing the shipments to ensure prompt acceptance by the remote disposal site upon arrival.

Based on the above considerations plus the cost of re-filling the excavation to grade with clean and compacted soil, it is estimated that the Excavation and Off-Site Disposal option would end up by costing well in excess of $4 million. This estimate far exceeds the cost of implementing the single barrier or multiple barrier cap options for source control.

Auxiliary Control Measures

The auxiliary controls that passed the Phase 1 screening were surface water controls and relocation of utilities. The following are the surface water controls evaluated during Phase 2 screening:

- Capture and re-route runoff from the roof of buildings up-slope of the waste disposal area by installing gutters and drain pipes.
- Intercept runoff from the road network up-slope of the waste disposal area by installing a sewer grate or other form of diversion.
- Line the drainage ditches that run immediately up-slope of the waste disposal area
- Re-route the up-gradient runoff through controlled channels and release the water down-gradient of the waste disposal area.
- Construct an earthen berm east of the waste disposal area to re-direct the flow of surface water towards a down-gradient release point.

Effectiveness

The effectiveness of these actions is greatest prior to the implementation of the primary remedial measure. Subsequently, they provide for the completeness of the containment system. By reducing surface water infiltration near the waste disposal area, the overall effect is to reduce or eliminate the leaching of the waste, lower the groundwater elevation and increase the degree of waste isolation.

Implementation

All of the auxiliary measures listed above are relatively easy to implement. Proper design and construction controls are critical to ensure satisfactory performance of these measures. Periodic inspection and maintenance should be conducted to maintain the initial performance standards.

Life Cycle Cost

The overall cost of installation and maintenance over the 30-year period has not been calculated, but is not expected to exceed $ 150,000.

Selection of Preferred Technology

Both the single barrier and multiple barrier cap options are considered cost-effective and viable alternatives for source control. Once infiltration is controlled and no additional leaching of the waste is taking place, the down-gradient plume of contamination that was traced in parts 4 and 5 of this course series, would be diluted over time by mixing with clean groundwater. Eventually the plume should dissipate entirely, with the contaminant concentrations falling back to below the detection limits.

While the single barrier cap offers ease of inspection and repair, the multiple barrier cap option, which incorporates a second flow barrier, offers a level of redundant protection against infiltration. The multiple barrier cap option meets the closure requirements specified in EPA technical Guidance Document: Final Covers on Hazardous Waste Landfills and Surface Impoundment (EPA/530-SW-89-047). The single barrier cap is also expected to meet the remedial requirements as well. As mentioned earlier, Federal Regulatory Agencies have approved the use of a synthetic single barrier membrane cap for the interim closure of a commercial low-level radioactive waste disposal site for a period of 100 years, with provisions for the replacement of the cap every 25 years.

The single barrier and multiple barrier caps are evaluated below with respect to environmental, human health, institutional, cost and monitoring considerations. In addition, to further enhance the performance of these cap options, the auxiliary control measures described in the previous section are also recommended for implementation. Together these measures will ensure that the waste is kept dry and that no leaching will take place. It is also recommended that the existing institutional controls, such as facility fence, posted signs and the padlocked gate, will be retained to guarantee that the waste disposal area will continue to remain undisturbed.

Environmental Considerations

Implementation of either alternative (the single barrier or multiple barrier cap option) will minimize the potential for short-term adverse impact on the environment by isolating the source of contamination. Infiltration of precipitation and surface runoff into the trench area will be stopped which, in turn, will minimize continued migration of the contaminants from the source into the groundwater.

Implementation of either of these measures has little to no potential for long-term adverse impact since they are both capable of effectively containing and controlling the contaminants over an extended period of time. Performing routine maintenance of the cap and the drain system will help ensure long-term protection of the environment. The continued monitoring of groundwater levels at the Site well into the future will enable the Institute to confirm the effectiveness of this passive method of source containment.

The potential for inadvertent release of contamination during implementation of either alternative is very low, since installation of the cap and drainage system are non-intrusive activities that are not expected to interfere with the contaminated material. Conventional controls, such as dust suppression and erosion management will be incorporated into the construction, as necessary, to ensure the protection of the ambient environment.

Human Health Considerations

The primary Contaminants of Concern at the Site are Tritium, chloroform, and 1,4-dioxane. These compounds are, and will continue to be, isolated from the accessible environment and do not pose a risk to on-site workers during the implementation of either the single or multiple barrier cap option. Either of the corrective alternatives will prevent human exposure to the contaminants by further isolating the trench contents and minimizing or eliminating the down-gradient migration of contaminated groundwater.

Construction of a cap will not require any excavation of contaminated waste material and no potential exists for short-term human exposure. Conventional health and safety measures, such as using Personal Protective Equipment (PPE) and dust suppression, will be incorporated into the construction as necessary to ensure the protection of both the on-site construction workers and the staff of the Institute. After the source has been contained, the single or multiple barrier cap option is expected to provide long-term protection to human health and the environment.

Institutional Considerations

The construction of a cap and implementation of the auxiliary measures for infiltration management are not subject to the land disposal restrictions on waste since they do not involve the removal and placement of the contaminated source material at a different location onsite or offsite. Placement would only occur if the waste was excavated and removed, or if the waste was excavated, treated and then back-filled at a different location onsite or offsite. Installation of the single or the multiple barrier cap options would not disturb the contents of the trenches in any way. Long-term groundwater monitoring would continue to be performed at regular intervals well into the future to document the effect of the remedial measure. The Institute would retain control of the waste that is contained and isolated.

Cost Considerations

The cost of implementing the single barrier cap is estimated to be on the order of $450,000, including the cost of a 30-year Operation and Maintenance period. The cost of implementing the multi-barrier cap is estimated to be on the order of $950,000 to $1,000,000, including the cost of a 30-year Operation and Maintenance period. A generalized breakdown of the costs for each option is provided in Tables 1 and 2, above. Site specific engineering considerations, such as slope stability issues, will have to be evaluated further before more precise cost estimates can be developed.

Monitoring Considerations

For either the single or multi-barrier option the effectiveness of the remediation will have to be monitored periodically to demonstrate effectiveness and to identify any degradation over time. Monitoring falls into the following categories:

- Visual inspection of the surface of the cap for degradation, tearing or cracking.
- Surveying the elevation of the cap for identification of settlement or collapse
- Groundwater Monitoring for water level and chemical concentration of contaminants.

