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Hazardous Materials Technical Center

NAVY ASSESSMENT AND CONTROL OF INSTALLATION POLLUTANTS
CONFIRMATION STUDY FOR SITES 2, 4, 6 and 20 AT THE
NAVAL WEAPONS SUPPORT CENTER
CRANE, INDIANA

Volume 1 of 3

June 1985

Prepared for

Crane Naval Weapons Support Center
Crane, Indiana

Prepared by

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NAVY ASSESSMENT AND CONTROL OF INSTALLATION POLLUTANTS CONFIRMATION STUDY FOR SITES 2, 4, 6 and 10 AT THE NAVAL WEAPONS SUPPORT CENTER CRANE, INDIANA

Volume 1 of 3

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468-2500

- Tom Grittel

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EXECUTIVE SUMMARY

Little or no contamination has been detected at the south portion of the Demolition Grounds/Old Rifle Range (DG/ORR). For this reason, no remediation or additional data requirements are recommended for this site.

Three sites show confirmed contamination, but in very low concentrations. These include the Rockeye site (RS), McComish Gorge (MG), and the Old Rifle Range (ORR) portion of the DG/ORR. Worst-case scenario risk assessments of the MG and the ORR portions of the DG/ORR indicate that the contaminant concentrations in receiving streams are likely to be several orders of magnitude below the public health standards. On the basis of this observation, these three sites are not considered a risk to public health and, therefore, remediation is not recommended. Continued monitoring, however, is recommended.

Additional monitoring of the RS is recommended due to the relatively high concentrations of explosives found at this site, and because of the large area within the fenced confines of the RS, which is likely to be contaminated and which has not yet been monitored. Five additional shallow monitoring wells to be analyzed quarterly for various parameters, including RDX, HMX, TNT, oil and grease, and priority pollutants are recommended for this site. A total of 30 soil samples is also recommended for sampling and analysis throughout the areas of the proposed additional monitoring wells.

A geophysical survey is recommended for the Dye Burial Grounds (DBG), despite the fact that only minor groundwater contamination has been detected at this site. This survey is warranted because of highly credible reports which indicate that containerized dyes and paints are present. Because of the presence of containers, a metal detection survey and/or a ground penetrating radar survey are recommended.

Until the sources of contamination have been better determined for both the DBG and the RS, no remedial efforts such as groundwater pumping and treatment are recommended. Furthermore, because these sites are remote, they do not appear to present a public health risk and, therefore, interim measures such as the control of off-site groundwater movement are not recommended.

I. INTRODUCTION

This is the third in a series of three reports prepared by the Hazardous Materials Technical Center (HMTC) to fulfill the requirements of work plan no. 048 under the DLA contract no. DLA 900-82-C-4426, with funds provided by the Naval Facilities Engineering Command, Philadelphia, PA. This report consists of three separate volumes, which together represent the Confirmation Study for the various hazardous waste disposal sites at the Naval Weapons Support Center (NWSC). Volume 1 is the text, Volume 2 is the appendices, and Volume 3 is the detailed cost estimates for various remedial options. Copies of Volume 3 are available only through Kathy Andrews at NWSC.

In 1975, DOD began its Installation Restoration Program (IRP) to assess past activities related to storage and disposal of toxic and hazardous materials on DOD installations. DOD policy is to identify and fully evaluate suspected problems associated with sites of former hazardous materials disposal, and to control hazards to health and welfare that may have resulted from past activities.

After the initiation of DOD's IRP, Congress created the Resource Conservation and Recovery Act (RCRA) of 1976 as the primary means for governing hazardous waste disposal. Under Sections 3012 and 6003 of this act, Federal agencies, such as DOD, are directed to assist the U.S. Environmental Protection Agency (EPA) and state agencies to inventory past disposal sites and to make the information available to the requesting agencies. Similarly, Congress created the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) of 1980 to assess and alleviate potential adverse public health and environmental impacts resulting from past hazardous waste management practices. On August 14, 1981, in Executive Order 12316, the President delegated certain authority specified in CERCLA to the Secretary of Defense. The current DOD IRP policy is contained in DEQPPM 81-5, dated 11 December 1981. DEQPPM 81-5 reissued and amplified all previous directives and memoranda regarding the IRP.

To fulfill the requirements imposed by DOD's IRP, the Department of the Navy initiated their program entitled Navy Assessment and Control of Installation Pollutants (NACIP). This document is intended to address Phases II and III of the NACIP program for various sites at NWSC. These phases relate to the confirmation of the extent of contamination and the identification of technically sound remedial action options.

This report discusses four hazardous waste sites at NWSC: the Rockeye Site (No. 10), the Dye Burial Grounds (No. 2), the Demolition Grounds/Old Rifle Range (No. 6), and McComish Gorge (No. 4).

II. BACKGROUND

LOCATIONS

Figure 1 illustrates the location of the NWSC within Martin County in southcentral Indiana; it is approximately 45 miles southwest of Bloomington and 75 miles southwest of Indianapolis. Figure 2 illustrates the locations at NWSC of the four hazardous waste sites discussed in this report.

The topographic settings of each of the present study sites are illustrated in Figure 3. The Rockeye Site (RS) is located along the top of an east-west trending topographic ridge within sections 4 and 5 of township 4 north, range 3 west. Located at RS is the Rockeye Production Facility which is a loading, assembling, and packaging facility for high explosives consisting primarily of various mixtures of RDX, HMX, and TNT. Operations at this facility are the suspected sources of contamination at RS. The total area encompassed by existing groundwater monitoring wells at this site is approximately 93 acres.

The Dye Burial Grounds (DBG) are located atop a northeast-southwest trending ridge (Figure 3) located in the southeastern corner of section 21 of township 5 north and range 3 west. Hazardous wastes suspected at this site include dyes, paints, and solvents, generally in 5-gallon pails or smaller. The total area encompassed by existing groundwater monitoring wells at DBG is approximately 4 acres.

The Demolition Grounds/Old Rifle Range (DG/ORR) consists of two separate sites which will be discussed together in this report. The Demolition Grounds (DG) portion of this site is located in the northeast corner of section 34 of township 5 north and range 4 west. It occurs along the top of a sinuous, generally north-south oriented ridge-top (Figure 3). The total area encompassed by the monitoring wells at DG is approximately 12 acres. Military ordnance and contaminated insulation from explosive handling facilities are reported to have been buried here. The Old Rifle Range (ORR)

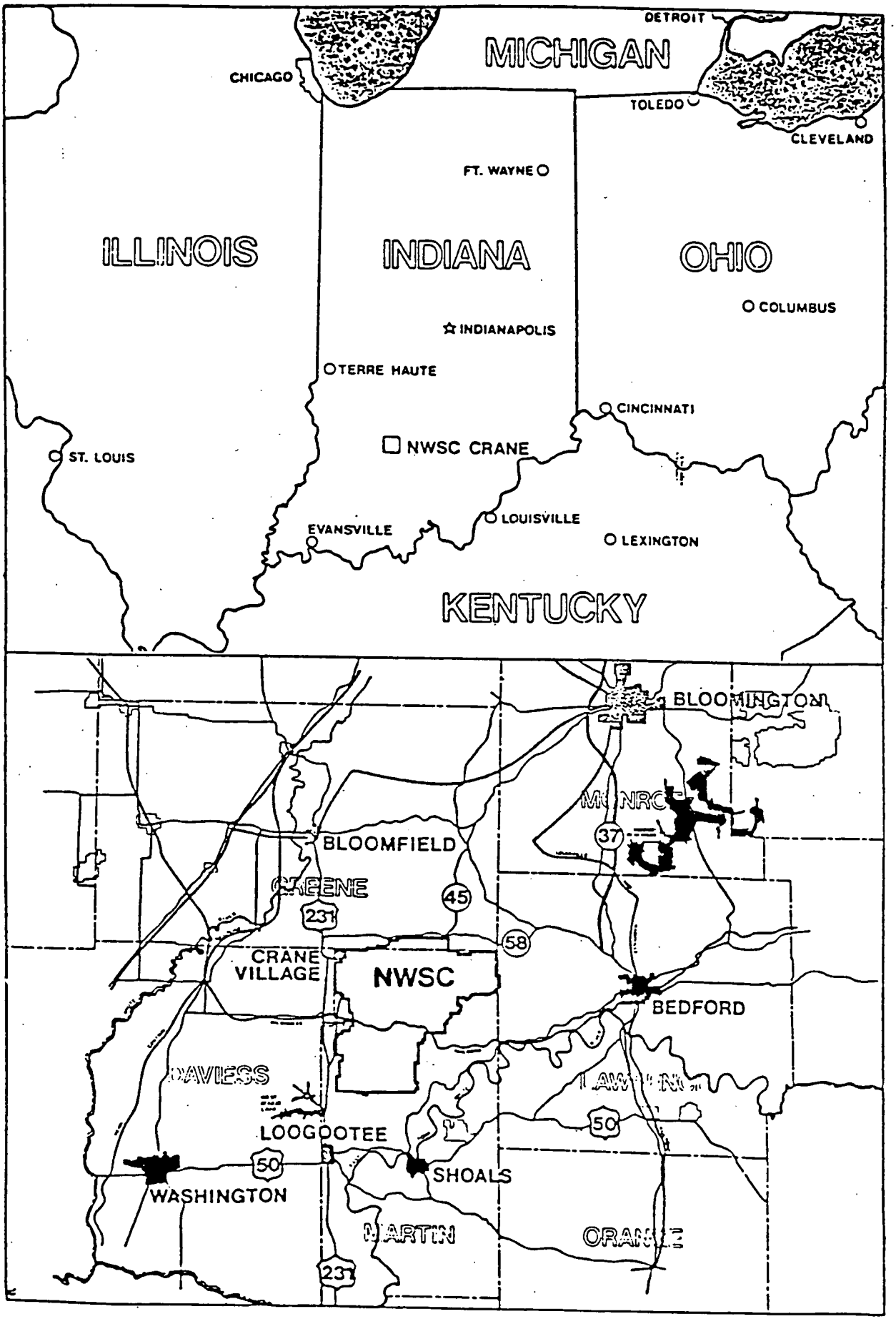
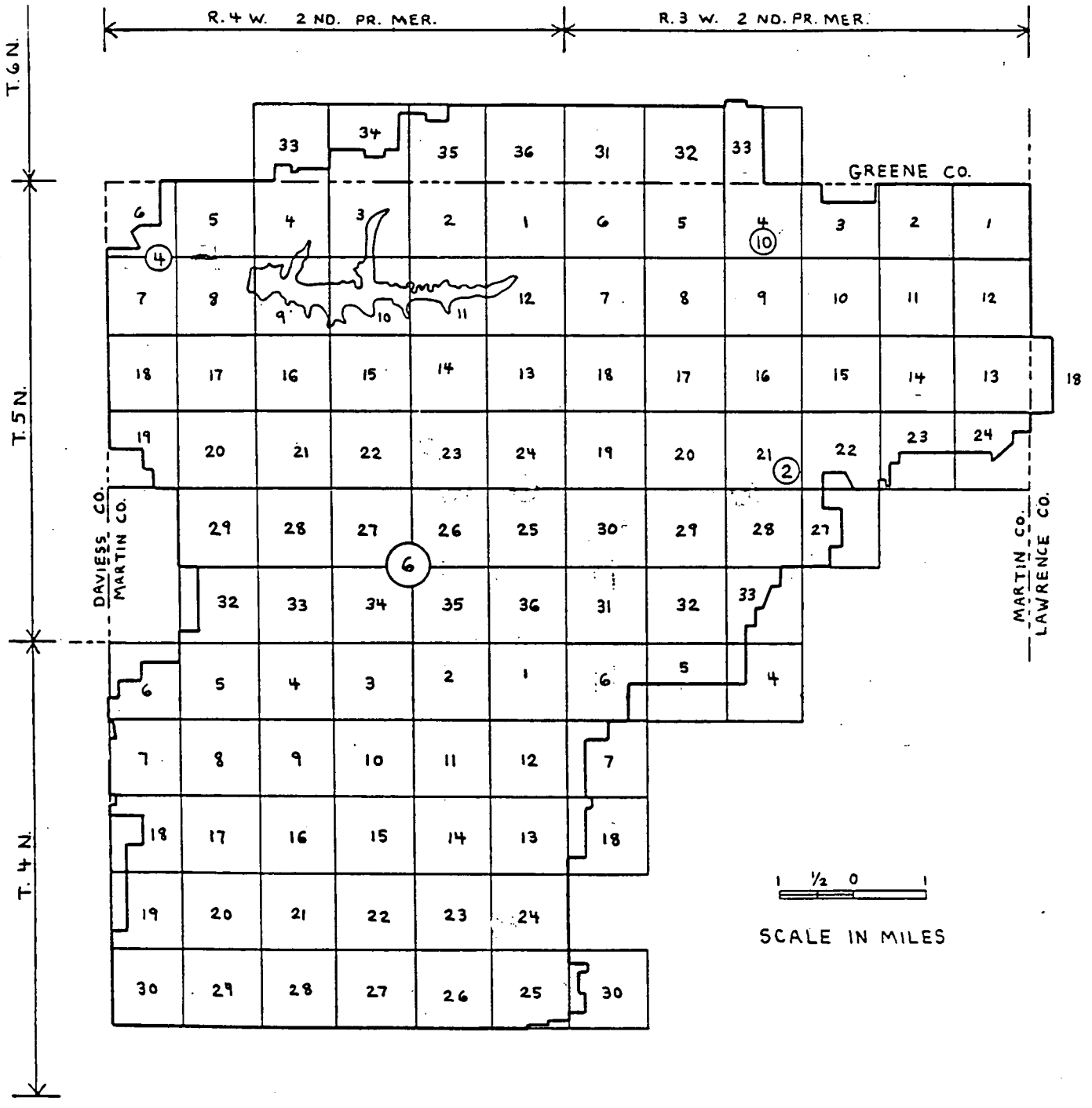


Figure 1. Location of NWSC Within Martin County, Indiana



Site Number	Site Name
2	Dye Burial Grounds
4	McComish Gorge
6	Demolition Area/Old Rifle Range
10	Rockeye Site

Figure 2. Location of Hazardous Waste Sites Discussed in This Report.

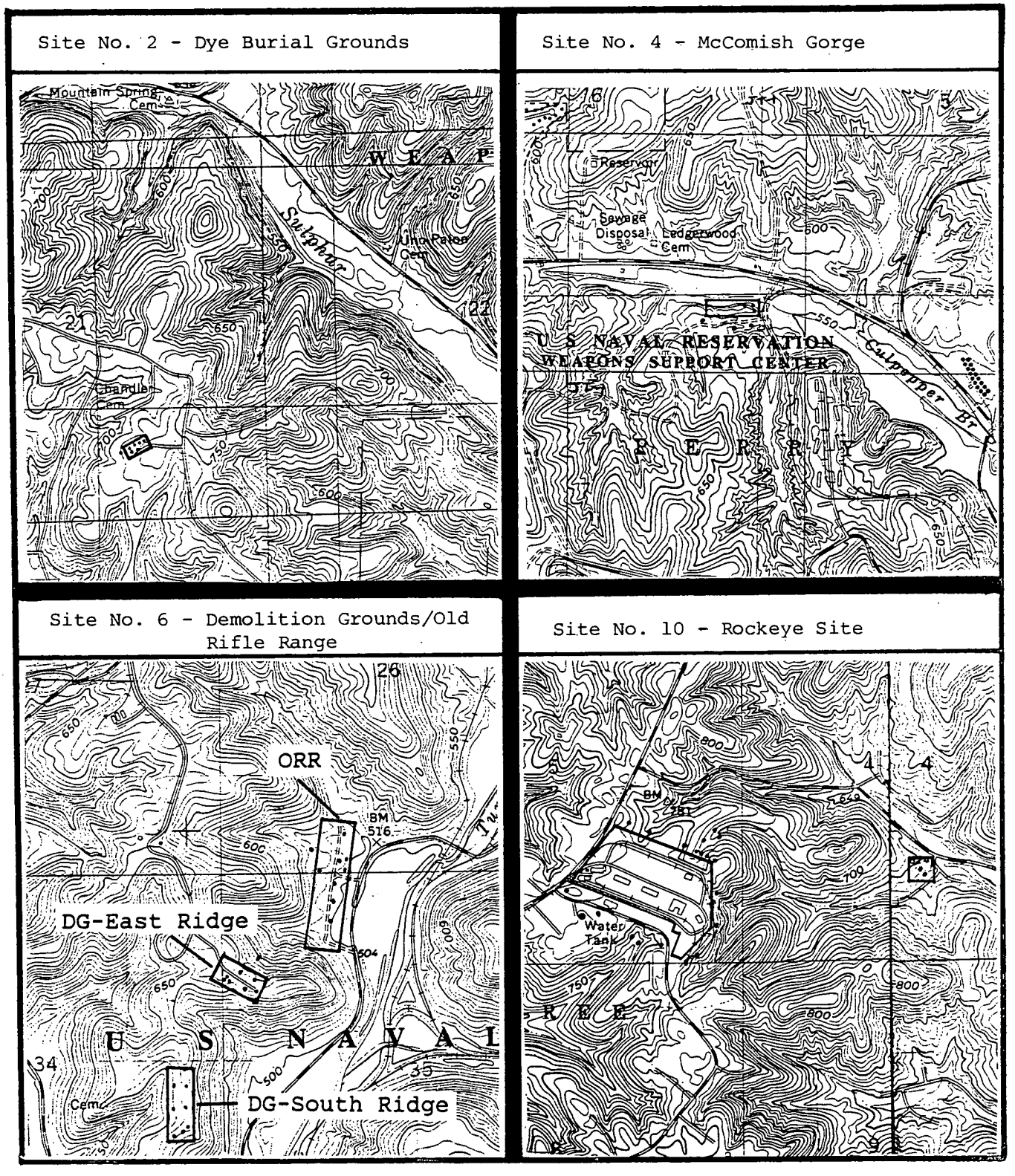


Figure 3. Topographic Settings of the Present Study Sites
(One inch equals 2000 feet)

portion of the DG/ORR is located approximately 2,000 feet east of the DG. The ORR occurs along the western margin of the floodplain associated with Turkey Creek, at the base of the ridge atop which the DG is located. Military ordnance, yellow dye, and red and white phosphorus were initially suspected at the ORR. The total area encompassed by the monitoring wells at the ORR is approximately 14 acres.

McComish Gorge (MG) is located immediately adjacent to Culpepper Branch, at the intersection of sections 5, 6, 7 and 8, within township 5 north, range 4 west. No contaminants are known to have been disposed of at this site; however, it was used as a fill site and, therefore, is suspect. MG is located immediately adjacent to the floodplain associated with Culpepper Branch (Figure 3).

INSTALLATION OF MONITORING WELLS

Fifty-nine monitoring wells are present at the subject hazardous waste disposal sites. Each well is identified by an alphanumeric code in which the first three letters are WES (e.g., WES 3-7-81). WES indicates that the well was installed by the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. The first number following WES is the hazardous waste disposal site number which, in this report, will be either 2, 4, 6, or 10. The second number identifies the particular well at the site. The last number is the year the well was installed.

At the RS (No. 10) 22 monitoring wells are present at the locations indicated in Plate 1. Wells WES 10-1-81 and WES 10-2-81 were installed in November 1981 and are located approximately 3,600 feet east of the RS, at the base of the ridge. Between July and October 1983, 20 additional wells were installed around the immediate perimeter of RS.

Eight monitoring wells are present around the perimeter of the DBG (No. 2). Their locations are indicated in Plate 2. All of these wells were installed during August and September 1981.

At the DG/ORR (No. 6), 23 monitoring wells and 5 borings are present. Wells WES 6-1-81 (15 wells!) through WES 6-13-81 are present at the DG portion of this site at the locations illustrated in Plate 3. Wells WES 6-14-81 through WES 6-23-83 and borings EPA-1-83 through EPA-5-83 are present at the ORR portion of this site at the locations illustrated in Plate 4. All wells and borings were installed during either September through November 1981 or June and July 1983.

Six monitoring wells are present at MG (No. 4) at the locations illustrated in Plate 5. All of these wells were installed during September and October 1981.

The installation of these wells enabled the acquisition of data including:

- Detailed logs of subsurface earth materials encountered during drilling, and the drilling techniques employed at each well (Appendix 1)
- Summary of the lithologies encountered at each monitoring well (Appendix 2)
- Summary of the construction details for each monitoring well (Appendix 3)
- Summary of the groundwater elevations observed in the monitoring wells shortly after their installation (Appendix 4)
- Laboratory test results for samples of the unconsolidated overburden collected from selected wells (Appendix 5)

Appendix 4 contains two sets of groundwater elevation data for wells 14 through 20 at the ORR. For those wells that were most recently installed (1983), only one set of groundwater elevation data is presented in Appendix 4. In addition to Appendix 4, groundwater elevation data are presented in those appendices (to be described in the following section) which summarize the results of groundwater sampling and analysis.

