PDHonline Course C390 (4 PDH)

Environmental Investigation and Remediation of a Hazardous Waste Site
 Part 5 - Results and Implications of Phase 2 Investigations

Instructor: Samir G. Khoury, Ph.D., P.G.

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5272 Meadow Estates Drive
Fairfax, VA 22030-6658
Phone: 703-988-0088
www.PDHonline.com

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Environmental Investigation and Remediation of a Hazardous Waste Site
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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 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.

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 (State 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 waste 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 (State GPA), the Institute installed five monitoring wells around the waste disposal site. The location of the five wells is shown on the following figure.

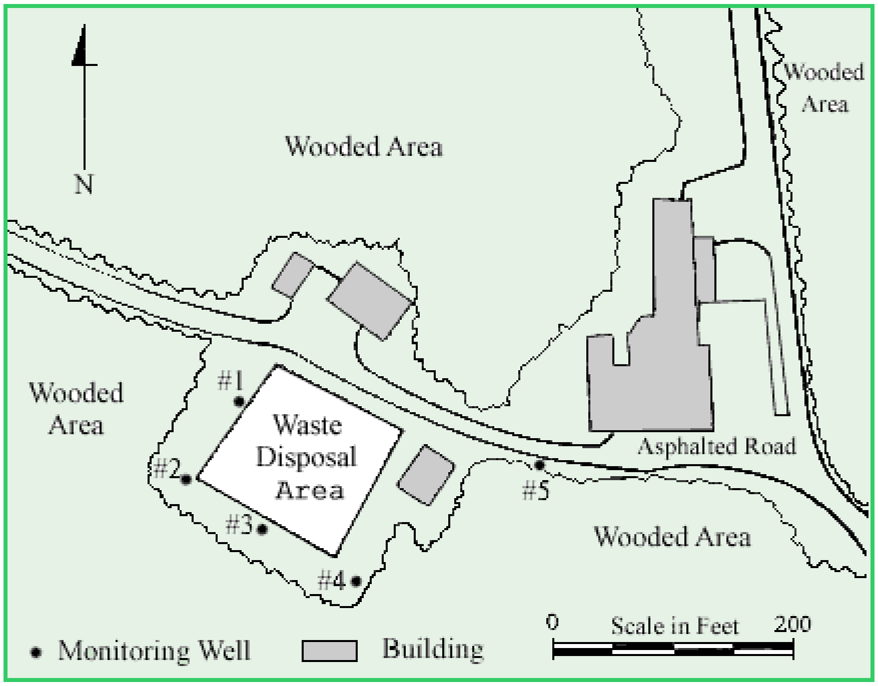

Figure 2: Location of Initial Monitoring Wells Surrounding the Waste Disposal Site

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 fence 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 to retain the services of a technical services consultant (Consultant). The winning bidder reviewed existing information 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 a characterization of the geology and hydrology of the area and the collection of additional soil, groundwater and surface water samples for analysis, including the installation of additional groundwater monitoring wells, in order to determine the size, extent, and characteristics of the contaminant plume.

Because the waste disposal site contained both 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.

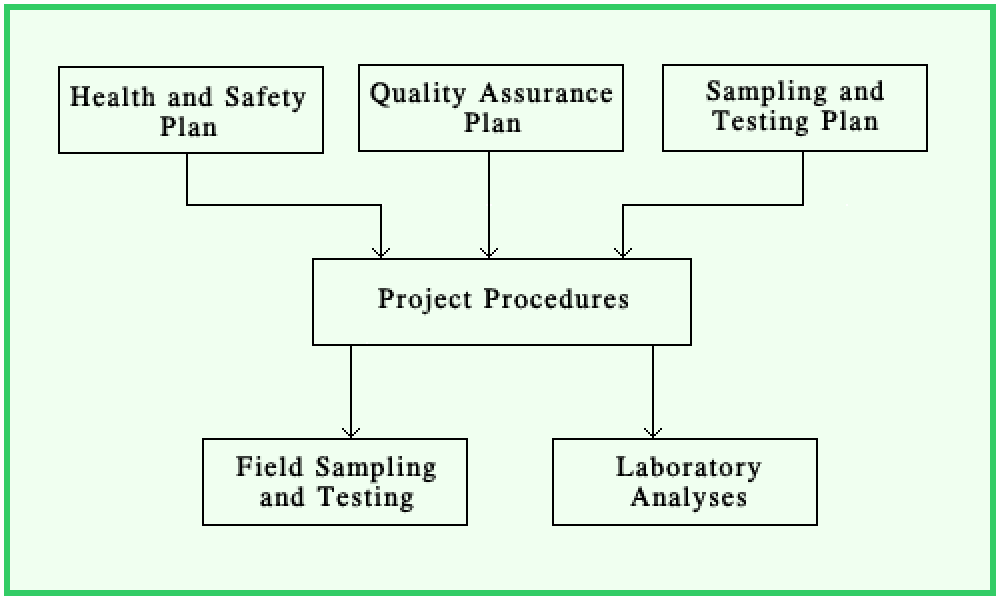

Figure 3: Relationship of the Various Project Plans, Procedures and Field and Laboratory Activities

Part 4 of this course series reviewed the results of the Phase 1 investigations. This work included field and laboratory testing, data analyses, interpretations, and recommendations for the design of the Phase 2 work. Part 4 also reviewed the concerns and comments expressed by the various state regulatory agencies and the press coverage of the Phase 1 Report. The Phase 1 work provided additional 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 Phase 1 was to initiate the Phase 2 field investigation program, including the performance of additional work in both the up-gradient and down-gradient directions. 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 the down gradient contamination.

The Phase 2 field investigations consisted of performing the following activities at the Site:

- Preparing an accurate topographic map
- Installing up-gradient monitoring wells
- Collecting geologic and hydrologic information from the new wells
- Performing permeability tests in the new wells
- Installing down-gradient monitoring wells
- Performing a Hydropunch™ investigation in the floodplain
- Collecting and interpreting new groundwater chemical data

The Phase 2 data were evaluated, integrated with the existing information and interpreted to arrive at the recommendation to perform an environmental and public health assessment and prepare a conceptual engineering study to evaluate appropriate options to control the contamination.

Preparation of an Accurate Topographic Map

To date, all work at the site was completed using 1:24,000 scale topographic maps published by the United States Geologic Survey. The contour interval on these maps is 10 feet, which proved to be too coarse for accurate interpretation of the field data. Additionally, it was also recognized that any engineering work completed to support the Feasibility study and the implementation of a selected remedial option will require an accurate topographic base map.

The data for the production of the updated topographic map were collected in the field by a licensed surveyor, using electronic surveying equipment. The field data were transferred to a Computer Aided Design (CAD) system for processing. Base maps were generated at a scale of 1 inch equals 40 feet, with a contour interval of one foot in the immediate vicinity of the waste disposal area, and a two-foot contour interval in the remainder of the surveyed area. This survey provided an accurate base map for locating the position of the monitoring wells, interpreting the site hydrology, planning the investigation of the down gradient plume, and evaluating the remedial alternatives. All figures generated for this course (Part 5) are based on the new survey. The area that was surveyed is shown on Figure 4, below.

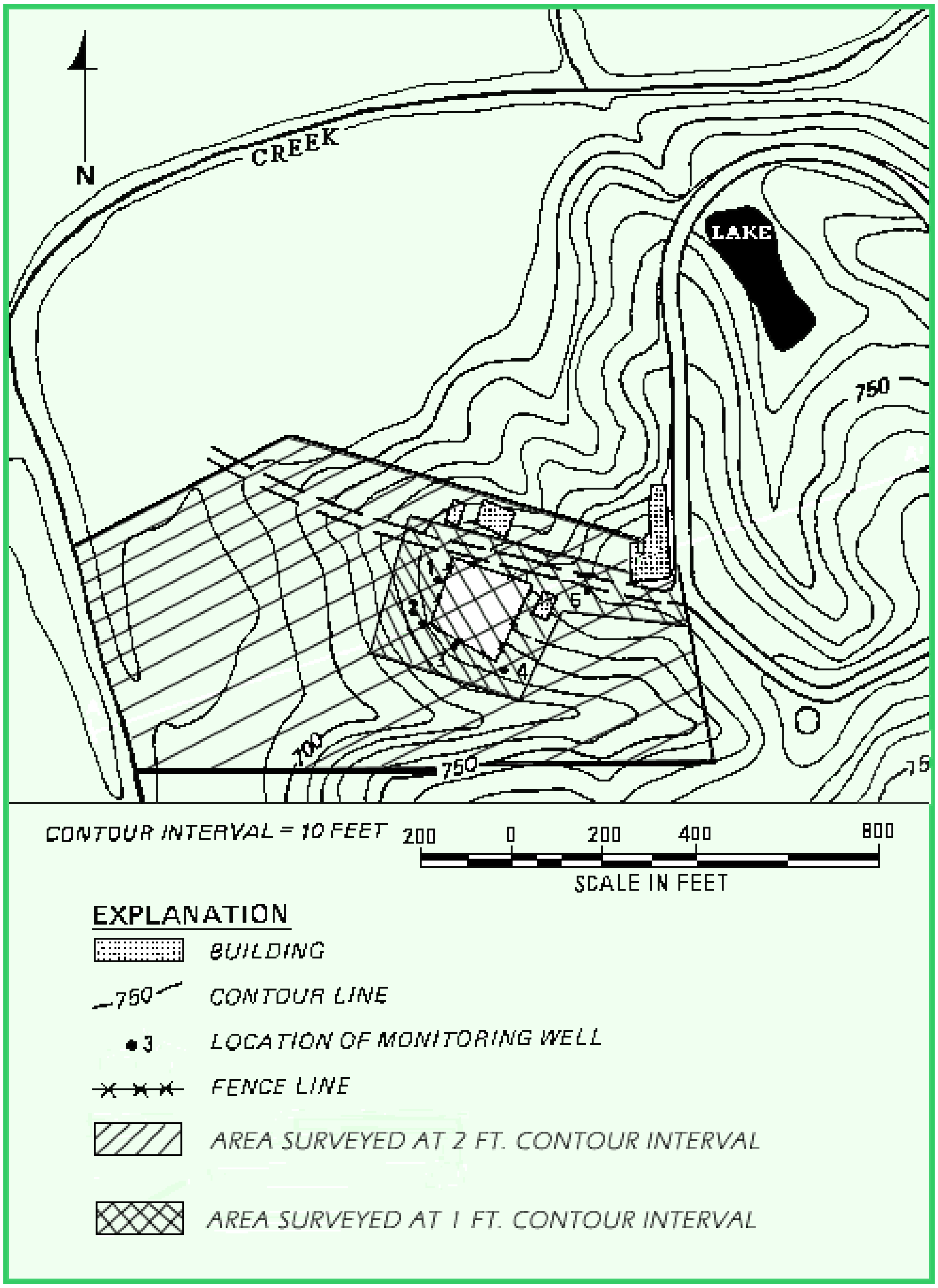

Figure 4: Map Showing the Outline of the Area covered by the New Topographic Survey

It is interesting to note at this point that the Consultant had recommended the preparation of a more accurate topographic map at the very start of the site investigations. However, the Institute was not convinced of the necessity of that expense at the time. Now that the value of working with an accurate map became clear, the Institute approved the implementation of this necessary topographic survey.

Up-Gradient Extension of the Field Investigations

Three new borings were drilled in the proximity of the waste disposal area to obtain site-specific geologic and hydrologic information. Boring No. 6 was positioned to address the question raised by the regulatory agencies that well No. 4 was considered by the Consultant to be up gradient. Borings Nos. 7 and 8 were located to ensure that no contamination is migrating into the lower topographic areas located to the north of the waste disposal site, especially during periods of high groundwater stands, and to provide controls in defining the configuration of the groundwater table beneath the waste disposal area.

In addition, the following field activities were also performed:

- New monitoring wells were installed in these borings
- Groundwater level measurements were taken
- Field permeability measurements were performed, and
- Groundwater samples were collected and analyzed

The results of these investigations are presented in the following sections.

Geology

Previous characterization of the Site geology was obtained from published regional information and the interpretation of surface soils and other geomorphic features. Although five monitoring wells had been previously installed around the waste disposal site, unfortunately no geologic information was recorded from those borings. Although these five initial monitoring wells were installed at the request of the State RPA, and drilled in place under the direction of the State GPA, neither of these regulatory agencies, nor did personnel from the driller of the wells, recorded any geologic information from these borings.

In contrast, the installation of three additional monitoring wells under the direction of the Consultant provided site-specific subsurface geologic information. The locations of these wells were selected to: 1) delineate as closely as possible the up-gradient extent of contamination, and 2) provide directional and quantitative constraints on the groundwater gradient beneath the waste disposal site.

The location of the new borings/monitoring wells, numbered 6, 7 and 8, are shown on Figure 5, below.

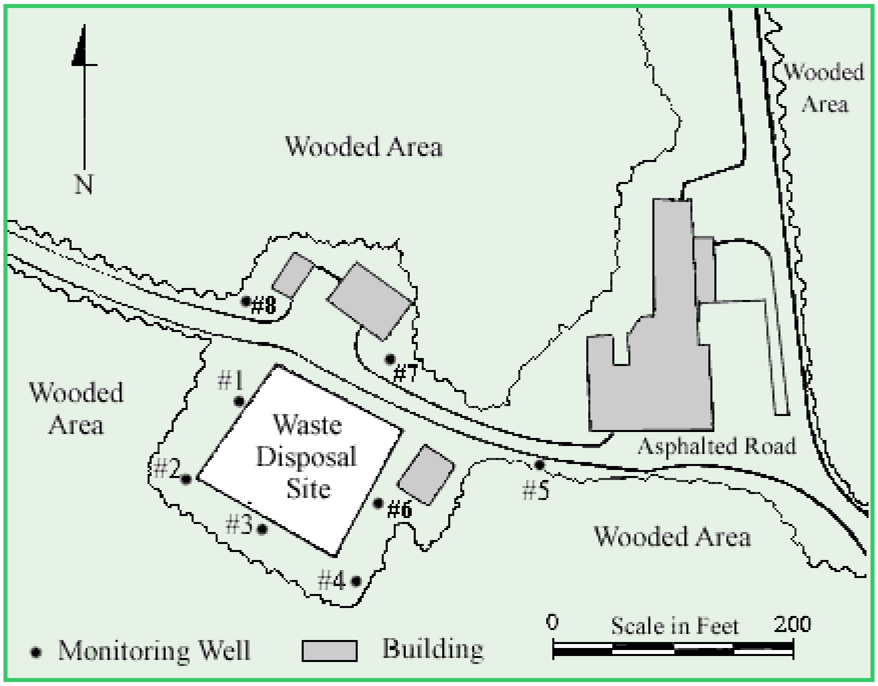

Figure 5: Map Showing the Location of Borings/Monitoring Wells 6, 7 and 8

All three new borings were initiated with a 7.25 inch Outer Diameter (OD), 4.25 inch Inner Diameter (ID) hollow stem auger. While boring through the residual soil, standard penetration tests were performed by driving a 2.0 inch OD split spoon sampler with a 140 pound hammer using a 30 inch drop (ASTM D1586-84). Standard penetration testing was done every five feet in borings 6 and 8, and continuously in boring number 7. This test was performed to obtain an estimate of the variation in soil density with depth. The split spoon sampler was 24 inches long. As per common procedure, the number of hammer blows to drive the spoon each 6 inches of the 24-inch test was recorded. Spoon refusal was defined as 100 blows per 6 inches or less of penetration. Auger refusal was defined as the depth the auger was no longer able to advance the boring.