Each of these components is briefly addressed below.

Surface Inspections - Single Barrier Cap

The single layer cap (synthetic membrane) should be visually inspected on a yearly basis, and following any unusually severe wind, hail and heavy precipitation. The inspection should be completed by a trained individual who would recognize signs of cracking or thinning of the membrane and failure along any of the welds. Special care should be taken to inspect the areas where the membrane approaches and is buried under the anchor trench, as these are areas of potential tears or other damage with time. Any damaged sand bags or other weights should be replaced. If areas of settlement and ponding water are noted, the membrane should be cut and removed, the subsurface re-graded, and a new patch of membrane should be welded over the area. Due to the age of the waste disposal area, no significant settlement is expected. However, re-grading during the construction may leave areas susceptible to minor settlement.

Should any large branches or tree limbs fall on the surface, they should be removed and the membrane in the area inspected carefully for any holes or tears. Damaged areas can be patched with strips or swatches of new membrane. Also, the membrane should be inspected for uplift or bulging due to gas accumulation. Given the age of the waste disposal area, it is not expected that significant quantities of gas are emanating from the burial trenches. However, this possibility must be included in the inspection activities. Should gas accumulation be noted, special measures must be taken to dissipate the build-up since the gas may be highly flammable or explosive.

Surface Inspections - Multiple Barrier Cap

The top surface of the multiple barrier cap option should be visually inspected at least once a year. Surface inspection should include removal of bushes or small trees that may have taken root, inspection and filling of animal burrows or other holes, re-grading and re-seeding of areas of dry, cracked or bare soil, and re-grading of any areas of settlement or where water tends to pond. Remember that both the clay barrier layer and the impermeable synthetic membrane are buried and therefore protected from exposure to the elements.

Surface Surveying

For either capping alternative, periodic surveying (every 5 years or so) of the surface should be completed to provide an early indication of settlement or subsurface collapse. Due to the age of the waste disposal area, minimal settlement is expected. However, in the case of the multiple barrier cap option, the additional weight may cause compaction or differential settlement of the waste and/or the trench fill soils. Also, with either cap option, subsurface soils will slowly dry due to cutoff of rainwater infiltration. Some shrinkage may be associated with such drying, possibly leading to some compaction and differential settlement.

Groundwater Monitoring

For either the single or multi-layer cap, the existing monitoring wells should suffice as monitoring points for groundwater. Water level measurements should be taken at least twice a year (summer and winter) in all perimeter monitoring wells. One round of geochemical sampling should be completed each year from the down-gradient wells. The geochemical testing can be limited to one of the Contaminants of Concern (Tritium, chloroform and 1,4-dioxane) and a more comprehensive geochemical testing suite should be considered about 5 years after cap installation. The cap has two purposes: lowering the groundwater table beneath the trenches and minimizing leaching of contaminants from the trenches into the groundwater. Therefore, periodic monitoring of groundwater levels beneath the disposal area and geochemical testing of the down-gradient wells should be an effective method of evaluating the effectiveness of the remediation over time.

Final Recommendation

Based on the information presented in the previous section (Selection of Preferred Technology), the Consultant recommended the implementation of the multiple barrier cap option and the auxiliary control measures as the best suited remediation alternatives for the waste disposal site. This recommendation is based on the fact that:

- The multiple barrier option provides a redundant level of protection by incorporating a low permeability clay barrier and an impermeable synthetic membrane layer.
- The two barriers to infiltration (clay layer and synthetic membrane) are protected from direct exposure to the elements by the overlying vegetation, top soil and incorporated synthetic layers (see Figures 15 and 16).
- The synthetic layers embedded in the soil, above the impermeable synthetic membrane, provide a measure of slope stabilization and drainage control.
- The shielding of the impermeable synthetic membrane from direct exposure to ultra-violet rays also guarantees its long lasting performance as a barrier to infiltration.
- The required periodic surface inspections during the custodial period will be less time consuming and easier to implement for the multiple barrier cap option than for the single barrier cap option.
- Implementing the up-gradient auxiliary control measures will help limit the available amount of surface water that recharges the groundwater beneath the waste disposal area.

Finally, the Consultant believes that the multiple barrier cap option, with its redundant level of protection and coupled with the execution of the auxiliary control measures, is likely to receive expeditious approval from the Regulatory Agencies.

Regulatory Review

The Risk Assessment, Engineering Feasibility and the Corrective Action Plan was submitted to the Institute. The Institute transmitted copies to the State RPA. The State RPA then transmitted copies to the State GPA and the State WMA, Superfund Section for their review and comments. The combined response of the State GPA and State WMA, and the directive of the State RPA are summarized below.

Combined Response of the SGPA and SWMA

Based on the Risk Assessment and Engineering Feasibility Study the Research Institute and its Consultant have proposed a multiple barrier cap as final remedy for the landfill. Because of the apparent lack of offsite disposal capacity for mixed radioactive and chemical wastes, we agree that capping the landfill is currently the best available remedy. We recommend that the Research Institute construct a multiple barrier cap as described in the Consultant's report. The cap should be designed and constructed in accordance with the following document: "Final Covers on Hazardous Waste Landfills and Surface Impoundments" (Technical Guidance Document, EPA 530/SW-89/047). For additional guidance on final cover systems, the Research Institute should also consult "Design and Construction of RCRA/CERCLA Final Covers" (EPA 625/4-91/025), and "Design, Construction and Maintenance of Cover Systems for Hazardous Wastes – An Engineering Guidance Document" (EPA 600/2-87/039). Note that these documents are updated regularly and you should check the EPA data base for the most recent revisions.

In order to ensure adequate oversight by the State, we suggest the following:

- The Research Institute should submit comprehensive pre-construction project plans for State review and approval, including final design plans, a construction quality assurance plan and a plan for long-term maintenance and monitoring.

- Selection of the engineering firm and construction contractor should be subject to review and approval by the State. Each firm should submit a "Statement of Qualifications" demonstrating the firm's experience in designing and constructing final cover systems at hazardous waste or mixed waste landfills.