GROUNDWATER SAMPLING AND ANALYSIS

Few state or federal guidelines specify the frequency and types of analytical tests to be conducted on groundwater samples from monitoring wells at non-RCRA unco trolled hazardous waste sites. Even though these sites are not active treatment, storage or disposal facilities, NWSC has taken the initiative of conducting groundwater monitoring as if they were subject to RCRA requirements.

Sampling and analysis of groundwater samples from most of these monitoring wells was initiated on a quarterly basis in November 1981. Many wells at the RS and some wells at the DG/ORR were not sampled according to first- and second-year protocol because these wells were not installed until completion of the first- and second-year monitoring episodes. Approximate sample collection dates for the second, third, and fourth quarters were March, June, and September 1982, respectively. Analytical parameters included those that characterize the suitability of the groundwater for drinking (Group I), those that establish groundwater quality (Group II), and those indicative of groundwater contamination (Group III). Appendix 6 contains the results of first-year analysis for Group I, II, and III parameters for the present study sites. Also during the first year, soil samples from well drilling sites at the DBG were analyzed for dyes and heavy metals. Appendix 7 presents the results of these analyses.

Second-year sampling and analysis were initiated in February, 1983. The first semiannual groundwater samples collected during the second year were analyzed for Group II and III parameters. The second semiannual samples were collected beginning in July, 1983, and were analyzed for Group III parameters. Explosives were also analyzed for during the second monitoring year at the RS and the DG/ORR. Appendix 8a contains the second-year analytical results for explosives and Group II and III parameters.

The third semiannual sampling episode was conducted in February, 1984 at DG/ORR and DBG. Resulting data are contained in Appendix 8b. The RS and

MG were not included in this monitoring episode. The only site monitored during the fourth semiannual sampling period was the RS; data are in Appendix 8c. For the fifth semiannual sampling episode conducted in January, 1985, all sites were monitored to varying extents. These data are contained in Appendix 8d.

Appendix 9 summarizes all the sampling and analytical methods that were followed for all analyses. Included with these methods are supplemental procedures for explosives analysis. Results of the monitoring program are summarized in the groundwater quality section of this report.

III. FINDINGS TO DATE

ENVIRONMENTAL SETTING

Background environmental setting information was compiled by Joseph B. Dunbar (1982) of the U.S. Army Corps of Engineers Waterways Experiment Station while he was conducting field work for the hydrogeological investigation of the present study sites. With his permission, portions of information relating to surface water, climate and topography, and soils are presented in Appendix 10.

REGIONAL GEOLOGY

NWSC is located on the edge of the Illinois Structural Basin; therefore, the underlying sedimentary bedrock dips slightly toward the west-southwest at a gradient of approximately 30 to 35 feet per mile. The sedimentary bedrock is composed of lower Pennsylvanian sandstones, shales, and coal beds of the Raccoon Creek Group and upper Mississippian sandstones, shales and limestones of the Stephensport Group. Table 1 presents lithologic descriptions of these units. Table 2 is a graphic representation of the stratigraphic column of bedrock formations encountered during drilling operations related to the present study. Since this region of Indiana was not covered by Pleistocene glacial deposits, the superficial deposits at the NWSC consist primarily of residual soils formed from the underlying bedrock and unconsolidated deposits of Pleistocene- to Recent-age alluvial, colluvial, and paludal silt, sand, and gravel; and lacustrine clay, silt and sand.

SITE-SPECIFIC HYDROGEOLOGY

The site-specific geology at each location was determined by the logging and installation of the previously mentioned groundwater monitoring wells according to the techniques described by Dunbar (1982). Appendix 11

Table 1. Lithologic Description of the Formations Encountered During Installation of the Monitoring Wells at the NWSC

Formation	Description
Unconsolidated Overburden	Deposits of alluvial and colluvial gravel, sand, silt, and clay; and lacustrine clay, silt, and sand. Occurrence of each of these sediment types varies rapidly both in the vertical and horizontal directions, as well as from site to site. Lower boundary of the overburden is gradational with residual bedrock.
Mansfield Formation	Variably colored (brown to black, light gray to dark gray, and buff), hard to soft interbedded sandstone and shale. Bedding thickness is variable with occasional siltstone, limestone, and coal/ seams.
Glen Dean Limestone	Gray to light gray, very hard, fine-grained limestone. This formation has been removed by erosion from most of the ABG. It was observed only in wells WES 3-2-81 and 3-9-81.
Hardingsburg Foundation	Variably colored (brown to gray, greenish and reddish), hard to soft, thin-bedded sandstone with interbedded shale. Occasional layers of lignite and iron nodules.
Golconda Limestone	Gray-brown, hard, dense, fine-grained, fossiliferous limestone. Occasionally interbedded with thin-bedded shale.
Big Clifty Formation	Green to dark gray, moderate to soft and uniform shale.
Beech Creek Limestone	Gray-brown to gray, hard, dense limestone with interbedded soft, greenish gray shale.
Elwren Formation	Interbedded sandstone and gray, uniform shale. Sandstone is brown, fine-grained and very poorly consolidated.

Table 2. Stratigraphic Column of the Bedrock Formations Present in the Vicinity of NWSC

TIME UNIT		MAP UNIT	THICKNESS (FEET)	LITHOLOGY	ROCK UNIT		
PERIOD	EPOCH				SIGNIFICANT MEMBER	FORMATION	GROUP
PENNSYLVANIAN	POTTSVILLIAN	P_2 P_1	250 to 500		SEELYVILLE COAL (III)	STAUNTON Fm.	RACCOON CREEK
					BUFFALOVILLE COAL LOWER BLOCK COAL	BRAZIL Fm.	
						MANSFIELD Fm.	
MISSISSIPPIAN	CHESTERIAN	M M_6	250 to 300			KINKAID Ls. MENARD Fm.	
		M_5	120 to 190			GLEN DEAN Ls. HARDINSBURG Fm. GOLCONDA Ls. BIG CLIFTY Fm. BEECH CREEK Ls.	STEPHENSPORT
		M_4	70 to 150			ELWREN Fm. REELSVILLE Ls. SAMPLE Fm. BEAVER BEND Ls. BETHEL Fm.	WEST BADEN
		M_3	250 to 550		LEVIAS ROSICLARE FREDONIA	PAOLI Ls. STE. GENEVIEVE Ls.	BLUE RIVER
						ST. LOUIS Ls.	

presents Dunbar's description of the field exploration techniques followed at the NWSC's waste disposal sites. In the following sections, the hydrogeology of each of the present study sites is discussed. Within each of these site-specific descriptions, reference to Figure 3 is made. It should be noted that the well locations indicated in Figure 3 are only approximate. Exact locations of the monitoring wells at each site are indicated in the attached drawings. For all sites, the site-specific geology was determined by installation and logging of the groundwater monitoring wells.

ROCKEYE SITE (SITE NO. 10)

Geology

The local geology in the immediate vicinity of the loading, assembling, and packaging (LAP) facility of the RS is described by Dunbar (1984) as consisting of 1 to 12 feet of soil underlaid by Pennsylvanian-age sedimentary rock from the Mansfield Formation of the Raccoon Creek Group. At this location, the Mansfield Formation consists of interbedded sandstone, shale, and coal beds. All of the rock types are characterized by rapid lateral variations in thickness, which makes the correlation of rock types between the various monitoring wells difficult. Figures 4a, 4b, and 4c are geologic cross-sections for the RS in the vicinity of the LAP, which illustrate the underlying geology. Plate 1 illustrates the locations of these cross-sections.

The quartz sandstone bedrock at this location, which is the dominant rock type, is described as being predominantly brown to tan or light grey, moderately friable, uniform, and very fine-grained. This sandstone varies in thickness from 20 feet to less than 1 inch. The shale bedrock ranges from a weathered, brownish grey shale near the surface to an unweathered grey to dark grey shale with depth. Its thickness varies from 10 feet to less than 1 inch. The bituminous coal beds at this location are less than 2 feet thick. Four major coal seams are present at elevations of approximately 790, 780, 770, and 757 feet msl. These seams are not continuous and, therefore, were not encountered by all monitoring wells.

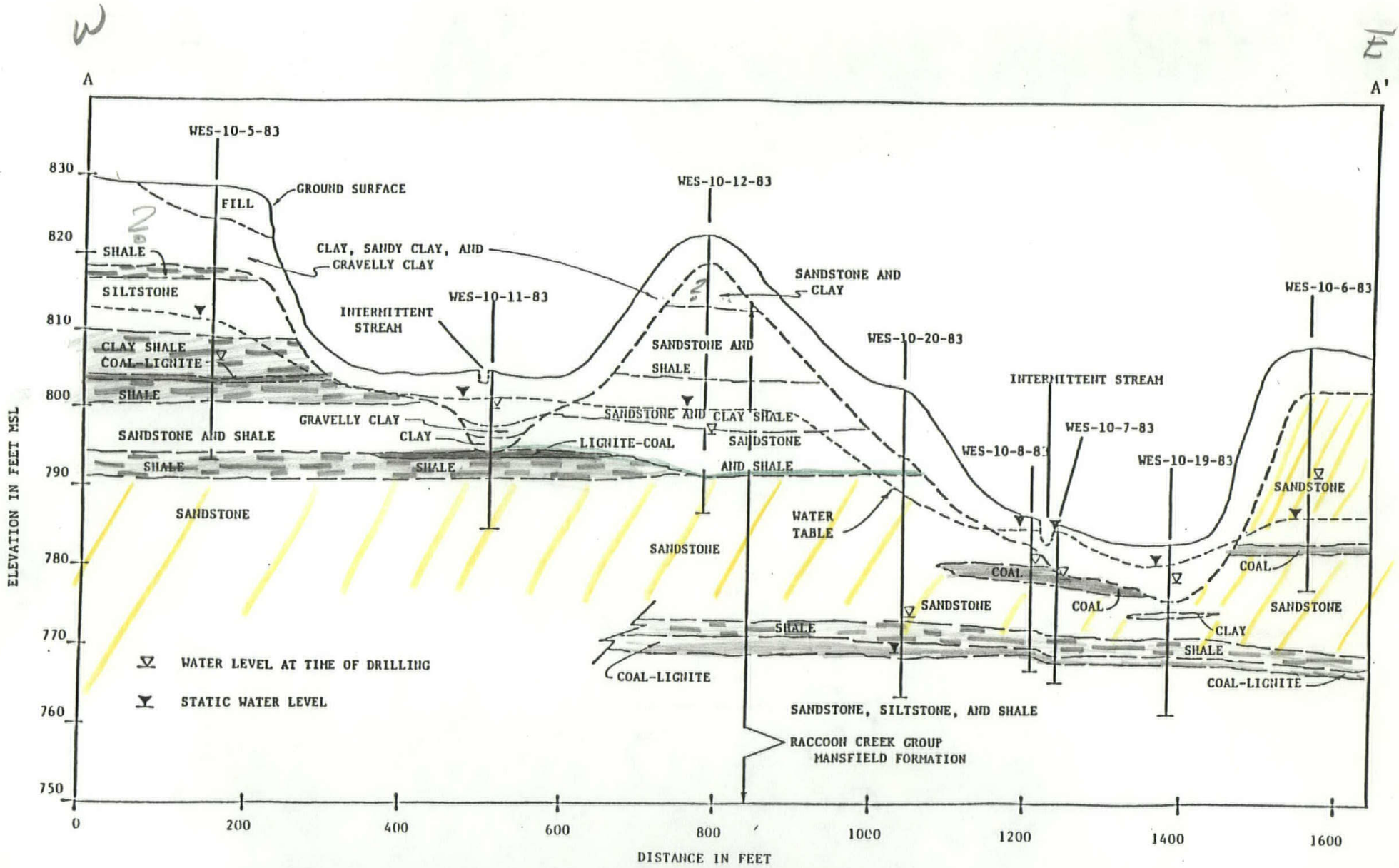


Figure 4a. Rockeye Munitions Facility Geological Cross-Section A-A'

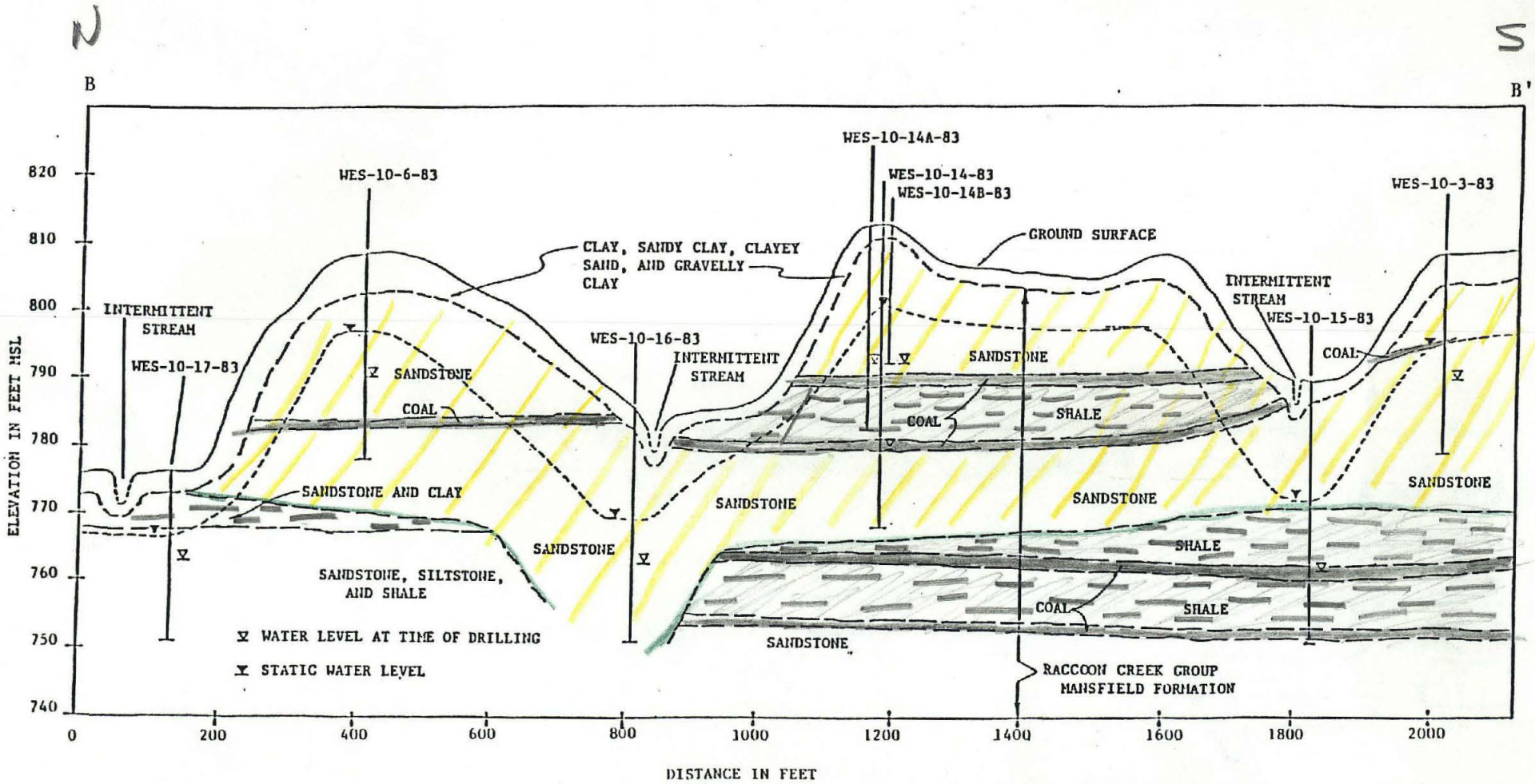


Figure 4b. Rockeye Munitions Facility Geological Cross-Section B-B'

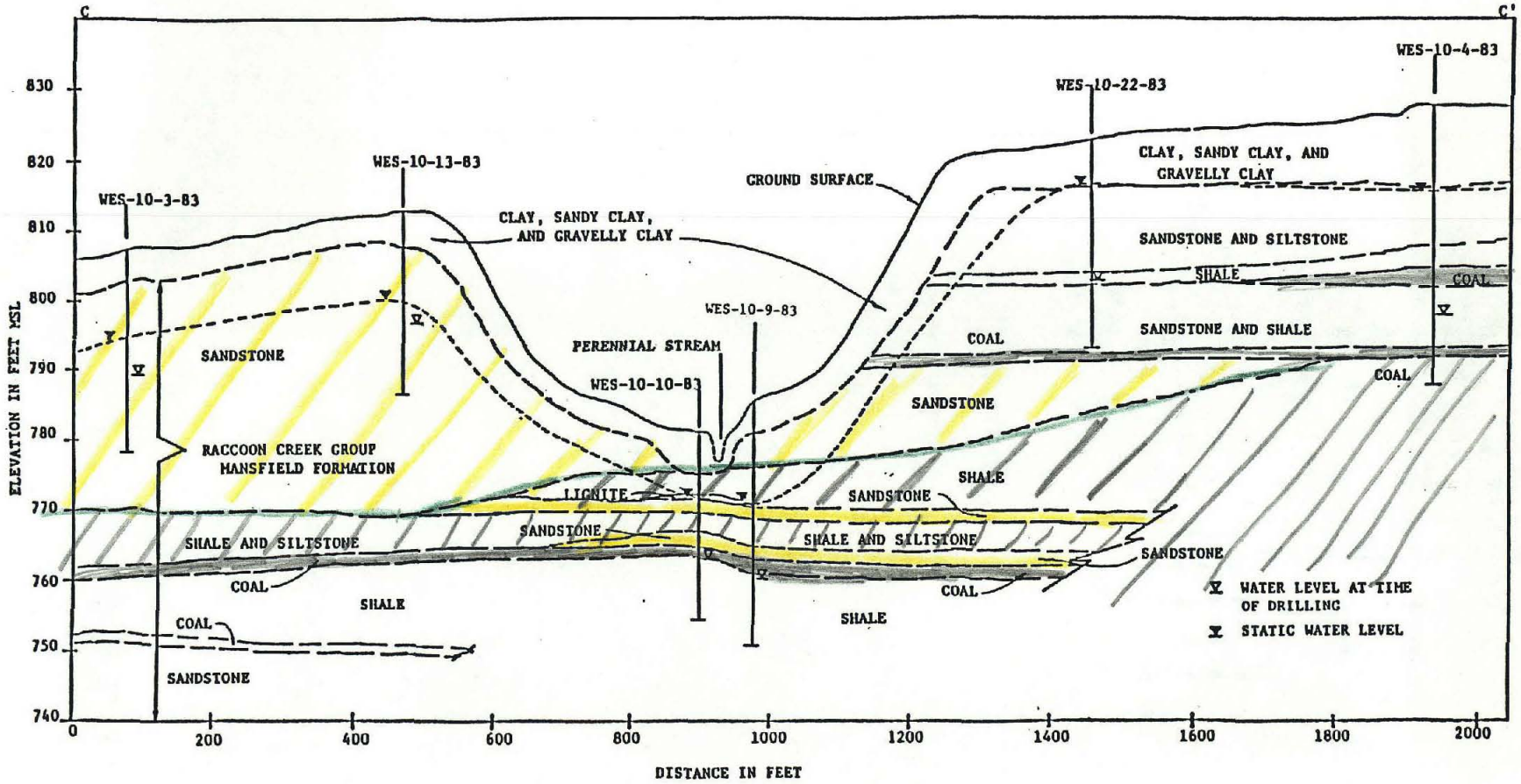


Figure 4c. rockeye Munitions Facility Geological Cross-Section C-C'

The two remote wells (WES 10-1-81 and 10-2-81) associated with the RS are located within strata which is approximately 200 feet lower within the geologic section than those wells at the LAP proper. The predominant rock type within the monitored interval at this location is a 20-foot-thick brown, fine-grained, quartz sandstone from the Mansfield Formation of the Raccoon Creek Group. The overburden to this sandstone is a 7-foot-thick sequence of clay, clayey sand-gravel, and silty sand. Underlying the sandstone bedrock is a grey, moderately hard limestone which represents the Glen Dean Limestone of the Stephensport Group. Figure 4d illustrates the cross-sectional geology at this site.

Hydrology

As with most locations at NWSC, groundwater at the RS primarily occurs within the bedrock fractures. Despite the presence of sand within much of the bedrock, the primary porosity of most of this sandy-bedrock is very low due to filling of the interparticle spaces by the process of cementation. The total void space represented by the secondary fractures is probably less than 10 percent. For this reason, the total volume of groundwater per unit volume of aquifer underlying the RS is probably relatively low; however, the rate at which it moves may be relatively fast due to the small total cross-sectional area of the void spaces through which it travels. The portion of this report entitled "Extents and Rates of Contaminant Migration" will give rough estimates of groundwater and contaminant transport rates.