If auger refusal was encountered before the boring had penetrated at least ten feet below the water table (estimated using observation of the wetness of the soil samples or auger cuttings), then the boring was advanced by using rock drilling methods. Rock drilling was performed using a 4.0 inch OD air hammer operated through the inside of the hollow stem auger. Since no core is recovered using the air-hammer, geologic interpretations were based on analysis of the cuttings. The air hammer technique was selected because any other approach would necessitate the use of water for cooling and cutting removal. Drilling water, if not fully recovered, would affect the chemical analyses of the groundwater samples taken from the well.

The following table lists the spoon refusal depth, auger refusal depth, total borehole depth and the screened interval for the three new borings (Nos. 6, 7, and 8). The depths to water table shown are based on measurements taken after the borings were converted to monitoring wells and developed, as discussed in the following subsections.

TABLE 1 – Summary Specifications of Borings 6, 7 and 8

Parameter:	Boring #6	Boring #7	Boring #8
Spoon Refusal Depth:	21 feet	17.5 feet	36.5 feet
Auger Refusal Depth:	43 feet	38.5 feet	49.0 feet
Total Hole Depth:	43 feet	46 feet	49.0 feet
Screened Interval:	33-43 feet	34-44 feet	37-47 feet
Depth to Water Table:	30.7 feet	32.9 feet	33.1 feet

Conversion of Borings to Monitoring Wells

Following the completion of each boring, a monitoring well was installed at that same location. Conversion of the boring to a monitoring well took place by implementing the following steps:

1. Extract the auger, leaving a 7.25 inch diameter hole.
2. Prepare the well pipe by connecting 10 feet of 2 inch diameter PVC screen to a length of 2 inch diameter PVC riser pipe sufficient to extend at least two feet above the ground elevation.
3. Lower the pipe and screen to the bottom of the hole or target elevation if not at the bottom.
4. Backfill the annular space around the screen with clean sand to act as a filter. The sand should extend at least 2 feet above the top of the screen.
5. Backfill the next 3 feet with bentonite pellets to form a seal at the top of the screened interval.
6. Backfill to within two feet of the surface with bentonite/cement mix to seal the riser pipe from the formation.
7. Install a concrete pad and upper seal, and embed a protective steel casing and locking cap around the extension of the riser pipe above ground.

Details of the installation of the monitoring wells in borings #6, #7 and #8 are presented in the following figures. The geology of each boring is also shown schematically on the Figures.

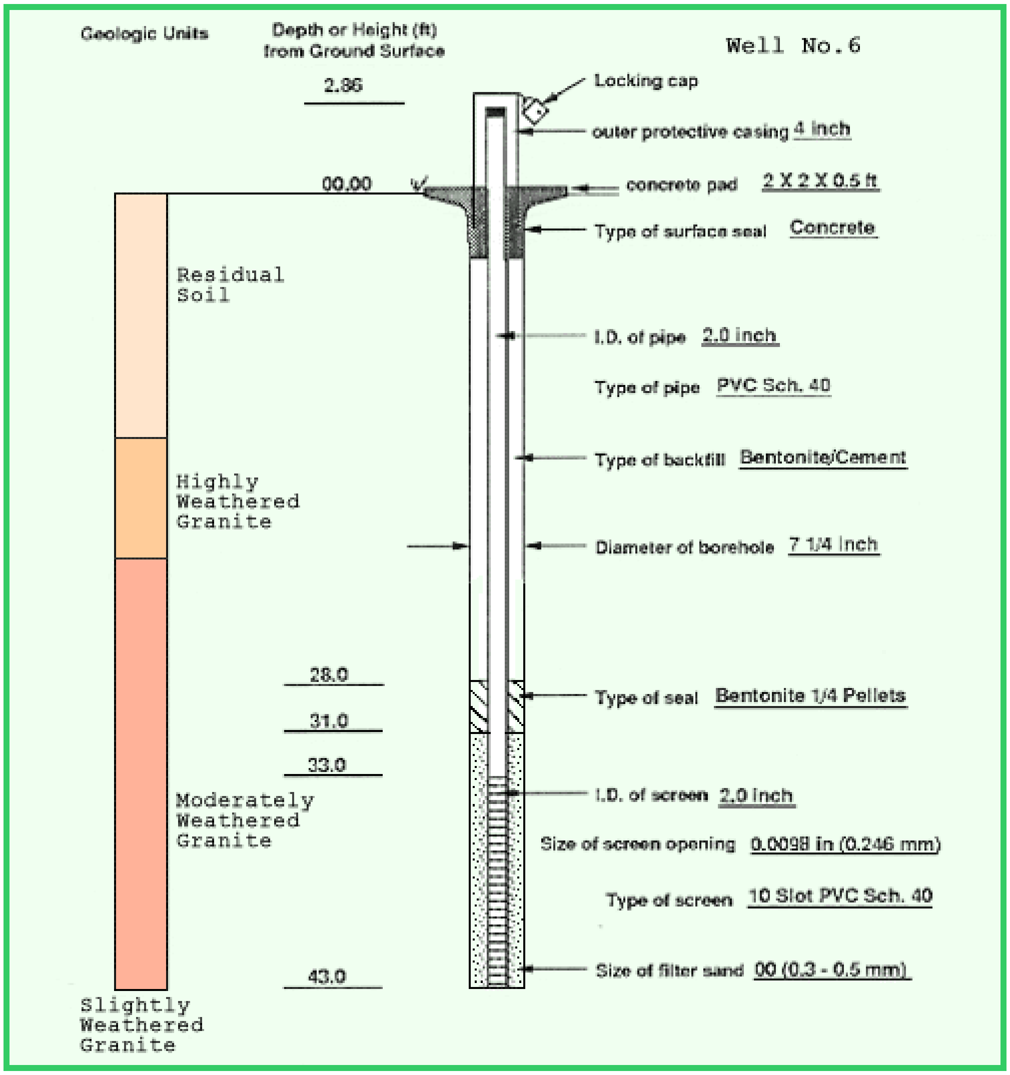

Figure 6: Installation Diagram and Geology Encountered in Boring #6

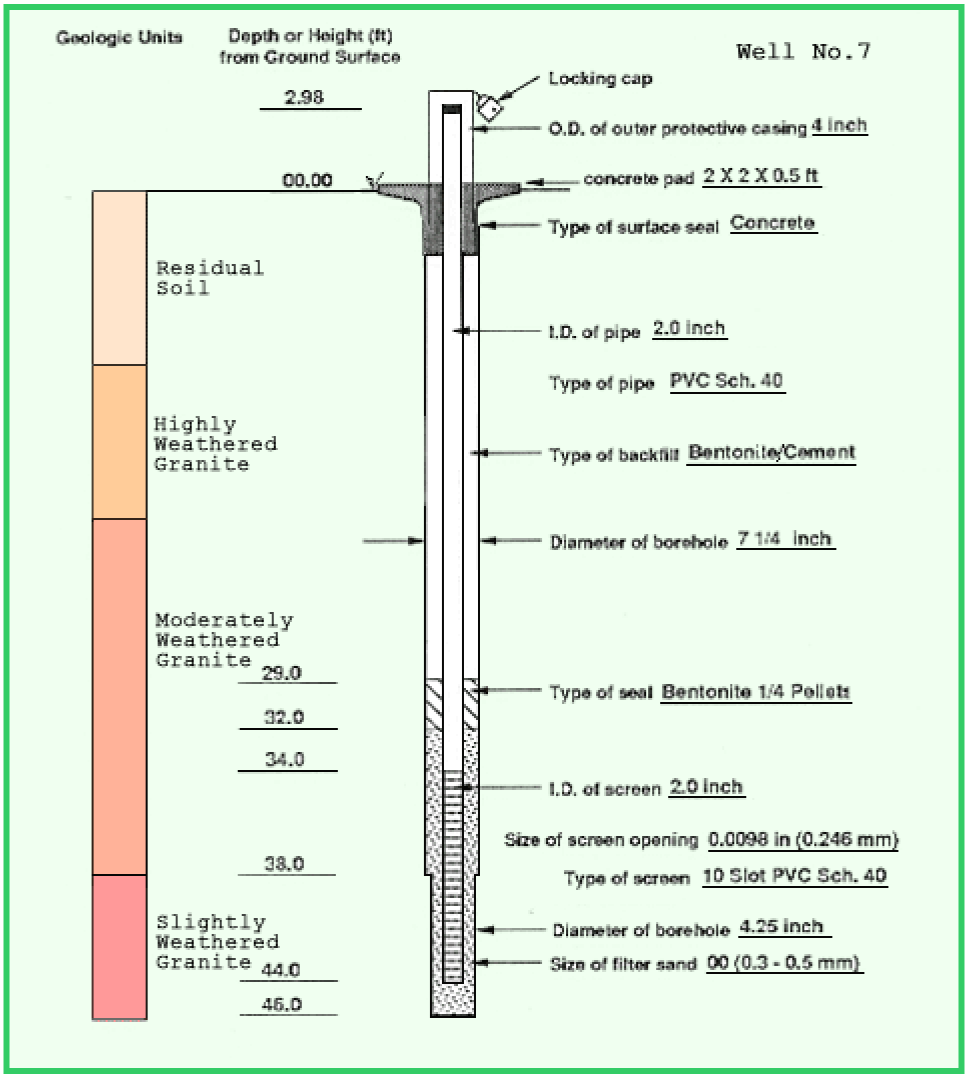

Figure 7: Installation Diagram and Geology Encountered in Boring #7

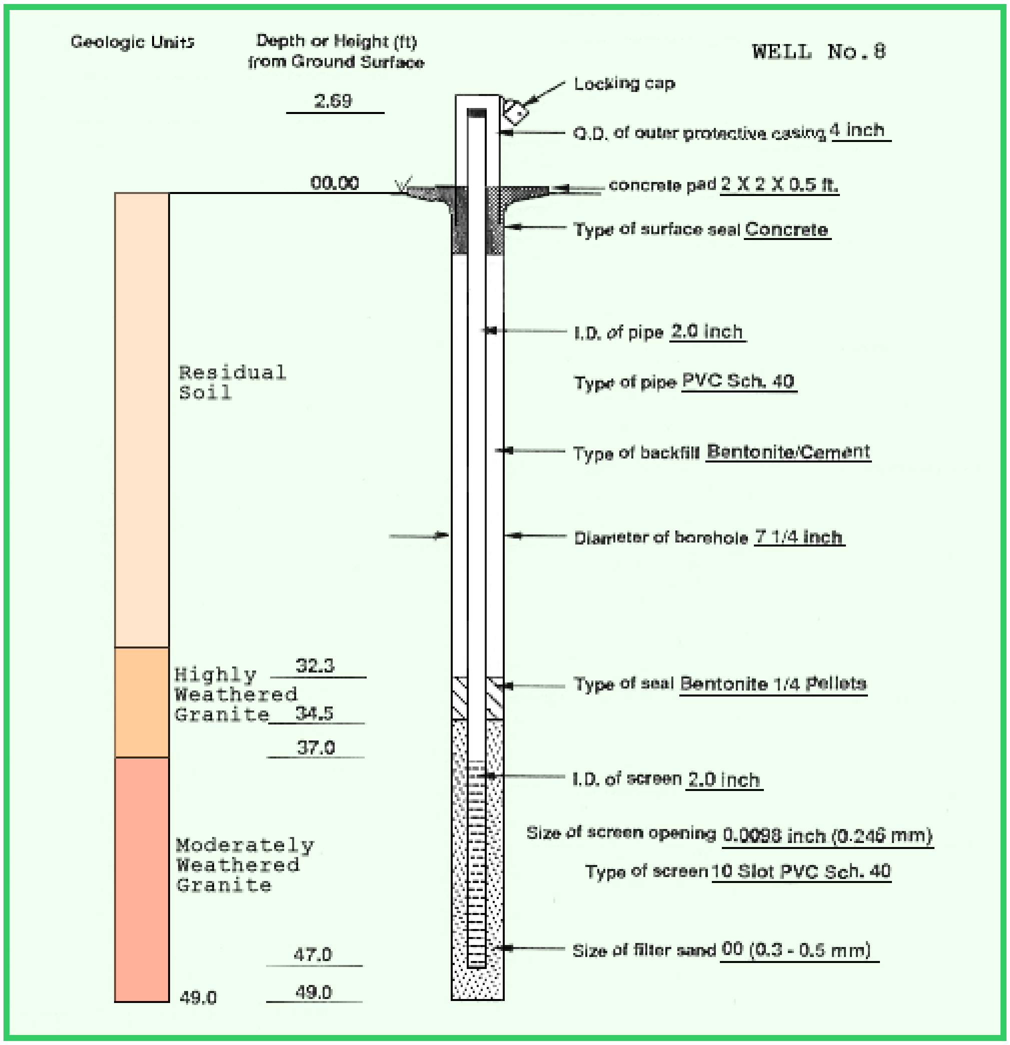

Figure 8: Installation Diagram and Geology Encountered in Boring #8

As shown on the figures, wells #6 and #8 were screened in moderately weathered rock. Well #7 was screened partly in moderately weathered rock and partly in slightly weathered rock. Screened intervals were selected to ensure that the entire well screen would be in the water table.

A geologic cross section through the three new borings is presented in Figure 9.