- The Research Institute should retain an independent construction quality assurance officer to monitor the installation of the cap. The quality assurance officer should be payed directly by the Research Institute and not by the engineering firm or construction contractor, and should report his findings directly to the State RPA.

- Following installation of the cap, the Research Institute should submit a final report, including a discussion of any variances from the approved work plan during construction and explain how these variances were resolved. The Research Institute should also submit copies of "as-built" drawings.

- All work plans, reports and engineering drawings must be sealed by a professional engineer registered in the State.

Finally, the Research Institute proposes to implement “Auxiliary Control Measures” consisting of surface water controls and the relocation of water lines. We concur and approve these measures.

Directive of the State RPA

The State RPA transmitted the combined response of the State GPA and State WMA to the Research institute and added the following directive:

It is still our primary desire that the old radioactive and chemical waste disposal area be capped to prevent further infiltration of surface water and the subsequent migration of contaminants into the surrounding parts of the site.

We have considered the recommendations made by the SGPA and SWMA and have determined that the recommendations should be followed. To that end, we urge the Research Institute to begin the planning and implementation of the work needed to cap the facility in accordance with the recommended standards.

Please note that time is of essence and you should proceed expeditiously since it is necessary that we bring this issue to a successful conclusion as soon as can reasonably be done.

Project Completion

The Research Institute retained the services of the Consultant to perform the supervisory Quality Assurance role requested by the State Regulatory Agencies. The institute also contracted the services of an experienced Design Engineering Firm and a Construction Contractor to design and install the recommended multiple barrier cap and implement the auxiliary measures of surface water controls evaluated during the Phase 2 screening.

As recommended by the State Regulatory Agencies the Design Engineering Firm initiated the process by preparing a pre-construction project plan for State review and approval. The report included final design drawings, an updated schedule and cost estimate for cap installation, a construction quality assurance plan and a plan for long-term maintenance and monitoring.

Re-evaluation of Groundwater Remediation

The Design Engineering Firm performed an independent evaluation of potential options for plume remediation. The Firm reviewed the following alternatives:

- Pump-and-treat
- Air sparging, and
- Passive remediation, by monitoring and reporting ground-water quality

The pump-and-treat option was eliminated as a remedial option because of the limited effectiveness of the technology at this site and the high costs of the remediation equipment, construction, operation and maintenance.

Air sparging, which consists of injecting air into the aquifer should be feasible based on the characterization of the site soils as silty sands and sandy silts. However, due to the low concentrations of the contaminants in the groundwater, mass transfer would be very inefficient and large volumes of air would be required to remove any significant amounts of contaminants. In addition, because the high costs of the equipment, construction, operation and maintenance, this technology was also eliminated.

Passive remediation, which relies on the natural processes of degradation and attenuation of contaminants, consists of monitoring and reporting the results regularly following the installation of the cap. Although it will take several years for the groundwater to naturally remediate it was adopted as the preferred approach because of the reasonable costs associated with this approach and the fact that there are no receptors that can inadvertently access the contaminated groundwater.

The groundwater monitoring program will at a minimum include an annual sampling of all down-gradient wells plus one up-gradient well. Groundwater samples will be analyzed for volatile priority pollutants using EPA Method 624. The sampling data reports will be issued annually and distributed to the State Regulatory Agencies. The monitoring program will be re-evaluated after each sampling and testing episode to monitor the effectiveness of the attenuation of the organic constituents. After 5 years of annual monitoring, the data will be reviewed to evaluate the success of the natural degradation and attenuation processes. If the remediation is not progressing as expected, other remedial alternatives will be considered. If, after 5 years, it is estimated that the passive remediation is progressing as expected, less frequent monitoring will be recommended. Once two consecutive sampling events indicate that no volatile organic compounds are detected above the state groundwater standards, a request for formal site closure will be submitted to the State Regulatory Agencies for approval.

Cap Design and Installation

The Design Engineering Firm reviewed the conceptual multiple barrier cap option proposed by the Consultant (figures 15 and 16) and used the guidance documents recommended by the State Regulatory Agencies (see Section on "Combined Response of the SGPA and SWMA") to prepare the final design drawings that are presented in this section of the course.

The surface features of the constructed remediation cap are shown on the following Figure.