In the spring or after precipitation, portions of the unconsolidated overburden are likely to become temporarily saturated as surface-derived water attempts to infiltrate to the zone of saturation. At these times, locally perched water tables are likely to exist. Such perched water systems are expected to be transient and to overlie the more impermeable portions of the overburden which are composed of materials such as clay or clayey sand. Because the spatial distribution of these low permeability zones is varied, the spatial distribution of the small perched groundwater systems is also varied.

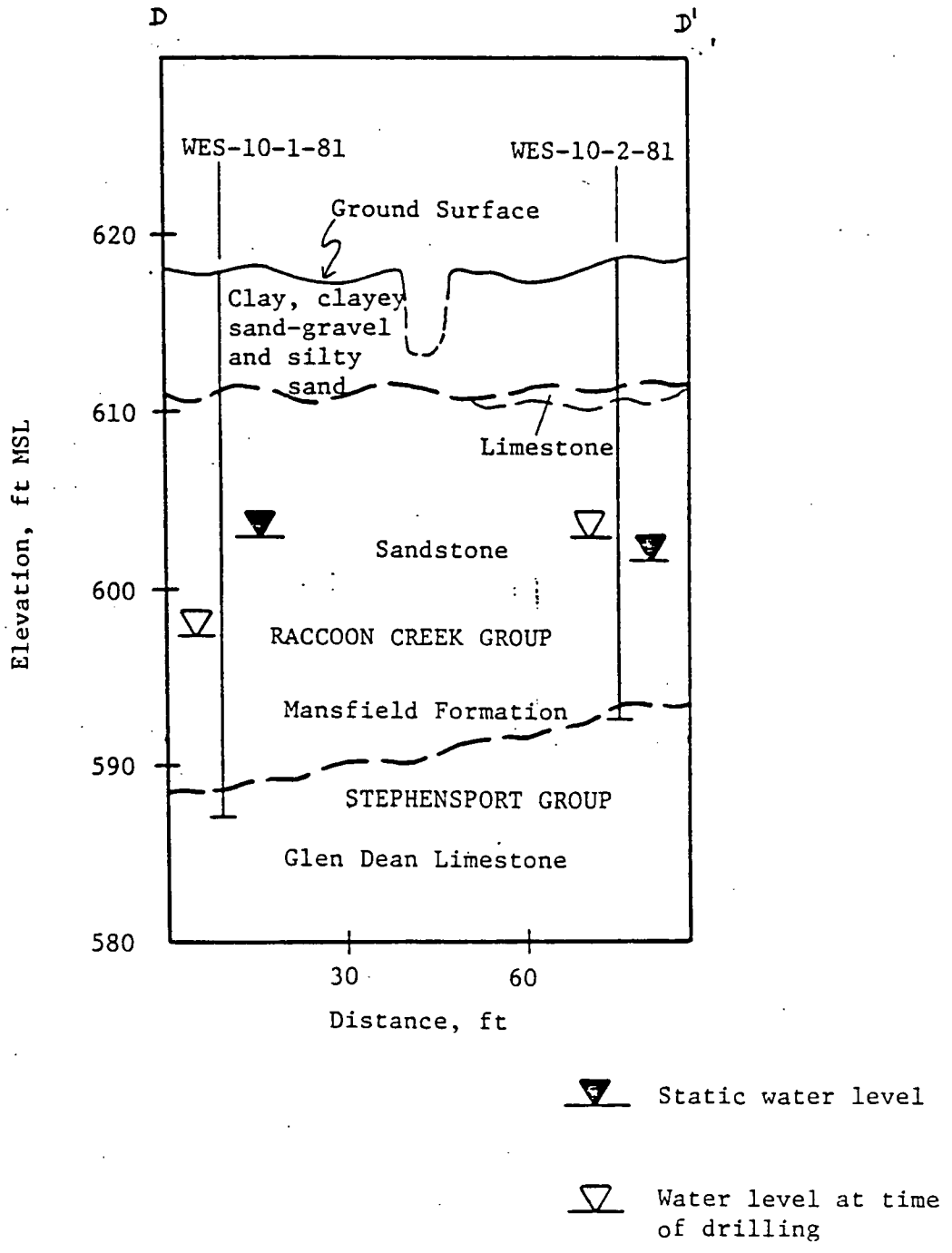


Figure 4d. Geological Cross-Section D-D' of Rockeye Site

The regional groundwater table at this site is a water-table aquifer for which neither the storage nor transmissive characteristics have been determined by field testing. The average depth to the groundwater table at the RS is approximately 17 feet below ground surface and tends to fluctuate laterally in elevation in accordance with topographical changes. In several wells at this site, the first occurrence of groundwater was observed to have been associated with coal seams. This suggests that the cleats or joints within the coal seams are fairly well developed, thus imparting relatively significant secondary porosity and water-bearing capacity to the coal.

Plate 1 presents a groundwater table contour map for this portion of the RS. This plate indicates that this site is coincident with a groundwater divide which trends southwest-northeast. Groundwater moves away from this divide; therefore, the direction of groundwater flow depends on whether the observation point is east or west of the divide. Near the divide, groundwater flow directions are poorly defined. At greater distances away from the divide, however, the groundwater flow directions become better defined and are toward the intermittent streams that drain this site. This suggests that these streams represent groundwater discharge zones.

For monitoring wells located close to intermittent surface streams at the RS, the elevation of the groundwater table is close to, and in some instances coincident with, the elevation of the intermittent stream channel. This increases the likelihood that surface and groundwater interaction occurs along these streams. Although neither seasonal fluctuations in groundwater elevations nor stream discharges have been well documented, it is reasonable to expect that these streams are effluent (groundwater discharges into the stream) during various times throughout the year. The potential effects of these interactions on the movement of contaminants at the RS will be discussed in the section of this document entitled "Extents and Rates of Contaminant Migration."

The depth to groundwater in the vicinity of wells WES 10-1-81 and WES 10-2-81 (3,600 feet east of the RS site) is approximately 20 feet. As with

the main RS site, observed groundwater at this location is unconfined (water-table aquifer), and was encountered in fractures within the bedrock. It is probable that groundwater flows generally towards the east at this location, approximately coincident with the direction of surface water drainage. Because only two wells are present at this location, a groundwater table contour map is not presented. As with the surface streams at the main RS, it is probable that the stream located near the two remote wells varies between being influent and effluent, depending on antecedent moisture conditions.

DYE BURIAL GROUNDS (SITE NO. 2)

Geology

Dunbar (1982) describes the local geology at the DBG as consisting of overburden ranging in thickness from 2 to 10 feet. This overburden is underlaid by interbedded shale and sandstone from the Mansfield Formation of the Raccoon Creek Group and the Glen Dean Limestone of the Stephenson Group. At this location, the sandstone ranges in color from brown, orange and red to various shades of grey. The primary particles that compose this sandstone are chiefly fine-grained to very fine-grained quartz sand. The amount of dark grey interbedded shale within this sandstone tends to increase with depth beginning at about 35 feet. Beginning at a depth of around 51 feet, the nature of this shale grades into a green, uniform, brittle shale. At an approximate depth of 65 feet at well WFS-2-3-81, hard and grey limestone was encountered. Figure 5 illustrates a geologic cross-section of this site, and Plate 2 illustrates the location of this cross-section.

Hydrology

Groundwater at the DBG primarily occurs within fractures in the bedrock. According to groundwater measurements from November 11, 1981, groundwater elevations at the DBG range from 684 to 678 feet above msl.

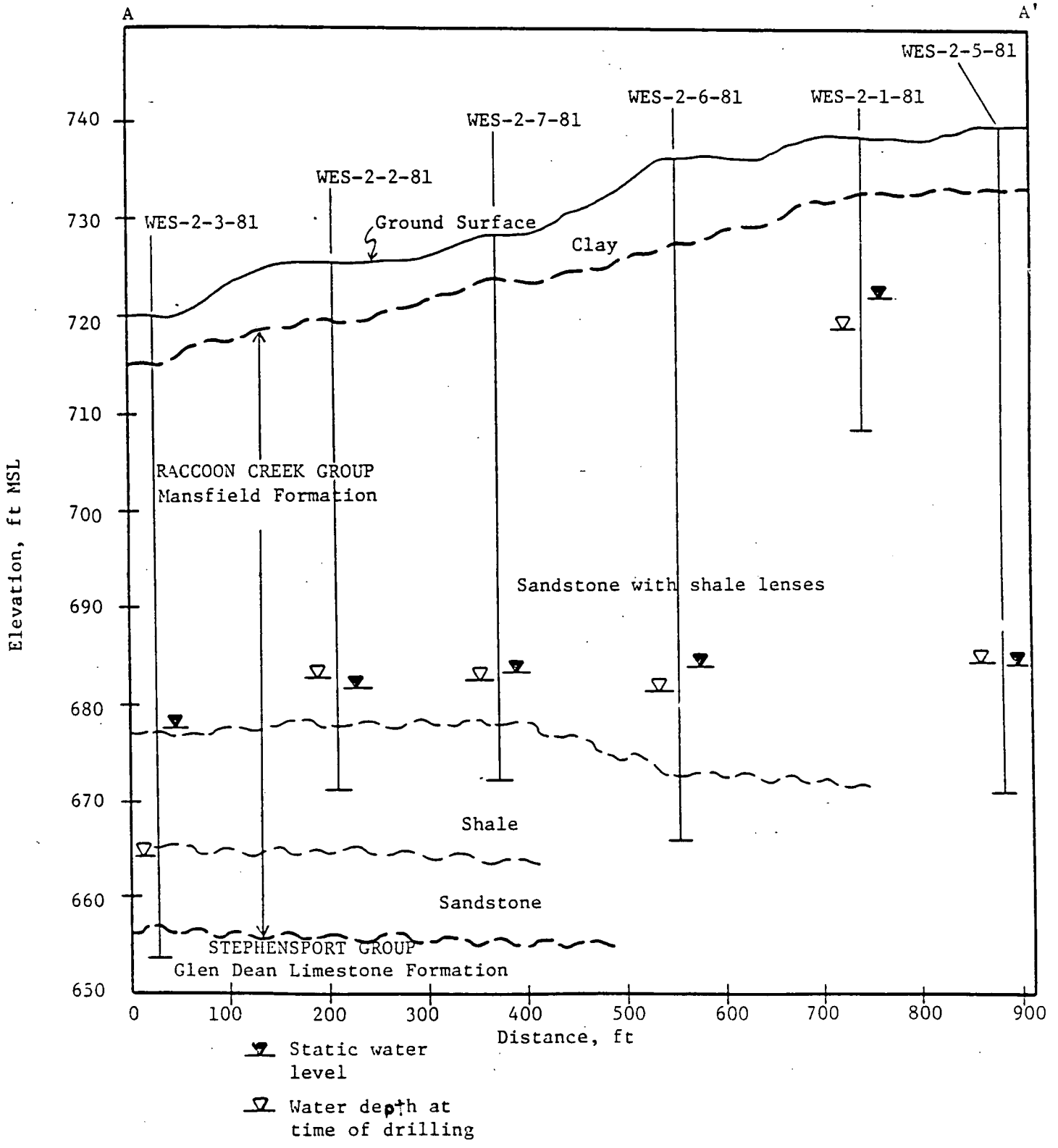


Figure 5. Geological Cross Section A-A' of Dye Burial Grounds

Based on these measurements, a groundwater table contour map was prepared and is presented in Plate 2. This map indicates that groundwater movement at the DBG is toward the west.

Figure 5 shows that a perched groundwater system was encountered by well WES 2-1-81. Because this groundwater system is apparently not connected, or is only poorly connected to the deeper system monitored by the other wells, elevation measurements from the non-extensive shallow groundwater system were not used to construct the groundwater table contour map for this site. The presence of a perched groundwater zone within the bedrock at this site is evidence that the fracture system is not everywhere equally well developed within the bedrock. Therefore, ill-defined, preferential flow paths are likely to be present. Preferential flow paths are likely occurrences at all of the present study sites, whether or not their presence is suggested by perched groundwater tables.

DEMOLITION GROUNDS/OLD RIFLE RANGE (SITE NO. 6)

Geology

For both the south and east ridges at the DG, the bedrock consists of interbedded sandstone, shale, and coal from the Mansfield Formation of the Raccoon Creek Group. At the south ridge the sandstone is variably described as weathered, brown, friable, and fine-grained or a thick sequence of brown to grey, fine-grained, moderately hard sandstone with interbedded black shale seams. The shale units at the south ridge are described as soft, grey to dark grey organic shale. Only minor amounts (non-extensive) of coal and limestone were observed at the south ridge.

At the east ridge the underlying sandstone is variably described as brown to orange-brown, weathered, friable, fine-grained quartz sandstone or light to dark grey, very fine-grained shaley sandstone. The shale is very similar to that previously described for the south ridge. Minor amounts of coal and no limestone were observed at the east ridge. Across both ridges,

the overburden varies from 2 to 13 feet in thickness and is described as clay and clayey sand. Figures 6a and 6b show geologic cross-sections across the south and east ridges, respectively, at the DG. Plate 3 indicates the locations of these sections.

The ORR portion of Site No. 6 is approximately 150 feet lower in elevation than the DG; therefore, the bedrock units at the ORR are stratigraphically lower than those at the DG. The majority of the bedrock at the ORR is Mississippian-aged sandstone from the Hardingsburg Formation of the Stephensport Group. In the vicinity of the temporary flashing pits Nos. 1 and 2, the sandstone is described as uniform, moderately friable, very fine-grained, massive, and ranging in color from tan to orange brown. The occurrence of bedrock is indicated in Figures 6c through 6e, which are geological cross-sections for the ORR. The locations of these sections are indicated in Plate 4. Section E-E trends north-south across the site and clearly illustrates the presence of a previous channel of Turkey Creek. The unconsolidated deposits within the channel extend to an estimated depth of approximately 30 feet below ground level and consist of mixtures of sand, clay and gravel. The overburden at this site contains a high percentage of clay and varies in thickness from less than 2 feet to 30 feet.

Hydrology

Groundwater at both the south and east ridges of the DG primarily occurs within bedrock fractures and its movement is topographically controlled. Plate 3 presents groundwater table elevation contour maps for the south and east ridges. From this it is apparent that a localized groundwater divide occurs along the south ridge such that the groundwater flow direction changes depending on whether the observer is on the east or west side of the south ridge. Groundwater movement, as indicated by the contour map, is toward the east along the east side of the ridge and toward the west along the west side of the ridge. At the east ridge, the direction of groundwater movement indicated by the available data is toward the east, southeast and south. However, the small number of observation wells used to construct the groundwater contour map may lead to slight distortion. If a greater number of

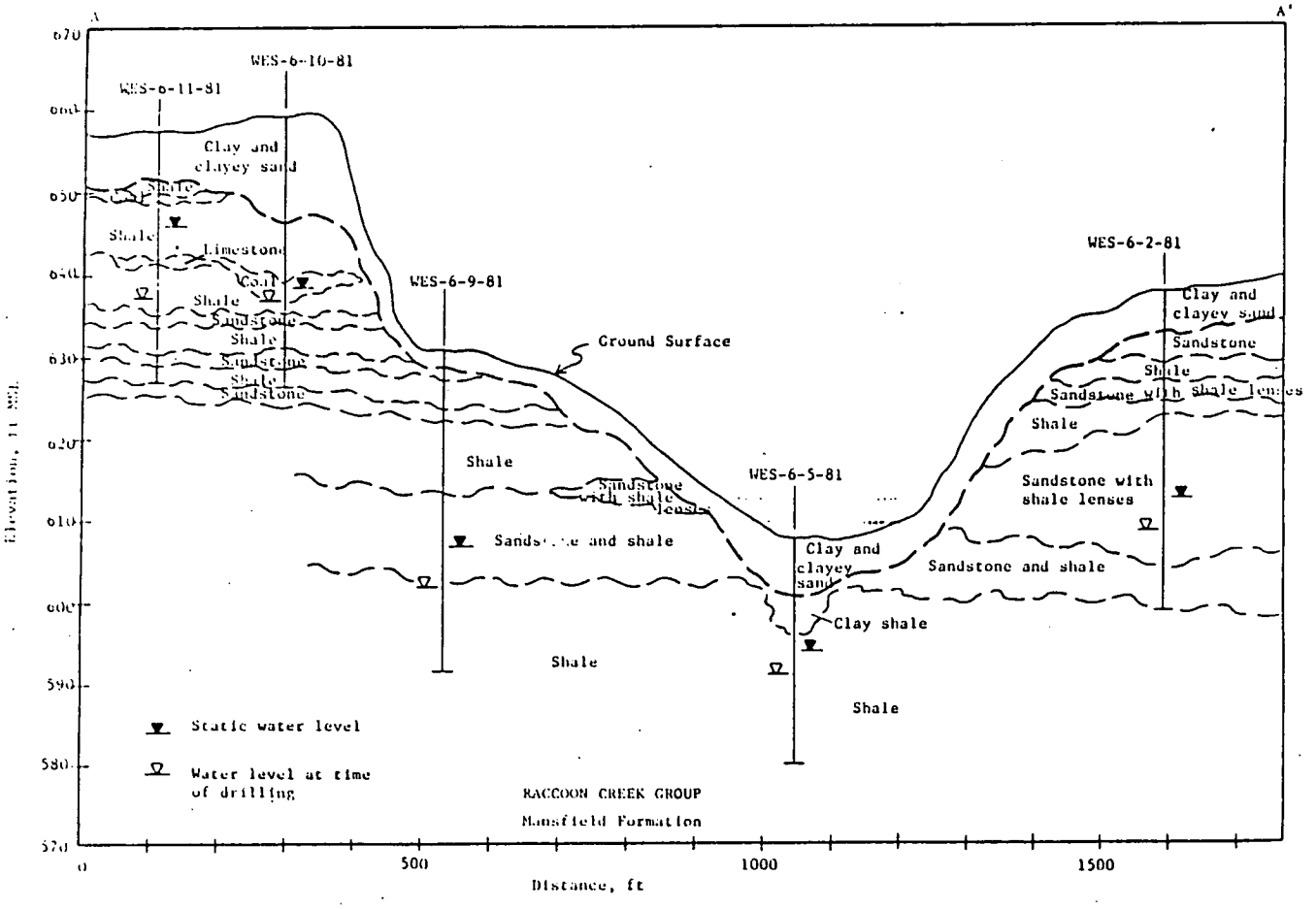
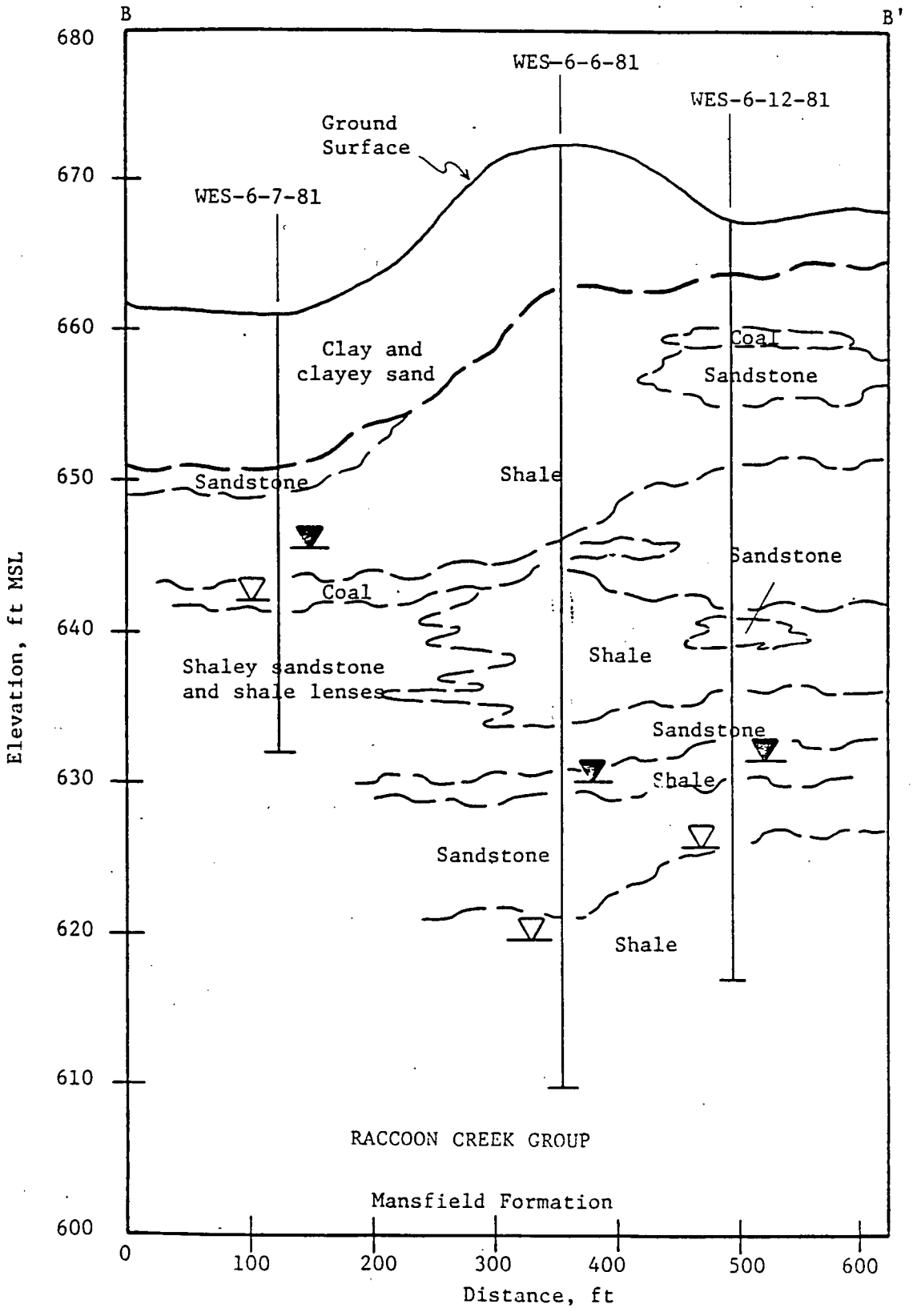