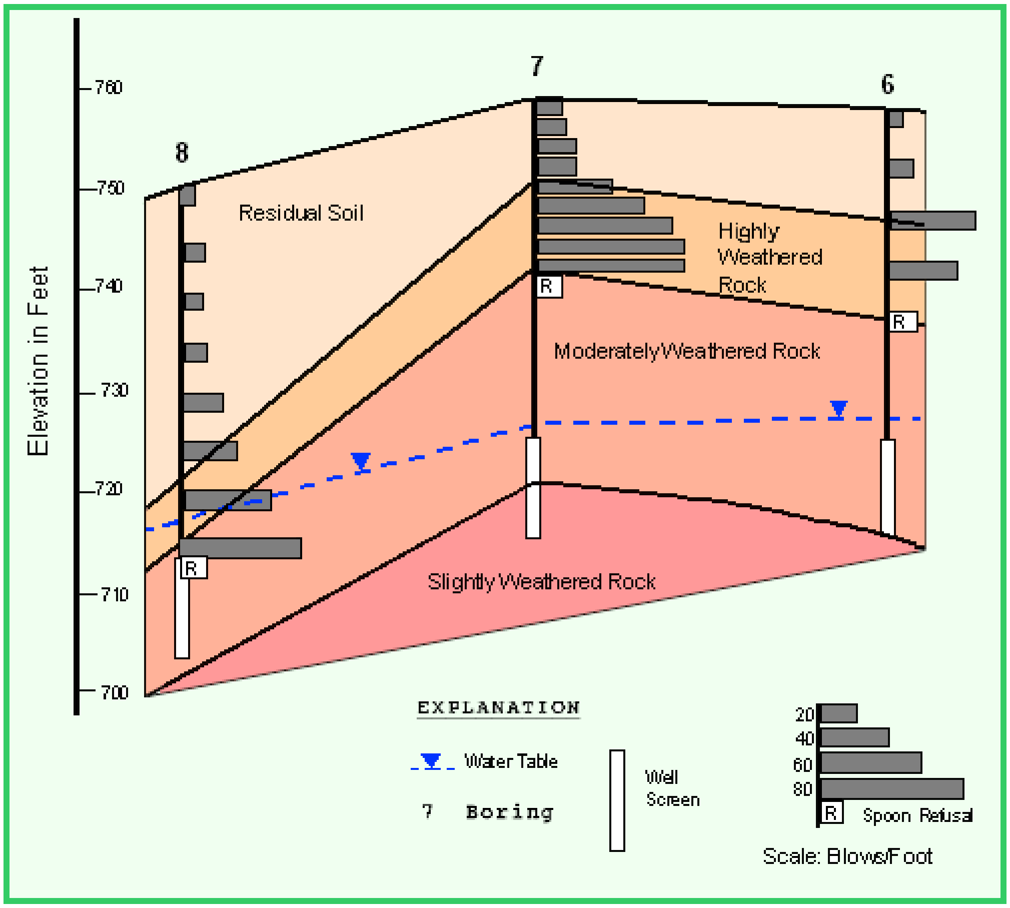

Figure 9: Geologic Profile Drawn through Borings 6, 7 and 8

As shown on the figure, the uppermost unit is residual soil, formed from the in-place weathering of the granite bedrock. Samples were typically medium orange-brown, fine to coarse-grained, micaceous silty sand. The residual soil in the upper 10 feet of borings 6 and 7, and the upper 30 feet of Boring #8 was classified as loose to medium-dense based on blow counts. Blow counts in these intervals ranged from 10 to 25 blows per foot, with blow counts generally increasing with depth.

The top of the highly weathered rock shown on Figure 9 was identified by a significant increase in blow count and a change in sample color from orange-brown to light grey and tan. Blow counts jumped to 50, 80 or more per foot at this contact. Samples recovered in the split spoon were tan to light grey, fine to medium-grained micaceous silty sand with numerous intermixed coarse-grained chunks of granite. With blow counts ranging from 50 to over 80 per foot, it is likely that the split spoon sampler broke up much of the weathered rock as it was driven. The material would be classified as medium to very dense based on blow counts, but this is a soil classification approach that is really not applicable to weathered rock.

The top of moderately weathered rock was defined as split-spoon refusal (more than 100 blows to advance 6 inches or less). This point in each boring is marked by an “R” on Figure 9. In all three borings, however, the auger was able to continue advancing below this point. Samples from the last split spoon samples were typically light grey granite chunks in a mixture of light-grey micaceous silty-sand. Since the blow counts were above 100 for 6 inches or less of penetration, it is likely that the sandy material in the samples was actually rock that had been crushed by the sampling process.

In Boring #6, auger refusal was encountered at 43 feet and the boring was terminated at that depth. In Boring #7, auger refusal was encountered at a depth of 38.5 feet. The driller switched to the air hammer and drilled hard rock to the target depth of 46 feet. Cuttings from the air hammer were light grey, fresh to slightly weathered granite, with minor indication of iron-stained joints. In Boring #8, auger refusal occurred at 49 feet, at the top of hard rock, at the base of moderately weathered granite or at the top of slightly weathered granite. The boring was terminated at this depth.

Well Development

Before water levels or groundwater samples can be taken from a monitoring well, the well must first be developed. Well development entails drawing sufficient water out of the well to ensure that all air is removed from the sand filter, and that good connection has been established with the formation water. Water was extracted using a new Teflon bailer for each well. Development is considered complete when the pH, temperature and specific conductivity of the extracted water stabilize to a near constant value. The amount of water that was required to achieve this stability in wells #6, #7 and #8 is listed below:

- Well #6 – six well volumes
- Well #7 – 20 well volumes
- Well #8 – 17 well volumes

Only after development and return to a static water level are the wells considered representative of the actual water table depth and available for groundwater sampling for radiological and chemical analyses. Because the water extracted during development was potentially contaminated, it was placed into 55-gallon drums and sealed. The Consultant recommended that the Institute awaits the results of the chemical analyses of the groundwater from these wells before deciding on how to dispose of the contents of the drums.

Depth to Groundwater

Groundwater level measurements were obtained from all eight monitoring wells and, together with the readings taken a year earlier in the initial five monitoring wells, are presented in Table 2, below:

TABLE 2 - Groundwater Table Elevations

Parameter / Well #:	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Surface Elevation	748.2	742.8	744.7	740.5	777.0	757.4	759.2	750.1
(Older Estimated Elev.)	(756.6)	(747.0)	(749.6)	(740.2)	(779.0)			
Measurement Period #1:								
Depth to Groundwater	32.6	29.9	27.3	15.4	41.8			
Groundwater Elevation:	715.6	712.9	717.4	725.1	735.2			

Measurement Period #2:								
Depth to Groundwater:	32.0	29.7	27.4	15.7	41.8	30.7	32.9	33.1
Groundwater Elevation:	716.2	713.1	717.3	724.8	735.2	726.7	726.3	717.0
Change in Elevation:	+0.6	+0.2	+0.1	-0.3	0.0			

Notes:
Surface elevation measurements based on new topographic survey.
The "Older Estimated Elev." is the surface elevation estimate based on the published topography.
Measurement Periods were in June of two consecutive years.
All measurements in feet. Elevations are in feet above mean sea level.

The measurements were obtained with an electronic water-sensing instrument. Groundwater elevations were calculated by subtracting the depth to the water from the surface elevation at the well site, as determined by the new topographic survey. The new topographic survey and accurate surveying of the well locations revised the elevations of the existing wells by as little as a few tenths of a foot to over 6 feet from the older estimate based on the USGS topographic map (see Part 4 of this course series). This revision changed both the absolute elevations of the groundwater table and the calculated groundwater gradient under the waste disposal site.

The elevation of the groundwater table varied only slightly in the one-year interval and ranged from an increase of 0.6 feet in Well #1 to a decrease of 0.3 feet in Well #4.

The depth to the groundwater table around the perimeter of the waste disposal area ranges from 15.7 feet in Well #4 to 41.8 feet in Well #5. This is consistent with the topographic position of the wells: Well #4 is topographically the lowest and Well #5 is topographically the highest. The average depth to water under the area of the waste disposal site is approximately 30 feet.

Groundwater Table Configuration

The updated configuration of the groundwater table in shown on Figure 10, below:

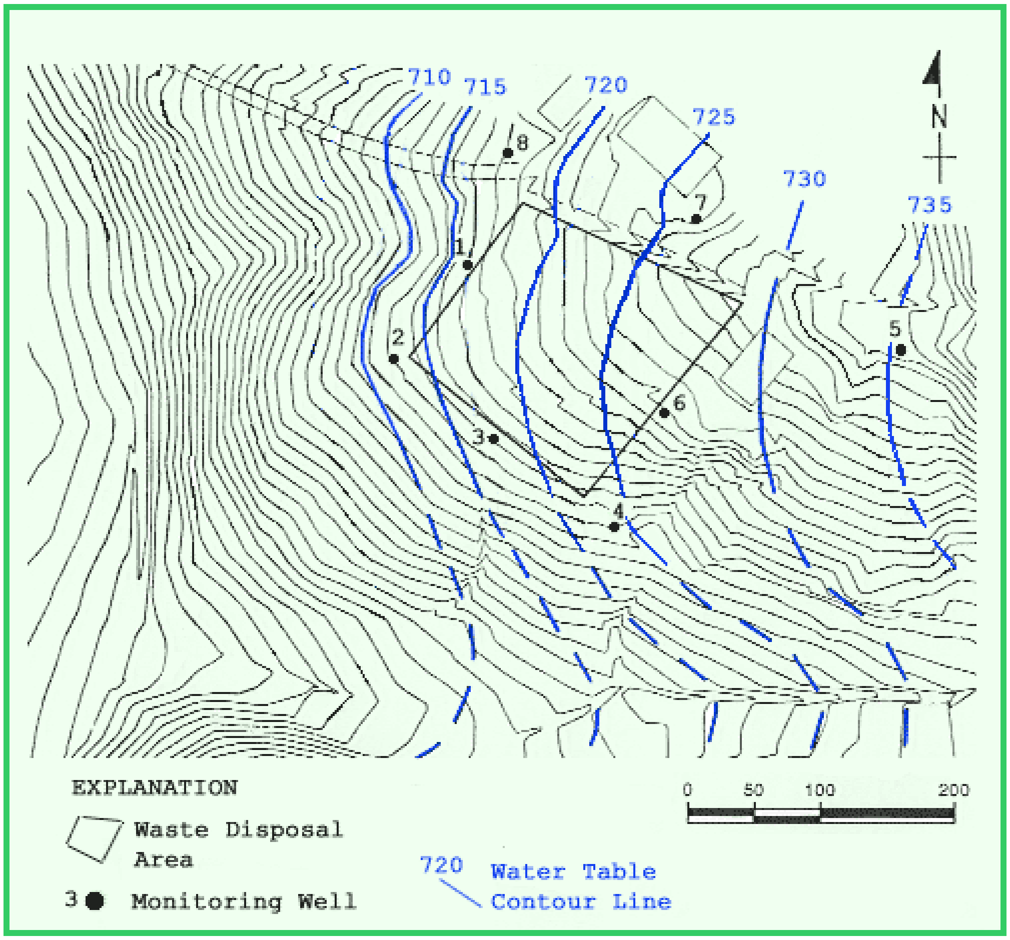

Figure 10: Map of the Groundwater Table beneath the Disposal Area

The map is based on the results of the updated topographic survey and the groundwater elevations measured in wells number 1 through 8. It is clear from the map that groundwater beneath the waste disposal site flows generally in a westerly direction, since the direction of groundwater flow is perpendicular to the contour lines. The gradient of the groundwater table beneath the waste disposal area is approximately 6 to 7 percent in a westerly direction.

Permeability Testing

Permeability tests were performed in Monitoring Wells 6, 7 and 8 after the completion of groundwater sampling. The tests were performed in the field by quickly submerging a stainless steel cylinder, or "slug", into the water which resulted in an essentially instantaneous rise of the water level. As the water level dropped back towards its original level, the changing water depth was recorded electronically and plotted in logarithmic time. Once equilibrium was re-established in the well, a second test was performed by quickly withdrawing the "slug", which resulted in the dropping of the water level, and recording the water level as it rose and re-equilibrated with the groundwater table. These tests were performed using a 4-foot long 1.5 inch diameter stainless steel slug. Additional tests were performed in monitoring wells 6 and 7 with the rapid addition of one gallon of distilled water into the well. Water level responses in the wells were measured using a pressure transducer and data were recorded with an electronic data logger.