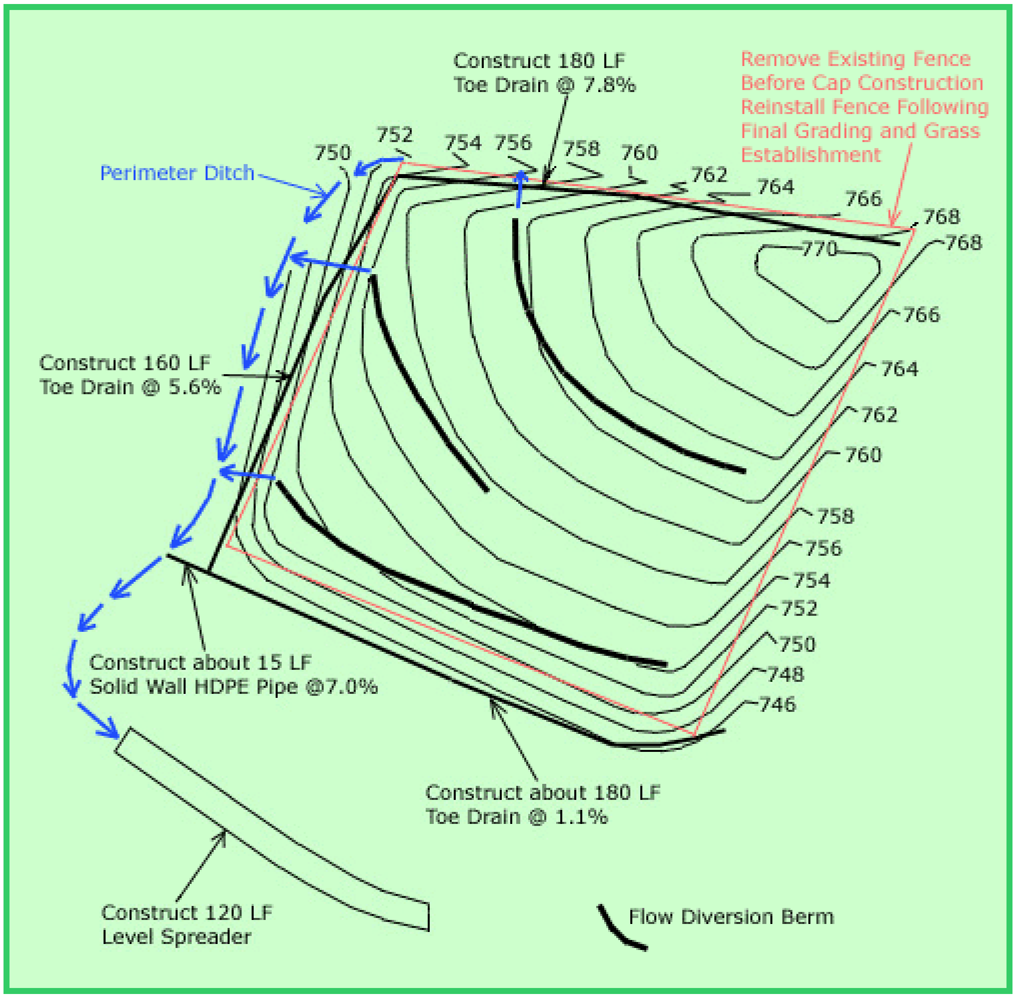

Figure 17: Map showing the surface features of the constructed remediation cap

Note that the existing fence around the disposal area was removed before the construction of the cap and was reinstalled following final grading and the establishment of the grass.

The multiple layers of the cap and associated surface water diversion features and drainage (diversion berm, perimeter ditch, toe drain and level spreader) that are shown on Figure 17 are presented below in a series of as constructed cross-sections.

Storm water runoff on the cap installed over the waste disposal area is diverted to a constructed perimeter ditch by a series of berms constructed directly on top of the cap. This surface water will travel a maximum distance of 80 feet on the cap before encountering and being diverted by a berm. Thus the berms will provide erosion control by intercepting sheet flow from the surface and directing that concentrated flow to the perimeter ditch. The construction details of the berms are shown on the following cross-section.

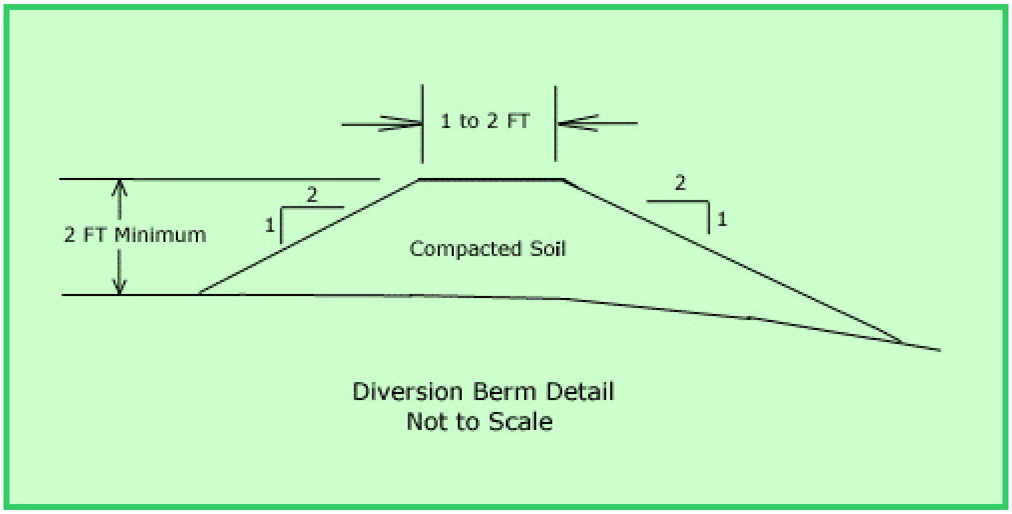

Figure 18: Construction detail of Diversion Berm

The surface water diverted by the berms is channeled to the constructed perimeter ditch through a set of constructed short diversion channels. The construction details of the diversion channels and perimeter ditch are shown on the following cross-section.

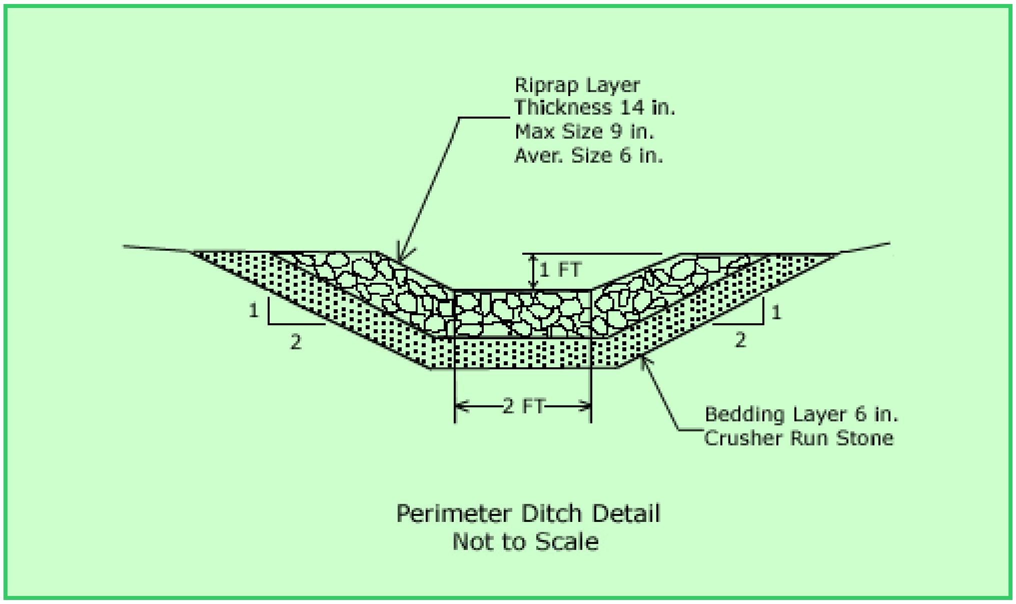

Figure 19: Construction detail of Diversion Channels and Perimeter Ditch

Water flowing in the perimeter ditch is directed along the northern and western perimeter of the waste disposal area towards a level spreader constructed down gradient and to the south of the buried waste. The flow in the Level Spreader will be discharged over a level crest 120 feet in length. The Level Spreader provides for the concentrated flow of the Perimeter Ditch to be returned to sheet flow at the discharge location. The southwestern rim of the level spreader is protected from erosion by the flowing water with the placement of matting material along its entire length. The construction details of the Level Spreader are shown on the following cross-section.