Figure 6a. Geologic Cross-Section Along A-A' at the South Ridge of the Demolition Grounds



Static water level

Water level at time of drilling

Figure 6b. Geological Cross-Section B-B' of the East Ridge of the Demolition Grounds

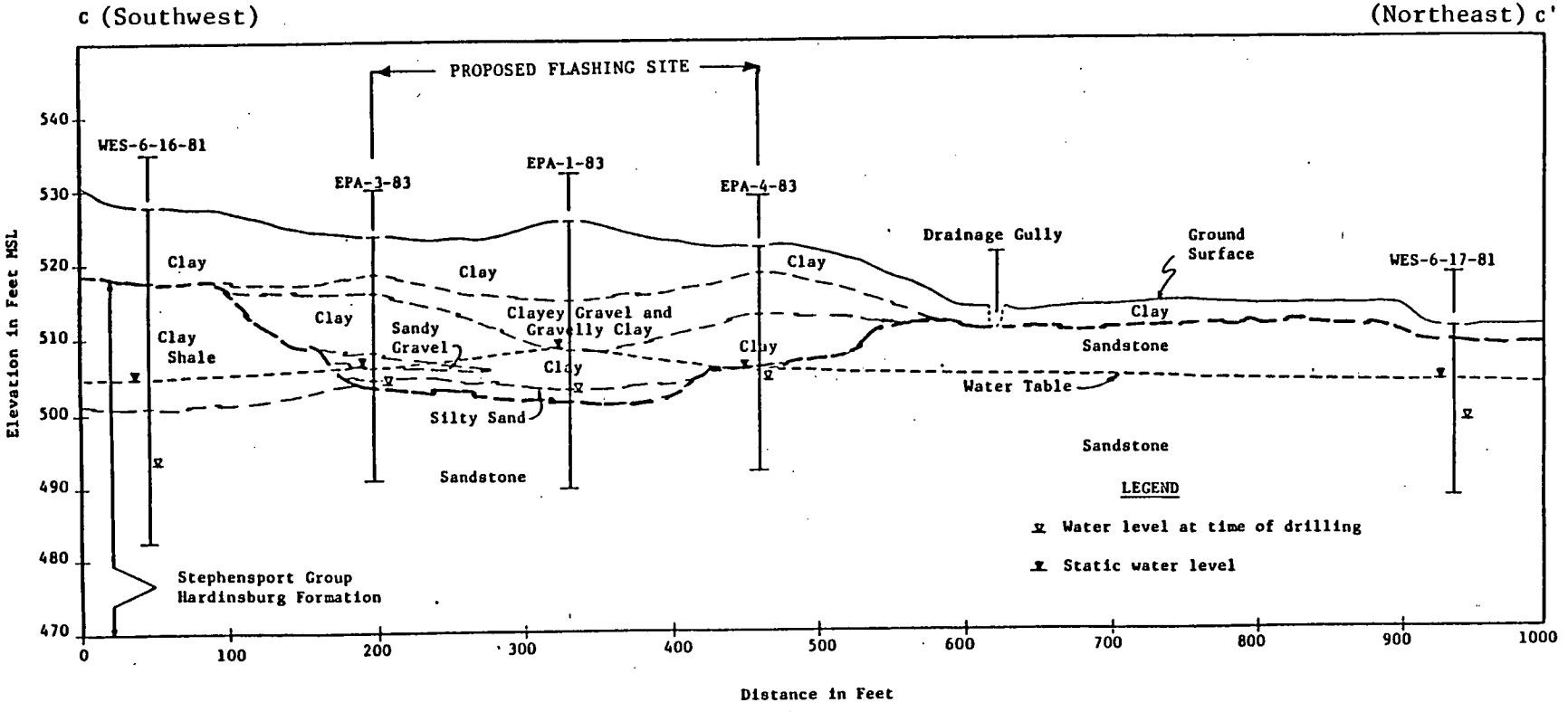


Figure 6c. Old Rifle Range Geological Cross-Section C-C'

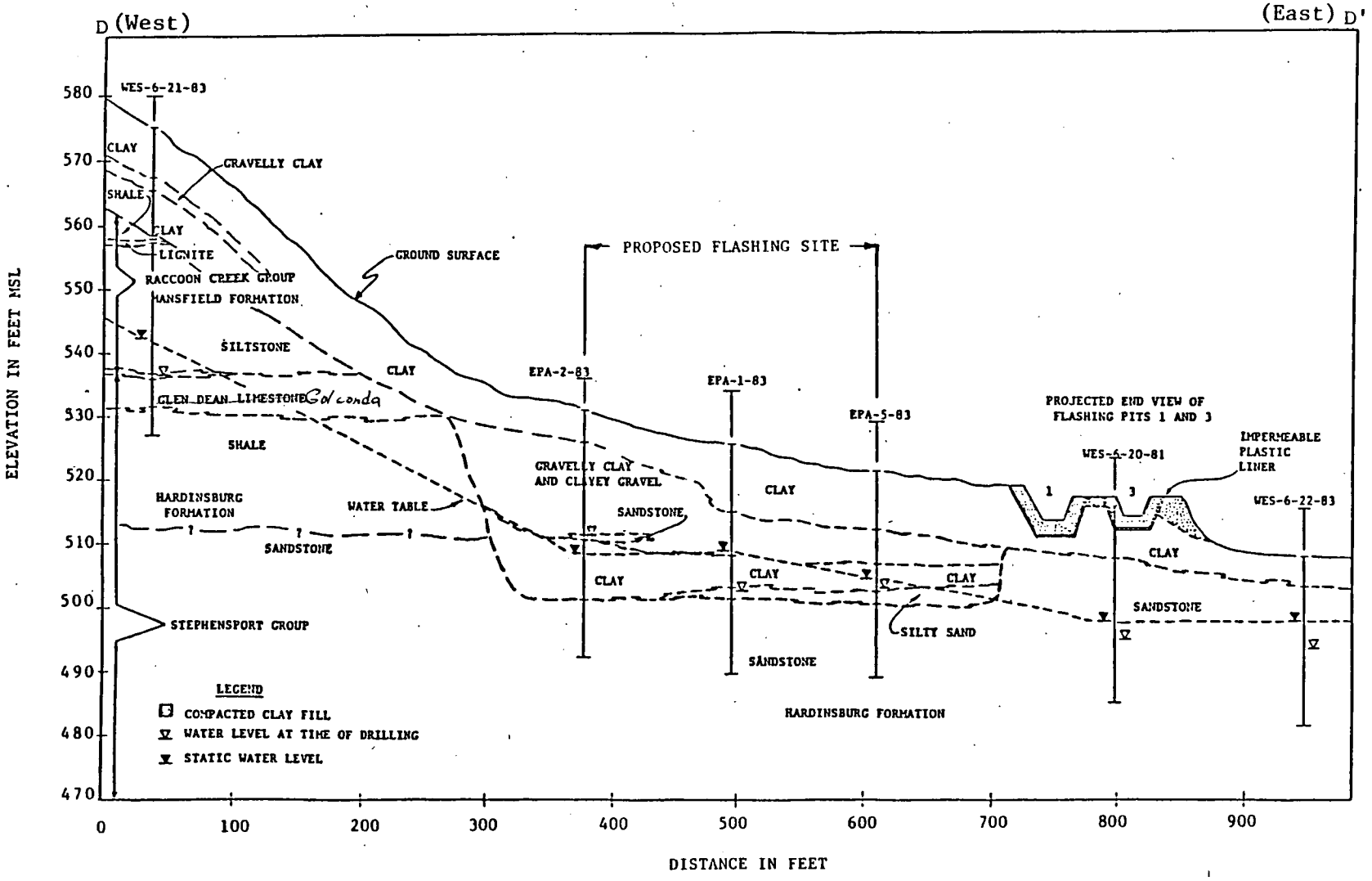


Figure 6d. Old Rifle Range Geological Cross-Section D-D'

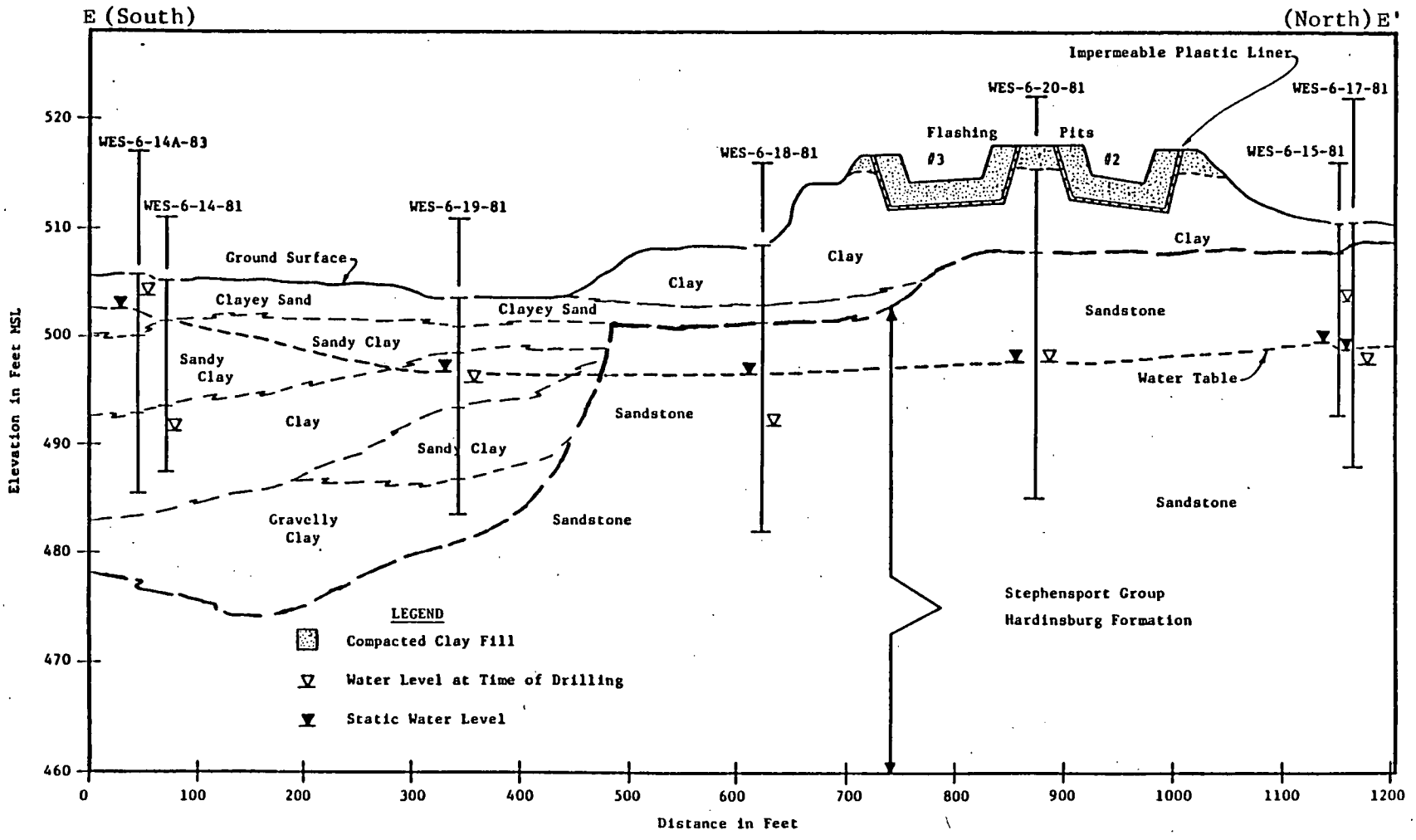


Figure 6e. Old Rifle Range Geological Cross-Section E-E'

groundwater observation wells were available it is likely that they would indicate that the elevation of the groundwater table more closely parallels the surface topography. In this case, an east-west trending groundwater divide coincident with the topographic ridge would probably be better defined, thus showing the primary groundwater flow directions to be towards the north, north of the divide, and toward the south, south of the divide.

At neither location at the DG were perched groundwater systems observed. This may suggest that the bedrock fracture system at this location is sufficiently well developed to allow more rapid downward movement of infiltrating water to the saturated zone; however, this is mere speculation.

Plate 4 is a groundwater table contour map for the ORR. It indicates that the groundwater flow direction at this site is generally eastward, coincident with the topography and toward Turkey Creek. A slight perturbation in the eastward-sloping groundwater table is revealed by boring EPA-1-83. This boring indicates a slight mounding of the water table at this location. Three possible reasons for this slight mounding include 1) the slight topographic high at this location, 2) perching of groundwater atop the clay layers encountered by this boring, or most likely, 3) an artifact of the construction characteristics of this boring, such that groundwater enters along the entire length of the boring rather than through a discrete screened interval.

MCCOMISH GORGE (SITE NO. 4)

Geology

The MG is located on unconsolidated lacustrine deposits, which are classified as part of the Atherton Formation of the Illinoian and Wisconsinan Stage of the Pleistocene Series. At this location, these deposits primarily consist of interbedded deposits of sand, silt, and clay. Only small amounts of coarse sand or gravel were encountered. Figure 7 is a geological cross-section across this site illustrating the heterogeneous nature of the

subsurface at this location. Plate 5 illustrates the location of the cross-section.

Hydrology

Plate 5 illustrates the groundwater contour map for MG. It indicates that the groundwater gradient is eastward, toward Culpepper Branch. The elevation of Culpepper Branch is approximately coincident with the elevation of the groundwater table; therefore, it is likely that groundwater from the MG discharges to Culpepper Branch. Across the site, the depth to the groundwater table ranges from approximately 15 feet near the western margin of the site, to less than 5 feet near Culpepper Branch.

GROUNDWATER QUALITY

The following section summarizes all analytical groundwater monitoring results available to date for each of the subject sites. Each site is discussed separately with regard to positive results and statistically significant changes in indicator parameters. Probable groundwater contaminants indicated on the basis of first-year results are described despite the realization that, from a regulatory viewpoint, first-year analyses are intended only to establish background groundwater quality rather than to indicate the presence of groundwater contamination. According to the regulations, this determination is reserved until the second year, when statistical comparisons of first- and second-year data can be made. First-year data are presently used as indicators of contamination via their comparison to the National Secondary Drinking Water Regulation (NSDWR) criteria and the National Interim Primary Drinking Water (NIPDW) Regulation standards.

Most first- and second-year samples were analyzed by Century Environmental Testing Laboratories, Inc., except for the first-quarter total coliform bacterial analyses, which were performed by the U.S. Army Medical

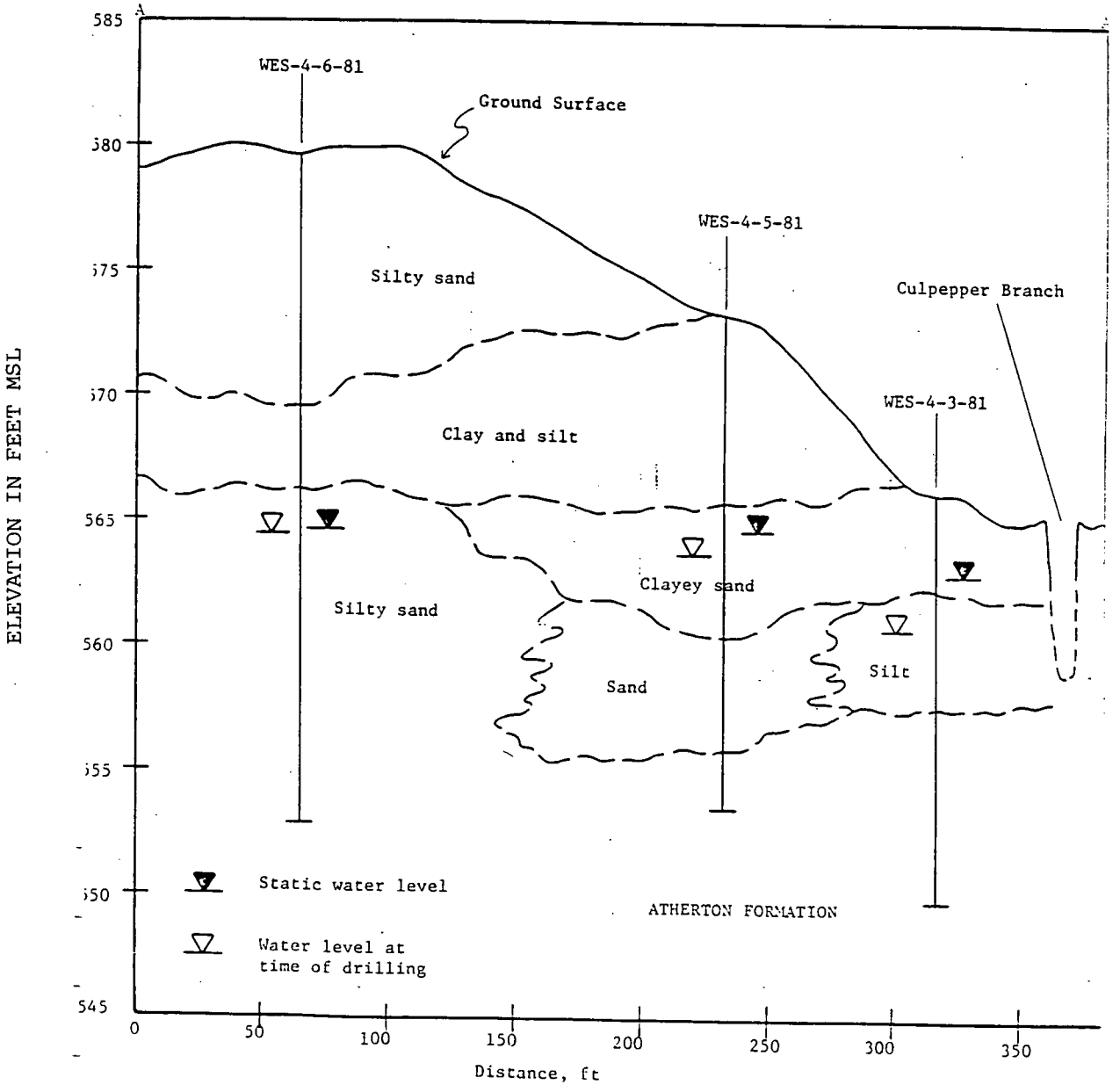


Figure 7. Geologic Cross-Section at McComish Gorge

Department Activity, Ft. Knox, Kentucky; and the analyses for explosives, which were performed by the U.S. Army Environmental Hygiene Agency, Aberdeen Proving Ground, Maryland, and Environmental Research Group Lab. Analysis since 1983 has primarily been conducted by the Environmental Research Group.

Rockeye Site (Site 10) - Groundwater Monitoring Results

The only parameters for which groundwater samples from most monitoring wells at this site have been analyzed are pH and various explosives, including cyclotrimethylenetrinitramine (RDX), cyclotetramethylenetetranitramine (HMX), and trinitrotoluene (TNT). Table 3a summarizes the results of analysis for explosives in groundwater samples from the monitoring wells at the RS. To date, groundwater samples from 10 different monitoring wells at the RS have had detectable levels of either RDX, HMX, TNT, or some combination thereof. These 10 wells include wells 1, 2, 7, 8, 9, 17, 18, 19, 20 and 21. The observed concentration ranges for RDX, HMX, and TNT are, respectively, 10 to 7,200 µg/l, 20 to 650 µg/l and 22 to 3800 µg/l. Most of the 22 wells at this site, however, had non-detectable levels of these explosives. Well WES 10-17-83 had the maximum observed concentration for all three of these explosives, based on the results of two separate episodes of sampling and analysis. Other wells that showed higher than average explosives concentrations are wells WES 10-7-83 and WES 10-2-83. Appendix 8a contains the results of explosives analyses.