Examples of the data collected and graphed for the "Slug in" and "Slug out" tests performed in monitoring well No. 6 are presented respectively in Figures 11 and 12, below:

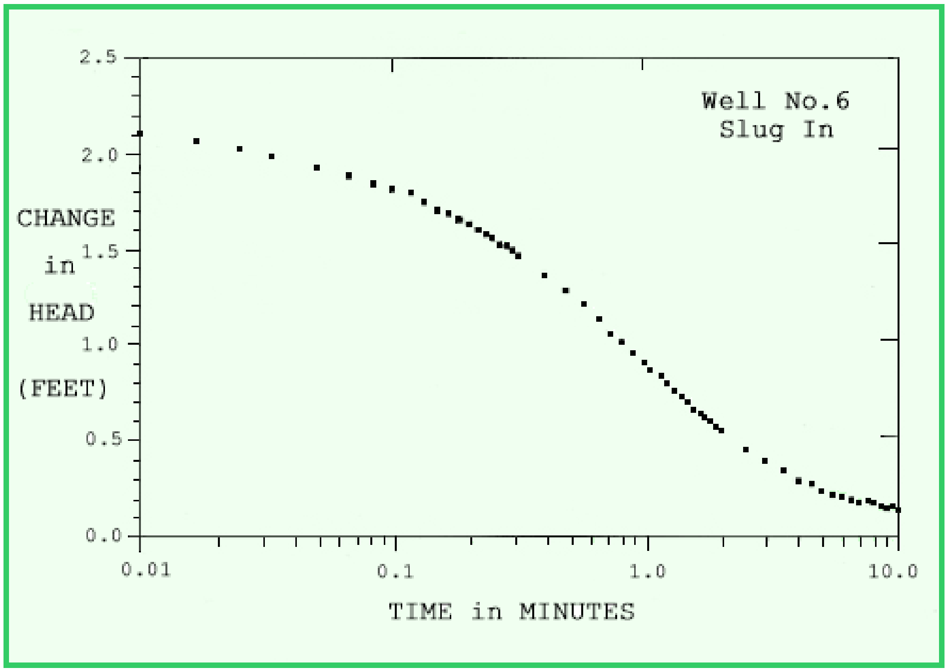

Figure 11: Graph of Groundwater Re-equilibration from a "Slug in" Test in Well #6

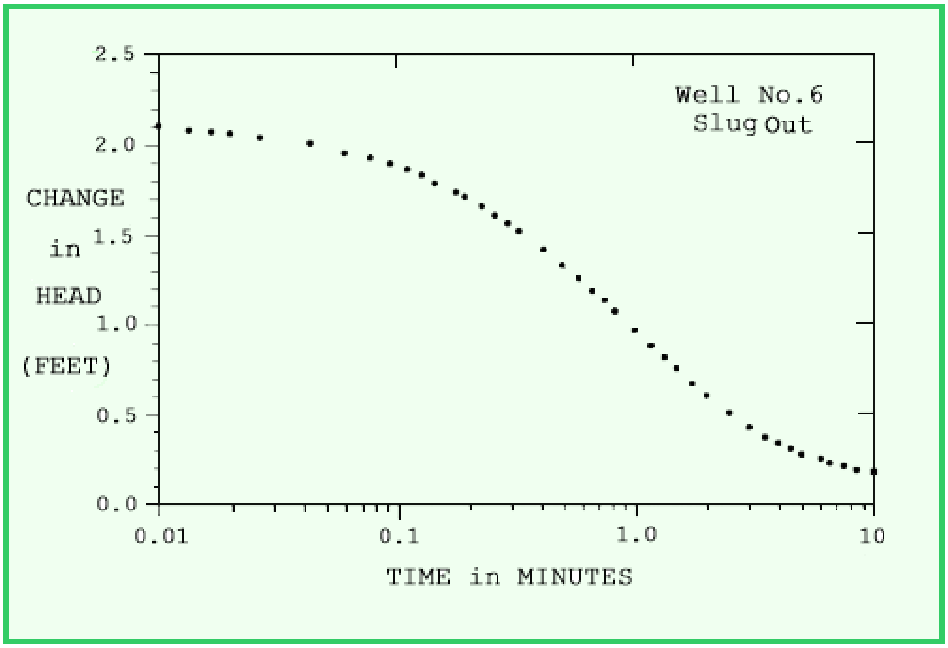

Figure 12: Graph of Groundwater Re-equilibration from a "Slug out" Test in Well #6

Information obtained from these tests were analyzed using a software computer program based on the 1976 Bouwer and Rice Method for determining the hydraulic conductivity of unconfined aquifers with completely or partially penetrating wells (Water Resources Research, vol. 12, No. 3, p. 423-428). The results of these tests are presented in Table 3, below:

TABLE 3 - Results of Permeability Tests

Parameter	**Well #6**	**Well #7**	**Well #8**
Screened Interval:	33-43 feet	34-44 feet	37-47 feet
Depth to Water Table:	30.7 feet	32.9 feet	33.1 feet
Slug In Test	4.1×10^{-4} cm/sec	1.3×10^{-4} cm/sec	2.8×10^{-4} cm/sec
Slug Out Test	3.8×10^{-4} cm/sec	1.1×10^{-4} cm/sec	2.0×10^{-4} cm/sec
One Gallon of Water	3.9×10^{-4} cm/sec	1.0×10^{-4} cm/sec	Not Performed
Average	**3.9×10^{-4} cm/sec**	**1.2×10^{-4} cm/sec**	**2.4×10^{-4} cm/sec**
Notes: Slug In Test measures aquifer response to a rise in initial head of 2.23 feet Slug Out Test measures aquifer response to a fall in initial head of 2.23 feet One Gallon measures aquifer response to a rise in initial head of 6.13 feet			

Down-Gradient Extension of Field Investigations

The down-gradient groundwater investigation initially proposed the installation of a monitoring well cluster at the base of the hill slope to characterize the extent of possible contamination towards the flood plain. The proposed cluster consisted of three wells designed to monitor the following zones: 1) the upper 10 feet of the aquifer, 2) the 10 feet of weathered rock directly above the slightly weathered granite, and 3) 10 feet beneath the top of the slightly weathered granite. The depth of the slightly weathered granite was anticipated to be about 40 to 50 feet.

Boring #9 was advanced in the same manner as borings #6, #7, and #8. Split spoon samples were taken at five-foot intervals through the center of the hollow stem auger. Blow counts ranged from 8 to 17 per foot, indicating very loose material. The last split-spoon sample was obtained at 21 feet. Auger refusal occurred at 23 feet. The relatively shallow depth to slightly weathered granite eliminated the need for the shallow well to monitor the upper ten feet of the aquifer. Therefore only two monitoring wells, numbered 9 and 10, were installed.

Since this was to be a well cluster, Boring #10 was started a few feet from #9, and advanced to a depth of 41 feet without sampling. Drilling rates and cuttings indicated that the material below 23 feet was slightly weathered to fresh granite bedrock. The locations of the borings are shown on Figure 13, below.

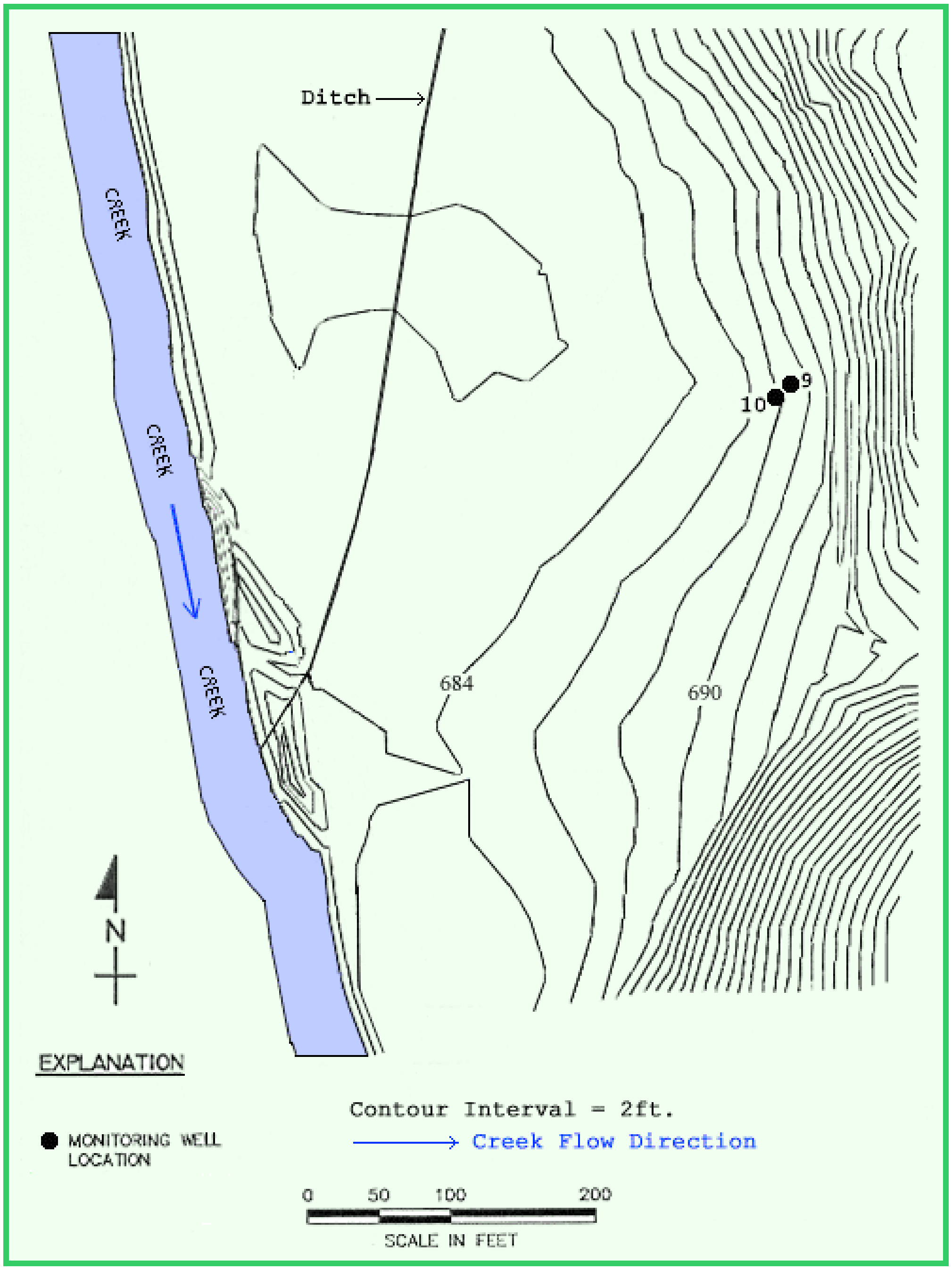

Figure 13: Map showing the location of Borings/Monitoring Wells 9 and 10

Geology

The geologic material encountered in borings 9 and 10 was similar to that sampled from up-gradient wells 6, 7 and 8. The material sampled in Boring #9 is a residual soil produced from the weathering of the underlying granite and is generally homogeneous with uniform gradations of color, texture, and density. The Unified Soil Classification System was used in the visual identification and description of the material recovered from the borehole. Typically the soil is a fine to medium grained, micaceous, silty sand. The color of the soil near the surface is yellowish brown grading with depth to a dark yellowish brown near the contact with the moderately weathered bedrock. The standard penetration tests indicated that the soil was loose from the surface to the top of the moderately weathered bedrock.

The bedrock encountered in Boring #10 is part of the same granite body encountered in borings 6, 7, and 8. Drilling rate and recovered cuttings indicated that the bedrock at depth is slightly weathered to fresh, strong granite with no indication of significant weathered zones in the penetrated interval.

Conversion of Borings to Monitoring Wells

Monitoring Well #9 is screened in the interval from 12.6 to 22.6 feet. Well #10 is screened in the bedrock from 30.9 to 40.9 feet. Conversion to monitoring wells followed the same procedure as that used for boring 6, 7, and 8 discussed above, although the loose material in the upper 18 feet of Boring #10 necessitated the use of a 10 inch steel casing to keep the hole open as the boring was advanced to the target depth of 41 feet. The well installation diagrams and geologic logs are presented in Figures 14 and 15, below.