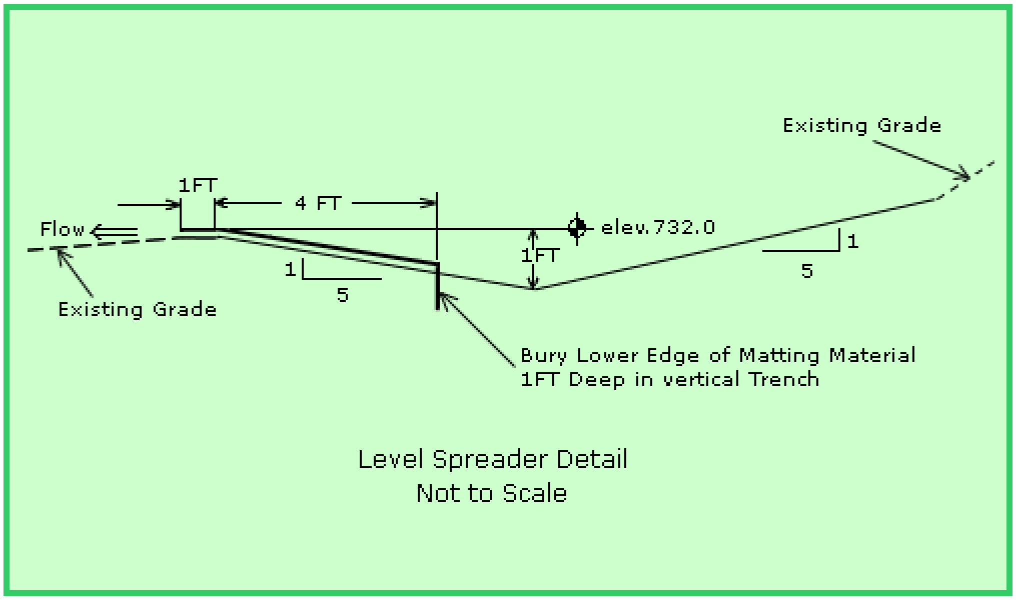

Figure 20: Construction detail of the Level Spreader

The components of the multiple layers cap and the construction details of the toe drain are shown on the following cross-section.

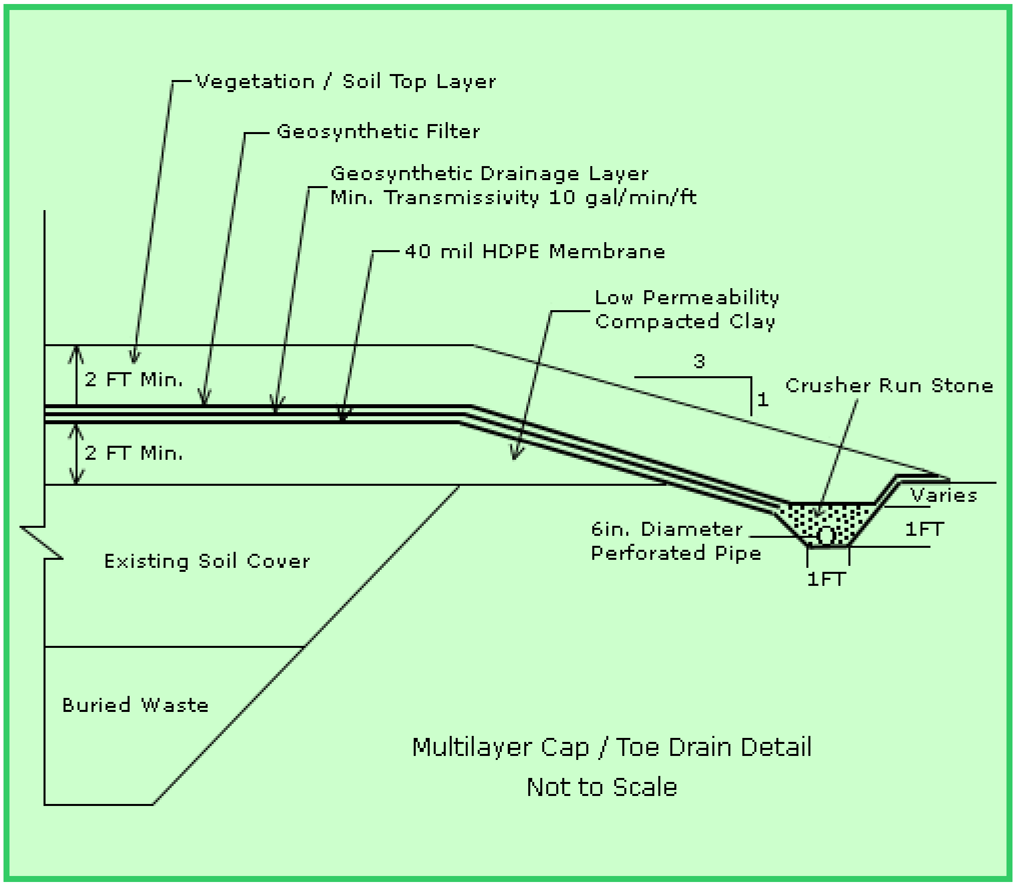

Figure 21: Construction detail of the Cap layers and Toe Drain

As shown on Figure 21, the cap consists from top to bottom of the following layers:

- A top vegetated surface installed over a topsoil or native soil layer with a minimum thickness of 24 inches. The cap was constructed at essentially the same slope as the existing landfill surface to avoid the necessity of bringing additional fill material to reduce the slope.

- A geosynthetic filter in the form of a geotextile fabric used to transmit fluids but prevent the migration of soil particles into the underlying geosynthetic drainage layer.