Observed explosives concentrations are highly variable through time at individual wells. Six different wells (wells 1, 2, 7, 9, 20 and 21) have fluctuated from non-detectable levels of explosives at one monitoring period, to levels as high as 260 µg/l at another monitoring period. Well 17 jumped from 26 µg/l RDX, 26 µg/l HMX and ND levels of TNT observed during February, 1984, up to 6,190 µg/l RDX, 765 µg/l HMX, and 4,850 µg/l of TNT, observed during January, 1985. Wells 8, 17, and 18 have consistently shown contamination by explosives during all monitoring periods. Wells 1 and 2 (off-site wells) did not show consistently detectable concentrations of explosives contamination until 1984, even though these wells were being monitored in May and April of 1983.

Table 3a. Results of Analysis for Explosive Compounds in Groundwater at the Rockeye Site (micrograms per Liter)

SAMPLE DATA:	3/83						7/83			8/83						9/83			10/83			12/83			2/84			6/84			11/84			1/85		
WELL / PARAMETER:	RDX	HMX	TNT	2,4-DNT	2,6-DNT	TETRYL	RDX	HMX	TNT	RDX	HMX	TNT	2,4-DNT	2,6-DNT	TETRYL	RDX	HMX	TNT	RDX	HMX	TNT	RDX	HMX	TNT	RDX	HMX	TNT	RDX	HMX	TNT	RDX	HMX	TNT	RDX	HMX	TNT
WES 10-1-83	ND*	ND	ND	ND	ND	ND				ND	ND	ND	ND	ND	ND										77	13	9	31	ND	ND	57	50	12	24	ND	ND
WES 10-2-83	ND	ND	ND	ND	ND	ND				255	ND	ND	ND	ND	ND										110	13	5	92	14	ND	114	100	56	70	ND	ND
WES 10-3-83	**						ND	ND	ND																									ND	ND	ND
WES 10-4-83							ND	ND	ND																									ND	ND	ND
WES 10-5-83							ND	ND	ND																									ND	ND	ND
WES 10-6-83							ND	ND	ND																									ND	ND	ND
WES 10-7-83							180	83	76							260	40	160				ND	ND	ND										72	104	23
WES 10-8-83							150	46	22							62	11	4				140	98	60										113	ND	29
WES 10-9-83							120	22	ND							ND	ND	ND				ND	ND	ND												
WES 10-10-83							ND	ND	ND							ND	ND	ND				ND	ND	ND										ND	ND	ND
WES 10-11-83																ND	ND	ND																ND	ND	ND
WES 10-12-83																ND	ND	ND																ND	ND	ND
WES 10-13-83																ND	ND	ND																ND	ND	ND
WES 10-14-83																ND	ND	ND																ND	ND	ND
WES 10-15-83																ND	ND	ND																ND	ND	ND
WES 10-16-83																ND	ND	ND																ND	ND	ND
WES 10-17-83																			7200	650	2900				ND	ND	3800							ND	ND	ND
WES 10-18-83																25	120	ND				22	37	ND	26	26	ND							6190	765	4850
WES 10-19-83																ND	ND	ND				ND	ND	ND										26	ND	ND
WES 10-20-83																10	ND	ND																ND	ND	ND
WES 10-21-83																ND	ND	ND							ND	20	ND							ND	ND	ND
WES 10-22-83																ND	ND	ND																ND	ND	ND

* None detected

** A blank space denotes not sampled nor analyzed (All other results as ug/l)

Dye Burial Grounds (Site 2) - Groundwater Monitoring Results

The most significant contaminant observed in groundwater at the DBG is chromium. It was observed in well WES 2-1-81 at a concentration of 0.070 mg/l, based on a third-quarter sample from July, 1982. Other parameters observed to exceed NIPDWR or NSDW regulation standards include fluoride and iron, manganese, sulfate, and bacteria. Fluoride was consistently present in well WES 2-4-81 at concentrations of either 1.5 or 2.0 mg/l, throughout all four quarters of the first monitoring year. Iron, manganese and sulfate were consistently present in most monitoring wells at the DBG, at concentrations in excess of the standards. Appendices 6 and 8 contain the analytical results for first- and second-year monitoring, respectively.

Table 3b summarizes the results of metals analysis for soil samples collected from various depths within monitoring wells 1, 2, 3, 4, and 5 at the DBG. Chromium, arsenic, and selenium are present in soil samples from all of the above wells. Chromium concentrations are the highest, and range from 0.0130 percent (130 ppm) to 0.0392 percent (392 ppm). Arsenic and selenium range from nondetectable to 0.069 percent (690 ppm) and nondetectable to 0.0206 percent (206 ppm). At most of the sample locations, these contaminants appear to decrease in concentration with depth, except for chromium. The observed concentration of chromium was higher at the 5- to 6-foot sampling depth than it was within the 0 to 2.5-foot interval at wells WES 2-2-81, WES 2-3-81, and WES 2-5-81. Well WES 2-2-81 showed the highest overall soil contamination from chromium, arsenic, lead, and selenium.

After the second year of monitoring at the DBG was completed, statistical comparison of first- and second-year results for indicator parameters was performed. Table 4 summarizes the pooled means and standard deviations of the values of the Group III parameters observed during the first year for the background monitoring well (well WES 2-5-81) at the OBG. This table contains the same information for background wells at the east ridge of the DG/ORR, west ridge of the DG/ORR, ORR portion of the DG/ORR, and MG.

Table 3b. Results of Metals Analysis in Soil Samples From the DBG

Sample ID	Metals							
	Ag	Cr	As	Cd	Pb	Se	Be	Hg
1-1A	.0016	.0163	.054	.005	.0176	.0206	.10	4.62×10^{-5}
1-2A	.001	.0392	.048	.005	.001	.0074	.10	1.62×10^{-5}
2-1A	.001	.0230	.069	.005	.001	.0072	.10	2.14×10^{-5}
2-2A	.001	.0131	.055	.005	.001	.0122	.10	1.11×10^{-5}
3-1A	.001	.0134	.010	.005	.001	.0105	.10	4.25×10^{-5}
3-2A	.001	.0355	.010	.005	.001	.002	.10	7.97×10^{-5}
4-1A	.001	.0326	.029	.005	.001	.080	.10	3.65×10^{-5}
4-2A	.001	.0318	.010	.005	.001	.002	.10	1.56×10^{-5}
5-1A	.001	.0274	.032	.005	.001	.0187	.10	1.67×10^{-5}
5-2A	.001	0.340	.018	.005	.0158	.002	.10	1.29×10^{-5}
2-6-1B	.001	.0270	.010	.005	.004	.002	.10	19.5×10^{-5}
2-6-2B	.001	.0200	.010	.005	.008	.002	.10	14.0×10^{-5}
2-7-18	.001	.0130	.010	.005	.003	.002	.10	36.7×10^{-5}
2-8-1B	.001	.0210	.101	.005	.016	.002	.10	43.1×10^{-5}
2-8-2B	.001	.0320	.010	.005	.005	.002	.10	25.9×10^{-5}
2-YD-1A	.001	1.08	.010	.005	5.49	.010	.10	28.1×10^{-5}

NOTES:

1. Test data based on 1 gram soil sample digested and diluted to 100 ml for analysis.

2. All values are reported as percent metal content in the soil submitted for analysis.

Table 4. Pooled Means and Standard Deviations of Observed Values of Group III Parameters for the Background Monitoring Wells at Sites 2, 4, and 6.

Site No 2: Dye Burial Grounds (Well WES 2-5-81)

Parameter	Mean	Standard Deviation	Number of Samples
pH	6.600	0.379	16
Specific Conductivity	2670.500	474.676	16
Total Organic Carbon (mg/l)	39.331	31.558	16
Total Organic Halogens (mg/l)	0.064	0.054	16

Site No. 6: Demolition Grounds/Old Rifle Range at the East Ridge (Well WES 6-7-81)

Parameter	Mean	Standard Deviation	Number of Samples
pH	4.235	0.287	20
Specific Conductivity	3784.375	169.822	16
Total Organic Carbon (mg/l)	26.412	22.442	16
Total Organic Halogens (mg/l)	0.015	0.008	16

Table 4 (continued)

Site No. 6: Demolition Grounds/Old Rifle Range at the West Ridge (Well WES 6-3-81)

Parameter	Mean	Standard Deviation	Number of Samples
pH	6.887	0.550	16
Specific Conductivity	1483.687	51.500	16
Total Organic Carbon (mg/l)	22.856	15.569	16
Total Organic Halogens (mg/l)	0.026	0.029	16

Site No. 6: Demolition Grounds/Old Rifle Range at the Old Rifle Range (Well WES 6-16-81)

Parameter	Mean	Standard Deviation	Number of Samples
pH	6.662	0.247	16
Specific Conductivity	373.875	21.728	16
Total Organic Carbon (mg/l)	18.419	8.388	16
Total Organic Halogens (mg/l)	0.050	0.042	16

Table 4 (continued)

Site No. 4: McComish Gorge (Well WES 4-1-81)

Parameter	Mean	Standard Deviation	Number of Samples
pH	6.819	0.226	16
Specific Conductivity	383.437	33.460	16
Total Organic Carbon (mg/l)	24.437	24.210	16
Total Organic Halogens (mg/l)	0.018	0.010	16

The data in Table 4 were used in conjunction with the t-test summarized in Appendix 12 to determine whether statistically significant increases in the values for first-year Group III parameters from the upgradient wells had occurred when compared with the second set of semiannual samples from all wells. Appendix 13 summarizes the results of these tests. Wells 4, 5, 6, and 8 at the DBG show significant changes for at least one indicator parameter. Table 5 indicates those parameters and the corresponding wells for which statistically significant changes in concentration were observed.

Demolition Grounds/Old Rifle Range (Site 6) - Groundwater Monitoring Results

At the DG portion of site no. 6, wells WES 6-6-81, WES 6-7-81 and WES 6-13-81, located at the east ridge, indicated the presence of groundwater contamination. During the first monitoring year, well WES 6-7-81 showed positive results for fluoride, arsenic, cadmium and selenium. The respective ranges of concentrations observed for these parameters were 2.0 to 3.5 mg/l, 0.062 to 0.063 mg/l, 0.023 to 0.025 mg/l, and 0.017 mg/l. This well also consistently showed pH values of 3.9 to 4.4. The most significant positive result for well WES 6-6-81 was the occurrence of selenium at a concentration of 0.017 mg/l during the third quarter. Well WES 6-13-81 also showed selenium during the third quarter at a concentration of 0.018 mg/l. None of the wells at the east ridge showed explosives contamination.

Monitoring wells at the west ridge (also at the DG portion of site no. 6) generally showed no groundwater contamination. Various parameters which were in excess of standards included those which are probably naturally occurring such as iron, manganese, and sulfate. These parameters frequently occur in many monitoring wells at all of the present study sites; however, their occurrence is not specifically summarized in the text due to their ubiquitous nature.

At the ORR portion of site no. 6, the most significant groundwater contaminants were nitrate and HMX. HMX was observed in well WES 6-16-81 at

Table 5. Wells for Which Group III Parameters Monitored During the Second Year Showed Statistically Significant Increases Over Background Values Established by the Upgradient Wells During the First Year of Monitoring

Site No 2: Dye Burial Grounds

Well	Parameter that showed significant change
WES 2-4-81	pH
WES 2-5-81	TOC
WES 2-6-81	Specific Conductivity
WES 2-8-81	TOC

Site No 6: East Ridge Portion of the Demolition Grounds/Old Rifle Range

Well	Parameter that showed significant change
WES 6-1A-81	pH TOX
WES 6-6-81	pH, TOX
WES 6-8-81	pH
WES 6-12-81	pH, TOX, Specific Conductivity
WES 6-13-81	pH, TOX, Specific Conductivity

Well	Parameter that showed significant change
WES 6-2-81	Specific Conductivity
WES 6-9-81	pH
WES 6-10-81	pH
WES 6-11-81	pH, TOX, Specific Conductivity

Table 5 (continued)

Site No 6: West Ridge Portion of the Demolition Grounds/Old Rifle Range

Well	Parameter that showed significant change
WES 6-14-81	pH, Specific Conductivity
WES 6-16-81	Specific Conductivity
WES 6-17-81	pH
WES 6-18-81	pH, Specific Conductivity
WES 6-19-81	pH, TOC, Specific Conductivity

Site No 4: McComish Gorge

Well	Parameter that showed significant change
WES 4-1-81	TOX
WES 4-2-81	Specific Conductivity
WES 4-3-81	pH, TOX, Specific Conductivity
WES 4-4-81	pH,
WES 4-5-81	pH, TOX, TOC, Specific Conductivity
WES 4-6-81	Specific Conductivity

a concentration of 0.1 mg/l during the second semiannual monitoring period for this location. This well showed no contamination by explosives during the first semiannual monitoring period. Nitrate was observed in well WES 6-18-81 during the first monitoring year at a concentration range of 11.9 to 16.1 mg/l. Appendix 6 contains all of the available first-year analytical results, and Appendix 8 contains the second-year analytical results, including explosives, for all wells at the DG/ORR.

Statistical comparisons of first- and second-year groundwater monitoring data were made for the DG/ORR. Because the wells at this site are clustered in three distinct areas (east ridge at the DG, west ridge at the DG, and the ORR) three different up-gradient wells were monitored to establish background groundwater quality. Table 4 summarizes the pooled means and standard deviations of observed values of Group III parameters for the up-gradient wells at these three areas of the DG/ORR. Table 5 identifies the various monitoring wells at each of the three areas of the DG/ORR for which Group III parameters measured during the second semiannual monitoring period of the second year showed statistically significant increases over the background values established by the up-gradient wells. Appendix 12 summarizes the T-test used to identify these statistically significant differences. Appendix 13 presents the results of this statistical test.

McComish Gorge (Site 4) - Groundwater Monitoring Results

The most significant groundwater contaminants observed at the MG are mercury and chromium. Mercury was observed at a concentration of 0.077 mg/l in well WES 4/1/81 during the fourth quarter. Chromium was also observed during the fourth quarter at a concentration of 0.1 mg/l in well WES 4-5-81. Several wells at this site had high total coliform bacterial counts, including well WES 4-3-81 in which a strong sewage odor was noticed at the time of sampling during the second quarter. Appendix 6 contains all of the available first-year groundwater monitoring results, and Appendix 8 contains the second-year results.

Subsequent to the completion of the second year of monitoring, statistical comparison of first- and second-year results for indicator parameters was performed. Table 4 summarizes the pooled means and standard deviations of the values of the Group III parameters observed during the first year for the background monitoring well (well WES 4-1-81).

The data in Table 4 were used in conjunction with the t-test summarized in Appendix 12 to determine whether statistically significant increases in the values for first-year Group III parameters from the upgradient wells had occurred when compared with the second set of semiannual samples from all wells. Appendix 13 summarizes the results of these tests. All wells at the MGBG, including the background well, show significant changes with regard to at least one indicator parameter. Table 5 indicates those parameters and the corresponding wells for which statistically significant changes in concentration were observed.

IV. EXTENTS AND RATES OF CONTAMINANT MIGRATION

Extents and rates of contaminant migration at the present study sites are influenced by many factors that vary depending on the nature of the contaminants and the environmental setting. These factors include the rate of groundwater flow, concentration of the contaminant at the source, dispersivity of the material through which the contaminants and groundwater are flowing, adsorptive or chemical reactions involving the contaminant, nature of the unsaturated zone, and the presence of highly permeable bedrock fracture zones. Quantitative determination of the effects of all of these variables on the movement of contaminants is generally not possible at any hazardous waste site due to the excessive data needed for a full evaluation. This section presents rough estimates based on limited current hydrogeochemical data of the present extent and rates of contaminant migration.

A significant shortcoming in the following estimate of rates and extents of contaminant migration is the lack of detail in describing vertical (downward) variations in hydraulic head and vertical thicknesses of the plumes. This is a consequence of the fact that the monitoring well installations at these sites do not facilitate determination of vertical variation in hydraulic head and contaminant concentrations due to the lack of sufficient vertical variation in the elevations of the screened intervals for the monitoring wells. Characterization of vertical variations in hydraulic head and plume thicknesses can only be accomplished by clusters of monitoring wells, which are located immediately adjacent to one another and which are screened at different depths; or by individual wells which have several screened intervals at different depths that are hydraulically isolated from each other.

Although they cannot be quantified for the present sites, vertical components of groundwater flow are most likely for those sites situated near the top of local topographic highs, especially the RS, the DBG, and the

demolition grounds portion of site No. 6. The most important effect of vertical flow would be to increase the thickness of the plume of contamination and to cause overestimates of horizontal groundwater flow velocities. In this regard, the occurrence of vertical components of flow assures conservative estimates of horizontal migration rates.

The extent of contamination at each site is described on the basis of the locations of the monitoring wells known to contain contaminants. Any apparent correlations between the distribution of the contaminant plume and suspected routes of preferred contaminant migration are highlighted. Estimates of the rates of contaminant migration are also provided for each site on the basis of limiting assumptions. Most likely sources of error associated with these estimates are summarized for each site, including their potential effects on the estimated migration rates.

The only contaminant transport mechanism considered for each site is advective transport due to bulk groundwater movement. Additional factors affecting transport rates such as dispersion, adsorptive retardation, and biological and chemical degradation are not considered. The effects of dispersion are being ignored because, due to the lack of site-specific data, the error associated with quantifying the effects of dispersion is large in comparison to the detail with which the contaminant plumes have been mapped using the existing monitoring wells.

The following discussions of estimated groundwater transport rates will indicate that there is significant uncertainty associated with these estimates. Despite these uncertainties, a "worst-case scenario," which addresses off-site groundwater contaminant migration, will indicate that none of the present sites represent a public health risk. This scenario will be presented in the section of this document entitled Remedial Alternatives and Recommendations.

ROCKEYE SITE

In the immediate vicinity of the RS, the observed groundwater contamination is concentrated within a 2-acre area located along the intermittent stream which flows northeastward, across the northeastern boundary of the facility. The rate at which the explosives contaminants are migrating northeastward at this location is likely to be very high because it is probable that the contaminated groundwater occasionally discharges to the surface stream at this location. Therefore, the dominant contaminant transport mechanism (in terms of the velocity-rate of contaminant transport, but not necessarily the mass-rate of contaminant transport) at the RS is almost certainly channelized overland flow. Although the velocity of flow within this surface stream has not been measured, reasonable estimates are on the order of 1 to 4 feet per second.

This statement is somewhat misleading because it implies that concentrations of explosives such as were observed in the groundwater (as high as 7.2 mg/l, RDX) are moving off-site at the indicated rate. In actuality, two factors lessen the impact of this estimated transport rate. First, it is probable that the contaminated groundwater is not always discharging to this stream. The times when groundwater discharge to this stream is occurring depend on antecedent moisture conditions and the timing of precipitation events. Second, when contaminated groundwater discharge to the stream does occur, it is highly probable that significant dilution of the contaminants also occurs, thereby resulting in contaminant concentrations in the stream which are far below those observed in the groundwater. The extent of dilution obviously depends on the mass-rate of mixing of contaminated groundwater and uncontaminated surface water, which cannot presently be estimated at this location.

Indirect evidence that surface streams at the RS are important off-site transport mechanisms is provided by the monitoring results for wells 10-1-81 and 10-2-81. These are the remote RS wells which are located 3,600 feet east of the main RS site. Both of these wells have shown groundwater contamination by explosives and both of these wells are located within 30 feet of the

stream along which most of the contaminated monitoring wells are located at the main RS site. One might argue that contamination may have reached the two remote wells via contaminated groundwater movement; however, this seems unlikely considering the fact that all contaminated wells (except well 10-12-83) at the main RS site are close to surface streams and none of the other nine monitoring wells that are not close to a surface stream have shown contamination.

The extent of groundwater contamination at the main RS site is probably more extensive than the existing data indicate. Presently, no groundwater contamination is indicated within the fenced confines of the main RS, which represents a total area of approximately 40 acres, for the simple reason that no monitoring wells have been installed within the fenced boundaries. Recommendations for additional monitoring within this area will be discussed in subsequent portions of this document.