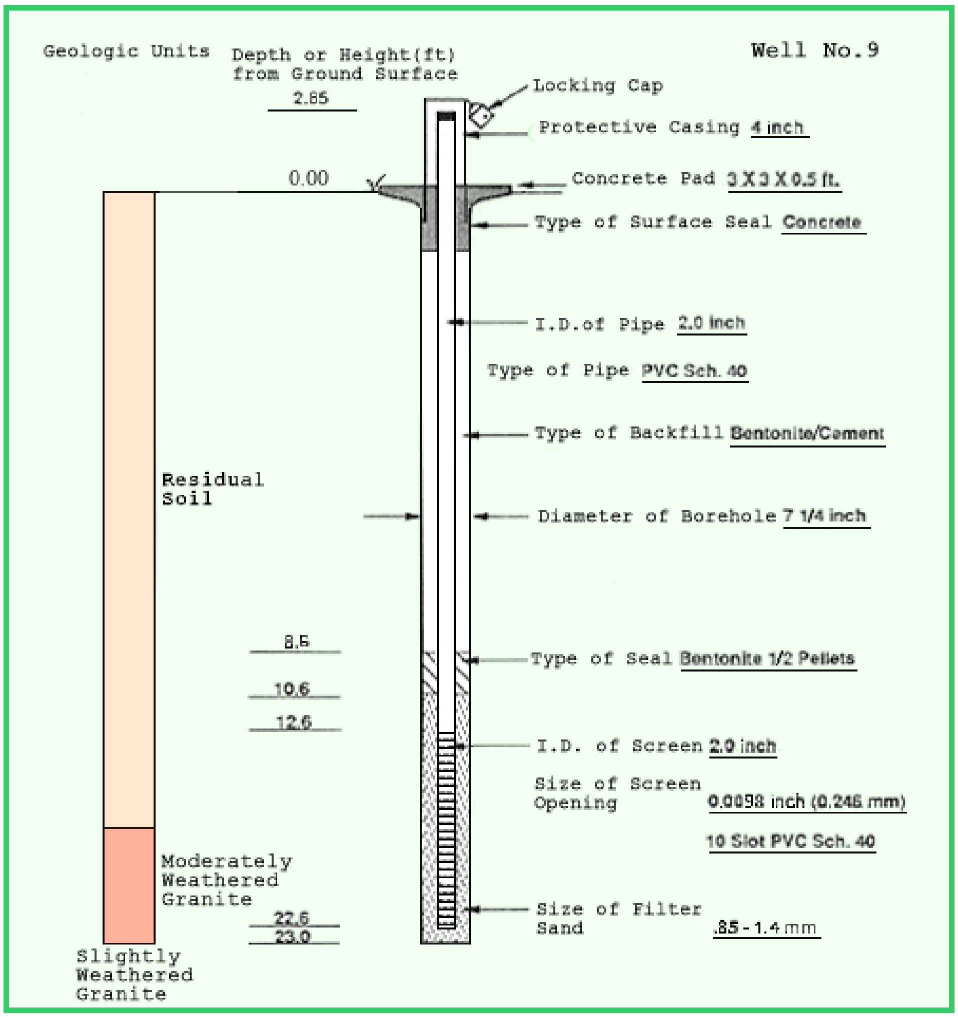

Figure 14: Installation Diagram and Geology Encountered in Boring #9

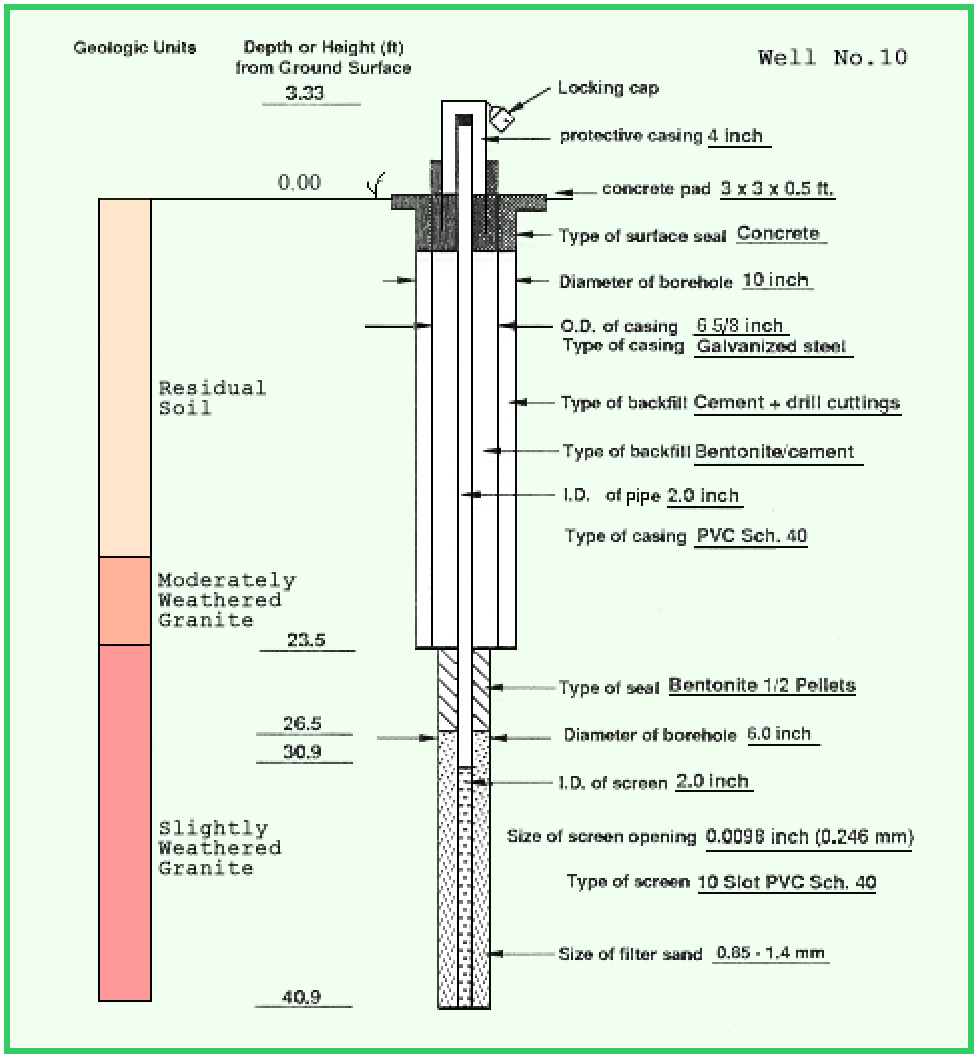

Figure 15: Installation Diagram and Geology Encountered in Boring #10

Well Development

A week after monitoring wells 9 and 10 were installed, they were developed using decontaminated stainless steel bailers in the same way as monitoring wells 6, 7 and 8. The development water was stored in 55 gallon drums placed beside the wells for later disposal. Well #9 was developed by removing a total of 10 well volumes, at which point the conductivity, pH and temperature had stabilized. One well volume was removed from Well #10 resulting in the removal of essentially all the water from the well indicating that recharge to the well was very slow. The water level in that well continued to be monitored monthly, and after about 4 months the water level appeared to stabilize. The groundwater level measurements indicated a very slow recharge rate.

Depth to Groundwater

Water level measurements in Monitoring Well #9 indicated a depth of 6.8 feet, yielding a groundwater elevation of about 681.7. Although Monitoring Well #10 recovered very slowly after development, the water level stayed below that encountered in Well #9, indicating the possible presence of a different groundwater regime.

Permeability Estimates

The very loose nature of the soils in Boring #9 suggests a high permeability (blow counts at the screened interval were on the order of 8 blows/ft). No slug test was performed. Boring #10 was screened totally within the slightly weathered to fresh granite bedrock. Based on the time it took for the well to recover after development, the permeability is inferred to be extremely low.

Groundwater Sampling and Analysis

The perimeter down-gradient monitoring wells, numbers 1, 2, 3, the up-gradient monitoring wells, numbers 6, 7, 8, and the two wells, numbers 9 and 10 located at the base of the slope, were sampled for radiological and chemical analyses. Monitoring wells Nos. 4 and 5 were not sampled because several rounds of previous analyses had not detected any groundwater contamination in these up-gradient wells.

All groundwater samples that were collected were analyzed for Tritium by method EPA-906. Volatile organic compounds were tested by method SW-846-8240. This method tests for 35 compounds. Due to its high solubility, 1,4-dioxane was analyzed by a modified method SW-846-8240 mostly by heating the samples to 80 degrees centigrade during the purging process to improve on compound recovery and to lower the detection limit. Heating assists in the removal of 1,4-dioxane from the sample onto the adsorbent trap in the sample concentrator.

In addition to analyzing for the target list of volatile organic compounds by the SW-846-8240 methodology, a search was made to identify additional compounds by comparison of the mass spectra with a computerized reference spectral library of 50,000 mass spectra. Analytical standards are not utilized in this procedure and any compounds identified in this manner are considered as tentative identifications only. Using this method, no new compounds above an estimated 50 ug/L concentration were identified. This technique was used at the request of the State Waste Management Agency (State WMA) during their review and comments on the Phase 1 Report (discussed in Part 4 of this course series).

Tests for semi-volatile organics (method SW-846-8270) and priority pollutant metals (method SW-846-6010) and several other tests were not performed because the Phase 1 testing did not reveal any of these compounds present in detectable amounts.

The results of the analyses are presented in Table 4, below:

TABLE 4 – Results of Phase 2 Groundwater Analyses

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
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 concentration 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.
'nd' indicates not detected (concentration below detection limit).

The highest Tritium activity is 14,000 pCi/L and was detected in the groundwater sample from Monitoring Well #3. The second highest Tritium activity was detected in the two samples collected from Monitoring Well #9, located at the base of the hill. Measured activities were 7,500 and 7,200 pCi/L. It is clear from these analyses that tritium was not present in any of the groundwater samples in activities above the National Primary Drinking Water Standard of 20,000 pCi/L.

The highest concentration of chloroform was detected in the groundwater samples from Monitoring Well #9, at the base of the slope. The measured concentrations in the two samples were 1,800 and 2,200 ug/L. Chloroform concentrations in the groundwater samples from the waste disposal area monitoring wells #1, #2 and #3 ranged between 1,300 and 1,500 ug/L.

The concentration of 1,4-dioxane in the groundwater samples from the waste disposal area monitoring wells #1, #2 and #3 ranged from 2,800 to 3,000 ug/L. The concentrations in the two samples from Monitoring Well #9 were 2,600 and 3,200 ug/L.

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 disposal area and at the base of the slope at the eastern edge of the floodplain, within the residual soil and moderately weathered granite.

Based on these findings, the Consultant reached the following conclusions:

1. The waste disposal area is still contributing contamination to the groundwater,
2. The rate of contaminant leakage from the waste disposal area is probably not diminishing,
3. The contaminant plume is not spreading laterally (dispersing) significantly as it moves downhill,
4. Minimal dilution of the contaminant plume is taking place as it moves downhill,

5. Well number 9 is close to the centerline of the plume, and
6. Contamination has already clearly reached the eastern edge of the floodplain.

The fact that the chemical concentrations are nearly equal but the Tritium concentration at the base of the slope (Well #9) is about half that found just south of the waste disposal site (Well #3) also provides additional insight into the travel time of groundwater, as discussed in the following section.

Revised Groundwater Travel Time Estimates

Part 4 of this course series presented an estimate of groundwater travel times based on the data available after the Phase 1 studies. The calculation was based on Darcy's law and an estimate of the effective porosity, as follows:

$$q = K * G; \text{ and } V = q / n$$

Where:

q = Darcy velocity
K = hydraulic conductivity
G = groundwater gradient
V = seepage velocity, and
n = effective porosity

At the end of Phase 1, since no permeability tests had been completed, two cases were calculated, using 1x10-3 cm/sec and 1x10-4 cm/sec as bounding estimates for hydraulic conductivity. The preliminary calculations for the travel time from the waste disposal area to the eastern edge of the floodplain of the Creek are shown on Table 5, as follows:

TABLE 5 - Estimated Groundwater Travel Times
Upland Area - Phase 1 Investigations

Parameter:	**Case 1**	**Case 2**
Hydraulic Conductivity (K):	1.0×10^{-3} cm/sec	1.0×10^{-4} cm/sec
Effective Porosity (n)	20%	20%
Groundwater Gradient – Upland	6% for 500 feet	6% for 500 feet
Travel time to edge of floodplain:	**1.6 years**	**16 years**

At the end of Phase2, the accurate topographic survey, additional wells, additional water level measurements and permeability testing in several of the wells permitted a recalculation of the preliminary groundwater travel time estimates presented above. Using the high and low values of the measured hydraulic conductivities, listed in Table 3, the following values were calculated.

TABLE 6 - Revised Groundwater Travel Times
Upland Area- Phase 2 Investigations

Parameter	High Value	Low Value
Hydraulic Conductivity (K):	3.9 x 10^{-4} cm/sec	1.2 x 10^{-4} cm/sec
Effective Porosity (n)	20%	20%
Groundwater Gradient – Upland	7% for 400 feet	7% for 400 feet
Travel time to edge of floodplain:	**2.8 years**	**9.2 years**

These revised calculations indicate that the travel time is bracketed between the lower and upper ends of the previously calculated range of 1.6 to 16 years. Note that the hydraulic conductivity value of 1.2 x 10-4 cm/sec was measured in well #7, which is partly screened in the slightly weathered granite, and may therefore be considered a reasonable lower value. These revised travel times should still be regarded as order of magnitude estimates rather than precise and exact figures because of the remaining parameter uncertainties that were used in the calculations.

The radiological and chemical data from the latest round of sampling provide an additional insight into the groundwater travel times. Recall that the concentrations of chloroform and 1,4 dioxane from the waste disposal site perimeter (wells #2 and #3) and the edge of the floodplain (well #9) were essentially identical. This would suggest that the Tritium concentrations at the two locations should also be comparable. However, the Tritium concentration in Well #9, at the eastern edge of the floodplain, is about half of the concentration in Well #3.

Once the Tritium leaves the base of the disposal trench, radioactive decay will slowly reduce its concentration in the contaminant plume. The half life of Tritium is about 12 years, which means that after 12 years, half of the material has decayed to a non-radioactive state. Given that the organic chemicals are in the same concentration at the base of the hill and the Tritium is about half the concentration, one could interpret this observation to mean the groundwater travel time to the eastern edge of the floodplain is about 12 years (which is the half-life of Tritium). This number (12 years) is close to the travel time (9.2 years) calculated above for the lower hydraulic conductivity value, and is in fact a remarkable agreement given the uncertainties and unknowns in the estimates that were used in the calculations.

Floodplain Investigations

Based on the chemical data from Well #9, contamination has clearly already reached the eastern edge of the floodplain. Therefore, sampling and testing of the groundwater in the floodplain and surface water in the creek was the next priority in order to determine the shape and extent of the contaminant plume in this area.

The most efficient and cost effective method to investigate the extent of contamination in the floodplain is to use a hydropunch screening technique. This approach is well suited to sampling in a short period of time the large area of soft sediment and shallow groundwater of the floodplain.

The Hydropunch™ Sampling Tool (HST) is a specialized field-screening tool that is capable of collecting a groundwater sample without requiring the installation of a groundwater monitoring well. The HST provides a fast, relatively inexpensive method to determine the presence or absence of groundwater contaminants.

The HST is pushed or driven into the aquifer either from the ground surface or from the bottom of a drilled borehole. This is typically accomplished by using a drill rig. The HST utilizes an airtight and watertight sealed PVC slotted intake screen (approximately 5 feet long) and sampling chamber attached to a disposable drive cone. The screen and internal parts of the tool are sealed by a disposable O-ring and isolated from the surrounding environment when the tool is in the closed position. As the tool is advanced the displaced soil compacts into the walls of the hole and produces a tight annular seal around the tool. When the desired depth for the collection of a groundwater sample is reached, the HST is opened by pulling back on the body of the tool to a maximum of about 5 feet. Soil friction holds the cone in position while the screen telescopes out of the body of the tool. A small outer diameter Teflon bailer is then lowered through the casing and the body of the HST into the screened interval to collect the sample. The Hydropunch™ operating principle is presented in Figure 16, below.

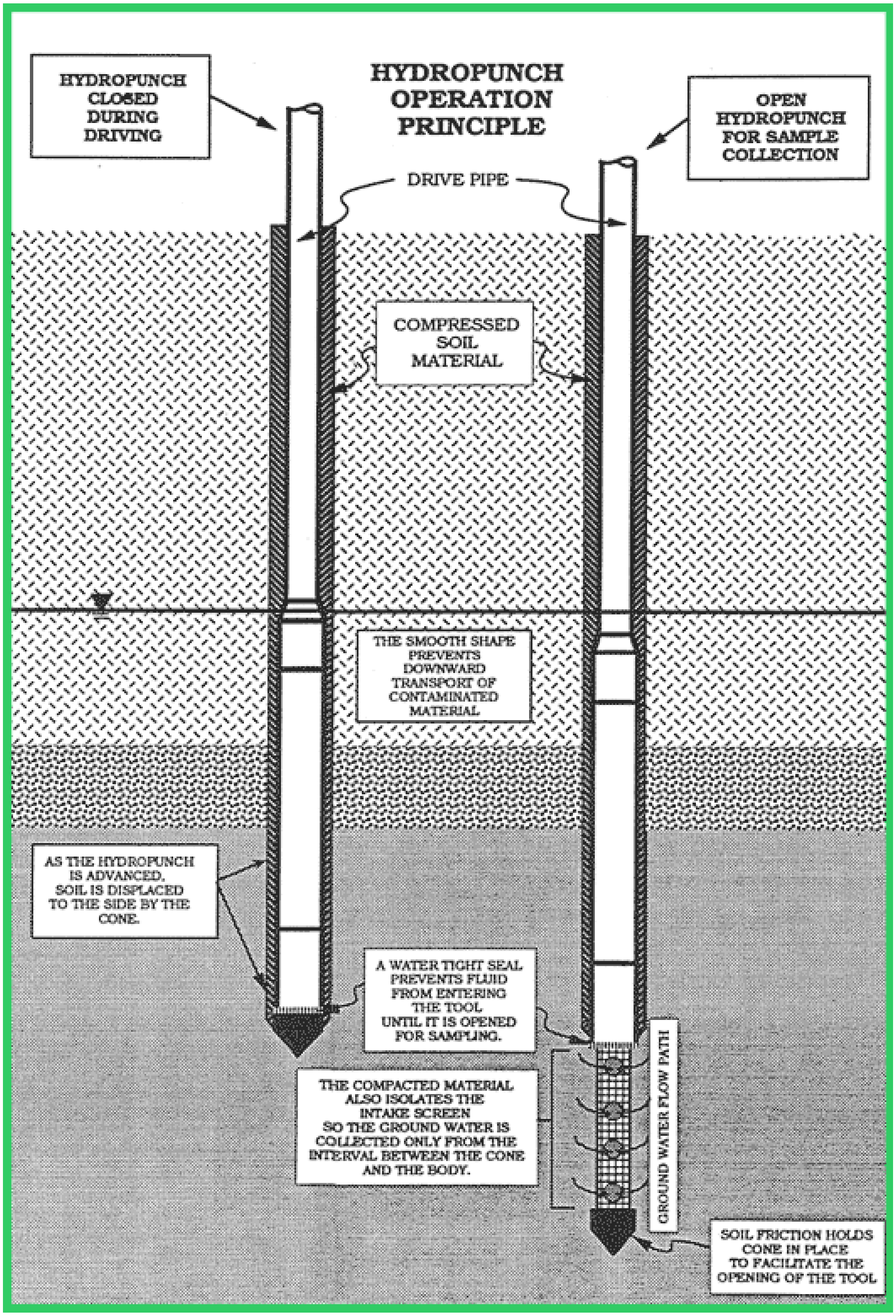

Figure 16: The Hydropunch^{TM} Operation Principle (modified from the User's Guide)

The HST is not intended to replace monitoring wells but assists the investigator in screening for contaminated water and selecting optimal locations for the installation of monitoring wells. It should be noted, as well, that the HST collects a groundwater sample from an interval of up to approximately five feet.