- A geosynthetic drainage layer in the form of a net-like product of two overlapping polyethylene strands which transmits fluids in the plane of the net. A big advantage of the net is its ease of installation and its very high hydraulic transmissivity (on the order of $2x10^{-3}m^2$/sec.). This product is used to replace the layer of sand and gravel specified by RCRA as a drainage medium in the past.

- A two-component low permeability layer, installed under the geosynthetic drainage layer, to limit water infiltration into the underlying wastes. EPA recommends that this two-component layer consists of an essentially impermeable flexible membrane liner of 20-mil thickness installed over a compacted clay layer that has a saturated hydraulic conductivity no greater than $1x10^{-7}$ cm/sec. In agreement with the Consultant, the Design Engineering Firm proposed to install an essentially impermeable flexible membrane liner with a thickness of 40-mil, which is twice the thickness recommended by EPA. The thicker membrane will reduce the potential for puncture during construction and further limit the amount of surface water infiltrating into the waste disposal area. The impermeable membrane was installed directly on top of a 2 ft. compacted layer of clay having a saturated hydraulic conductivity no greater than $1x10^{-7}$ cm/sec.

As shown on the construction detail of the toe drain, the 40-mil impermeable flexible membrane extends into and lines the bottom and sides of the toe drain. The geosynthetic drainage layer discharges the collected water directly into the toe drain excavation which is filled with crusher run stone and covered by the extension of the geosynthetic filter fabric. As shown on Figure 17, the water collected by the toe drains is in turn directed into the perimeter ditch.

Finally, it took the Construction Contractor, under the supervision of the Design Engineering Firm and the Quality Assurance checks of the Consultant, three months to install the multiple-barrier cap over the landfill and implement the recommended Auxiliary Control Measures. As anticipated, the grading and construction were conducted entirely with standard earth moving equipment. With the successful installation of the multiple barriers cap work on the project was completed to the satisfaction of the client and the Regulatory Agencies. However, as part of the approved Corrective Action Plan (CAP), long term monitoring of the groundwater on a yearly basis was continued to document the natural attenuation and degradation of the contaminants in the plume. The result of this monitoring is presented below.

Results of Long Term Monitoring

Presented below are the levels of chloroform concentration in the down-gradient monitoring wells #1, 2, 3 and 9. These concentrations were recorded on a yearly basis for two years before the installation of the engineered remedial measure and for five years following the successful installation of the recommended remedial measure. Year "0" on each graph denotes the year during which the construction of the remedial measure took place at the waste disposal site. For well #9 there was only a one year concentration measurement before year "0".

The following figure presents the variation in the concentration of chloroform in well #1 over a period of two years prior to the installation and five years after the installation of the corrective action measures. Note that the initial reading (4,300 ug/L) was measured by the State RPA. A year later, the concentration recorded by the Consultant was about 1,500 ug/L, prior to the installation of the remedial measures. Following the installation of the remedial measures, the concentration dropped to 25 ug/L five years later.

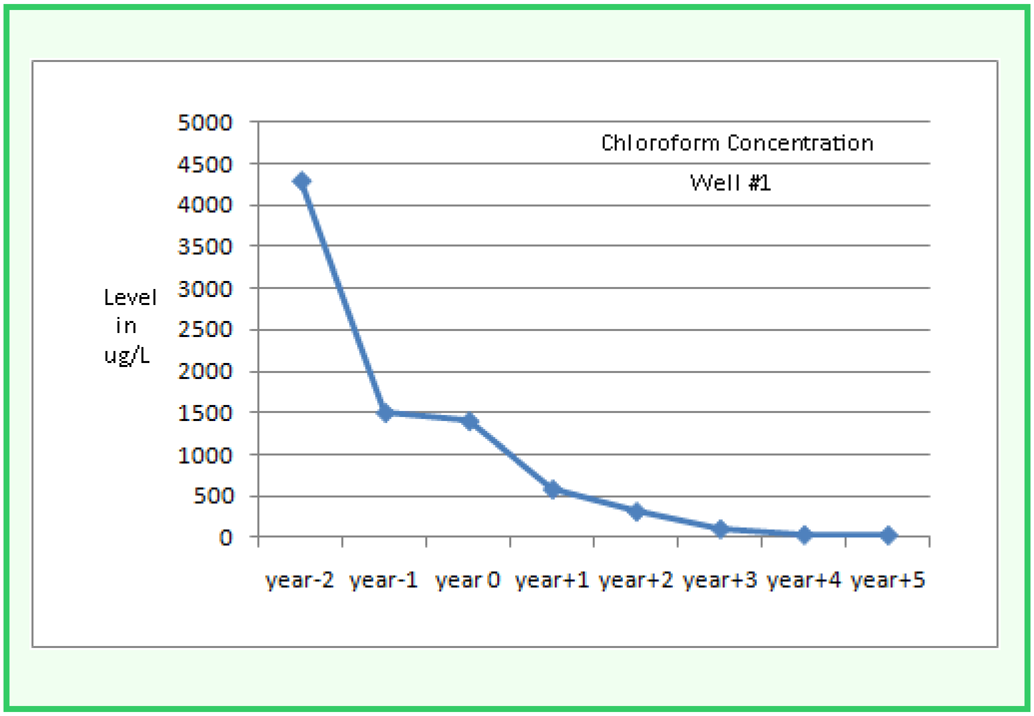

Figure 22: Graph of Well #1 Chloroform levels in micro-gram per liter over a period of eight years

The next figure presents the variation in the concentration of chloroform in well #2. Prior to the installation of the corrective action measures chloroform concentration fluctuated between 1,300 and 1,600 ug/L. Following the installation of the remedial measures, the concentration dropped to 250 ug/L five years later.