Groundwater movement is another mechanism operative at the RS that is probably causing off-site contaminant migration. Groundwater flow rates and, therefore, advective contaminant transport rates can be estimated from Darcy's Law. Darcy's Law is an empirically derived equation that defines the relationship between the velocity of groundwater flow, the hydraulic gradient, and the hydraulic conductivity of the porous material through which groundwater movement occurs. The modified steady-state form of Darcy's Law (equation 1) defines the average linear groundwater flow velocity as:

$$V = K\,(\Delta H/\Delta L)(1/n) \qquad (1)$$

where

V = average linear groundwater flow velocity (length/time)

K = hydraulic conductivity (length/time)

ΔH = change in hydraulic head (length)

ΔL = lateral distance over which the change in hydraulic head is observed (length)

n = effective porosity (dimensionless)

Dunbar (1983) provided previous estimates for K and n for other sites at Crane whose hydrogeologic settings are similar to those of the RS. His estimates were based on field information gathered during drilling rather than actual pump-testing data; therefore, error in his estimates by as much as an order of one magnitude are possible. For lack of better data, his estimates of $K = 1 \times 10^{-3}$ cm/s and $n = 0.1$ are used in the present analysis. The hydraulic gradient in the vicinity of the contaminated wells at the RS (between wells 10-7-83 and 10-21-83) is on the order of 0.11, as indicated by the groundwater contour map for the RS (Plate 1). Thus, from Darcy's Law, the groundwater flow velocity at this portion of the RS is estimated to be 1.1×10^{-3} cm/s, or 3.12 feet per day toward the northeast. Because the RS is coincident with a groundwater divide, the direction of groundwater flow varies across the site as indicated in Plate 1.

The applicability of Darcy's Law to this site is highly suspect for two important reasons. The first is that the porous medium (bedrock) is not homogeneous and isotropic because of the presence of bedrock fractures. As a result, it is very possible that zones of abnormally high permeability are present which may facilitate the movement of groundwater at rates in excess of the rate indicated above. Second, the Darcy assumption of non-vertical components of flow is probably violated due to the location of this site at a groundwater recharge zone (along the top of a ridge) where vertical (downward) flow is likely to occur. Assuming that the estimated hydraulic gradient is due, in part, to vertical changes in head, then the groundwater flow rate indicated above is probably overestimated.

To accurately determine the actual groundwater flow rate at this site would require substantially more site-specific data such as could be provided by aquifer testing and large numbers of additional monitoring wells.

DYE BURIAL GROUNDS

As previously indicated, the only groundwater contamination observed at the DBG was 0.07 mg/l of chromium in well WES 2-1-81. It is difficult to estimate the extent to which this groundwater contamination may extend beyond

this well because the closest adjacent wells are WES 2-6-81 and WES 2-5-81. Their distances from the contaminated well are, respectively, 190 feet and 140 feet. Unfortunately, considering the groundwater contour map for this site (Plate 2), neither of these wells is optimally located to detect groundwater contamination with a source near well WES 2-1-81 (neither well is directly down-gradient). Therefore, it is conceivable that a contaminant plume centered on well WES 2-1-81 and with a length in excess of 140 to 190 feet could be present and still not be indicated by the existing monitoring wells. Even if this situation did exist, it does not represent a major concern, considering the very low level of chromium observed.

Considering the hydraulic gradient (0.004) indicated in Plate 2 for the area in the vicinity of the contaminated well and estimated values for hydraulic conductivity and effective porosity of 1×10^{-3} cm/s and 0.10, respectively, the resulting groundwater flow velocity is 4×10^{-5} cm/s or 0.11 foot per day toward the west.

The hydrogeologic setting for this site is very similar to that of the RS; therefore, the above estimates of groundwater flow velocities are subject to the same limitations. These limitations are the occurrence of possible bedrock fracture zones which would facilitate more rapid off-site movement of groundwater than presently indicated, and the occurrence of downward components of groundwater flow which would cause the present estimates to be relatively high.

As previously indicated, soil contamination at this site was observed to be greatest at well WES 2-2-81. This observation contrasts with the groundwater monitoring data, which indicate that no groundwater contamination was observed at well WES 2-2-81. A probable cause is the relatively great depth to the water table (approximately 45 feet) at well WES 2-2-81, which would provide ample opportunity for adsorptive retardation of the contaminants as they migrated downward through the unsaturated zone. Shale layers containing small amounts of organic matter, such as were encountered by well WES 2-2-81, would encourage adsorption of the contaminants. In

contrast, the depth to the contaminated water table (WES 2-1-81) is only approximately 18 feet. Thus, it appears that the contaminants at this location are able to reach the perched water table before being attenuated by adsorption. Based on this observation, it is reasonable to expect that metals migration from this site will occur more slowly than the estimated groundwater flow rate.

DEMOLITION GROUNDS/OLD RIFLE RANGE

The present data do not indicate the presence of a plume of contaminants at the south ridge area of the DG. At the east ridge area of this site the contaminant plume presently appears to be confined to the vicinity of wells WES 6-7-81, 6-13,81, and 6-6-81, as indicated in Plate 3. The indicated southern and eastern boundaries of this plume are more reliable than the indicated northern and western boundaries due to the occurrence of non-contaminated monitoring wells to the south and east. If one assumes a hydraulic gradient of 0.045 between wells WES 6-1-81 and WES 6-12-81, as indicated by the groundwater contour map in Plate 3, and a hydraulic conductivity and porosity of 1×10^{-3} cm/s and 0.1, then the estimated groundwater flow velocity at this site is 4.5×10^{-4} cm/s or 1.28 feet per day toward the southeast on the basis of Darcy's Law. The groundwater contour map indicates that groundwater flow is divergent along this site, in directions approximately coincident with the local topography. For this reason, groundwater flow rates may be greater toward the northeast and southwest, down the flanks of the east ridge. Significant off-site migration of the contaminants observed at this site is not anticipated, considering the low concentrations observed and the tendency for their migration to be retarded by adsorption, as the data at the DBG indicate is likely to occur.

Other than slightly elevated concentrations of nitrate in well WES 6-18-81 and the 0.1 mg/l concentration of HMX observed in well WES 6-16-85, no groundwater contamination was observed at the ORR. The extent of the nitrate and HMX plumes cannot be estimated on the basis of the existing data

because there are no monitoring wells located down-gradient of well WES 6-18-81. At a maximum this plume appears to be no wider than 280 feet since this is the closest distance to an adjacent (not down-gradient) uncontaminated monitoring well. This, of course, assumes that the screened interval for the adjacent well is coincident with the elevation of the plume. The probable direction and rate of nitrate migration in the vicinity of well WES 6-18-81 is on the order of 1.14×10^{-4} cm/s or 0.32 foot per day toward the east. This assumes that Darcy's Law is applicable and that the site-specific estimates for hydraulic conductivity (1×10^{-3} cm/s) and effective porosity (0.1) are valid.

MCCOMISH GORGE

The only two wells at MG which showed contamination are located at the extreme eastern and western boundaries of the suspected debris disposal limits. Two wells which are located between the two contaminated wells showed no contamination. This implies that there may be two separate contaminant sources at this site, rather than simply a single source with an associated plume extending down-gradient. A reasonable groundwater flow velocity estimate is 0.049 foot per day, assuming a hydraulic conductivity of 1×10^{-4} cm/s and the hydraulic gradient of 0.014 indicated in Plate 5. Because there are no monitoring wells downgradient of well WES 4-5-81 (one of the wells which showed contamination) it is not possible to determine the extent to which groundwater contamination may extend beyond this well.

V. REMEDIAL ALTERNATIVES AND RECOMMENDATIONS

Remediation options are presented below for only the DBG and the RS. For both of these sites, the proposed remediation consists of additional data aquisition intended to better define the sources of contamination observed at these sites, rather than recommendations for remedial efforts to decontaminate or control the movement of groundwater which is presently observed to be contaminated. Groundwater control and/or decontamination options are not discussed for these sites for two reasons. First, the source(s) of contamination at these sites are not sufficiently defined to warrant development of remedial options aimed at treating the effects of the contaminant sources. Control/treatment of contaminated groundwater would be a never-ending process if the source of contamination is not first eliminated. Second, the contaminated groundwater at these sites does not appear to endanger public health, considering conservative estimates of human exposure to these contaminants based on information such as estimated off-site contaminant mass-transport rates, location and size of surrounding populations, and dilution of the contaminants during transport to the human receptors.

For the remaining two sites, the DG/ORR and MG, no remedial alternatives are discussed or recommended for the following reasons: either no public health risk is associated with these sites, based on the above-mentioned considerations, or no contamination is observed to be associated with the site. Each site is individually discussed in the following sections.

ROCKEYE SITE

The following discussion describes likely "hot-spots" at the RS which may be acting as sources of groundwater contamination and, therefore, which will be recommended for additional sampling and analysis. These areas have been identified on the basis of a review of operations information for the RS that was originally compiled by Nancy Hegan of NWSC.

Past Operations

Before 1978 there was no active treatment system for the explosive contaminated water generated in the LAP plant at the Rockeye facility. Pink water from the washing of equipment and buildings was collected in concrete sumps which overflowed to the natural watershed. Sludge was periodically removed and incinerated off-site. In addition to the contaminated water, airborne explosive wastes from the steam-fed tray wash area were discharged to the atmosphere. As a result of these uncontrolled waste discharges, it is likely that the soil in the immediate area of the facility is contaminated. Rainfall runoff from this area probably picks up contaminates and carries them downstream.

Based on available information, the primary areas of surface contamination are probably those surrounding the four sumps which hold contaminated water (A, B, C, and D; not shown on present drawings), as well as the area downwind from the tray wash area.

Current Operations

In 1978, an activated carbon treatment system was installed to treat wastewater for use as a recycle stream. A scrubber was added in 1979 to remove airborne explosive contaminants from the emissions of the steam-fed tray wash area. Wastewater from the scrubber is treated in the activated carbon treatment system.

Despite these waste treatment systems, some contamination continues to occur. The sumps and holding tank used to store contaminated water occasionally overflow because of electrical or mechanical failures, or excess rainfall. This results in contamination of the soil in the immediate area. Runoff from an overflow may carry contaminants into nearby streams as well, particularly if an overflow occurs during a wet season when the ground may be saturated.

There seem to be three problems in the system which cause the sumps to overflow. First, rainfall is allowed to run into the sumps, resulting in an excessive volume of contaminated water. The activated carbon treatment system was not designed to handle this additional hydraulic load. This problem could be solved simply by preventing rainfall from entering the sumps.

Second, it appears that the level switches in the sumps do not always function properly. These switches should activate the drain pumps when the level in the sump goes above a predetermined height. These switches need to be repaired, if possible, or replaced.

The third problem seems to be a lack of hydraulic equalization within the system. The recycle stream of treated water cannot keep up with demand for water during peak production times. Therefore, fresh water is added to the system, increasing the hydraulic load. The increased load sometimes exceeds the capacity of activated carbon treatment system, resulting in release of untreated, contaminated water. This problem could be overcome by adding a large holding tank for treated water. The tank should be large enough so that it will not be emptied even during excessive water use at peak periods. Additional holding volume may also be required for contaminated water awaiting treatment.

Drainage from the roof and earth-filled explosion walls is another source of contamination. The water from the roof is not contaminated and can be channeled to the surface drainage system. Drainage from the earth-filled explosion walls should be channeled to sump A to be held for treatment. It is not clear from the information available whether this additional contaminated water will overload the existing activated carbon treatment system.

Hydraulic oil leaks from hydraulic drills are a problem. This oil is carried to one of the sumps by contaminated water. An attempt is made to remove the oil, but some of it reaches the activated carbon treatment system

where it adheres to the carbon and reduces the available surface area for adsorption of explosive particles.

Other sources of contamination are leaks in pumps, piping, and sumps. Pipework throughout the system is leaking, resulting in puddles of contaminated water. The pumps that recirculate water for the washout process leak, resulting in puddles of pink water in the area. Cracks in sump A result in contaminated water leaking out. The area downhill from sump A is often wet, probably due to leaking.

On the basis of this information it is recommended that additional soil and groundwater monitoring be conducted within the fenced confines of the RS. Initially, this additional monitoring should include the analysis of soil and groundwater samples for RDX, HMX, and TNT. Follow-on quarterly monitoring will include analysis of groundwater samples but will not include additional soil analysis. It is recommended that one monitoring well be installed immediately down-gradient from each of the four sump areas previously described as being used to hold contaminated water. Water samples from these wells should be analyzed for RDX, HMX, and TNT. Additionally, five shallow subsurface (less than 2 feet in depth) soil samples should be collected from the areas down-gradient from each sump area, giving a total of 20 soil samples. These soil samples should be analyzed for RDX, HMX, and TNT.

The exact locations where the monitoring wells should be installed and the soil samples should be collected are not presently indicated due to uncertainty regarding the exact locations of the sump areas and the areas down-gradient from the sumps. However, consultation with individuals familiar with the RS operations should facilitate identification of these areas.

In addition to monitoring of the four sump areas, it is also advisable that ten soil samples be collected and a monitoring well be installed in the area at the activated carton treatment system. These soil samples and

groundwater samples from this monitoring well should also be analyzed for the above explosives as well as oil and grease because oil and grease have reportedly been a problem in this area. Additionally, a priority pollutants scan should be conducted. A greater number of soil samples are recommended at this location due to the extensive time period when atmospheric discharges of contaminated steam associated with tray cleaning operations occurred. Table 6 summarizes the present recommendations relative to the RS. It indicates that a monitoring effort requiring 5 additional monitoring wells, 30 soil samples, and 5 groundwater samples is initially recommended. Follow-on sampling should consist of quarterly monitoring of these additional monitoring wells. This follow-on quarterly groundwater monitoring should include analysis for the parameters of RDX, HMX, and TNT for the four sump area monitoring wells. It should include analysis for the parameters of RDX, HMX, TNT, oil and grease, and a priority pollutants scan for the monitoring well near the activated carbon treatment system. Subsequent cost estimates for this monitoring effort are based on cost requirements for:

- Twenty soil samples to be analyzed for RDX, HMX, and TNT
- Ten soil samples to be analyzed for RDX, HMX, and TNT, oil and grease, and a priority pollutants scan.
- Five additional shallow groundwater monitoring wells
- Additional quarterly analytical costs for four groundwater samples to be analyzed for RDX, HMX, and TNT, and one groundwater sample to be analyzed for RDX, HMX, TNT, oil and grease; and a priority pollutants scan.
- Four groundwater samples to be analyzed for RDX, HMX, TNT, and oil and grease, and a GC-MS priority pollutants scan (includes quarterly monitoring requirements for the first year)

If these additional monitoring efforts confirm additional contamination, it is recommended that the existing wastewater treatment system and/or standard operating procedures be modified to eliminate discharges of contaminated water to the environment. Such changes should be implemented prior to conducting remedial efforts designed to eliminate existing surface and groundwater contamination.

Table 6. Additional Monitoring Recommendations for the Rockeye Site

	Area 1	Area 2
Sample Location Requirements	Immediately downgradient from sumps A, B, C, D	Immediately downgradient from the activated carbon treatment system
Monitoring Wells	One shallow monitoring well (down to the first occurrence of groundwater) at each sump area	One shallow monitoring (down to the first occurrence of groundwater)
Total Number of Soil Samples	Five shallow soil samples downgradient from each sump	Ten shallow soil samples downgradient from the treatment system and associated holding tank
Analytical Parameters for Soil Samples	RDX, HMX, TNT	RDX, HMX, TNT
Number of Groundwater Samples per Quarterly Sampling Episode	Four samples, one from each well	One sample from the only well recommended for this site
Analytical Parameters for Groundwater Samples	RDX, HMX, TNT	RDS, HMX, TNT, oil and grease, priority pollutants scan
Initial Number of Groundwater Samples	Four samples, one from each well	One sample from the only well recommended for this site
Number of Groundwater Samples to Meet Additional Quarterly Analytical Requirements	Four groundwater samples to be analyzed for RDX, HMX, and TNT	One groundwater sample to be analyzed for RDX, TNT, oil and grease, and priority pollutants

DYE BURIAL GROUNDS

No remedial action involving the manipulation or treatment of groundwater is recommended for the DBG because of the minimal groundwater contamination presently observed. However, interviews with individuals knowledgable about the history of operations at the DBG provide strong evidence that large amounts of paints and/or dyes are present at the DBG. The inability to pinpoint the location of this material using existing groundwater monitoring information is obviously related to the fact that this material is not causing extensive groundwater contamination or, if significant groundwater contamination is occurring, it is not being detected by the existing monitoring wells. This second possibility seems highly unlikely, considering the locations of the existing wells at this site; therefore, additional monitoring wells are not recommended for this site.

Remedial efforts at the DBG should be directed toward pinpointing the location of the buried dyes and paints. This may be accomplished by either direct or indirect techniques, or by a combination of both. Direct techniques would include sampling and analysis of soil samples, whereas indirect techniques would include geophysical techniques such as metal detection survey or ground-penetrating radar (GPR). These various options are discussed in the following sections.

Geophysical Techniques

Depending on site conditions, geophysical techniques are often useful for investigating relatively large areas for the presence of buried materials whose physical properties are significantly different from those of the surrounding soils. Lord, et al. (1982) conducted a field study in which they evaluated ten different geophysical techniques to determine their effectiveness in locating buried materials such as would be found at a hazardous waste site. The results of their study were published and are presented in Appendix 14. Table 7 summarizes their assessment of the ten techniques. Based on their study, metal detection would be the chosen

technique for application at the DBG. A possible problem with this technique is that it may not be effective for locating items buried below 5 feet. However, considering the fact that soil contamination at the DBG is located at depths as shallow as 1 foot, and that the clay overburden at the DBG is generally less than 10 feet thick, it is likely that the buried material at the DBG is within the depth range of this technique. If there is reason to believe that the buried waste is not contained in metal containers or if the results of the metal detection survey are inconclusive, then GPR is the chosen option. Typical GPR systems are effective to depths of about 10 feet, depending on soil moisture conditions. Regardless of the technique used, it should be applied throughout the entire area referred to as the "approximate disposal site limits" in Plate 2.

Ideally, the results of the geophysical investigation will define the location of the buried materials at this site with sufficient precision to allow confirmation by excavation, followed by complete excavation and off-site disposal. If buried hazardous wastes are confirmed by these techniques, then additional monitoring of the saturated and unsaturated zones in the immediate vicinity of the waste would be advisable. Estimates of the scope of these additional monitoring requirements and the associated costs must await review of the geophysical data. Existing data do not define the buried waste location(s) at the DBG with sufficient detail to allow these estimates to be made at the present time.

Direct Sampling

It is recommended that extensive sampling and laboratory analysis of soil samples not be conducted until the suspected waste disposal locations are better defined by the geophysical survey. This recommendation is made considering:

- The large size of the possible area within which the buried dyes and paints may be located (35,000 $ft.^2$)

Table 7. Assessment of Most Widely Used NDT Techniques for Identification and Location of Buried Containers (From Lord, et al., 1982)

Method	Equipment Cost ($)	Field Deployment	Data Interpretation	Container Detail	Maximum Penetration Depth (Approx.)
Ground-probing radar	35,000	Moderate	Moderate	Excellent	4' to 15'
Metal detector	500	Easy	Simple	Poor	2' to 5'
Magnetometer	4,000	Easy	Moderate	Poor	4' to 30'
Resistivity	2,000	Moderate	Difficult	Poor	2' to 50'
VLF(EM)	7,000	Moderate	Moderate	Poor	2' to 20'
Refraction	5,000	Moderate	Moderate	Poor	2' to 100'
Sonar (pulse echo acoustics)	10,000	Difficult	Moderate	Good	1' to 3'
Infrared	15,000	Moderate	Moderate	Moderate	1' to 5'
Nuclear-high energy	30,000	Difficult	Moderate	Moderate	1' to 2'
CW microwave	10,000	Moderate	Moderate	Moderate	2' to 12'

- The small total area that the wastes may actually occupy
- The observed tendency for wastes at this site not to migrate and, therefore, the probable necessity for the soil sample locations to be situated very close to the waste in order to detect contamination.

The soil sampling and analysis would serve the purpose of confirming the presence of the waste indicated by the geophysical survey and would facilitate development of cost-estimates and/or contract plans and specifications for excavation and removal of the waste. The most cost-effective method for acquiring the soil samples is likely to be via the use of a simple handheld (two men) soil augering device instead of through the use of a drilling rig with depth capabilities beyond those required. Cost estimates are not presented for soil sampling and analysis because sampling and analysis requirements cannot be quantified until the area to be sampled is defined by the geophysical survey.

DEMOLITION GROUNDS/OLD RIFLE RANGE AND MCCOMISH GORGE

For both the DG and ORR no remediation is recommended. Also, no additional sampling or analysis is recommended other than to continue semiannual monitoring to assure that the observed groundwater contamination does not unexpectedly become worse. The rationale for these recommendations follows.