Field Implementation

The locations of the 10 hydropunch borings that were driven in the floodplain for this study are shown in Figure 17, below:

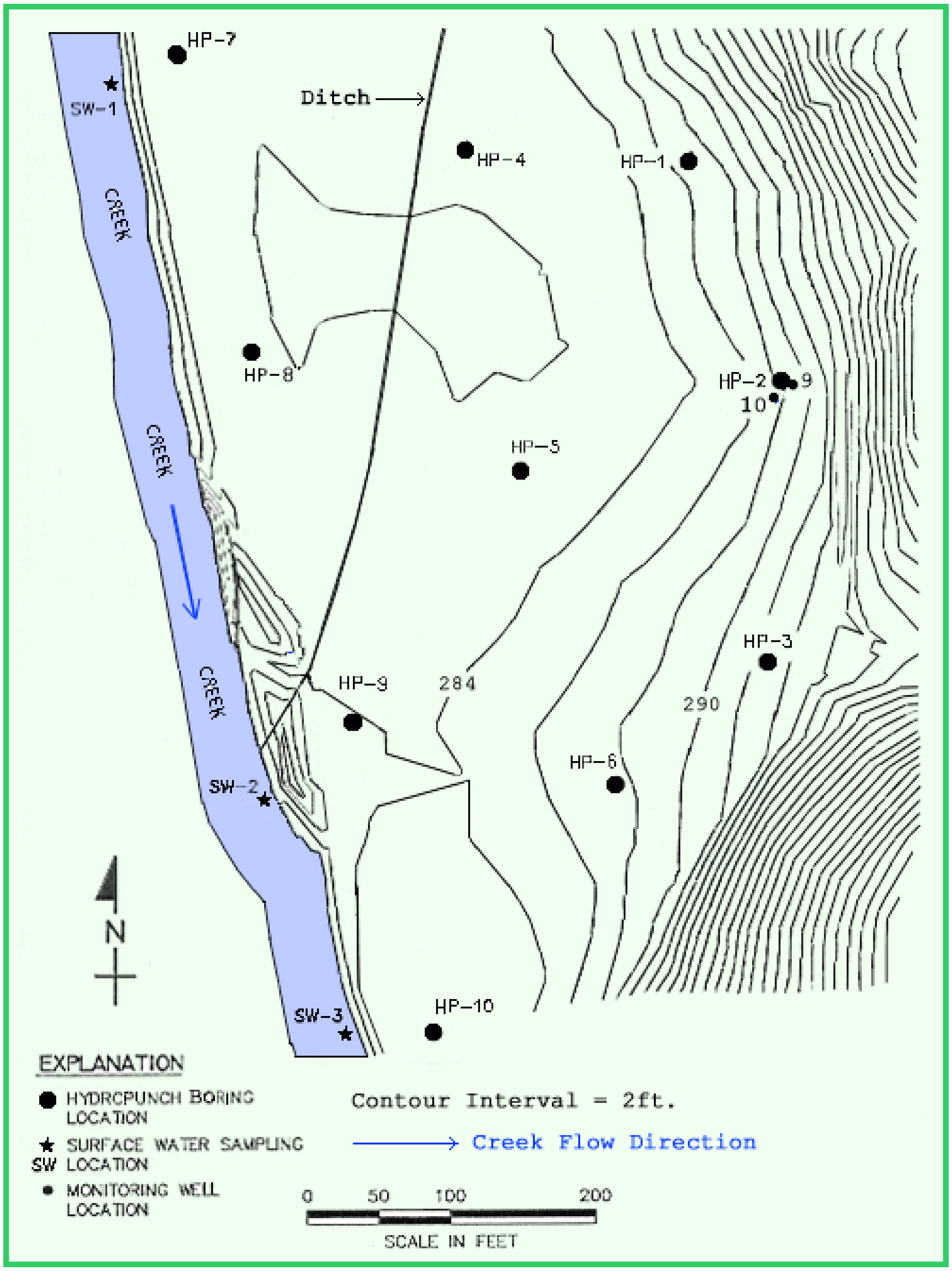

Figure 17: Location Map of Hydropunch™ Borings

Sampling was performed at all the Hydropunch™ locations. All drilling and sampling equipment was decontaminated as per the Project Procedures (Part 3 of this course series).

Field investigation at each location was initiated by boring with a hollow stem auger to the top of the groundwater table. The groundwater was present in the borings at depths ranging between six and ten feet. The HST was inserted through the hollow stem auger and lowered to the top of the groundwater table. The HST was then pushed with a drill pipe to a depth approximately 6 to 7 feet below the surface of the water table. The sleeve of the tool was then pulled back to expose the screen of the tool to the formation groundwater. Screen length was about 5 feet. Groundwater samples were then collected in sufficient volume to perform the planned chemical and radiological analyses.

After collecting the groundwater samples from the HST, the boring was advanced with auger drilling until bedrock was encountered. Soils were described as the cuttings were brought to the surface using the Unified Soil Classification System. The static groundwater level was measured and recorded for each boring. All borings were abandoned in compliance with the governing state regulations by filling them with cement grout.

In addition to the samples collected by the hydropunch™ methodology, a groundwater sample was collected from Monitoring Well #9 and three surface water samples were collected from the Creek. The specific conductivity of each water sample was measured and recorded in the field. Immediately after collection, the samples were placed in laboratory shipping coolers packed with ice. A chain of custody form was duly filled and the samples were delivered to the laboratory for analysis in less than 24 hours after collection.

Geology

The soil types identified in the floodplain borings were silty sand, clayey sand, and poorly sorted mixtures of sand and silt. All borings were terminated at the top of the underlying granite bedrock. The soils encountered in the floodplain appear to be fluvial in origin in contrast to the weathered, in-place soils found in the borings previously drilled up-slope, near the waste disposal area.

The thickness of the soil overlying bedrock ranged from 11.0 feet in Boring HP-1 to 20.0 feet in Boring HP-6. The soil present above the groundwater table was generally yellowish brown to reddish brown silty sand, or yellowish brown clayey sand. Borings HP-1, -4, -7, -8, and -9, located in the northern and western portion of the floodplain, contain soils below the ground water table that range in color from yellowish brown to medium brown. This coloration of the soil generally indicates the presence of an oxidizing environment. The borings located to the southern and eastern portion of the floodplain (HP-3, -5, -6, -10, and Well #9) contain sections of soil in the saturated zone that are colored gray to blue gray. Present in some of these grayish soils were small fragments of organic matter. The gray coloration and presence of organic matter is indicative of a reducing (oxygen poor) environment. In addition, the soils in the northern and western parts of the floodplain appear to be coarser-grained and more permeable than those located in the southern and eastern portions of the floodplain.

Depth to Groundwater

The depth to the groundwater table was measured in each of the floodplain Hydropunch™ borings. The groundwater elevation stabilized quickly (within 15 to 30 minutes) in most borings. Surface elevation, depth to groundwater and groundwater elevation for the 10 hydropunch locations is presented in Table 7, below:

TABLE 7 – Groundwater Levels at Hydropunch Locations

Hydropunch Location	Surface Elevation	Depth to Groundwater	Groundwater Elevation
HP-1	687.0	10.0	677.0
HP-2	688.5	8.3	680.2
HP-3	693.0	8.8	684.2
HP-4	682.5	6.5	676.0
HP-5	683.0	5.8	677.2
HP-6	687.5	8.2	679.3
HP-7	682.5	6.8	675.7
HP-8	682.5	6.4	676.1
HP-9	684.5	7.7	676.8
HP-10	685.0	6.7	678.3
Note: All measurements in feet			

A map of the elevation of the groundwater table under the floodplain is shown in Figure 18, below:

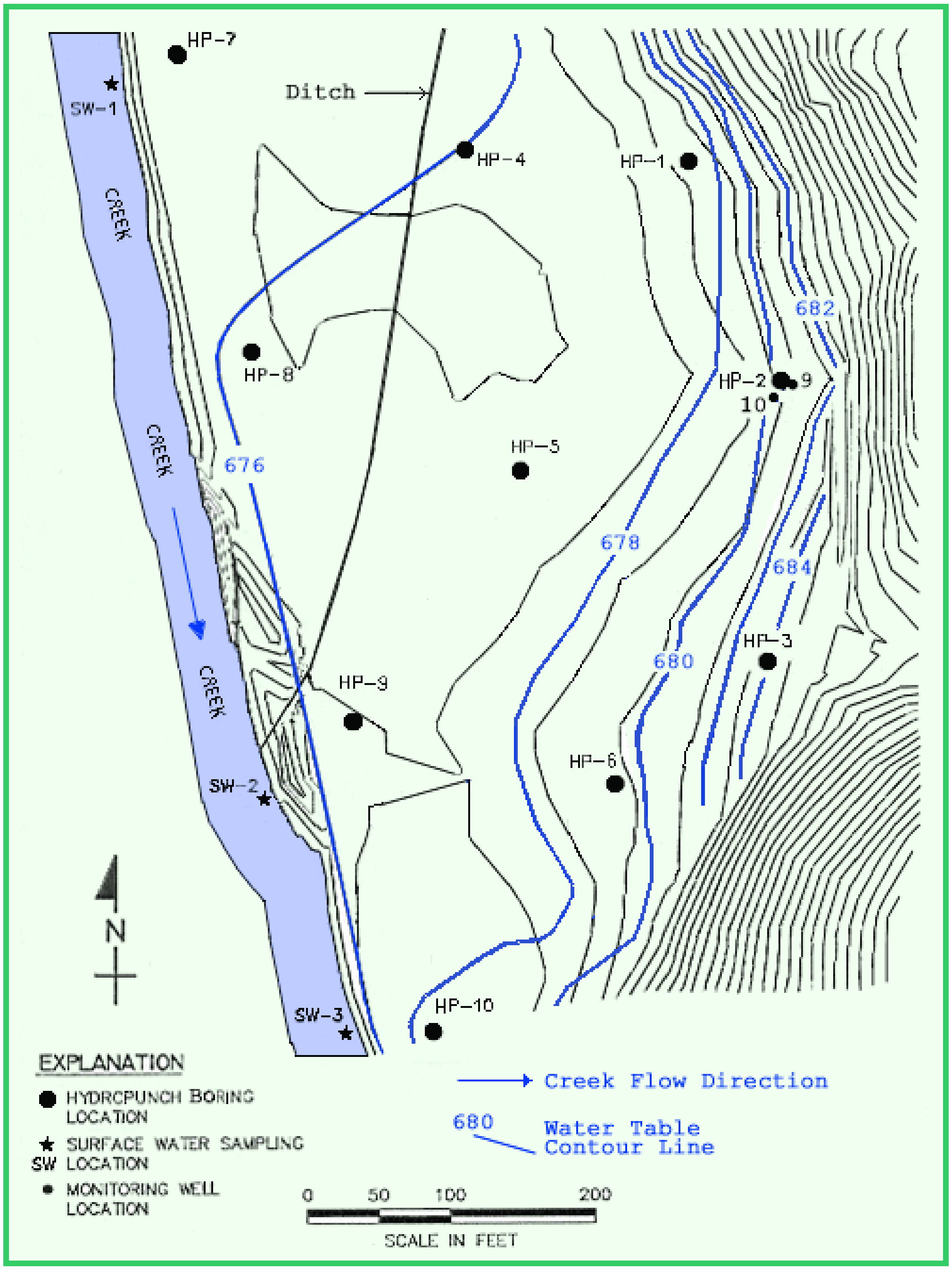

Figure 18: Map of the Groundwater Table beneath the Floodplain

This map shows that groundwater within the flood plain flows in a westerly direction, toward the Creek.

Revised Groundwater Travel Time Estimates

Although no permeability measurements were conducted in any of the Hydropunch™ holes, observations made during the process of collecting ground water samples provided some insight regarding the rate of the groundwater flow within the flood plain sediments. It took generally less than 15 minutes in the north and northwest portions of the floodplain (HP-1, -4, -5, -7, -8, and -9) to collect a groundwater sample of approximately 1.2 liters. Groundwater samples from the southern and southeastern portion of the floodplain (HP-2, -3, and -10) were obtained more slowly, requiring from 30 minutes to over one hour to collect a 1.2 liter sample. However, groundwater flow in HP-6 was so slow that the sampling tool was removed and the boring advanced to bedrock. The groundwater was left to accumulate in the open bore hole overnight and a new 2 inch standard monitoring well PVC pipe with a five foot screen was lowered into the hole. A new Teflon bailer was used to collect the groundwater sample from that hole. These variations in recharge time are probably related to the differences in the nature of the fill within the floodplain, which are sandier in the northern and more clayey in the southern parts of the floodplain.