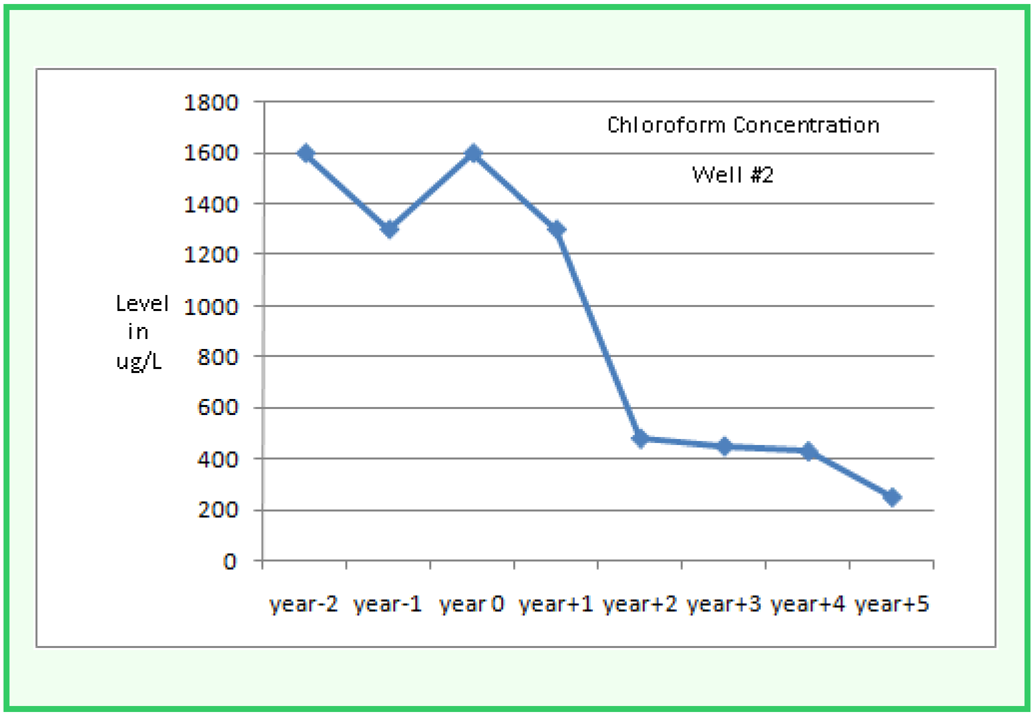

Figure 23: Graph of Well #2 Chloroform levels in micro-gram per liter over a period of eight years

The next figure presents the variation in the concentration of chloroform in well #3 over a period of two years prior to the installation and five years after the installation of the corrective action measures. Note that the initial reading (2,800 ug/L) was measured by the State RPA. A year later, the concentration recorded by the Consultant was about 1,500 to 1,600 ug/L, prior to the installation of the remedial measures. Following the installation of the remedial measures, the concentration dropped to 240 ug/L five years later.

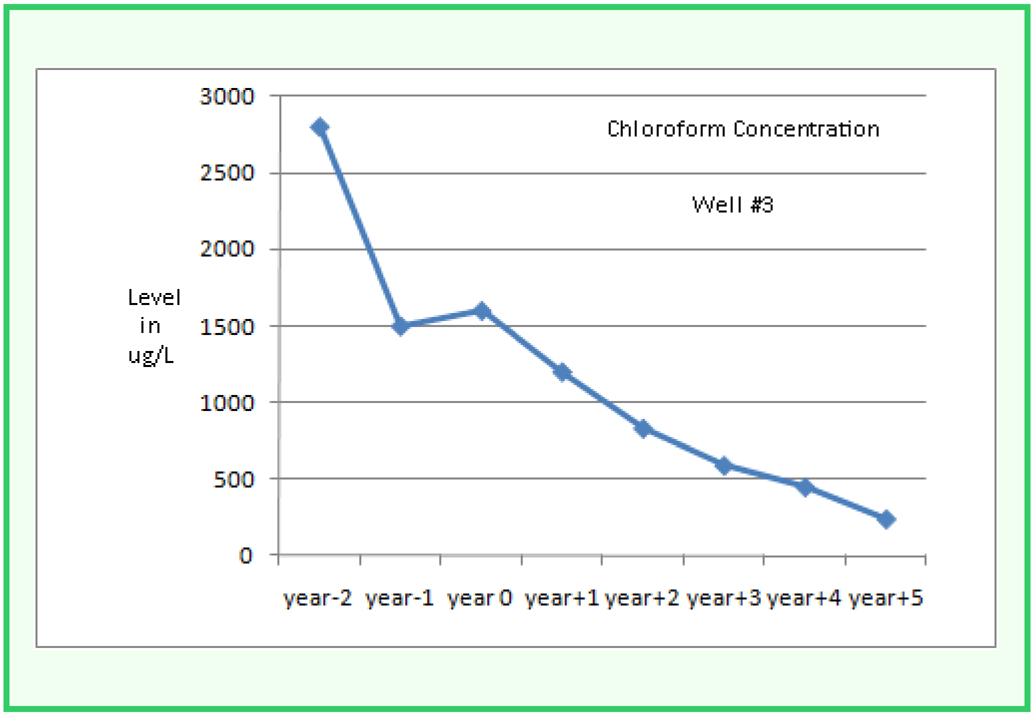

Figure 24: Graph of Well #3 Chloroform levels in micro-gram per liter over a period of eight years

The last figure presents the variation in the concentration of chloroform in well #9. Prior to the installation of the corrective action measures chloroform concentration fluctuated between 1,800 and 2,200 ug/L. Following the installation of the remedial measures, the concentration dropped to less than 100 ug/L five years later.