A conceptual model was developed in which three important processes were considered with regard to the worst-case concentrations of site-specific contaminants that could possibly result at the NWSC boundary. The three processes considered were the mass-rate of contaminant migration away from the site, discharge of this contaminant mass into a receiving stream, and subsequent dilution of the contaminant concentration considering estimated receiving stream discharge rates. Detailed calculations applicable to the ORR are presented below in order to illustrate the methodology. These and similar calculations for the DG and MG (not shown) will indicate that resulting contaminant concentrations in receiving streams are, in most cases, several orders of magnitude below the standards established for these contaminants.

The mass rate of contaminant migration from the ORR is assumed to be primarily dependent on off-site migration of contaminated groundwater. Other mechanisms such as air-transport of contaminated particulates and erosion of surface soils are probably operative; however, their effects are considered minimal compared to the groundwater route. The mass-rate of contaminant movement via groundwater depends on the volume-rate at which groundwater leaves the site and the concentration of the contaminants within this water. For the ORR, the volume-rate of off-site movement volume groundwater is addressed first, followed by contaminant concentration.

The annual volume of contaminated groundwater leaving the ORR is assumed to be equal to the sum of the volume resulting from surface infiltration of precipitation plus the volume of natural groundwater flow below the site, in response to the observed hydraulic gradient at the site. The total volume of surface infiltration is conservatively estimated to be 1.71×10^{-3} ft^3/sec. This number is derived by assuming that 10 inches [(total precipitation (44 inches) minus evapotranspiration (34 inches)] will infiltrate through a surface area equivalent to the area represented by the contaminant plume. The area of the contaminant plume (6.5×10^5 ft^2) was conservatively estimated by drawing circles around the only two wells at the ORR that were contaminated (WES 6-16-81 and WES 6-18-81) and then calculating and summing their areas using the distance between these contaminated wells and the closest non-contaminated wells as the radii. The estimate of 1.72×10^{-3} ft^3/sec of contaminated surface infiltration that is ultimately discharged to the adjacent surface stream via the groundwater flow path is conservative for several reasons:

- Of the 10 inches of precipitation assumed to infiltrate downward through the site, a significant fraction actually leaves the site via direct runoff and never becomes contaminated by pollutants within the subsurface.
- The surface area of the contaminant plume is grossly over-estimated.
- Not all surface water which infiltrates also becomes contaminated.

To get an estimate for the total volume of contaminated groundwater leaving the site, we must add to 1.72×10^{-3} ft^3/sec the volume of

groundwater which intersects the contaminated area as a result of lateral movement beneath the site in response to the local hydraulic gradient. To make this estimate we use the form of Darcy's Law expressed as:

$$Q = KiA \tag{2}$$

where

Q = volume of contaminated groundwater discharge (L^3/T)

K = hydraulic conductivity (L/T)

i = hydraulic gradient (dimensionless)

A = cross-sectional area of the contaminant plume, perpendicular to the direction of groundwater flow (L^2)

The hydraulic gradient for this site in the vicinity of the contaminated wells is estimated to be 0.006 on the basis of information provided within the groundwater table contour map (Plate 4). The hydraulic conductivity is estimated to be 1×10^{-3} cm/sec and the area of the plume normal to the groundwater flow direction is estimated to be 14,375 ft^2. The estimate of 14,375 ft^2 assumes that the width of the contaminated subsurface area is equal to two times the distance between the contaminated well (WES 6-18-81) and the closest non-contaminated well, and the depth to which contamination extends is equal to the bottom of the screened interval for well WES 6-18-81. From equation 2, Q is then determined from:

$$Q = (3.28 \times 10^{-5} \text{ ft/sec})\ (0.006)\ (14{,}375 \text{ ft}^2)$$

$$Q = 2.83 \times 10^{-3} \text{ ft}^3/\text{sec}$$

The estimated groundwater discharge calculated from Q=KiA is very conservative because the actual hydraulic conductivity is likely to be much lower than the value used and the actual cross-sectional area of the contaminated zone through which lateral groundwater movement occurs is almost certainly less than the area used in the present calculations. Adding the above groundwater discharge rate to the previously estimated volume of precipitation which infiltrates (1.72×10^{-3} ft^3/sec) gives a total estimated volume-rate of contaminated groundwater discharge from the site equal to 4.55×10^{-3} ft^3/sec.

The mass-rate of contaminant discharge is calculated by multiplying the total volume-rate of groundwater discharge times a representative contaminant concentration for this discharge. In keeping with a conservative approach, the representative contaminant concentration is assumed to be equal to the maximum observed contaminant concentration observed on the basis of the groundwater monitoring data. Two contaminants were detected above standards in groundwater at the ORR. These are HMX at a maximum observed concentration of 0.1 mg/l and nitrate at a maximum observed concentration of 16.1 mg/l. Multiplying these concentrations by the total volume-rate of groundwater discharge (4.55×10^{-3} ft^3/sec) gives total mass transport rates for HMX and nitrate, via groundwater discharge, of 1.29×10^{-2} mg/sec and 2.07 mg/sec, respectively.

In order to calculate what the concentration in the receiving stream will be, it is necessary to estimate the flow rate for the receiving stream. Because the receiving stream at the ORR (Turkey Creek) is not gauged, its discharge must be estimated by comparing its drainage area to the drainage areas of other comparably sized drainage basins near NWSC which are located in similar geologic environments and whose streams are gauged.

Figure 8 illustrates the locations of streams near NWSC which are gauged and whose recorded discharges were used to estimate a discharge rate for Turkey Creek at the position along the stream which is down-gradient from the ORR. Table 8 summarizes the drainage basin areas and stream discharge rates for the streams highlighted in Figure 8. Appendix 15 presents the discharge records for these gauge stations. The average annual discharge for these five streams, normalized according to drainage basin area, is 17.57 in/yr. Assuming this rate to be a valid estimate for the Turkey Creek drainage basin, then the discharge rate for Turkey Creek at the position along the stream which is directly down-gradient from the ORR is 4.85×10^8 ft^3/year or 436 liters per second, given that the Turkey Creek drainage basin area upstream from the ORR is 3.31×10^8 ft^2. Relating 436 liters per second to previously determined contaminant mass transport rates gives resulting concentrations in Turkey Creek of 2.9×10^{-5} mg/l HMX and 4.7×10^{-3} mg/l nitrate. This nitrate concentration is over

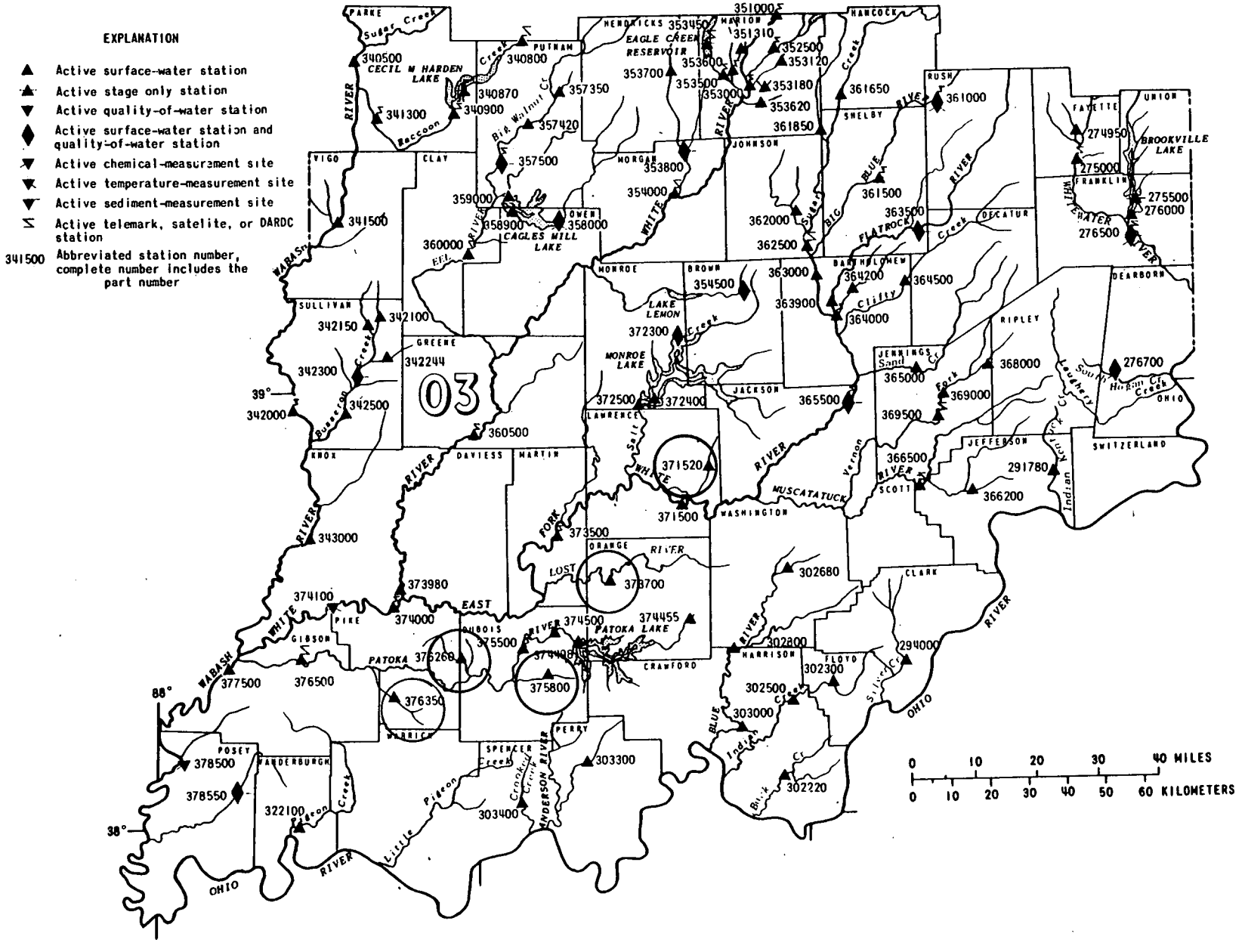


Figure 8. Locations of Streams Near NWSC for Which Recorded Discharges and Drainage Basin Areas Were Used to Estimate Discharge Rates for Streams at NWSC

Table 8. Summary of Stream Discharge Data for Small Streams Close to NWSC

	Gauge	Period of Record	Drainage Basin Area	Average Discharge Over the Period of Record
1.	03371520	Oct 70 to Sep 82	24.1 mi^2	34.4 ft^3/sec (19.38 in/yr)
2.	03373700	Dec 64 to Sep 82	287 mi^2	365 ft^3/sec (17.27 in/yr)
3.	03376260	Oct 64 to Apr 82	21.3 mi^2	22.8 ft^3/sec (14.54 in/yr)
4.	03376350	Oct 64 to Sep 82	42.8 mi^2	50.0 ft^3/sec (15.86 in/yr)
5.	03375800	Oct 70 to Sep 82	21.8 mi^2	33.4 ft^3/sec (20.81 in/yr)

three orders of magnitude below the allowable limit cited in the standards. The resulting HMX concentration is over three orders of magnitude below the detection limit for this compound.

Applying this procedure using data from the east ridge of the Demolition Grounds and data from McComish Gorge gives similar results for contaminant concentrations in receiving streams. Table 9 summarizes pertinent information related to this risk-assessment methodology, as applied to these sites. This includes information such as the resulting contaminant concentrations in receiving streams into which the contaminated groundwater at these sites is presumed to discharge.

Table 9. Summary of Contaminant Concentrations in Receiving Streams Associated With the East Ridge of the DG/ORR and the MG on the Basis of a Worst-case Scenario Risk Assessment

	East Ridge of the DG/ORR	McComish Gorge
Observed groundwater contaminants and their maximum observed concentrations	0.017 mg/l selenium 0.063 mg/l arsenic 0.023 mg/l cadmium 0.070 mg/l chromium	0.077 mg/l mercury 0.1 mg/l chromium
Maximum estimated plume area	97,200 ft^2	119,800 ft^2
Percipitation infiltration over area of plume	81,000 ft^3	99,833 ft^3/yr
Verticle plume x-sectional area	12,312 ft^2	10,500 ft^2
Hydraulic conductivity	1.0×10^{-3} cm/s	1×10^{-4} cm/s
Hydraulic gradient	0.045	0.014
Volume of groundwater movement through contaminated subsurface	1.82×10^{2} ft^3/s	4.82×10^{-4} ft^3/s
Total groundwater discharge from the site	2.08×10^{-2} ft^3/s	3.65×10^{-3} ft^3/s
Mass rate of contaminant discharge	1.0×10^{-2} mg/s selenium 3.7×10^{-2} mg/s arsenic 1.3×10^{-2} mg/s cadmium 4.1×10^{-2} mg/s chromium	7.9×10^{-3} mg/s mercury 1.0×10^{-2} mg/s chromium

Table 9. (Continued)

	East Ridge of the DG/ORR	McComish Gorge
Estimated discharge rate of receiving stream	5.92×10^8 ft^3/yr (5.32×10^2 l/sec)	6.32×10^7 ft^3/yr (56.7 l/sec)
Resulting concentration in receiving stream	1.9×10^{-5} mg/l selenium 7.0×10^{-5} mg/l arsenic 2.4×10^{-5} mg/l cadmium 7.7×10^{-5} mg/l chromium	1.4×10^{-4} mg/l mercury 1.8×10^{-4} mg/l chromium

VI. COST ESTIMATES

The only sites for which additional remedial action has been recommended and for which cost estimates are presented are the RS and the DBG. The costs for the RS fall into three main categories. These are the costs for the installation of the additional monitoring wells, the costs for the first-time sampling and analysis of groundwater samples from these wells and the associated soil samples, and the costs for ongoing quarterly monitoring of the groundwater. DBG costs fall into two main categories: the costs to perform a metal detection survey and/or costs of a ground-penetrating radar survey, which may be necessary depending on the results of the metal detection survey. The costs are summarized below for each site.

Rockeye Site

Initial, Up-Front Cost

	Activity	Cost
1.	Installation of five monitoring wells	$3,500
2.	Analysis of 20 soil samples for RDX, HMX, and TNT	$6,000
3.	Analysis of 10 soil samples for ADX, HMX, TNT, oil and grease, and priority pollutants scan.	$15,000
4.	Analysis of four groundwater samples for TNT, RDX, and HMX	$1,400
5.	Analysis of one groundwater sample for RDX, TNT, HMX, oil and grease, and priority pollutants scan	$1,500

Subsequent Quarterly Monitoring Costs

	Activity	Cost
1.	Four groundwater samples to be analyzed for TNT, RDX, and HMX	$5,600
2.	One groundwater sample to be analyzed for RDX, TNT, HMX, oil and grease, and priority pollutants	$6,000

Dye Burial Grounds

	Activity	Cost
1.	Metal Detection Survey	$2,050
2.	Ground-penetrating radar survey	$1,600

VII. CONCLUSIONS

1) Little or no contamination has been detected at the south portion of the DG/ORR. For this reason, no remediation or additional data requirements have been recommended for this site.

2) Three sites show confirmed contamination; however, the concentrations are very low. These sites include the RS, the MG, and the ORR portion of the DG/ORR. Worst-case scenario risk assessments performed on the MG and the ORR portion of the DG/ORR indicate that the resulting contaminant concentrations in receiving streams are likely to be several orders of magnitude below the public health standards established for these parameters. On the basis of this observation, these three sites are considered to not pose a risk to public health and, therefore, remediation of these sites is not recommended. Continued monitoring is recommended.

3) Additional monitoring of the RS is recommended due to the relatively high concentrations of explosives found at this site, and because of the large area within the fenced confines of the RS that is likely to be contaminated and for which no monitoring has yet been conducted. The type of monitoring recommended for this site consists of the installation of five additional shallow monitoring wells to be analyzed quarterly for various parameters, including RDX, HMX, TNT, oil and grease, and priority pollutants. Also, a total of 30 soil samples have been recommended for sampling and analysis throughout the areas where the additional monitoring wells are recommended.

4) A geophysical survey has been recommended for the DBG, despite the fact that only minor groundwater contamination has been detected at this site. The geophysical survey is warranted because of the high degree of confidence associated with reports that indicate that containerized

dyes and paints are present at this site. Because of the presence of containers, a metal detection survey and/or a ground-penetrating radar survey is recommended.

5) Until the sources of contamination have been better determined for both the DBG and the RS, no remedial efforts such as groundwater pumping and treatment are recommended. Additionally, because these sites are remote, they do not appear to present a public health risk and, therefore, interim measures such as the control of off-site groundwater movement are not recommended.

VIII. REFERENCES

1. Dunbar, J.B., Hydrogeologic Investigation of Waste Disposal Sites at the Naval Weapons Support Center, Crane, Indiana, USAE Waterways Experiment Station, Vicksburg, MS, 1982.

2. Dunbar, J.B., Definition of Contaminated Groundwater Plumes at Selected Waste Disposal Sites, Naval Weapons Center, Crane, Indiana, USAE Waterways Experiment Station, Vicksburg, MS, 1983.

3. Dunbar, J.B., Definition of Contaminated Groundwater Plumes at Selected Waste Disposal Sites, Naval Weapons Center, Crane, Indiana, USAE Waterways Experiment Station, Vicksburg, MS, 1984.

4. Letter report from Dunbar to NWSC regarding estimated contaminant migration rates for sites 1, 3, 5, and 9, February, 1984.

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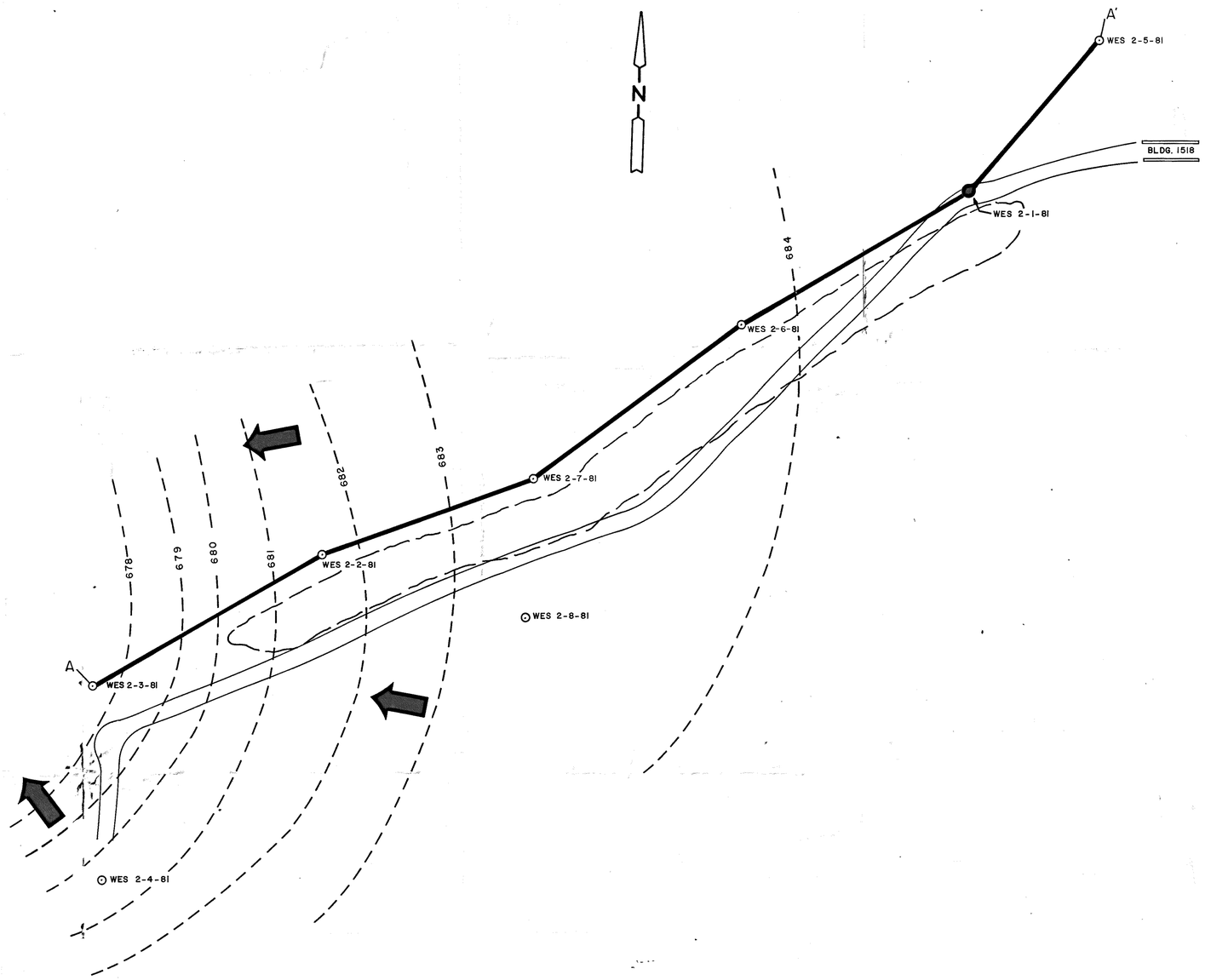