The measured groundwater elevations in the floodplain and the groundwater flow observations presented above, permit a recalculation of the groundwater travel time estimates presented in Part 4 of this course series. Table 8 reviews the estimates calculated at the end of the Phase 1 work, as discussed in Part 4.

TABLE 8- Estimated Groundwater Travel Times
Floodplain - Phase 1 Investigations

Parameter:	**Case 1**	**Case 2**
Hydraulic Conductivity (K):	1.0 x 10-3 cm/sec	1.0 x 10-4 cm/sec
Effective Porosity (n)	20%	20%
Groundwater Gradient – Floodplain	0.5% for 500 feet	0.5% for 500 feet
Travel time across floodplain to creek:	**19.3 years**	**193 years**

The groundwater contour map generated during the Phase 2 floodplain investigation indicates that the groundwater gradient in the wider part of the floodplain is instead about 1%. Also, given that the floodplain materials are fluvial sands and silts, the original estimate of 1 x 10-4 cm/sec for the minimum hydraulic conductivity is likely too low. Using the Phase 2 data and observations, a revised estimate of travel time within the floodplain is presented in Table 9, below.

TABLE 9- Revised Groundwater Travel Times
Floodplain- Phase 2 Investigations

Parameter	**High Value**	**Low Value**
Hydraulic Conductivity (K):	1.0 x 10-3 cm/sec	5.0 x 10-4 cm/sec
Effective Porosity (n)	20%	20%
Groundwater Gradient – Floodplain	1.0% for 450 feet	1.0% for 450 feet
Travel time across floodplain to creek:	**8.7 years**	**17.4 years**

The updated calculations suggest that the travel time is considerably shorter than the previously calculated range of 19.3 to 193 years. Again, these revised travel times should still be regarded as order of magnitude estimates rather than precise and exact figures because of the remaining parameter uncertainties that were used in the calculations.

Groundwater Sampling and Analysis

All groundwater and surface water samples were analyzed for volatile organic compounds (targeting the site contaminant chloroform) by EPA method 601. This method tests for 29 different compounds, including chloroform. Tritium analyses were performed as per the previous investigations. The analytical results obtained from the water samples collected during this phase of work are summarized in Table 10, below. Note that two intervals were sampled at location HP-2, labeled HP-2A and HP-2B.

TABLE 10 - Analytical Results of Water Samples Collected from the Floodplain

Sample Type and Number	Sample Interval	Depth to Bedrock	Chloroform (ug/L)	Tritium (pCi/L)
Hydropunch™:				
HP-1	8.5-11.5 ft	11.5 ft	- -	- -
HP-2A	8.5-12 ft	19.5 ft	- -	na
HP-2B	13-17 ft	19.5 ft	400	1,522
HP-3	10.5-14 ft	18.5 ft	- -	- -
HP-4	9.5-13 ft	15.0 ft	96	- -
HP-5	8.5-13 ft	14.5 ft	27	718
HP-6	8.5-20 ft	20.0 ft	- -	- -
HP-7	9.5-13 ft	15.0 ft	7	308
HP-8	8-12 ft	12.5 ft	- -	248
HP-9	10-13 ft	13.0 ft	- -	- -
HP-10	10-13 ft	15.0 ft	- -	- -
Monitoring Well:				
No. 9	12.6-22.6 ft	18.0 ft	1,400	7,400
No. 10	30.9-40.9 ft	18.0 ft	- -	- -
Surface Water:				
SW-1	0 ft		- -	- -
SW-2	0 ft		- -	- -
SW-3	0 ft		- -	- -
Detection Limit:			1.0 ug/L	200 pCi/L

Notes:
Sample interval and depth to bedrock in feet below ground surface.
- - = not detected. Concentration is below detection limit.
na = not analyzed (sample HP-2A, Tritium)

Note that no testing was done for 1,4-dioxane. To date, all wells tested and found to be contaminated with chloroform were also found to be contaminated with 1,4 dioxane. Therefore, it is assumed that the presence or absence of chloroform in the floodplain samples also indicates the potential presence or absence of 1,4-dioxane. This approach saved the cost of additional expensive analyses. Note that the main purpose of the floodplain study was to assess, in a reconnaissance and expeditious manner, the presence or absence of contamination, not necessarily to measure the actual concentrations of all contaminants across the entire extent of the floodplain.

Only locations HP-2B, -4, -5, -7 and Monitoring Well #9 revealed chloroform contamination (and, by extension, probably also 1,4-dioxane). The following figure shows the area of detectable chloroform.

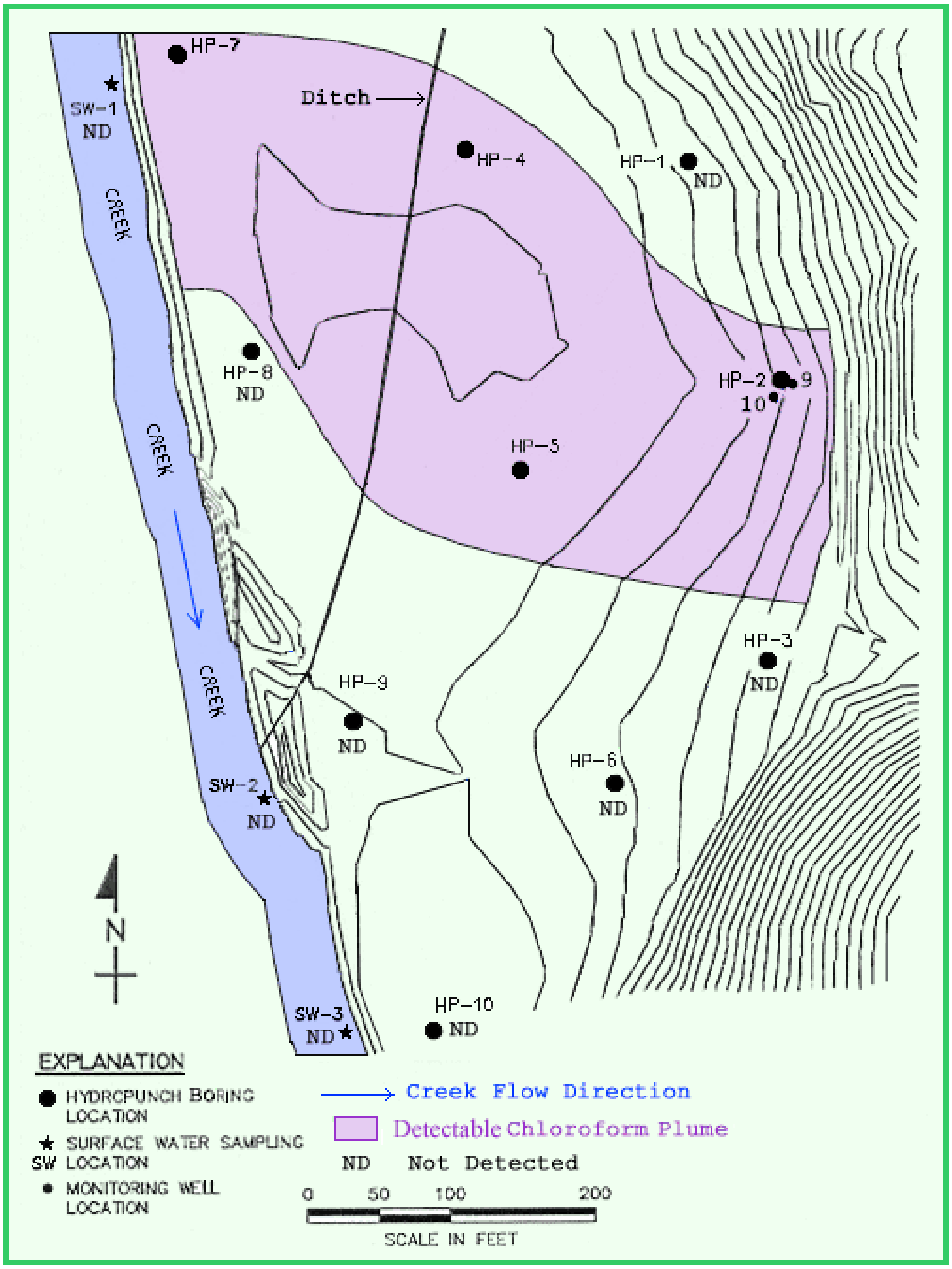

Figure 19: Area of the Chloroform plume above the detection limit of 1 ug/L

The plume of chloroform-contaminated groundwater appears to be limited to the shaded area in the figure. No chloroform was detected in the groundwater samples that were outside of the shaded area on Figure 19 or in any of the three surface water samples collected from the Creek. The lack of detectable concentrations in the surface water samples may be due to the large dilution factor provided by the surface water in the creek, especially for sample SW-1, and/or because any detectable contamination is below the bottom elevation of the creek. If the groundwater contamination is below the creek's bed, it will begin at this point to migrate southward towards the property boundary of the Institute.

The area of the floodplain with detectable levels of Tritium is shown on Figure 20, below.

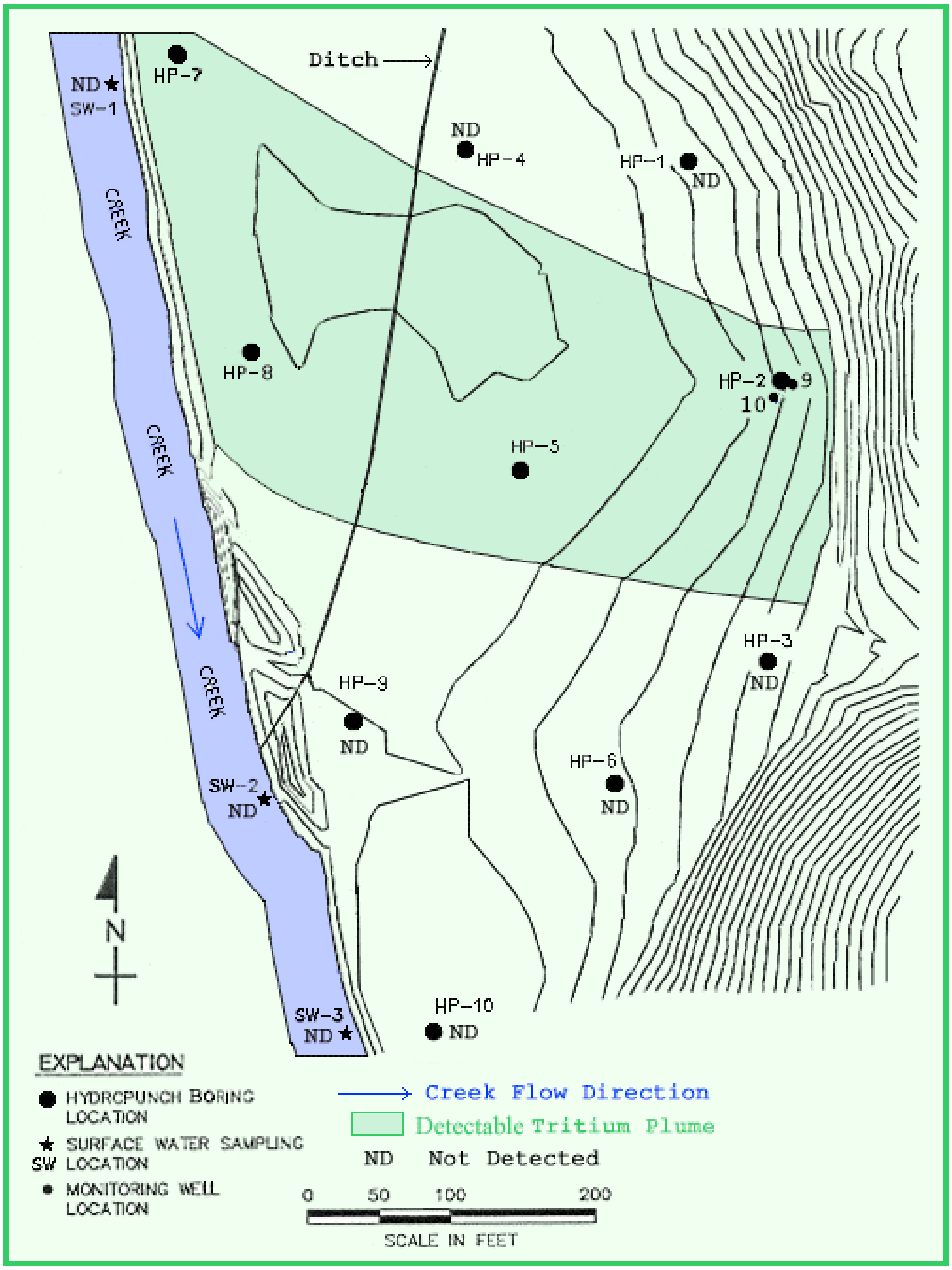

Figure 20: Area of the Tritium Plume above the detection limit of 200 pCi/L

The distribution of Tritium contamination coincides with the distribution of chloroform contamination, indicating a continuation of the contaminant plume from the upland area into the floodplain and extending at least as far as the Creek. However, the concentration of the contamination at the western end of the flood plain is just above the detection limit of the analytical methods. This lower concentration is probably the result of dilution by mixing with the larger volume of groundwater within the floodplain.

Tritium was not detected in any of the surface water samples collected from the Creek, probably due to the large dilution factor provided by the surface water in the creek and/or because any detectable contamination is below the bottom elevation of the creek, especially for sample SW-1.

Vertical Stratification of the Contaminant Plume

In order to assess the vertical distribution of contamination within the groundwater, hydropunch location HP-2 was placed adjacent to monitoring wells #9 and #10 to provide several different sampling depths. A summary of the results of this investigation is presented in Table 11, below.

TABLE 11 – Vertical Distribution of Contamination at Location HP-2

Sampling Point	Sampled Interval	Geologic Material	Chloroform (ug/L)	1,4-Dioxane (ug/L)	Tritium (piC/L)
HP-2A	8.5-12 ft	soil	nd(1)	-	-
HP-2B	13-17 ft	soil	400	-	1,522
Well #9	12.6 –22.6 ft	soil/w. rock(*)	1,400	2,600	7,400
Well #10	30.9-40.9 ft	fresh rock	nd(1)	nd(2)	nd(3)

Notes:
soil/w. rock(*) = soil to 18 foot depth, then moderately weathered rock.
nd(1) = not detected. Detection limit = 1 ug/L
nd(2) = not detected. Detection limit = 50 ug/L
nd(3) = not detected. Detection limit = 200 piC/L
- 1,4-dioxane was not tested for in HP-2A or -2B
- Tritium was not tested for in HP-2A
Sampled interval is in feet below ground surface.