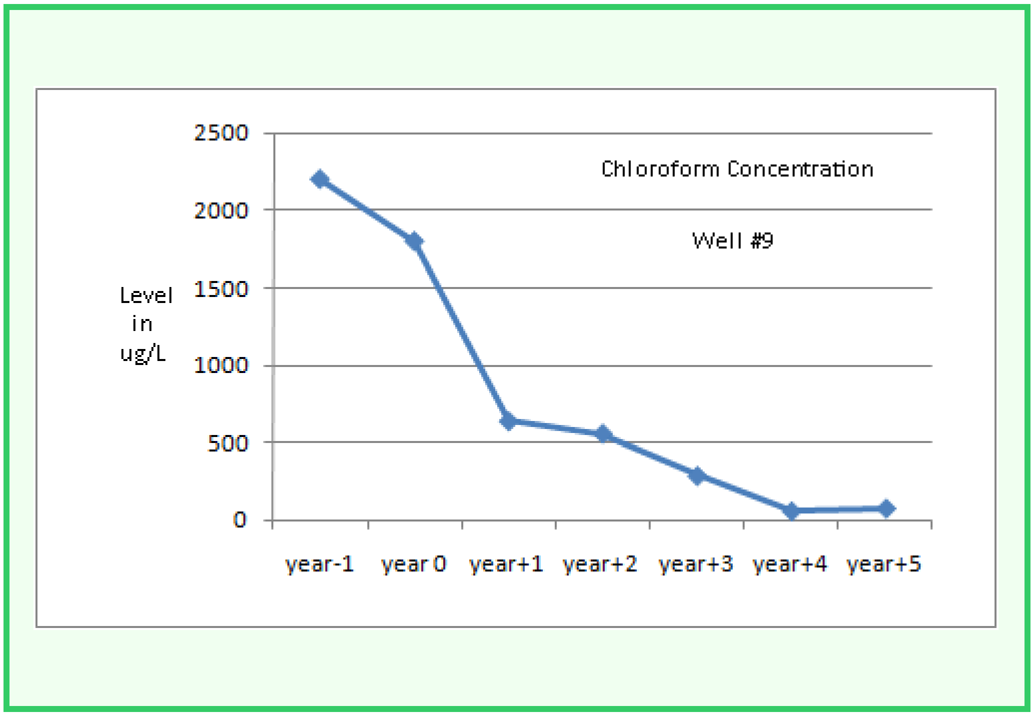

Figure 25: Graph of Well #9 Chloroform levels in micro-gram per liter over a period of seven years

In final conclusion to the course series, the four graphs presented above provide convincing documentation that the remedial measures that were implemented at the site performed as intended and were successful in reducing the levels of contamination significantly. In closing, the Consultant anticipates that over a longer period of time the levels of contamination will eventually come down even further, to possibly below the detection limit of the analytical methods used to analyze the samples.

Summary

All of the information collected at the Institute's waste disposal site: including the history of burial of chemical and radioactive waste and the geology, hydrology and geochemisty of the subsurface soils and groundwater was used to determine:

1) If an emergency situation existed at the site, and
2) The extent to which remediation of the waste disposal area and the down-gradient plume were necessary.

These issues were addressed by performing an assessment of the risk posed by the waste disposal site to human health and the natural environment. Following these assessments, a set of corrective action objectives were developed and used to guide the performance of an engineering Feasibility Study to identify the optimal corrective measures that could be implemented to effectively isolate the waste disposal area from its surrounding environment. Once a corrective action plan was developed, it was submitted to the State Regulatory Agencies for review and approval.

Following the guidance and recommendations provided by the State Regulatory Agencies a qualified design engineering firm prepared the construction drawings and applicable specifications for execution by a qualified constructor under the Quality Assurance supervision of the Consultant. The constructed features of the remedial measure that was implemented are presented on maps and cross-sections at the end of this course (Part 6). The efficacy of the remedial measure is documented by a series of graphs that illustrate the gradual decrease of the contamination over time in the down-gradient monitoring wells. Finally, the Consultant anticipates that over a longer period of time the levels of contamination will eventually come down even further, to possibly below the detection limit of the analytical methods used to analyze the samples.

Glossary of Terms and Acronyms used in this Course Series

1,4-dioxane	para-dioxane (p-dioxane), a hazardous chemical
AEC	Atomic Energy Commission
adsorption coefficient	measure of adherence of ions in solution to the surface of solids with which they come in contact
alluvial soil	a young soil on flood plains that is being actively deposited
ASTM	American Society for Testing and Materials
bailer	cylindrical container designed to remove water from a well
biotite	a widely distributed rock forming mineral of the mica group
C-14	Carbon-14, a radioactive form of carbon
CFR	Code of Federal Regulations
cm/sec	centimeter/second
Curie	A unit of measurement of radioactivity, which is approximately equal to the decay rate of one gram of pure radium.
DOT	Department of Transportation
Down-gradient	A direction towards which groundwater is likely to flow
draw	A small natural watercourse or gully, also a dry streambed whose water results from periodic rainfall.
Effective porosity	The percent of the total volume of a given mass of soil or rock that consists of interconnecting interstices.
EPA	Environmental Protection Agency
ft.	feet
GC/MS	Gas Chromatograph/Mass Spectrometer
H&S	Health and Safety
HASP	Health and Safety Plan
H2SO4	Chemical formula of sulfuric acid
H-3	Tritium, a radioactive form of hydrogen
HCL	Chemical formula of hydrochloric acid
HNO3	Chemical formula of nitric acid
in.	inches

mafic rock	igneous rock composed mainly of dark-colored minerals
mCi	milli-Curie, scale for the measurement of radioactivity
my	million years
NaOH	Chemical formula of sodium Hydroxide
OVA	organic vapor analyzer
pCi/L	pico-Curie/liter, scale for the measurement of radioactivity in liquids
pCi/gr	pico-Curie/gram, scale for the measurement of radioactivity in solids
permeability	capacity of a porous rock to transmit a fluid, ease of fluid flow
pH	hydrogen-ion activity in solution, a measure of acidity
pluton	A geologic igneous intrusion
potentiometric surface	a surface representing the total head of water in an aquifer
ppb	parts per billion
ppm	parts per million
purging	volume of water extracted from a well prior to sampling
QA/QC	Quality Assurance/Quality Control
Saprolite	A thoroughly decomposed rock, formed in place by the weathering of igneous, sedimentary or metamorphic rocks.
SCS	Soil Conservation Service
State RPA	State Radiation Protection Agency
State EPA	State Environmental Protection Agency
State GPA	State Groundwater Protection Agency
State WMA	State Waste Management Agency
Superfund	Acronym referring to the resources allocated by Federal or State Agencies for the clean-up of decommissioned waste disposal sites. The funds are disbursed by priority based on the degree of hazard
total head	the height of a column of water above a datum plane
ug/L	micro-gram/Liter
ug/kg	micro-gram/kilogram
uS/cm	microsiemens per centimeter, a measure of specific conductivity
Up-gradient	A direction opposite to that in which groundwater is likely to flow
USDA	United States Department of Agriculture
US-DOT	United States Department of Transportation
USEPA	United States Environmental Protection Agency

End