LEGEND

- WES 2-3-81 — WELL LOCATION AND NUMBER
- CONTAMINATED WELLS
- ACCESS ROAD
- A——A' CROSS-SECTION LOCATION
- APPROXIMATE DISPOSAL SITE LIMITS
- GROUNDWATER FLOW DIRECTION
- GROUNDWATER TABLE CONTOUR

40 0 40 80
SCALE IN FEET

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SATISFACTORY TO DATE	DESIGN W. D. E. DRAWN L. L. CHECKED D. R. T. SUPV. D. J. W.	SITE 2 DYE BURIAL GROUND **CONFIRMATION STUDY** SITE AND GROUNDWATER CONTOUR MAP
SATISFACTORY TO DATE	APPROVED DATE PUBLIC WORKS OFFICER	SIZE F — CODE IDENT. NO. 80091 — NAVFAC DRAWING NO. CONSTR. CONTR. NO. N624
		SCALE — SPEC. NO. — SHEET 1 OF 5

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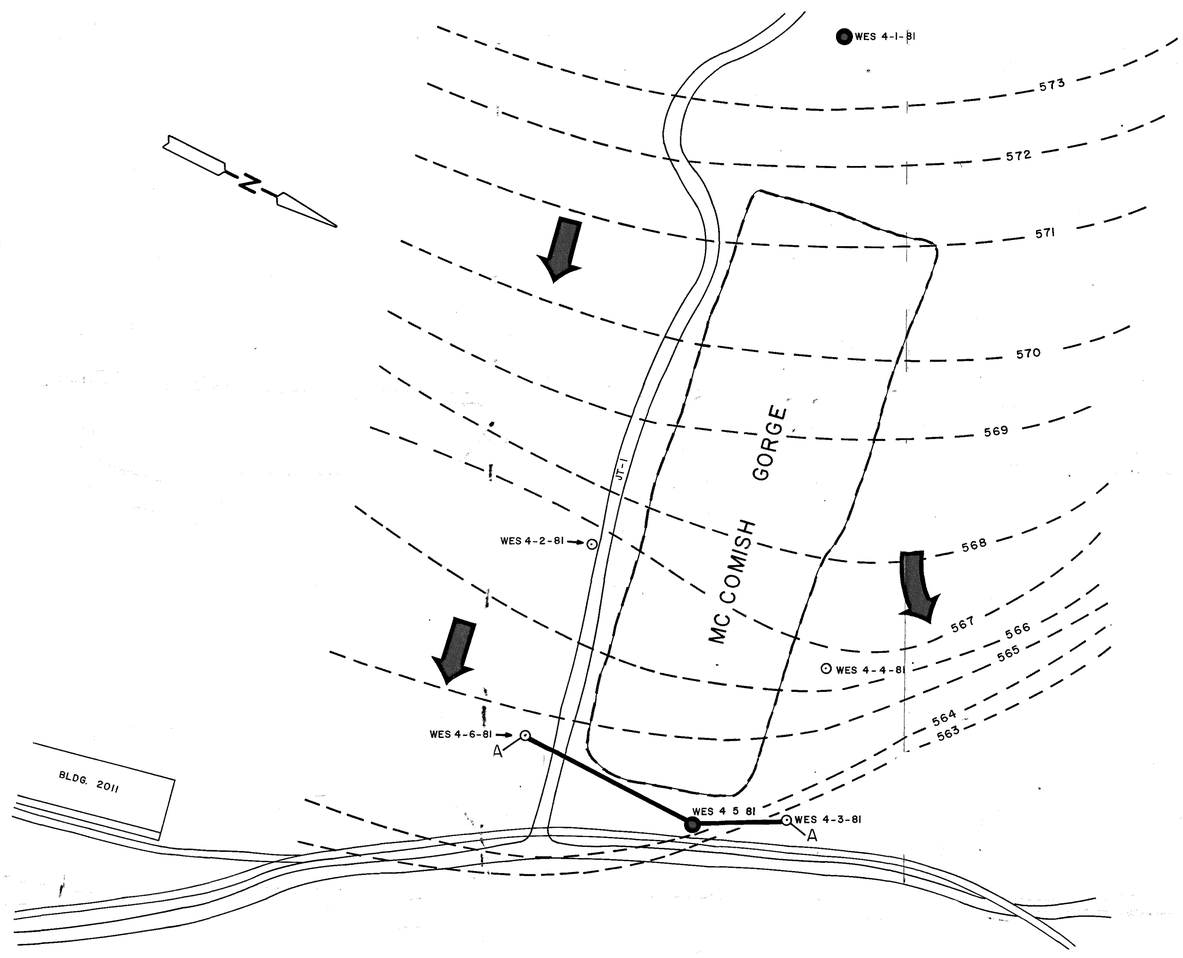

LEGEND

- WES 4-1-81 — WELL LOCATION AND NUMBER
- JT-1 — ACCESS ROAD
- A——A' — CROSS-SECTION LOCATION
- APPROXIMATE DISPOSAL SITE LIMITS
- DIRECTION OF GROUNDWATER FLOW
- CONTAMINATED WELLS

60 0 60 120
SCALE IN FEET

SATISFACTORY TO DATE	PWO DWG REF PWO DRAWING NO.	DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND **NAVAL WEAPONS SUPPORT CENTER** CRANE, INDIANA
SATISFACTORY TO DATE	DESIGN W. D. E. DRAWN L. L. CHECKED D. R. T. SUPV D. J. W.	SITE 4 McCOMISH GORGE **CONFIRMATION STUDY** SITE AND GROUNDWATER CONTOUR MAP
SATISFACTORY TO DATE	APPROVED DATE PUBLIC WORKS OFFICER	SIZE F — CODE IDENT. NO. 80091 — NAVFAC DRAWING NO. CONSTR. CONTR. NO. N624
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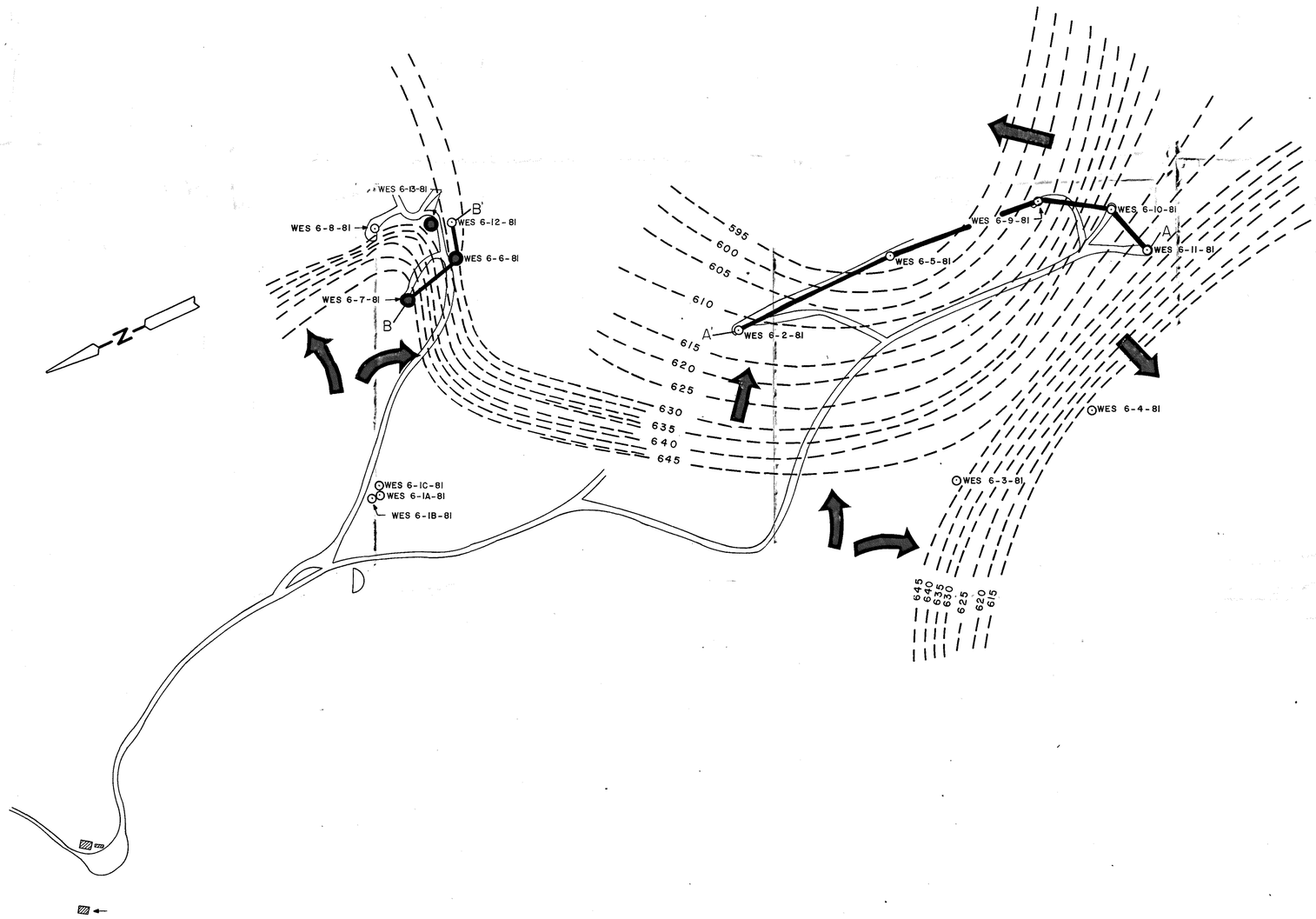

LEGEND

- ⊙ WES 6-3-81 — WELL LOCATION AND NUMBER
- ACCESS ROAD
- A——A' — CROSS-SECTION LOCATION
- — — — GROUNDWATER TABLE CONTOUR
- DIRECTION OF GROUNDWATER FLOW
- ● CONTAMINATED WELLS

200 0 200 400
SCALE IN FEET

SATISFACTORY TO DATE	PWO DWG REF PWO DRAWING NO.	DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND **NAVAL WEAPONS SUPPORT CENTER** CRANE, INDIANA
SATISFACTORY TO DATE	DESIGN W. D. E. DRAWN L. L. CHECKED D. R. T. SUPV. D. J. W.	SITE 6A – EAST AND SOUTH RIDGES AT THE DEMOLITION GROUNDS **CONFIRMATION STUDY** SITE AND GROUNDWATER CONTOUR MAP
SATISFACTORY TO DATE	APPROVED DATE PUBLIC WORKS OFFICER	SIZE F — CODE IDENT. NO. 80091 — NAVFAC DRAWING NO. CONSTR. CONTR. NO. N624
		SCALE — SPEC. NO. — SHEET 3 OF 5

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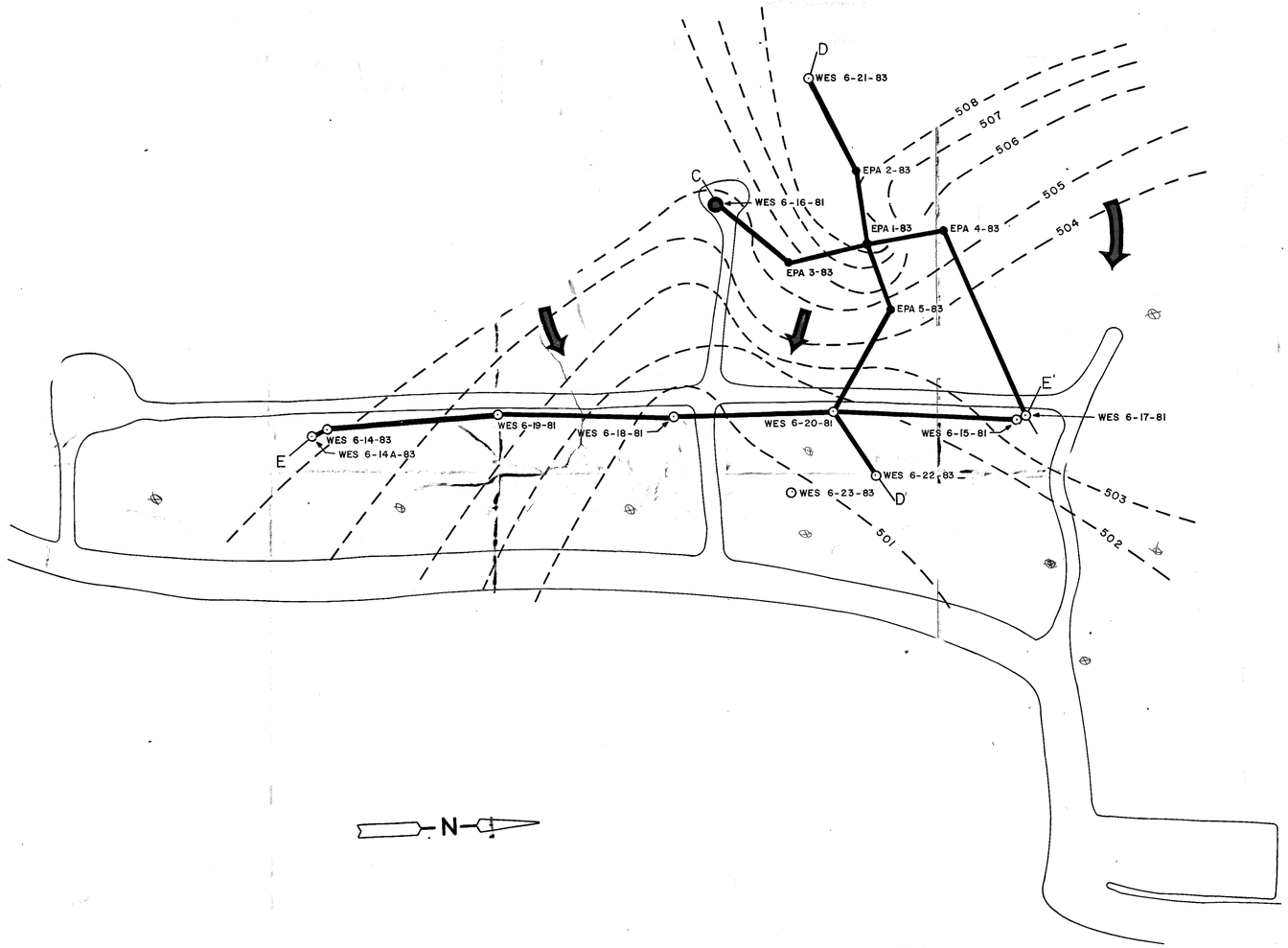

LEGEND

- WES 10-6-81 — WELL LOCATION AND NUMBER
- CONTAMINATED WELLS
- ACCESS ROAD
- A——A' CROSS-SECTION LOCATION
- BORINGS
- GROUNDWATER FLOW DIRECTIONS
- GROUNDWATER TABLE CONTOUR

100 0 100 200
SCALE IN FEET

SATISFACTORY TO DATE	PWO DWG REF PWO DRAWING NO.	DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND **NAVAL WEAPONS SUPPORT CENTER** CRANE, INDIANA
SATISFACTORY TO DATE	DESIGN W. D. E. DRAWN L. L. CHECKED D. R. T. SUPV. D. J. W.	SITE 6B OLD RIFLE RANGE PORTION OF THE DG/ORR **CONFIRMATION STUDY** SITE AND GROUNDWATER CONTOUR MAP
SATISFACTORY TO DATE	APPROVED DATE PUBLIC WORKS OFFICER	SIZE F — CODE IDENT. NO. 80091 — NAVFAC DRAWING NO. CONSTR. CONTR. NO. N624
		SCALE — SPEC. NO. — SHEET 4 OF 5

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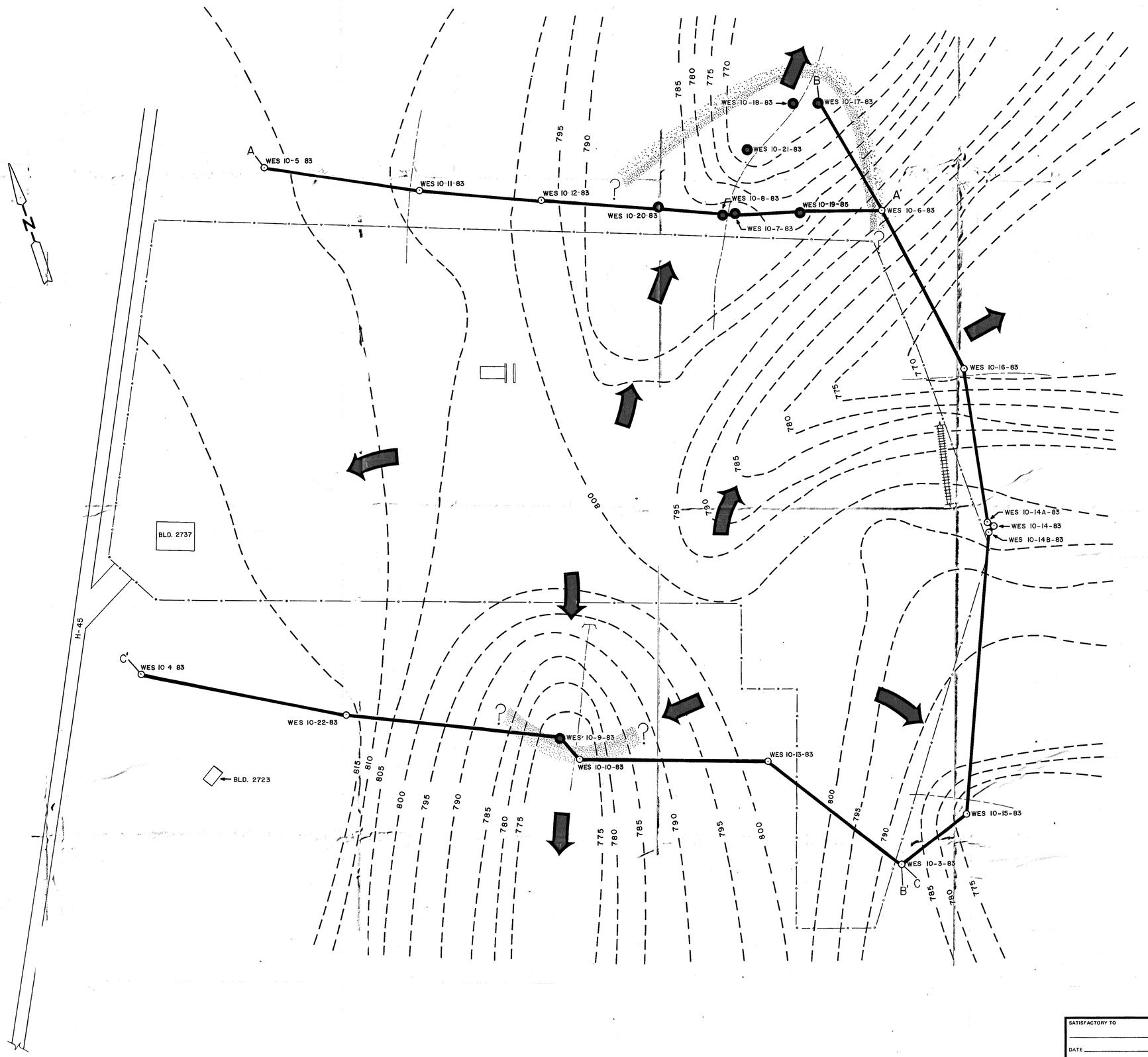

LEGEND

- WES 10-6-81 — WELL LOCATION AND NUMBER
- RAILROAD
- H-45 — ACCESS ROAD
- A——A' — CROSS-SECTION LOCATION
- APPROXIMATE CONTAMINANT PLUME BOUNDARY
- GROUNDWATER FLOW DIRECTIONS
- GROUNDWATER TABLE CONTOUR
- FENCE
- STREAM
- CONTAMINATED WELLS

100 0 100 200
SCALE IN FEET

SATISFACTORY TO DATE	PWO DWG REF PWO DRAWING NO.	DEPARTMENT OF THE NAVY — NAVAL FACILITIES ENGINEERING COMMAND **NAVAL WEAPONS SUPPORT CENTER** CRANE, INDIANA
SATISFACTORY TO DATE	DESIGN W. D.E. DRAWN L. L. CHECKED D. R.T. SUPV. D. J.W.	SITE 10 ROCKEYE **CONFIRMATION STUDY** SITE AND GROUNDWATER CONTOUR MAP
SATISFACTORY TO DATE	APPROVED DATE PUBLIC WORKS OFFICER	SIZE F — CODE IDENT. NO. 80091 — NAVFAC DRAWING NO. CONSTR. CONTR. NO. N624
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