Based on the information presented in this table, the following observations can be inferred:

1. The highest contamination levels are in the weathered rock portion of the aquifer (Well #9).
2. The underlying slightly weathered to fresh granite bedrock is essentially impervious and appears to be uncontaminated (Well #10).
3. The concentration of contaminants in the groundwater appears to increase with depth (compare the analytical results in HP-2B and Well #9).

The question arises as to whether the contaminants should sink or float in the groundwater. The density of water is 1.0 gram per cubic centimeter. Chloroform has a density of 1.48 and will readily sink in water. The density of 1,4-dioxane is 1.03, so it will sink, but not as aggressively as chloroform. Tritium is radioactive hydrogen, which in this case is already bound in water molecules (H2O) and so moves with the water. Therefore, the observations at the floodplain are consistent with the physical properties of the contaminants that were detected.

Based on the above observations, we can therefore also infer that the concentration of contaminants detected in HP-4, HP-5, HP-7 and HP-8 could be somewhat higher if the samples had been collected from the lower portion of the water table, within the weathered rock layer. Sampling and determining the maximum concentration of contaminants at these locations will require the installation of monitoring wells screened into the moderately weathered rock zone. Recall, however, the primary purpose of the floodplain investigation was to determine the location and geometry of the down gradient plume and to find out if the contaminants had reached the creek, which they appear to have, but at concentrations that are just above the detection limit. HP-5, HP-7, and HP-8 may be converted into monitoring wells, screened in the moderately weathered rock zone, to augment the long term groundwater monitoring network down gradient of the waste disposal site.

Preparation of the Phase 2 Investigation Report

At the close of Phase 2, considerable new information had been developed about the geology, hydrology and the state of contamination at the site. This information was compiled into the Phase 2 Investigation Report for review by the client, their legal consultants and the state regulatory agencies. The information in this report was also used to plan the next phase of work, which was to complete a health risk assessment, an engineering feasibility study to examine viable options for remediation and the implementation of a corrective action plan.

The main conclusions of the Phase 2 Report are summarized below:

- The entire site and the floodplain and creek are underlain by granite bedrock. The slightly weathered to fresh bedrock is hard and appears to have few fractures and an extremely low permeability.

- The groundwater in the upland areas appears to be within the moderately weathered granitic bedrock. Measured permeability of this material range from a low of 1.2×10^{-4} to a high of 3.9×10^{-4} cm/sec.

- The monitoring wells along the northern and eastern segments of the waste disposal area showed no contamination, and therefore are considered up-gradient of the waste.

- The groundwater contour map and the distribution of contamination show that contaminants are migrating from the western and southern portions of the waste disposal area and moving westward towards the floodplain and creek.

- The contaminant plume on the Institute’s property appears to have reached a “steady-state” condition, since the concentration of organic chemicals is virtually identical at the edge of the waste disposal site (Wells #1, 2 and 3), and about 500 feet down-gradient, at the eastern edge of the floodplain (Well #9).

- The contaminant plume shows little evidence of longitudinal dispersion or dilution between the waste disposal area and the eastern edge of the floodplain (at well #9).

- Groundwater travel time from the waste disposal area to the eastern edge of the floodplain is on the order of 10 to 12 years, based on both hydraulic calculations and the observed decrease in Tritium concentration at the base of the slope.

- The groundwater in the floodplain is within a valley-fill sequence of clay, silt and sand on top of a thin mantle of moderately weathered granite above the slightly weathered to fresh bedrock.

- Within the floodplain, the contaminants appear to be more concentrated within the lower portion of the water table, within the moderately weathered granite.

- Contamination appears to have reached the floodplain and is just above the detection limit at the creek. Surface water samples from the creek showed no contamination, possibly due to dilution of the groundwater by the large volume of surface water in the creek and/or because most of the contamination may be migrating below the bottom elevation of the creek.

- Groundwater travel time from the eastern edge of the floodplain to the creek is estimated to be on the order of 8.7 to 17.4 years, based on the groundwater gradient and higher permeabilities of the fluvial sequence. If most of the contamination is limited to flow within the moderately weathered bedrock, the travel time could be somewhat longer.

The next phase of work was approved by the Institute and was initiated after regulatory review of the Phase 2 Report. The results of the health risk assessment, the engineering feasibility study and the implementation of a corrective action plan are presented in Part 6 of this course series.

Regulatory Review

The Phase 2 Investigation Report was printed in multiple copies and submitted to the Institute. The Institute transmitted copies to the State Radiation Protection Agency (SRPA). The State Radiation Protection Agency then transmitted copies to the State Groundwater Protection Agency (SGPA) and the State Waste Management Agency (SWMA), Superfund Section. Written comments were collected by the State RPA and sent to the Institute, with a directive that the agencies involved must have all their concerns addressed.

The State RPA provided no written comments. They verbally expressed to the Institute that the Phase 2 investigations re-affirmed their earlier position that they had no serious concerns relating to radiation exposure to the general public. They noted that although during a first round of groundwater sampling the radioactive contamination exceeded drinking water standards at only one well at the edge of the disposal area, subsequent rounds of analyses from the same well resulted in concentrations below the drinking water standards. The State RPA originally felt that decay and dilution was likely to lower the tritium activity considerably by the time the groundwater reached the Creek and the southern property boundary. The results of the Phase 2 work supported their opinion.

State Groundwater Protection Agency Review

In a letter to the State RPA, the Chief of the State GPA expressed the views of his staff as follows:

- We regard the study that we have reviewed to be an early step in the process to restore the quality of the groundwater beneath the site to its state prior to the construction of the facility and will be followed by a determination of the extent of groundwater and soil contamination, a corrective action plan and remediation. The responsible party (the Institute) and their consultants need to proceed in due haste with the determination of the extent of groundwater contamination.

- The use of the Hydropunch™ equipment as a reconnaissance tool for the determination of the lateral and vertical extent of the contaminant plume in the floodplain is an acceptable methodology. The importance of the vertical distribution comes into play with the construction of monitoring wells and plans for remediation. We recommend that new monitoring wells have much shorter screened intervals than those previously installed at the site (10 feet). In fact, screens of the monitoring wells to be constructed should not exceed five feet in length; better they should not exceed two to three feet in length.

The Consultant responded to these comments as follows:

Comment: We regard the study that we have reviewed to be an early step in the process to restore the quality of the groundwater beneath the site to its state prior to the construction of the facility and will be followed by a determination of the extent of groundwater and soil contamination, a corrective action plan and remediation. The responsible party (the Institute) and their consultants need to proceed in due haste with the determination of the extent of groundwater contamination.

Response: The work completed to date indicates that the extent of groundwater contamination is limited to a narrow plume extending from the waste disposal area to the edge of the floodplain, and then to a broader area across the floodplain to the creek. Contamination levels at the edge of the creek are very low, just slightly above the detection limit of the analytical methods that were used. No contamination has been discovered in the surface water of the creek. Only three contaminants: Tritium, chloroform and 1,4 dioxane have been detected in any of the monitoring wells, although more than 150 organic compounds and 23 radio nuclides have been tested for. We believe we have adequately characterized the extent of groundwater contamination and are in a position to perform a health risk assessment and evaluate remedial alternatives without conducting additional characterization of the groundwater.

The health risk assessment will provide guidance as to whether and to what extent the quality of the groundwater beneath the site needs to be "restored to its state prior to the construction of the facility".

Comment: We recommend that new monitoring wells have much shorter screened intervals than those previously installed at the site (10 feet). In fact, screens of the monitoring wells to be constructed should not exceed five feet in length; better they should not exceed two to three feet in length.

Response: The work completed to date indicates that the groundwater table and the contaminant plume reside primarily in a mantle of weathered rock overlying the slightly weathered to fresh granite bedrock. The underlying fresh granite appears to be essentially impermeable and therefore acts as the "bottom" of the hydrologic system. Water level measurements and chemical analyses coupled with this geologic data suggest that the contaminant plume is vertically confined to a zone probably no more than 10 to 15 feet thick immediately above the slightly weathered to fresh bedrock. Vertical stratification data from the floodplain indicates that the highest concentration of contaminants is near the base of the moderately weathered rock zone, at least in the floodplain area. The Consultant will consider installing shorter screened intervals in the monitoring wells that may be set at the positions of hydropunch™ holes HP-5, HP-7 and HP-8. At this time, however, there appears to be no need to define the vertical distribution of contaminants in any greater detail than is already known from the Phase 2 Investigation.

End of answer

Note: It is important for the student to note at this point that in providing comments and suggestions, the regulatory agencies are not constrained by cost and schedule considerations. Although desirable, the construction of a large number of monitoring wells with short screen intervals and sampling them for chemical analysis is an expensive and time consuming proposition. However, for the client's benefit, it is important for the Consultant to understand the concerns of the regulators and develop the required information by alternative methods that can be considered appropriate and cost effective.

State Waste Management Agency Review

The State WMA submitted the following written comments:

- The Institute has not yet collected any samples from the (waste in the) disposal area. Soil and waste samples will need to be collected to identify contaminants present. Further, the extent of soil contamination should be defined and a determination of whether the material is a hazardous waste or a mixed waste should be conducted before remedial alternatives can be evaluated.

- The (waste from the) disposal area samples should be analyzed for volatile and semi-volatile organic compounds using the EPA Target Compound List by Methods 8240 and 8270 with a library search to produce a list of tentatively identified compounds; cyanide, hazardous substance list metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); and any other hazardous substance suspected to have been disposed in the area.

- The extent of groundwater contamination should be defined and remedial alternatives for groundwater should be evaluated.

- A sampling plan should be prepared to respond to the above three comments and not implemented until reviewed and approved by the State.

The consultant responded to these comments as follows:

Comment: The Institute has not yet collected any samples from the (waste in the) disposal area. Soil and waste samples will need to be collected to identify contaminants present. Further, the extent of soil contamination should be defined and a determination of whether the material is a hazardous waste or a mixed waste should be conducted before remedial alternatives can be evaluated.

Response: The Institute currently has no plans to drill or sample the waste in the disposal area or the underlying soil. Drilling through the waste and sampling may expose workers to hazardous materials and may breach intact containers and release additional contamination. This procedure may also be dangerous as buried flammable or explosive materials may be ignited by the drilling process, or flammable gases may be allowed to escape. The disposal inventory presented in the Site Condition Report and the contaminants discovered in the down-gradient monitoring wells are consistent and provide sufficient information to perform a health risk assessment and develop remedial alternatives.

Clearly the soils beneath the disposal area down to the water table are also contaminated, since chemical compounds and tritium have been identified in all down-gradient monitoring wells.

With respect to the nature of the material, the disposal inventory clearly shows that low-level radioactive wastes were deposited at the site. The waste also included fluids containing various radioactive isotopes and hazardous chemicals. Although most of the radioactive isotopes have decayed to near zero levels, there is still a relatively large quantity of Tritium in the trenches. For the purposes of moving forward, all the materials should be considered mixed waste. If excavation turns out to be the preferred remedial alternative, testing during the removal process would be the best way to segregate the mixed waste materials from the purely radioactive and the purely chemical wastes.

Comment: The (waste from the) disposal area samples should be analyzed for volatile and semi-volatile organic compounds using the EPA Target Compound List by Methods 8240 and 8270 with a library search to produce a list of tentatively identified compounds: cyanide, hazardous substance list metals (antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc); and any other hazardous substance suspected to have been disposed in the area.

Response: All of the samples tested to date from the monitoring wells around the waste disposal area were tested using the EPA Methods 8240 and 8270, and tested as well for cyanide, metals, and phenols, in addition to 23 radio nuclides. Should additional samples be taken in the waste disposal area, the same recommended procedures will be followed.

Comment: The extent of groundwater contamination should be defined and remedial alternatives for groundwater should be evaluated.

Response: The work completed to date indicates that the extent of groundwater contamination is limited to a narrow plume from the waste disposal area to the edge of the floodplain, and then to a broader area across the floodplain to the creek. Contamination levels at the edge of the creek are very low and only slightly above the detection limit of the analytical methods that were used. No contamination has been discovered in the surface water of the creek. Only three contaminants, Tritium, chloroform and 1,4 dioxane have been detected in any of the monitoring wells, although more than 130 organic compounds and 23 radio nuclides have been tested for. We believe at this point that we have adequately characterized the nature and extent of groundwater contamination and are in a position to perform a health risk assessment and evaluate remedial alternatives without additional characterization of the groundwater. Should it be required, the health risk assessment will provide a basis to consider if a remedial alternative for groundwater treatment is necessary.

Comment: A sampling plan should be prepared to respond to the above three comments and not implemented until reviewed and approved by the State.

Response: As noted above, there are currently no plans to drill and sample the waste buried within the disposal area itself. Also, as noted, we believe that the extent and nature of groundwater contamination has been sufficiently characterized to provide a basis to develop a health risk assessment and develop an engineering feasibility study. Should additional sampling be needed, the State will definitely have the opportunity to review and comment on any additional sampling plans that would be developed before sampling and testing is undertaken.

Summary

This course presented the results of the Phase 2 Field Investigations, which started with the preparation of an accurate topographic map of the Site and its vicinity. Three borings were drilled around the perimeter of the waste disposal area to provide subsurface geologic information. Monitoring wells were then installed in these borings to provide hydrologic data; and groundwater samples were taken for radiological and chemical analysis.

Investigations in the floodplain west of the waste disposal site included installation of two clustered wells at the eastern edge of the floodplain and driving 10 Hydropunch™ boreholes at selected locations within the floodplain for groundwater level measurements and the collection of groundwater samples for analysis. Surface water samples from the Creek were also tested for contamination.

The results of this work were published in the Phase 2 Investigation Report and reviewed by the Institute, their legal consultants and the State Regulatory Agencies. Comments were received and addressed by the Consultant.

The Phase 2 Investigation Report and all the previous work formed the basis for the recommendation to perform a health risk assessment, evaluation of engineering options for remediation of the site and the implementation of a corrective action plan. These topics are addressed in Part 6 of this course series titled: Risk Assessment, Feasibility Study and Engineered Remediation.

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
USNRC	United States Nuclear Regulatory Commission
USGS	United States Geological Survey
well screen	section of well casing perforated or slotted to allow water inflow